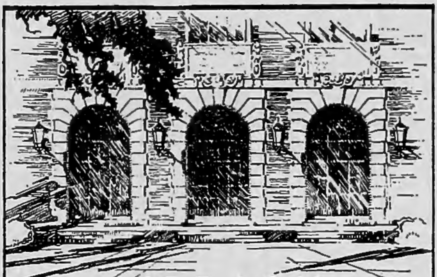

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NATURAL HISTORY
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STATE OF ILLINOIS

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NATURAL HISTORY SURVEY DIVISION

STEPHEN A. FORBES, *Chief*

BULLETIN

OF THE

Illinois State Natural History Survey

URBANA, ILLINOIS, U. S. A.

Vol. XVII CONTENTS AND INDEX 1927-1928

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ERRATA

Page 117, third line in table, for *Sofe* read *Soft.*

Page 118, transpose *Heavy soils* and *Light soils* in columns 3 and 4 of Table VIII.

Page 170, third line above figure, for *83* read *169.*

Page 200, fourteenth line, for *sand* read *stand.*

Pages 208, 211, 214, 219, in headings, for *Bacellariaceae* read *Bacillariaceae.*

Page 209, middle of table, for *oligactus* read *oligactis.* Same correction on page 213, first line of table, and on page 225, second line from bottom.

Page 211, fifth line in table, for *Aphanotheca* read *Aphanothece.* Same correction on page 218, sixth paragraph.

Page 215, fourth line in table, for *acuminata Ehr.* read *acuminatum (Kutz.) Cl.* Same correction for *acuminata* on page 220, fifth paragraph.

Page 224, fourth line from bottom, for *Pandorin* read *Pandorina.* Omit last line and read *Traverse Bay region.*

Page 228, fifth line from bottom, for *Antario* read *Ontario.*

Page 267, for *top row* read *bottom row,* and *vice versa.*

Page 327, second line, for *Eutettic* read *Eutettix.*

Page 348, third line in second paragraph, for *rosesus* read *roseus.*

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Vol. XVII. BULLETIN Article I.

Epidemic Diseases of Grain Crops in Illinois, 1922-1926

The Measurement of Their Prevalence and Destructiveness and An Interpretation of Weather Relations Based on Wheat Leaf Rust Data

BY

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CONTENTS

EPIDEMIC DISEASES OF GRAIN CROPS IN ILLINOIS, 1922-1926

The Measurement of Their Prevalence and Destructiveness and An Interpretation of Weather Relations Based on Wheat Leaf Rust Data

L. R. TEHON

As the first of the necessary steps in a study of the epidemiology of crop diseases, the Natural History Survey published a report in 1924 on the occurrence and distribution of the common diseases of crop plants in Illinois*, which was based chiefly on specimens and notes secured during the three years 1921, 1922, and 1923, but which also contained brief histories of each disease.

The second step consists of the accumulation of data which will show the differences in abundance and severity of disease from year to year, from season to season, in diverse regions, and even in diverse localities. In order to fulfill these requirements, the data must be both precise and as accurate as circumstances governing the work will permit. Comparative words, such as "mild", "light", "moderate", "heavy", and "severe", which have been used commonly, are not sufficiently precise when applied to diseases, for their meanings are as varied as the experiences of the persons who hear or speak them. The most satisfactory statement, and the one most likely to be understood by everyone, is therefore the one which presents the facts of disease attack in numerical terms. This implies not only that it is possible to measure the attack but also that the measuring can be done by means of quantitative units quite as definite in their particular application as are the feet, pounds, and gallons of commerce.

Since the beginning of the survey in 1921, methods have been adapted and devised by which disease abundance can be measured with a considerable degree of accuracy, and large quantities of data have been secured each year for many diseases.

In both the accumulation and the analysis of data, problems have arisen which have made it necessary to adopt standard arithmetical methods, the use of which is quite as important in plant disease surveying as

* A preliminary report on the occurrence and distribution of the common bacterial and fungous diseases of crop plants in Illinois. By L. R. Tehon. Bull. Ill. State Nat. Hist. Surv. Vol. XV, pp. 173-325. 1924.

are the calculations made by the civil engineer with the data he secures by transit and chain.

The detailed account given in these pages of the means used to measure diseases, of the methods by which the data are analysed, and of the results obtained, is confined to the diseases of cereals. It is presented, not merely because it follows so directly the task accomplished by the first report, nor yet because it represents the first intimate and extensive study of crop diseases growing naturally in Illinois fields, but especially because it will enable the grower of crops to understand, better than he ever has, the destructive effect of diseases which he all too often ignores.

GENERAL METHODS USED IN THE SURVEY

The survey of crop diseases was begun in midsummer of 1921. The first task, that of determining the kinds and the distribution of diseases attacking crop plants in Illinois, was undertaken at once. At the same time, a start was made toward securing quantitative records of the amounts of each disease, for it was clearly seen that a means of arriving at definite comparisons could be found only in measurements of disease abundance.

One of the first difficulties encountered was that of handling diseases difficult to identify in the field because of the lack of distinctive symptoms. This problem, after six years of work, has not been solved entirely, for the certain identification of some diseases requires equipment and a personnel for routine work that is beyond our resources. However, for diseases more or less readily identifiable by the eye, the hand lens, or the compound microscope, a system was developed by the beginning of the growing season of 1923, which, though requiring variation in its application to different types of disease, has the following general plan.

Whenever the identification of a disease can not be made with absolute certainty in the field, a typical, representative, and copious sample of it is taken at the time the field is examined. The specimen is given a temporary "collector's" number, which is placed on a small paper label along with other identifying and suggestive information, such as the name

SPECIMEN LABEL

Collector's No. *T 76*

Host *Wheat—Kanred mixed.*

Disease *Node cankers.*

Cause *Examine for pycnidia of Septoria nodorum.*

Town *Fisher* County *Champaign*

Date Collected *July 29, 1926.*

of the crop, a brief note of the type of injury, and the place and date of collection. The specimen, with its label, is then packed in a small pressing and drying device carried by the observer. As often as convenient, the collected samples are sent to the laboratory where, when the process of drying is completed, they are arranged in sequence in the order of their numbers and stored away to await further examination.

As a matter of convenience, and to assure the inclusion of sufficient information with each specimen, the labels have been printed and arranged in pads. The label with typical notes, shown at the bottom of the preceding page, furnishes an example of its use.

For recording the amount of disease in a field, standard blanks measuring 8 by 11 inches are used. They also are printed and arranged in pads convenient to carry. The reproduction on the following page shows the type of blank that has been developed and the use that was made of it in recording the leaf rust infection in one wheat field.

A complete statistical summary of the information carried on these blanks would show the number of fields in which a disease was found, the number of acres comprised by them, the particular varieties of the crop on which a disease was mild or serious, whether or not preventive treatments were used consistently, the average percentage of diseased plants, and the average amount of disease per plant. There would also be data bearing on the ability of disease to reduce yield, on differences in the dates of first appearance from season to season and in various localities, on common sources of infection, local histories, and kinds and numbers of diseases encountered in a field, as well as special notes on local weather relations.

Finally, the number given by the observer to the sample he collected is noted in the lower right hand corner of the blank. It connects the record blank to the disease sample preserved in the laboratory.

The filled-in record blanks are sent, at suitable intervals, to the laboratory, where they are sorted according to crops and diseases. They are kept in a permanent file, the records for the various diseases being allotted individual folders which are arranged in the alphabetic order, first of the crop and then of the disease names. Separate folders are maintained, as a rule, for each year's records of a disease.

In securing the information required for the field record, it has been found that the greatest care must be exercised, both in the identifying and estimating of amounts of disease. The observer must not be over-confident of his ability to distinguish diseases in the field but must be constantly watchful to provide adequate evidence, by means of representative samples, of the accuracy of his judgments and the reliability of his estimates.

In estimating disease abundance, different procedures are necessary for different types of disease. An estimate of the amount of loose smut in a wheat field may be secured by determining the number of smutty heads among a representative number in the field, but an estimation of rust

1926

PLANT DISEASE RECORD BLANK

Crop *Wheat* Disease *Leaf rust (Puccinia triticina)*

County *Adams* Locality *Camp Point*

Variety of crop *Kanred (somewhat impure)* Size of field *20 acres*

State of development *Heads just now emerging from the boot.*

Control measures (Applied (not applied *X* Kind used

When used

How applied

Infection: % of culms diseased *25.8* Amount per plant *20.8 per cent*

Data: *362 in 800*

580 in 3000

348 in 1200

1290 in 5000

Scale classes:

	0	*5*	*10*	*25*	*40*	*65*	*100*
F.	*3*	*19*	*37*	*26*	*14*	*7*	*1*
C. × F.	*0*	*95*	*370*	*650*	*560*	*455*	*100*

$$\frac{S.\,C.\,F.}{S.\,F.} = \frac{2230}{107} = 20.8 \text{ per cent}$$

Type of injury

Estimated damage *20.8% × 25.8% = 5.36%*

Date first observed Source of infection

Past history

Association with other diseases *Stem rust, loose smut, bunt, scab, speckled leaf spot, Septoria nodorum on culm nodes.*

Additional notes (weather, phenology, etc.)

Date of observation *June 19* Specimen No. *T 421*

Observer *L. R. Tehon.*

infection requires not only an examination of numerous plants to prove the presence of the disease but also a close examination of the diseased parts of the plants to determine the average amount of rust on those parts.

To obtain reliable data from any field, the number of plants examined must be large enough to give an average which will be representative of the entire field. There must be standards, also, for measuring the diseased area of leaf and stem, which can be carried and used with ease in the field. One of these standards is already widely used; it, and the others which we have devised, will be described in connection with the diseases with which they are used.

ANALYSIS OF DATA

In order that the observations made in fields by the methods outlined briefly above may be of use, they must be subjected to an analysis which will reduce them to brief and concise statements.

The first step is to make certain that the diagnosis made of the disease in the field is correct. In most instances, a microscopic examination of the sample indicated by the collector's number is sufficient. The sample is labeled with its proper scientific name; this name is noted at the top of the field record; and the serial "accession" number given to the specimen replaces the collector's number on the record blank. The sample is filed according to a system (the details of which are immaterial here) and serves as permanent and substantial evidence particularly of the accuracy of the diagnosis but also to some extent of the severity of the attack. Reference can be made between record sheet and specimen at any future time, and the two together constitute the entire record.

In many cases, two items enter into a calculation of the amount of disease present in a field. One is the proportion of diseased plants, and the other is the amount of disease present on each diseased plant. The latter is expressed as the area of leaf or stem destroyed by disease, or as the proportion of the head injured or destroyed.

With cereals, data are secured for the entire area of a field by making counts of a representative number of stems. In taking data on the leaf rust of wheat, for example, a hundred stems may be counted in one place, two hundred in another, and other quantities in other places, until a large number—10,000 if necessary—have been examined. The same proportion of diseased stalks is not found, as a rule, in each group, and an average must be secured for all the counts. This is done in either of the following ways:

1. If 5000 stalks are examined, the counting may show that

362	stalks	among	800	bore	disease
580	"	"	3000	"	"
348	"	"	1200	"	"
1290	"	"	5000	"	"

The totals show that 1,290 of the 5000 stalks were diseased. The proportion of diseased stalks, expressed finally as a percentage derived from the totals, is in this case 25.8.

2. If, in the same instance, the group counts had been recorded directly as percentages, the following data would appear on the record blank.

45.2	per	cent	among	800	stalks	bore	disease
19.3	"	"	"	3000	"	"	"
29.0	"	"	"	1200	"	"	"

It is not permissible to add and average these percentages. Such a procedure gives for the above figures 31.2 per cent, which, as can be seen from the percentage obtained by the first method, is entirely erroneous. The error arises from the fact that in this average the high percentages found among the smaller numbers of stalks are each given equal weight with the low percentages found in a much larger number of stalks. To avoid this error, these differences must be equalized by giving the percentage of each group a proper weight with respect to the other groups. This may be done by proportion. In the example just cited, in which the total count is 5000, the first count of 800 stems is four twenty-fifths of the total, the second fifteen twenty-fifths, and the third six twenty-fifths; hence the first count, representing 4 of a total of 25 parts, has a relative value, or weight, of 4, while the second and third counts have similar values or weights of 15 and 6, respectively. It is necessary now to multiply the percentage secured in each group count by the weight of its group, add the multiple percentages thus obtained, and compute the average percentage by dividing the total multiple percentage by the total of the weights. The process is as follows:

Group percentage		Group weight		Multiple percentage
45.2	×	4	=	180.8
19.3	×	15	=	289.5
29.0	×	6	=	174.0
		25		644.3

$$644.3\% \div 25 = 25.77\%$$

The average percentage of 25.77 secured in this way is found to be very nearly correct when compared with the 25.8 per cent obtained by the first method.

When the numbers involved are small or so constituted as to be handled easily, this "weighting" may be done more conveniently by carrying the calculations through without first reducing the items to their least common denominator. In the example just given it is immaterial whether the first group is regarded as 4/25 or $\frac{800}{5000}$ of the entire count. Hence the calculation can be performed as follows:

Group percentage		Group weight		Multiple percentage
45.2	×	800	=	36,160
19.3	×	3000	=	57,900
29.0	×	1200	=	34,800
		5000		128,860

128,860% ÷ 5000 = 25.77%

Dividing the sum of the multiple percentages by the total weight of the counts, an average of 25.77 is obtained, which is identical with that secured when the group weights were reduced to their least common denominator. This short-cut is used in the tabulated calculations of the disease data appearing in the tables which exemplify other parts of the analysis.

The method of calculating "weighted" averages, though mathematically a very elementary process, is emphasized and explained in detail at this point because it is of vital importance not only in the treatment of data from a single field but also in the proper evaluation of the data from many fields of varying sizes and locations. It is employed as a basic principle in all the statistical summaries of data reported in this paper.

The foregoing example illustrated only the means of arriving at the proportion of plants bearing disease, but in most cases this alone is not a sufficiently complete statement of the amount of disease. With diseases such as the rusts, a large part of the plant is capable of becoming infected and destroyed; but usually the infection does not reach its maximum; and the result is that it is necessary to measure the extent of the infection on the diseased plants. By comparing a number of representative diseased parts with prearranged standards which indicate accurately the surface area, or some similar characteristic, occupied or destroyed by the disease, an exact statement of the extent of infection can be obtained for a sample; and the average of an adequate sample may be considered as representing the average amount of disease on each diseased plant.

Because they apply only to the diseased plants in the field, the data thus far secured are not yet satisfactory. An average is needed which is applicable to every plant in the entire field, and which may be compared with averages from other fields. The method used to obtain such an average can be explained best by continuing the example that has been in use.

In it, leaf rust was shown to occur on 25.8 per cent of the wheat stems in a field. A number of leaves selected at random from these stems show, when compared with the rust-measuring standard, an average of 20.8 per cent of their surface area occupied by rust. Since these leaves were taken only from rust-infected plants, this figure represents only the average amount of disease on each diseased plant. In order to transform it so that it will be applicable to the entire field, the following theoretical calculation is used as a basis.

Let the various items of the calculation be indicated by symbols, as follows:

D = the average amount of disease per diseased plant.
P = the number of diseased plants.
T = the total amount of disease on all the diseased plants.
N = the total number of plants in the field, whether diseased or not.

Then, the average amount of disease per plant in the field may be found by evaluating $\frac{T}{N}$.

However, as it is apparent from the above that $T = D \times P$, by substituting, the average amount of disease per plant is equivalent to $\frac{D \times P}{N}$.

Since percentages can be used as well as integral numbers, the percentages of the example can be substituted for the symbols of the formula, giving $\frac{20.8 \times 25.8}{100}$, the value of which, 5.3664 per cent, represents the average amount of disease for every plant in the field in question.

As it is customary to record data secured in routine field examinations as percentages, a convenient short-cut may be taken, in which the percentages are treated as decimals—.208 x .258 in our example. Percentages being expressions of parts per hundred, the use of the decimal point automatically eliminates the denominator of the fraction given in the preceding paragraph, and the result—.053664—appears at once as the product of the two decimals. This product may be expressed as a percentage by moving the decimal two places to the right.

By the methods now outlined, the following data have been secured from the field represented by the record blank shown on page 4.

1. 20 acres of wheat.
2. 25.8 per cent of the stems bearing disease.
3. 20.8 per cent of the leaf area on these culms destroyed by disease.
4. 5.36 per cent of the leaf area infected, on an average, for every stem in the field.

These items are recorded for every field examined, as many fields of each crop being visited each season as circumstances will permit. In bringing together the data for each disease, the field record sheets, assorted by diseases, are arranged in their folders first by counties (the counties, for convenience, following one another in the alphabetic sequence of their names), and then in the order of dates of examination. Finally, they are given numbers which are placed at the upper right-hand corner and serve the same purpose as the numbering of the pages of a book.

The data presented by the sheets in each folder are then arranged in a table, in the manner illustrated by the following short tabulation.

TABLE I

AN EXAMPLE OF THE FIRST TABULATION AND CALCULATION MADE WITH THE DATA PRESENTED BY THE FIELD RECORD SHEETS

The data used relate to wheat leaf rust

			Prevalence: Stems with diseased leaves			Destructiveness: Leaf-area diseased		
Record sheet No.	County	Acres examined	Percentage observed	Acreage-percentage product	Weighted percentage	Percentage observed	Acreage-percentage product	Weighted percentage
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	Adams	20	25.8	516		20.8	10,732	(5.3)
2	Adams	12	100.0	1,200		40.0	48,000	(40.0)
3	Adams	20	90.0	1,800		65.0	117,000	(58.5)
	Total	52		3,516	67.6		175,732	**33.7**
37	Tazewell	40	100.0	4,000		55.0	220,000	(55.0)
38	Tazewell	20	90.0	1,800		60.0	108,000	(54.0)
39	Tazewell	20	90.0	1,800		30.0	54,000	(27.0)
40	Tazewell	20	60.0	1,200		20.0	24,000	(12.0)
	Total	100		8,800	88.0		406,000	**40.6**
42	Will	1	100.0	100		7.0	700	(7.0)
43	Will	40	90.0	3,600		15.0	54,000	(13.5)
	Total	41		3,700	90.2		54,700	**13.3**
	Total	193		16,016	82.9		636,432	**32.9**

The first column contains the page numbers of the record sheets, which serve as a means of referring the figures in the table to the sheets from which they are taken. In the second column appear the names of the counties in which the observations were made, and in the third column are the acreages of the fields examined.

The fourth, fifth, and sixth columns are concerned with data bearing on the proportion of disease-bearing plants. In column 4 appear the observed percentages shown by the record blanks; and, in order that the necessary calculations may be made, column 5 contains the products secured by multiplying the acreage of each field by the percentage of diseased plants found in it. For want of a better term, this quantity is called the "acreage-percentage product." Since the individual percentages entered in column 4 usually apply to fields of different sizes, computing this product gives a proper acreage weight to each observation. The process of weighting in terms of acreage is exactly similar to that explained already (see pp. 6 and 7), the construction of the table permitting, however, the use of the short-cut described therewith.

The sixth column contains the percentages indicated by the weighting process as the proper averages for the county groups of data on prevalence and, finally, the weighted average for all these data.

The last three columns show the amount of disease per plant. The percentages of disease observed in the individual fields are entered in column 7 directly from the record blanks. The process of "weighting" to secure the true average percentage for all the observations requires that the product of the items of columns 3, 4, and 7 shall be obtained in each instance. When secured, it is listed in column 8. From it, a percentage, listed in column 9, is obtained for each observation by dividing by the acreage. In the table above, this final figure for each field is shown in parentheses because it is not used in computing the final results. In practice, it is neither computed nor written into the table. The weighting accomplished in column 8 permits direct computation of average percentages of diseased leaf-area for each county and for all the data. These important items appear in bold-face type, in the last column, and in practice they are the only figures entered there.

This table, which is made up entirely from the data secured in the field, is designed to show:

1. Prevalence of disease, by counties, in terms of diseased stems.
2. Severity of disease attack, by counties, in terms of plant parts occupied, or killed, by the disease-producing organism.
3. Prevalence and severity for the total acreage examined.

To distinguish between prevalence and severity is not only logical but necessary. It is comparable to the distinction made between the prevalence and the mortality-rate of human diseases. The prevalence of diphtheria, for example, is expressed as the proportion of the population contracting the disease, but the mortality—the deaths—due to it, being much less than the former, is a separate consideration. The proportion of plants becoming infected is, quite comparably, a measure of the prevalence of plant disease, and the amount of plant tissue occupied or killed is likewise a proper measure of what may be termed "plant mortality." Hence, the figures which conclude the above table may be interpreted as meaning that the disease to which they refer was 82.9 per cent prevalent and resulted in a "mortality"—destruction—of 32.9 per cent of leaf, in the acreage examined.

The term prevalence is quite appropriate; but the fact that few diseases bring about either immediate death or complete destruction of the plants they attack makes it desirable to replace "mortality" with a more suitable word. The attacks of cereal diseases are limited, in the main, to specific plant parts, either actually, as are leaf spots and rusts, or in their outstanding effects, as are smuts. The damage they do is correspondingly limited, consisting of a measurable destruction of particular parts. For this reason, "destructiveness", applied to the parts of an individual plant, is a better expression of the severity of attack.

The weighted prevalence and destructiveness percentages determined in the foregoing table and in two others described on subsequent pages, besides being precise analytical summaries of data, may be regarded also as arbitrary indexes. Complete prevalence or destructiveness would have an index of 100, while lesser degrees of prevalence or destructiveness would have indexes proportionately less—82.9 and 32.9 in the example.

Because the quantity of data pertaining to any disease that is secured in a season is limited by the amount of help available, the duration of the period of prevalence, and the opportunities for examining the crop it infects, that which is obtained is regarded as exemplifying the disease condition existing not only in the fields that were seen but also in the territory adjacent to them, and in the State as a whole. It is, therefore, necessary to transform the field data, by more extensive calculations, into terms representative of these larger areas.

Statistics relating to acreages and yields of crops in Illinois are furnished in the reports of the Agricultural Statistician*, in which the counties, used as statistical units, are grouped into the nine geographic districts shown in Figure 1. Acreages and yields are given not only for

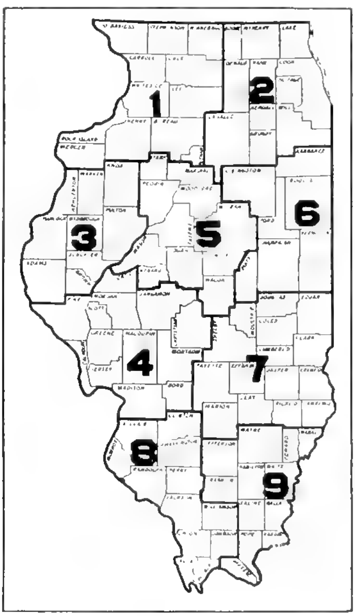


FIG. 1. THE DISTRICTS INTO WHICH ILLINOIS IS DIVIDED IN COMPILING AGRICULTURAL STATISTICS

The counties of Illinois are divided by the Agricultural Statistician into these 9 nearly-equal groups. The same grouping is utilized conveniently in the analyzing of plant disease data in connection with agricultural statistics.

the entire State but for the counties and districts as well. Because the observations on diseases of cereals are made on an acreage basis, the statistical units adopted for crops are conveniently utilized in the further analysis suggested above.

Adjacent territory is defined, for statistical convenience, as the acreage devoted to a particular crop in the county in which disease prev-

* Illinois crop and livestock statistics. Issued by the U. S. Dept. Agr., Bureau of Agricultural Economics cooperating with Illinois Dept. Agr.

alence and destructiveness have been measured in sample fields. The weighted percentages, expressive of prevalence and destructiveness, that were obtained for county groups of data in the foregoing table are held to represent the prevalence and destructiveness of disease in the entire acreage devoted to the diseased crop by those counties. Proceeding on these assumptions, the county acreages reported in the agricultural statistics and the disease indexes for the counties shown in the first table are combined in a second tabular computation, in the following manner.

TABLE II

AN EXAMPLE OF THE SECOND TABULATION AND CALCULATION MADE WITH DISEASE DATA

The county acreages for a given crop, as estimated by the Agricultural Statistician, are combined with the county indexes of prevalence and destructiveness computed in the first tabulation, and indexes obtained from them for the total acreage directly represented by the sample fields. These data apply to the leaf rust of wheat.

County	Wheat acreage per county	Prevalence: Stems with diseased leaves		Destructiveness: Leaf-area diseased	
		Weighted percent-ages per county	Acreage-percentage product per county	Weighted percent-ages per county	Acreage-percentage product per county
1	*2*	*3*	*4*	*5*	*6*
Adams	61,400	90.0	5,526,000	40.4	2,480,560
Gallatin	29,600	100.0	2,960,000	15.0	444,000
Hamilton	24,500	22.8	558,600	7.7	188,650
McLean	42,300	93.7	3,963,510	39.8	1,683,540
White	59,300	97.4	5,775,820	38.6	2,288,980
Totals for the counties listed	217,100	86.6	18,783,930	32.6	7,085,730

In column 1, all the counties are listed which appeared in the first tabulation. Their acreages of the crop concerned, taken from the Agricultural Statistician's reports, are listed in the second column. In columns 3 and 5 appear the weighted percentages of prevalence and destructiveness, respectively, which were computed for each county in the first table. As the acreage devoted to a given crop in one county is seldom the same as in another, it is necessary to give the percentages of each county weights which are proportionate to their acreages. Weighting is done here in the same manner as in the first tabulation, except that, since a true percentage of destructiveness is used in column 5, the acreage-percentage product in column 6 is obtained directly as the product of the items in columns 2 and 5.

When all the items needed for the tabulation have been set down or computed, the figures in columns 2, 4, and 6 are added, and the totals of columns 4 and 6 are each divided by the total of column 2. More specifically, the sums of the acreage-percentage products for prevalence and destructiveness each are divided by the total acreage of the crop in the counties listed. The resulting quotients—86.6 and 32.6 in the example—are weighted percentages indicative of the prevalence and destructiveness, respectively, of the disease in question in the entire territory adjacent to the fields from which data were obtained by examination.

In order to compare prevalence and destructiveness of diseases year by year for the entire State or for smaller districts, it is necessary to go a step further and compute indexes which will apply to the State's total acreage of a given crop in each year, and to the acreages of the statistical districts (see page 11). Satisfactory indexes can be obtained for this purpose by extending the observed data, first to the county acreages, as was done in the foregoing table, and then to the total acreages of the agricultural districts and of the State. An example of the method is given in the following table.

TABLE III

AN EXAMPLE OF THE TABULATION AND CALCULATION USED TO OBTAIN INDEXES OF PREVALENCE AND DESTRUCTIVENESS FOR EACH OF THE NINE DISTRICTS AND FOR THE ENTIRE STATE

These data apply to the leaf rust of wheat. For the sake of brevity, it is assumed in this example that the State is composed of the three districts listed.

Counties grouped by districts	Wheat acreage per county	Acreage-percentage products by counties		Weighted percentages by districts		Wheat acreage per district	Acreage-percentage products by districts	
		Prevalence	Destructiveness	Prevalence	Destructiveness		Prevalence	Destructiveness
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Dist. 2								
Cook	3,200	10,560	512					
La Salle	41,300	4,130,000	826,000					
Total	44,500	4,140,560	826,512	93.0	18.5	146,000	13,578,000	2,701,000
Dist. 3								
Adams	61,400	5,526,000	2,480,560					
Hancock	57,300	5,512,260	1,358,010					
McDonough	44,000	4,400,000	880,000					
Total	162,700	15,438,260	4,718,570	94.8	29.0	343,000	32,516,400	9,947,000
Dist. 7								
Coles	22,100	360,230	50,830					
Douglas	21,600	1,944,000	388,800					
Fayette	44,100	4,410,000	934,920					
Marion	14,600	1,460,000	511,000					
Shelby	40,800	3,170,160	428,400					
Total	143,200	11,344,390	2,313,950	79.2	16.1	303,000	23,997,600	4,878,300
State total	......	....	....	88.5	22.1	792,000	70,092,000	17,526,300

With the exception of the district acreages shown in column 7, which must be secured from the reports on agricultural statistics, this table is made up entirely from Table II.

First, the counties appearing in the two previous tables are arranged in proper district groups in accordance with the districting in the statistical reports (see page 11). They then are listed in column 1. In columns 2, 3, and 4, the acreage of the crop per county and the acreage-percentage products relating both to prevalence and destructiveness are entered, the figures being transferred directly from Table II. Totals are taken of the items in these columns for each district, and the weighted district percentages shown in columns 5 and 6 are obtained by dividing the two sums of the acreage-percentage products by the total county acreage. The resulting quotients represent prevalence and destructiveness by districts.

In column 7 are the acreages reported by the Agricultural Statistician to be devoted to the crop in question in each of the districts. The acreage-percentage products in columns 8 and 9 are based on these district acreages. They are obtained by multiplying the district acreages by the corresponding weighted percentages entered in columns 5 and 6.

When all of these items are entered, totals are taken for columns 7, 8, and 9. The totals of columns 8 and 9 are divided by the total of column 7, which is the State acreage of the diseased crop. The quotients thus obtained are placed, for convenience, at the foot of columns 5 and 6. These final weighted percentages—88.5 and 22.1 in the example—are concise expressions of the average prevalence and average destructiveness of a disease throughout the State.

It probably has been noticed that in the sample tables no calculations have been carried farther than one decimal place. Because most of the computations involve percentages, which are arithmetically really decimals extended to the second place, the usual mathematical procedure would be to stop the calculations with the first decimal and then either increase the unit place by one or discard the decimal, as it was either greater than 0.5 or less than 0.6. However, as round numbers occur very often in the acreage statistics, it is possible to retain the decimal without adding greatly to the labor. The result is that the final percentages, though not greatly influenced, are a trifle more accurate than they otherwise would be.

In practice, computations similar in all respects to those just described are made whenever possible for every disease for which field data are secured, and each year's folder of field records for each disease contains these statistical analyses, comprised of the three complete tables, as a part of the permanent record.

DATA ON THE YEAR-TO-YEAR PREVALENCE AND DESTRUCTIVENESS OF CEREAL DISEASES

In order to obtain useful data on disease prevalence, fields must be examined in as many parts of the State as possible. Traveling by automobile, observers go from county to county, visiting fields along the way. This amounts in practice to a random sampling of disease conditions in crops throughout the State, the quantity of samples taken of each disease on each crop depending on the intensity of cultivation accorded it, the number of observers at work, and the length of time elapsing between the appearance of a disease and the arrival of harvest.

The procuring of the data presented in this paper has been influenced also by the fact that the observers at the same time were gathering similar information on diseases of the tree and bush fruits and forage and truck crops. Through the summer of 1922, four men acted as observers; in the summers of 1923, 1924, and 1926, two men; and for the greater part of the summer of 1925, only one man. This, together with the large size of the State, the number of crops to be examined, and the number of diseases—more than 200 of which are serious—to be seen, contributed to what may appear an unnecessarily haphazard grouping of the grain fields subjected to examination. But the wide prevalence of diseases and the comparative uniformity of their destructiveness in regions having the same latitude compensate in a large measure for these apparent but unavoidable faults.

Cereal crops are grown throughout the State, some intensively in all parts, others only in restricted regions. The acreages devoted to particular kinds vary considerably in different regions, as shown by Figure 2 which presents graphically the acreage statistics reported for 1925 by the Agricultural Statistician. The lines in this figure which divide the State into four roughly equal parts follow county boundaries, separating the counties into groups characterized in the main by the intensity with which certain cereals are cultivated.

Corn predominates in each of the four sections, with a total of 9,240,000 acres in the State, or almost 56 per cent of the total acreage for all grain crops. Oats rank next to corn except in the south where the oat acreage is exceeded by the wheat acreage. Wheat has large acreages everywhere, although it is exceeded by barley in the north. Barley is important only in the north, and rye is unimportant when compared with the others.

In the two central sections, which together have 62 per cent of the State's grain acreage, the order of importance of the various crops is: (1) corn, (2) oats, (3) wheat, (4) rye, and (5) barley.

In the northern section, the order of importance of crop acreages is: (1) corn, (2) oats, (3) barley, (4) wheat, and (5) rye.

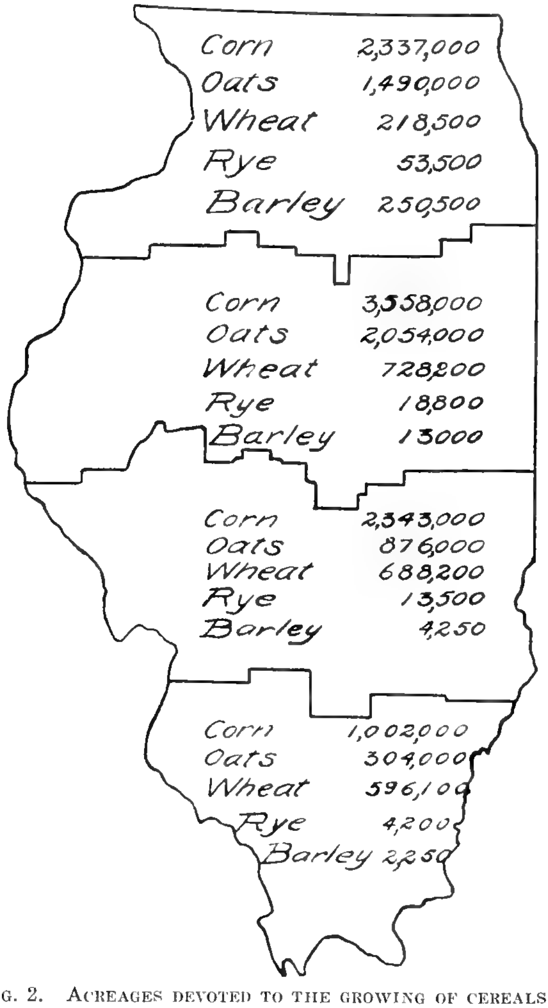


FIG. 2. ACREAGES DEVOTED TO THE GROWING OF CEREALS IN DIFFERENT SECTIONS OF ILLINOIS (1925)

Next to corn, which is the most important crop throughout the State, oats have the largest acreages in all sections except the south where wheat is grown more extensively than oats. Wheat is a major crop in all sections except the north where its acreage is slightly smaller than the barley acreage. Rye, though important in the north, is almost negligible when compared with the other cereals.

A slightly different order prevails in the south, where wheat is second only to corn, with an acreage almost twice as great as the oats acreage. Rye and barley, both unimportant, are fourth and fifth, as in the two central sections.

The data secured in sample fields representing these acreages and analyzed in accordance with the simple methods described in the preceding pages will serve as bases for comparing both the prevalence and the destructiveness of diseases during the period covered by the survey—1922-1926. For brevity of treatment, it is advisable to group cereal diseases into general classes according to the kinds of injury they cause, thus bringing together those requiring similar handling both in securing and in analyzing data, in order to eliminate constant repetition of method and description. If descriptions of individual diseases more complete than those given here are desired, they may be found in the report referred to at the beginning of this paper.

Cereals are grown in fields comprising, as a rule, rather large acreages. The plants are small and grow closely crowded together. These two facts have an important bearing on the obtaining of disease data, for even in a very small field an examination of every plant is an impossibility and, furthermore, the crowding of plants makes it extremely difficult to distinguish one from another without digging out and carefully separating them—a procedure which would not, and should not, be tolerated by the owner of a field.

Hence, it is necessary, in securing data representing prevalence, to use the stem instead of the plant as a unit. The degree of prevalence is indicated by the proportion of disease-bearing stems. Counts are made of a number of stems sufficiently large to give a dependable representation of the infection in the field. Because of variations in soil and topography, disease prevalence is apt to vary noticeably from one part of the field to another. In order to equalize such variations, parts of the field count are apportioned to different places. The selection of the places for the counts and the decision as to the comparative number of stems to be counted in each place rests upon the judgment of the observer, but his aim must be to secure as true a representation as possible.

Inasmuch as each disease destroys a particular part of its host, the measure of destructiveness must be suited to that part. The device used is described in the discussion of each disease.

It should be explained at this point, however, that although neither the devices for measuring destructiveness nor the methods of computing values from the data obtained by using them were employed extensively or consistently in the first years of the survey, the collection and preservation of adequate and representative samples enabled us to measure, at a later time, the destructiveness of diseases during those years.

CEREAL RUSTS

The most constantly prevalent type of disease in our grain fields is that known as rust. No cereal crop grown in Illinois escapes attack, and with the exception of corn, each is subject to two distinct rust diseases. The rusts are almost unique, in that they are not amenable, under present agricultural practices, to treatments designed either to prevent their attack or reduce their destructiveness. They present, therefore, the outstanding opportunity for a study of the relation of disease to the natural environment.

Rusts do not kill their hosts. Individual infections are limited to very small portions of the plant, seldom extending over an area twice that of the rusty pustule which is the outward sign of the disease; but a multiplicity of individual infections results in the conversion of a large part of the host tissue to the uses of the parasite, giving the appearance of a heavily rusted plant. Measuring the destructiveness of a rust attack thus becomes a matter of ascertaining the relative abundance per plant of the individual infections, or—for convenience—the relative amount of plant surface occupied by pustules. An actual measurement of this area would be impracticable, of course, under field conditions, and a substitute must be used.

A standard was devised by N. A. Cobb in 1892, which he used extensively and successfully while studying rust diseases of grains in Australia. An adaptation of it which has been used extensively in experimental work has been found equally useful for field work. As indicated in Figure 3, it consists of a number of diagrammatic pictures

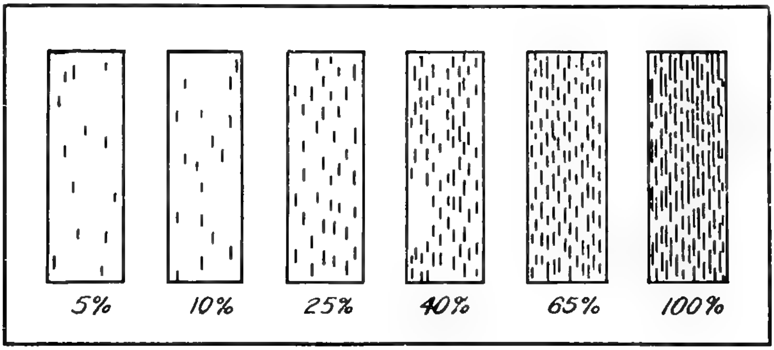


FIG. 3. SCALE USED IN MEASURING THE INTENSITY OF RUST ATTACKS

Because the diagram at the right represents the highest possible degree of infection, it is assigned an arbitrary value of 100 per cent., and the gradations represented by the other diagrams are in the indicated proportions with respect to it. Specimens of rust, selected at random in a field, are compared with the standards in this scale, and an average of the readings so secured represents the infection in the field. (See page 19.)

which illustrate a series of typical rust attacks ranging from slight to heavy by easily distinguishable intervals. The classification of the units in the series is based on the relative abundance of rust pustules. The heaviest attack illustrated is the heaviest infection possible and is given an arbitrary value of 100 per cent, the lesser infections being graded as percentages in their proper relation to the heaviest.

A copy of this scale is carried by the observer in a small notebook. As he makes his counts in a field to determine the number of stems carrying rust, he selects from time to time and quite at random a copious sample of the disease, which, either then or later, is compared with the scale by fitting its individual parts, one after another, between the two diagrams which they most closely resemble. In order to eliminate errors of judgment as completely as possible, each part of the sample is classed as the lesser of the two units of the standard between which it falls, rather than being assigned an estimated intermediate value. From one sample so measured (see the typical record sheet on page 4), the following data were secured.

Scale classes of rust abundance	Number of parts of the sample in each class	Class value times frequency
0 per cent	3	0
5 " "	19	95
10 " "	37	370
25 " "	26	650
40 " "	14	560
65 " "	7	455
100 " "	1	100
	107	2,230

Destructiveness (mean for the sample) of rust on disease-bearing stems, $\frac{2230}{107} = 20.8$ per cent.

These items are recorded on the field record sheet, and serve as a complete and permanent record of the examination made in that field.

Since the individual values given above have no adaptability as a usable figure, they must be reduced to a single value representative of the whole sample. The simplest way to obtain it is to compute the arithmetical mean. This process will require some explanation. Since it is obvious that the larger numbers of moderately rusted sample parts will have a greater significance than the lesser number of heavily and lightly rusted parts in determining the average of the sample, it is necessary to give each class of infection its proper weight with respect to the other classes, as determined by the number of parts of the sample falling in it, by multiplying the value of the rust-class by the frequency with which it occurred in the sample. The product in each instance, indicated in the above tabulation as "class value times frequency," shows approximately the total rust infection in that class, and the sum of these products is approximately the total rust infection in the sample.

To find the average rustiness of the sample, it is now necessary only to divide the sum of the products of the class values and frequencies by the number of parts in the sample. The value resulting, 20.8 per cent in the above example, is considered to represent the destructiveness of the rust on the disease-bearing stems. For the field as a whole, destructiveness is calculated by the methods outlined previously (p. 8).

In the main, the rusts of cereal crops are classified as "stem" rusts and "leaf" rusts, according to the plant part which they customarily inhabit. This characteristic demands that the destructiveness of stem rusts be measured as diseased stem surface and that of leaf rusts as diseased leaf surface. It is customary to speak of stem area and leaf area, rather than "surface."

WHEAT LEAF RUST

Caused by *Puccinia triticina* Erikss.

The period during which wheat leaf rust has been under observation extends from the spring of 1922 through the harvest of 1926. In each of these five seasons, fields of many varieties of wheat were examined in many parts of the state, and careful records were kept and summarized in accordance with the statistical methods previously explained. Each year's records represent as accurate a statement of the prevalence and severity of leaf rust as could be obtained by sampling, with the means at hand.

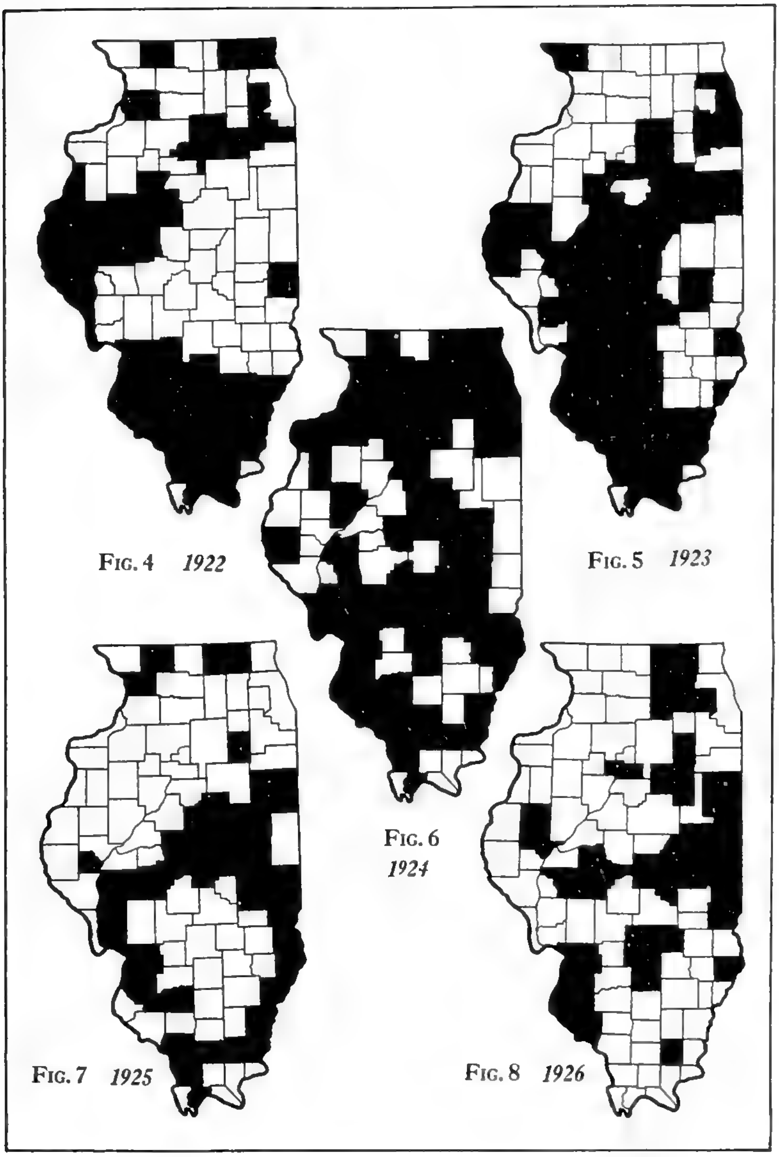
During the early summer of 1922, before wheat harvest, leaf rust was observed in 139 fields, so distributed as to furnish data applying to the territory shown in black in Figure 4. This being the first season of attempted quantitative recording, it was found later that only 43 of these fields had been sufficiently well examined to allow statistical consideration of the observations. These fields, which were distributed among 17 counties, contained 862 acres. In them, an average of 95.4 per cent of the wheat stems bore rust-infected leaves, and an average of 50.6 per cent of the entire leaf area was occupied by pustules.

An exceedingly large number of fields were examined in 1923, records relating to leaf rust being secured from a total of 10,963 acres distributed among the 52 counties shown in Figure 5.

In this acreage, the average proportion of stalks bearing rust-infected leaves was 92.0 per cent; in the entire acreage of the counties represented, 91.0 per cent; and for the state as a whole, 89.7 per cent. It was determined that the rust pustules occupied an average of 46.6 per cent of the leaf area of every stem in the acreage examined, 33.8 per cent in the county acreage, and 31.3 per cent in the state's acreage.

Records were taken on the prevalence of leaf rust in 1924 from fields containing 8,686 acres. They were distributed among the 68 counties shown in Figure 6.

For the acreage involved, an average of 74.6 per cent of the wheat stems bore rust-infected leaves, and 49.5 per cent of the leaf area per stem was occupied by pustules. When the data were extended to the county acreages, the index of prevalence became 67.4 and that of destructiveness 19.1; while for the entire state the index of prevalence was 68.3 and of destructiveness 19.1.



FIGS. 4–8. SOURCES OF WHEAT LEAF RUST DATA, 1922–1926

The black regions on these maps show the territory from which data were taken each year. Nearly 16,500 acres of wheat were examined in the five years. These maps do not represent the distribution of the disease, which is supposedly state-wide every year, but simply show the counties in which our observations were made. (See page 20.)

In 1925 records of leaf rust were taken in fields aggregating 3,225 acres. The fields in which the observations were made were distributed among the 36 counties shown in Figure 7. When the data that were secured were subjected to analysis, the ratio of stalks bearing rusted leaves in the acreage examined was found to be 63.5 per cent and the average amount of rust-occupied leaf area per plant 6.5 per cent. The index of prevalence for the total county acreage represented by the sample fields was 46.3 and the index of destructiveness was 6.0, while for the entire state the indexes were 52.6 and 17.1, respectively.

Fields aggregating 1,445 acres and distributed among the 31 counties shown in Figure 8 furnished leaf rust data in 1926. Since agricultural statistics have not yet been provided for this year, it has been impossible to carry out all of the usual computations; but the data secured show in their preliminary analysis, that in the acreage examined 57.2 per cent of the stems carried rusted leaves and 11.2 per cent of the leaf area was occupied by pustules.

As a very close agreement has been evident between the indexes secured directly from field data and those secured for district and State acreages by indirect computation, the direct indexes for 1926 will be compared in subsequent pages with the computed indexes of previous years.

The summarized data for the five seasons are brought into closer comparison in the following table:

Year	Acreage examined	Prevalence: Calculated percentages of wheat stems bearing diseased leaves			Destructiveness: Calculated percentage of leaf area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State's wheat acreage	For the acreage examined	For the county acreage represented	For the State's wheat acreage
1922	862	95.4	94.9	94.1	50.6	53.9	50.3
1923	10,963	92.0	91.0	89.7	46.6	33.8	31.3
1924	8,686	74.6	67.4	68.3	49.5	19.1	19.1
1925	3,225	63.5	46.3	52.6	6.5	6.0	17.1
1926	1,445	57.2	....	....	11.2	....	....

There is a considerable difference in both the prevalence and the destructiveness of leaf rust between any two years, and there has been a marked and continued decrease in both through the five-year period. The first two of the five years were characterized by very heavy attacks, while in each of the last three years the attack was moderate or light. When considered from the point of view of destructiveness alone, these contrasts are especially evident, but they are borne out in very certain terms also by the corresponding decrease in prevalence.

OATS CROWN RUST

Caused by *Puccinia coronata* Corda.

The crown rust of oats is essentially a leaf rust, at least under average Illinois conditions, for though it often attacks the stems, infection as a rule does not occur there until a day or two before harvest and usually results in but little damage. Quite early in the season, however, its red pustules appear on the leaves, multiplying rapidly until harvest.

Measurements of the destructiveness of crown rust are obtained in exactly the same way, and by employing the same standard, as are those of the leaf rust of wheat (see page 19 and Figure 3).

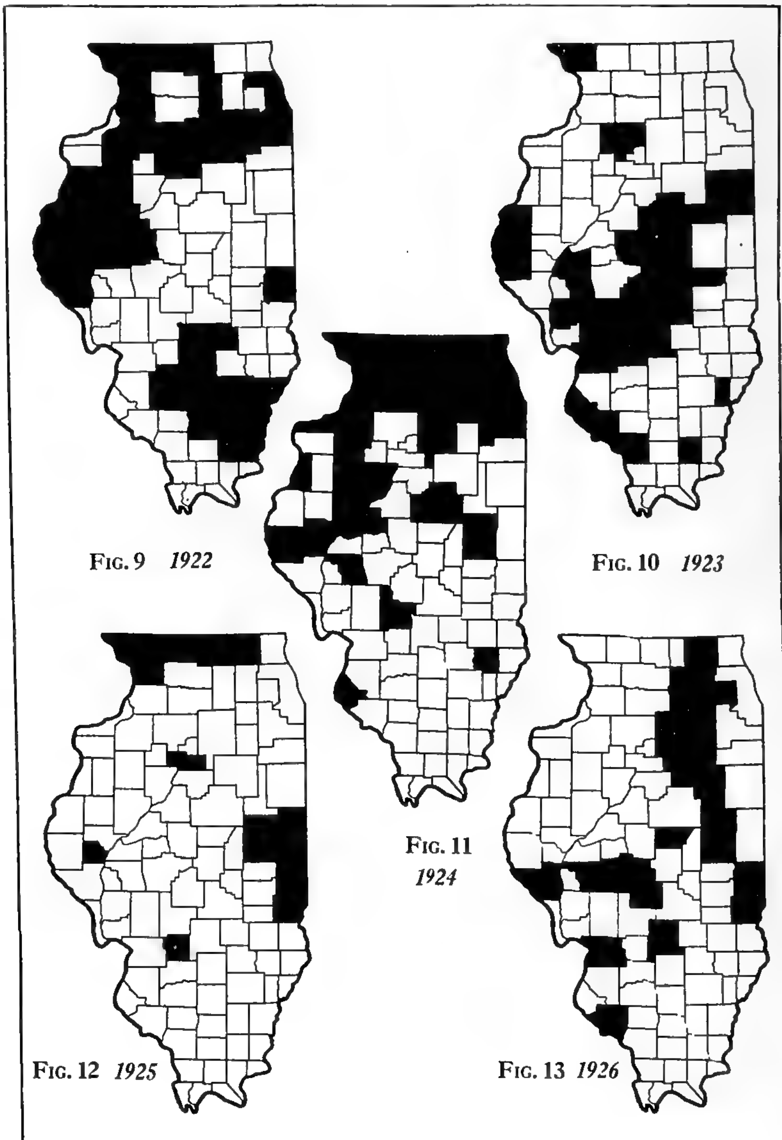
In 1922 crown rust was seen in oat-fields distributed among the 44 counties shown in Figure 9. Data were secured from 705 acres, the remaining fields not having been sufficiently well examined to give usable information. In this acreage, 78.7 per cent of the stems bore rust infected leaves, 37.6 per cent of the leaf area being occupied by pustules. The field data when applied to the total acreages of the counties which they represented, gave a prevalence index of 69.2 and a destructiveness index of 28.0. The indexes for the State's acreage are respectively 67.0 and 27.3.

The epidemic of 1922 was preceded by an abundant and heavy fall infection on volunteer oats throughout at least the southern half of the state. This infection is known to have extended on the eastern side of the state as far north as Champaign County where specimens of actively sporulating rust were collected as late as the latter part of October.

In 1923 crown rust infection was observed in fields located in the 28 counties shown in Figure 10. Fields totaling 1,306 acres were examined, and the records secured in them indicate a prevalence of 93.5 per cent and a destructiveness of 41.2 per cent. For the total county acreage to which the data applied, the indexes were 83.3 and 28.8 for prevalence and destructiveness, respectively, while for the State's acreage they were 83.1 and 30.6.

The epidemic of 1923 was early in starting. By June 4 an infection was observed in Jackson County involving an average of 25 per cent of the leaf area on 50 per cent of the stems, and two days later infection was seen in Saline County involving 1.5 per cent of the leaf area on about 10 per cent of the stems. The infection, thus started, spread and increased until, by harvest, the heavy epidemic indicated by the figures given above had developed.

In 1924, crown rust was observed in fields located in the 33 counties indicated in Figure 11. It is remarkable that the epidemic of this year, as suggested by the map, was confined largely to the northern section of the state, the crop in the south almost completely escaping attack. Field data were secured from 1,080 acres parcelled among 29 counties. The analysis of them indicates that in those fields 79.9 per cent of the oats stems bore infected leaves and that 14.8 per cent of the leaf area was occupied by pustules. The data, when applied to the total county acreage of which they are typical, show a prevalence index of 65.7 and a destructiveness index of 10.7. For the State's acreage, these indexes are 64.3 and 11.9, respectively.



FIGS. 9–13. SOURCES OF DATA ON OATS CROWN RUST, 1922–1926

The black regions on each of these maps show the territory from which data were taken in each year of the period. The fields examined contained more than 4,000 acres. (See page 23.)

The rust was late in getting started. All the observations were made during July and August, the earliest July fifth in Adams and Brown Counties, at which time the crop was already ripening. One isolated and very early report from the north (June 27 at Rockford) showed an exceedingly light infection apparently originating from a crown rust infected buckthorn hedge nearby, but elsewhere the usual seasonal development prevailed.

Crown rust was not a very important disease in 1925. Records of its presence were secured only from the 13 counties shown in Figure 12, which lie chiefly in the northern half of the state. The earliest infection was seen near Greenville, in Bond County, where, by June 26, an average of .03 per cent of the stems bore rusted leaves, one leaf on each of these stems having one or two pustules.

The fields from which data were secured contained only 297 acres In them, an average of 14.8 per cent of the stems bore rust, only .17 per cent of the leaf area being occupied by pustules. These data may seem to be insufficient for further use, but in view of the very mild attack it is worth while to evaluate them for the greater acreages. For the total county acreages of which they are typical they indicate a prevalence of 28.2 per cent and a destructiveness of .4 per cent, while for the State's acreage the corresponding figures are 27 per cent and .6 per cent, respectively.

In 1926, crown rust appeared early. It was found first June 2 near Marshall, Clark County. Throughout the southern half of the state this original infection was so slow in spreading that it never reached heavy proportions; but farther north, after becoming established, it spread rapidly and became exceedingly abundant. As a result, records were obtained chiefly in the north. The fields from which records were taken were distributed among the 20 counties indicated in Figure 13, aggregating 697 acres.

In them, 70.4 per cent of the culms bore crown rust and 9.9 per cent of the leaf area was occupied by pustules. Owing to the lack of acreage statistics, the data can not be carried farther to show the prevalence and destructiveness of the disease throughout the state.

For closer comparison of the differences in crown rust infections in the years concerned, the data are brought together in the following table:

Year	Acreage examined	Prevalence: Calculated percentages of oat culms bearing diseased leaves			Destructiveness: Calculated percentages of oat leaf area occupied by rust pustules		
		For the acreage examined	For the county acreage represented	For the State's oats acreage	For the acreage examined	For the county acreage represented	For the State's oats acreage
1922	705	78.7	69.2	67.0	37.6	28.0	27.3
1923	1,306	93.5	83.2	83.1	41.2	28.8	30.6
1924	1,080	79.9	65.7	64.3	14.8	10.7	11.9
1925	297	14.8	28.2	27.0	.17	.4	.6
1926	697	70.4	....	....	9.9	....	....

No two years show exactly the same indexes, and even when the indexes of prevalence are similar, as in 1922 and 1924, those of destructiveness are quite different. With respect to prevalence, the five years listed fall into two groups, 1922, 1923, 1924, and 1926 showing great prevalence and 1925 slight; but with respect to destructiveness, there is an even more distinct grouping, 1922 and 1923 ranking high and the subsequent years very low.

BARLEY LEAF RUST

Caused by *Puccinia simplex* (Koern.) E. & H.

The method of measuring the leaf rust of barley is the same as that used in the two leaf rusts just discussed, but since the host crop is confined in a very large measure to the northernmost third of the state (see page 16), the data must be held to apply particularly to that region.

Owing to the limited distribution of the barley fields, which are concentrated in the north but occasional elsewhere, data for this disease have not been obtained in the same abundance as for the ones previously discussed. Although in some cases they are too few to be treated statistically, they are summarized here very briefly in order to afford such comparison as they will permit in the latter part of this paper.

In 1922, in a single field examined in Boone County 25 per cent of the stems carried rusted leaves, about 5 per cent of the leaf area being rust-covered. This indicates an average destructiveness of about 1.2 per cent. In 1923, a single examination, similar to the one above, made in Ogle County showed a prevalence of 100 per cent and a destructiveness of 5 per cent.

Single fields were examined in 1924 in Kendall, McHenry, Lee, and Ogle Counties. They contained a total of 40 acres, in which 100 per cent of the stems were so lightly rusted that only 4.4 per cent of the leaf area was occupied. Only 1 field furnished data in 1925. In 15 acres near Rockford 5 per cent of the leaf area was occupied by pustules, but the disease was confined to 34.6 per cent of the stems.

The data for 1926 were more complete. In the north, records taken from fields in Boone, DeKalb, DuPage, Kane, and McHenry Counties showed 100 per cent of the stems to be rust-infested and 10 per cent of the leaf area rust-covered. Other records were secured in Jackson and Mason counties. Only a trace of rust was found in the first county, but in the second 1 or 2 infected leaves, each bearing from one to five pustules, occurred on 13 per cent of the stems. Averages of these data indicate a prevalence of 76.1 per cent and a destructiveness of 7 per cent.

The several years compare as follows:

Year	Prevalence: Observed percentage of stems carrying rust	Destructiveness: Observed percentage of leaf area occupied by pustules
1922	25.0	5.0
1923	100.0	5.0
1924	100.0	4.4
1925	34.6	5.0
1926	76.1	7.0

These data, insofar as they are indicative, show fluctuation from year to year in prevalence, but not equally in destructiveness, for the indexes of the latter were closely similar every year.

RYE LEAF RUST

Caused by *Puccinia dispersa* Erikss.

Leaf rust data can be secured more readily for rye than for barley, not only because the rye acreage is greater but also because the fields are more widely distributed. Nevertheless, in comparison with wheat and oats, the acreage is small, and its wide distribution results in fields of small size, except in the small regions especially adapted to its culture, which are characterized especially by sandy soils.

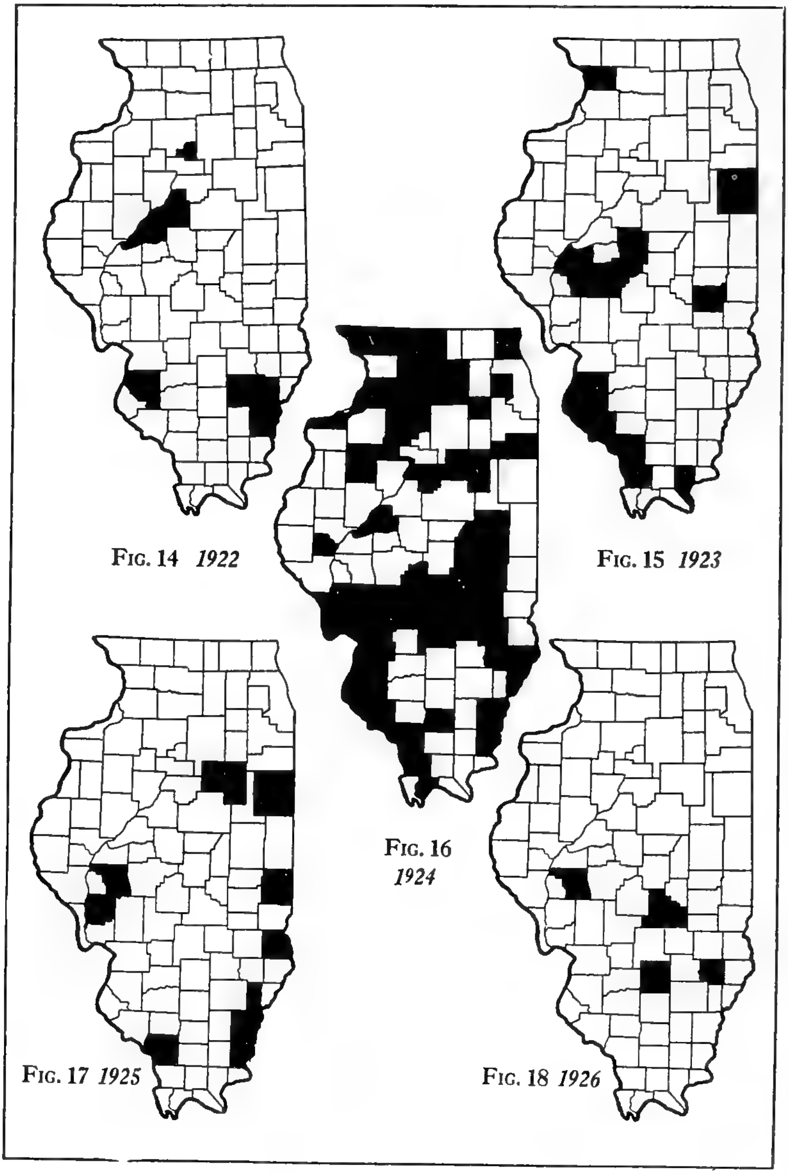
In 1922 data were secured from fields located in the seven counties shown in Figure 14. Although taken from a small number of fields, they have considerable weight, both because of their relative uniformity and because of the representative distribution of the fields. A considerably greater acreage of rye was examined for leaf rust in 1923, the fields being distributed among the 13 counties shown in Figure 15. The examinations yielded data of considerable significance, especially because a fairly large number of the fields were located in regions of intensive rye culture.

The season of 1924 provided data much more complete than any other year included in this report. The 48 counties shown in Figure 16 each furnished data from one or more fields, the fields examined reaching 73 in number and containing a total of 393 acres. Fields located in the 11 counties shown in Figure 17 furnished data on rye leaf rust in 1925. With the exception of Morgan County, where three fields were examined, observations were made in one field in each county. The wide distribution of the counties, however, gives weight to the data, particularly since important rye sections are included. While very little data could be secured in 1926, several small fields were examined in the 4 rather centrally located counties shown in Figure 18.

The results of the field examinations, as shown by an analysis of the data, are briefly as follows:

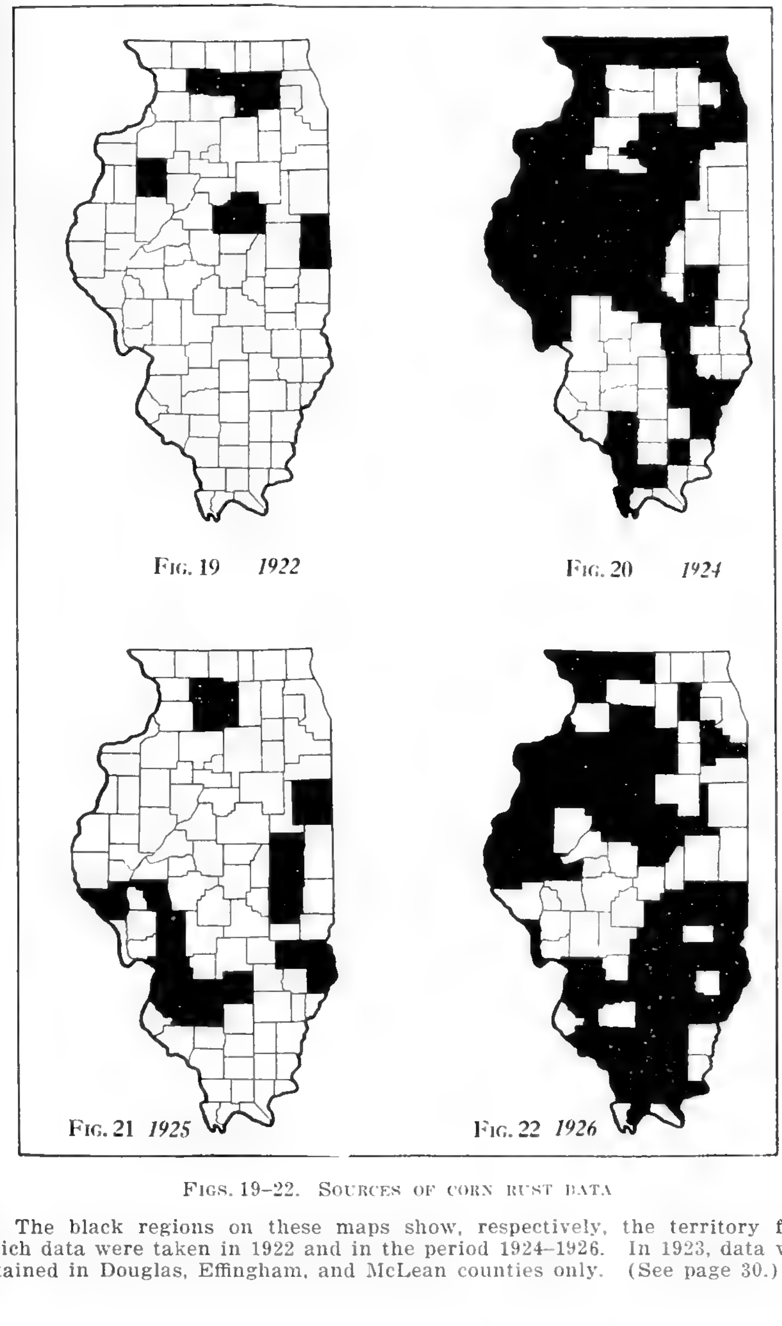
Year	Acreage examined	Prevalence: Calculated percentages of rye stems bearing rust infected leaves			Destructiveness: Calculated percentages of rye leaf area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State	For the acreage examined	For the county acreage represented	For the State
1922	97	77.2	97.7	99.1	46.4	34.0	55.1
1923	217	59.8	54.8	50.3	12.0	9.2	8.2
1924	393	39.7	45.0	22.2	6.3	2.7	2.0
1925	230	75.0	30.9	44.5	1.9	0.6	0.9
1926	23	19.1	....	....	1.7	....	...

Here, as in the cases of the rusts previously discussed, there is variation in both prevalence and destructiveness from year to year.



FIGS. 14–18. SOURCES OF RYE LEAF RUST DATA, 1922–1926

The black regions on these maps show the territory from which data were taken in the years making up this period. There were, in all, 960 acres in the rye fields examined. (See page 27.)



FIGS. 19–22. SOURCES OF CORN RUST DATA

The black regions on these maps show, respectively, the territory from which data were taken in 1922 and in the period 1924–1926. In 1923, data were obtained in Douglas, Effingham, and McLean counties only. (See page 30.)

This rust has been, on the whole, much milder than the other leaf rusts, the season of 1922 being the only one in which a really destructive attack occurred. The yearly variation appears to have been concerned with prevalence more than with destructiveness.

CORN RUST

Caused by *Puccinia sorghi* Schw.

Corn, the most important both in yield and acreage of all the cereals grown in Illinois, is subject to the attack of but one rust. It is a leaf rust.

In securing data on corn rust, the only phase of the attack that has been studied is prevalence. The intensity of the attack is exceedingly hard to estimate, first because of the large size of the corn leaf, and second because the pustules occur very sparsely on the leaf and only in limited spots. No means for estimating the severity of the attack has yet been devised.

In 1922, corn rust was not very prevalent. As a result, data were secured only from the 6 counties shown in Figure 19, the small acreage represented being located entirely in the northern half of the State. The data, though meagre in comparison with other years, were nevertheless representative. Even less abundant in 1923 than in the previous year, rust was recorded in only three fields, one in Douglas, one in Effingham, and one in McLean Counties. If the infection in these fields was typical of that throughout the State, the prevalence would be expressed as 3 per cent.

An abundance of data was obtained in 1924. In the 60 counties shown in Figure 20, data were taken from 84 fields aggregating 3762 acres. For 1925 the data are less copious than for the preceding year, but the 17 counties shown in Figure 21 contributed records from fields aggregating 450 acres.

Exactly 70 fields, distributed among the 63 counties shown in Figure 22, furnished data in 1926. Rust prevalence was exceedingly variable, being very high in some districts and very low in others. The data for the 5 years are brought together in the following table for more intimate comparison.

Year	Acres examined	Prevalence: Calculated percentage of corn stems bearing rust-infected leaves		
		For the acreage examined	For the county acreage concerned	For the State
1922	115.7	41.8	42.2	34.6
1923	40.5	3.0		
1924	3,762.0	63.0	61.0	62.6
1925	450.0	26.6	30.0	33.3
1926	1,333.0	11.4		

Although prevalence only has been recorded, a difference from year to year is evident. It is remarkable that the greatest prevalence occurred in 1924, succeeding the year of least prevalence.

Comparison of all leaf rust data

In the preceding pages the yearly indexes of prevalence and destructiveness shown by data taken directly from cultivated fields have been given for the several leaf rusts. As they were considered, it became apparent that, though year-to-year variation was a common characteristic, the particular years of greatest and least intensity of attack were not the same for all. This fact is brought out more clearly in Figures 23 and 24.

The indexes of prevalence for the entire state, as listed in the foregoing tables (see pp. 22-30), are shown graphically for all the leaf rusts in Figure 23. The year 1922 appears to have been very favorable to the leaf rusts of wheat, oats, and rye, but unfavorable to those of

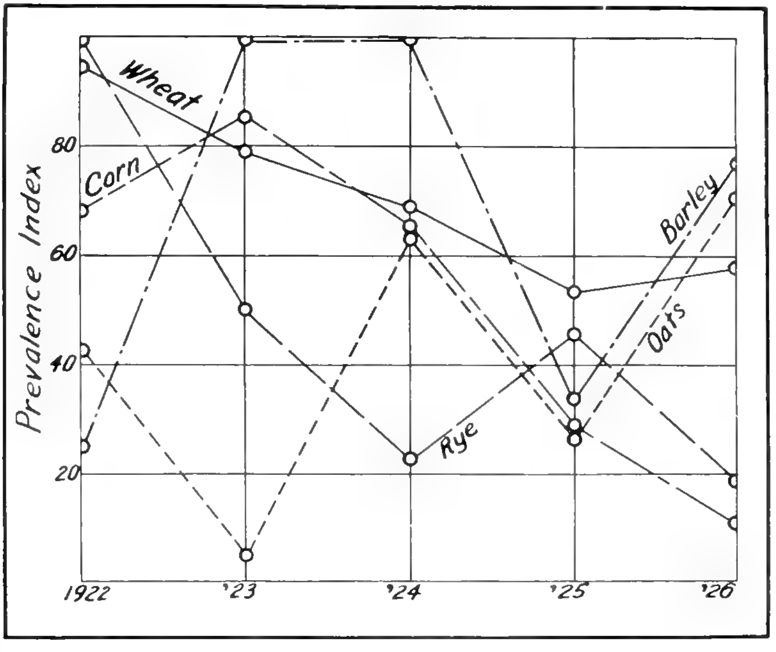


FIG. 23. PREVALENCE OF CEREAL LEAF RUSTS, 1922–1926

The prevalence indexes computed for the leaf rusts from field data and given in tables in the text are shown graphically here. The wide differences in the prevalence of these rusts in each year and in the trend of prevalence from year to year suggest that there is a particular combination of weather conditions most suitable for the maximum prevalence of each rust. (See page 32.)

corn and barley. The following year, 1923, was somewhat less favorable for wheat leaf rust and very much less favorable for the corn and rye rusts, while the oats rust found better conditions and the barley rust attained its maximum prevalence. The general trend in 1924 was downward, as compared with 1923, although the barley leaf rust maintained the high prevalence of the previous year, and corn rust found the best conditions of any of the five years. Rye leaf rust, alone of the five, was able in 1925 to increase its prevalence over that of the preceding year, the four others showing very marked decreases. Definite increases in prevalence were shown by the barley, oats, and wheat leaf rusts in 1926, while those of corn and rye decreased beyond their low points of the year before.

Through the five years to which these records apply, the same trend of prevalence has been followed by the leaf rusts of barley and oats in one instance, and of wheat and rye in another; but corn rust has had an individual trend, quite distinct from either of the two other groups. It is especially noteworthy that in no one year did the prevalence indexes of all move in the same direction.

In contrast with the foregoing is the fact, illustrated in Figure 24, that through all of the four years previous to 1926 the general trend of destructiveness was downward, ranging from severe attacks in 1922 and 1923 to mild and insignificant attacks in 1924 and 1925. With the exception of wheat leaf rust, a general upward trend is apparent for 1926.

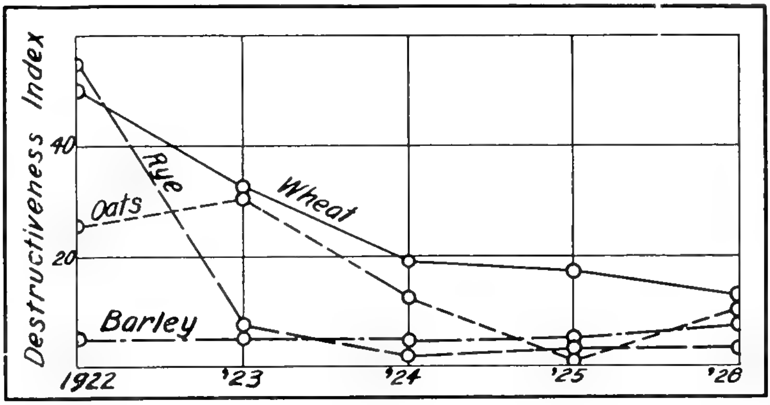


FIG. 24. DESTRUCTIVENESS OF THE CEREAL LEAF RUSTS, 1922–1926

The indexes of destructiveness computed from field data and given in tables in the text are shown graphically here. Since 1922, the general trend has been downward; but crown rust increased in 1923 and 1926, and barley leaf rust increased in 1926.

The Stem Rust of Cereals

Caused by *Puccinia graminis* Pers.

Although each of the cereal crops grown in Illinois has an individual leaf rust, the stem rust is the same for all, attacking all but corn. Special races of the stem rust exist, however, which are so limited in their ability to attack that each occurs on one crop only. The varied requirements of each crop in length of season and planting and growing periods present diverse conditions for the development of stem rust epidemics on each crop. Hence, it is not likely that the same phenomena of prevalence and destructiveness will be exhibited by this rust upon any two crops in a given year. It is necessary, therefore, to treat the stem rust on each crop as though it were a separate rust.

The method of measuring the prevalence of stem rust is similar to that used for the leaf rusts. Instead of individual plants, individual stems are taken as units, and prevalence is computed according to the method described on pp. 6-8. Destructiveness is expressed in terms of stem area occupied by the rust pustules, and the standard shown in Figure 3 is used as described on pages 18 and 19 as a measure of stem area.

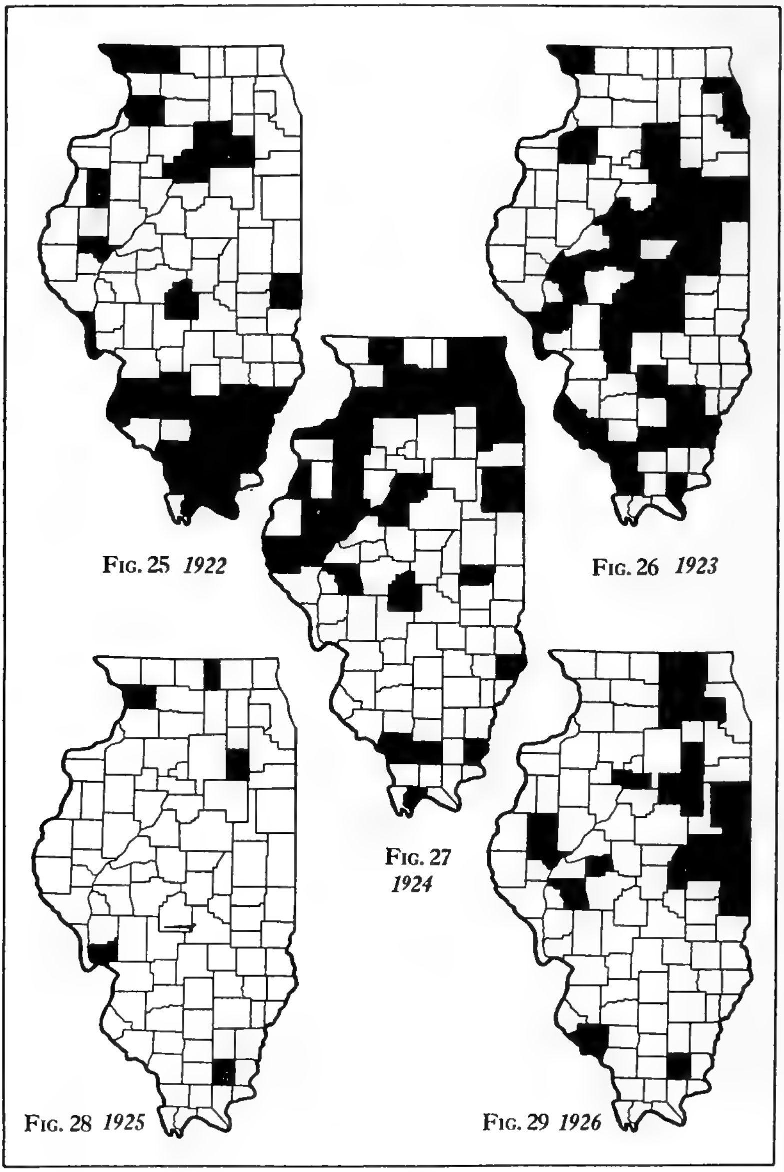
THE STEM RUST ON WHEAT

At the time field work was begun in 1922, stem rust infection was already widely prevalent on wheat. Its occurrence was demonstrated in the 30 counties shown in Figure 25. Although no definite records of prevalence or severity were secured from the southern territory marked on the map, data were taken from 17 fields in the northern part of the state, and the destructiveness indicated by them agrees well with that shown by the specimens collected in the south.

The earliest record of infection in 1923 was made June 4 in Jackson County. Isolated infections such as those subsequently found June 7 in Bond County, June 12 in Franklin County, and June 14 in Hamilton and White Counties served as *foci* from which, about June 16, disease dissemination began; and by June 22 the epidemic had become general. Data were secured from 72 fields distributed among the 39 counties shown in Figure 26. The extent of the territory from which the data were secured is particularly fortunate, in view of the intensity of the rust attack.

During 1924 stem rust was more prevalent in the north than in the south. Data were secured from 61 fields parcelled among the 31 counties shown in Figure 27. The original infections took place at least 8 days later than was the case the year before, and the period of moderate temperatures was so curtailed in the south that only a mild epidemic resulted there.

So rare was stem rust during 1925 that only six records of it were obtained. The fields from which these records were taken were located



FIGS. 25–29. SOURCES OF STEM RUST DATA FOR WHEAT, 1922–1926

The black areas on these maps show the regions from which the data discussed in the text were taken in each year. The fields from which records were taken during the five years contained 3,851 acres. (See page 33.)

in the counties shown in Figure 28. A recrudescence of stem rust occurred in 1926, which, by comparison with the light attack of the previous year, gave rise among wheat growers to grave fears of damage, fortunately not realized. During the season data were taken from 27 fields located in the 19 counties shown in Figure 29. As in previous years, abundant infection was found less readily in the south than in the north.

The variations in prevalence and destructiveness alluded to in the foregoing paragraphs are illustrated in the following table, in which the final figures arrived at in the statistical analyses of the data are brought together.

Year	Acreage examined	Prevalence: Calculated percentage of diseased stems			Destructiveness: Calculated percentage of diseased stem area		
		For the fields recorded	For the county acreage represented	For the State's acreage	For the fields recorded	For the county acreage represented	For the State's acreage
1922	256.5	9.9	41.2	22.06	1.8	32.8	17.8
1923	2,305.8	42.0	33.4	35.7	8.1	7.3	8.0
1924	659.0	22.0	15.7	11.1	0.7	0.5	0.6
1925	90.0	23.8	8.4	14.9	2.1	0.6	1.2
1926	540.0	57.8	....	....	11.2	....	....

The figures relating to the epidemic of 1922 are very inconsistent, showing much too wide a divergence in the separate columns of the table relating to both prevalence and destructiveness. This is due to exceedingly uneven weights given, of necessity, to the observations, in terms of the acreages to which they apply. It was to be expected, however, that in the first season of quantitative measuring of disease abundance some such discrepancies would appear. Since the indexes of prevalence and destructiveness secured for the acreage examined are more in harmony with those secured in subsequent years and with the general trend of the notes taken, they will be used in later discussions.

The figures for the remaining years are generally consistent, not only for the acreage examined, but also for the county acreage represented and for the State's acreage. They illustrate variation in both prevalence and destructiveness, and they show in a very emphatic way the fact that, of the two wheat rusts, stem rust has been the less significant.

THE STEM RUST ON OATS

In 1922 stem rust was prevalent on oats only in the northern part of the state. Its presence was observed in the 17 counties shown in Figure 30, but usable data were secured from only 14 fields in counties located in the extreme west and north. So rare was infection of oats during 1923 that not one specimen of stem rust was collected. No notes or data of any kind could be secured to show either its relative prevalence or destructiveness. As more than 1,300 acres of oats were examined without a single stem rust infection being found, the indexes of prevalence and destructiveness may be considered as zero for the year.

In contrast with the preceding year, in 1924 oats throughout the State were abundantly infected. The infection was particularly heavy in the northern half of the State. Fifty-eight fields distributed among the 34 counties shown in Figure 31 furnished data on prevalence and destructiveness. Again in 1925, the oats crop was infected throughout the northern half of the State. Data were taken from 8 fields in the seven counties shown in Figure 32. Although apparently inadequate in total acreage, the fields were widely distributed and were representative, to that extent, of the entire oats acreage.

Data were taken from 42 fields in 1926, these fields being scattered among the 29 counties shown in Figure 33. They were representative to a remarkable degree of the oat acreage of the State. Stem rust was very abundant, and quite destructive in the northern counties, as compared with previous years.

The indexes of prevalence and destructiveness for the five years are brought together in the following table.

Year	Acreage examined	Prevalence: Calculated percentage of infected stems			Destructiveness: Calculated percentage of stem area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	232	27.7	54.7	56.9	14.6	25.8	29.0
1923	1,306	0	0	0	0	0	0
1924	1,079	41.6	38.1	45.5	8.8	13.8	13.8
1925	162	27.8	26.3	21.6	6.7	5.1	4.5
1926	728	85.5	....	....	42.7	....	....

The variation exhibited by the indexes recorded above for 1922 is to be expected, partly because of lack of experience in measuring the quantity of rust and partly because of the very limited distribution of the fields from which data were taken. In their computation the southern part of the state was not represented. For the other years, the indexes, though modified in accordance with the extent of the territory to which the data are applied, are consistent and representative, giving by comparison with each other a fairly accurate depiction of the infections in each year.

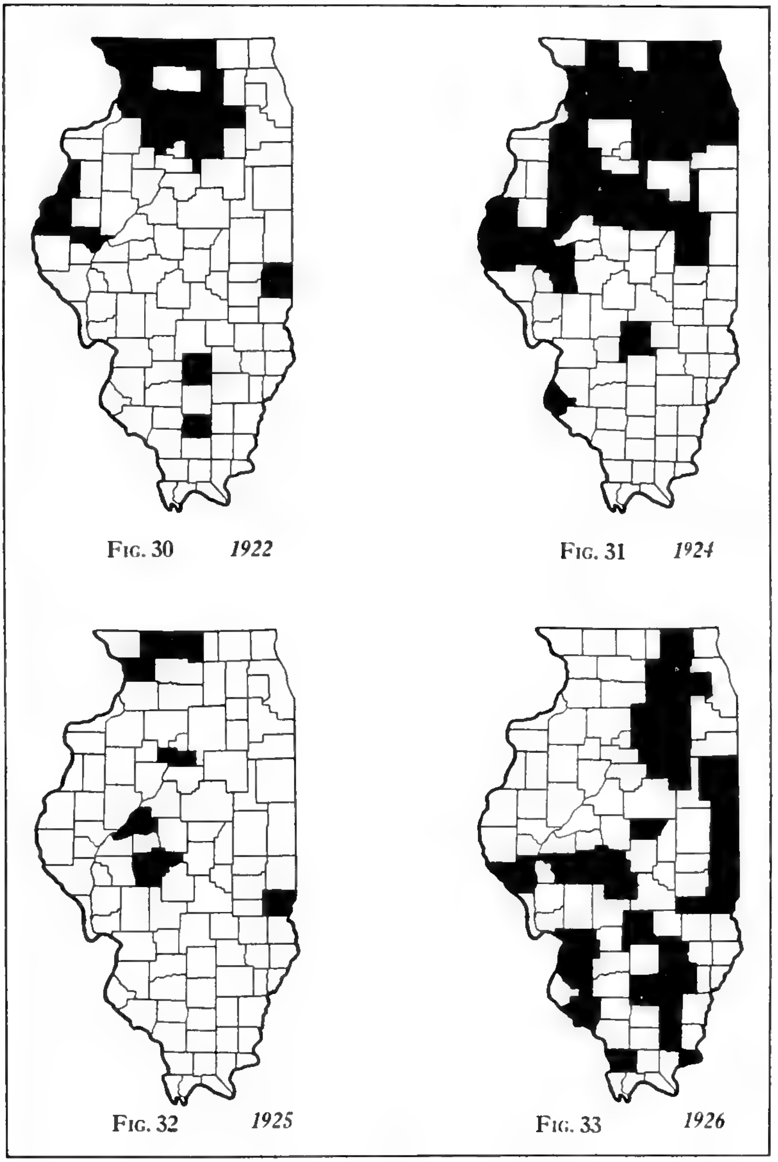


FIG. 30 1922 FIG. 31 1924 FIG. 32 1925 FIG. 33 1926

FIGS. 30–33. SOURCES OF STEM RUST DATA FOR OATS

The black areas on these maps show the regions from which the data discussed in the text were taken in 1922, 1924, 1925, and 1926. No infection was found in 1923, though more than 1,300 acres were examined. The fields examined in the other four years contained a total of 2,201 acres. (See page 36.)

The Stem Rust on Barley

Very few records of the occurrence of stem rust on barley have been made in Illinois south of the north third of the State. So far as the annual epidemic on barley is concerned, only the northern third of the State needs to be considered, not only because of the rarity of the rust southward but also because of the scarcity of the crop there. Because of the limited range of the crop and the limited acreage devoted to it, records of its diseases are much fewer than those for more common and more widely grown cereals.

In 1922 infection was found in the five counties shown in Figure 34. Data were obtained from eight fields which were representative of the barley district. Stem rust appeared to be completely absent in 1923, but in 1924 the infection became very general in the north. During the latter season, one barley field was examined in each of the 15 counties shown in Figure 35.

In 1925, fields were examined in the four counties shown in Figure 36, and stem rust was found to be prevalent, though in a very light form, in each.

By the time the observer reached the barley region in 1926 the crop had been cut and was standing in shocks. Although examinations made under these conditions are not wholly satisfactory, one field in each of the three counties, Boone, DeKalb, and McHenry, was given a very careful examination; and the data taken from them may be considered typical of the stem rust infection in the barley region.

The indexes of prevalence and destructiveness secured from the computations made with field data are as follows:

Year	Acreage examined	Prevalence: Calculated percentage of stems infected with stem rust			Destructiveness: Calculated percentage of stem area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	52	14.1	48.1	45.5	5.8	12.3	12.4
1923	...	0	0	0	0	0	0
1924	194	5.6	6.9	8.0	.5	.5	.6
1925	65	15.7	11.3	11.1	.1	.2	.2
1926	60	100.0	....	....	28.7	....	....

The figures given above, which are reliable indexes of the seriousness of stem rust on barley during each of the five years 1922-1926, indicate definitely the relative importance, in each year and throughout the period, of this rust and the leaf rust (see page 26) as agents in reducing the barley yield, stem rust being in the main much the less significant.

FIG. 34 *1922*

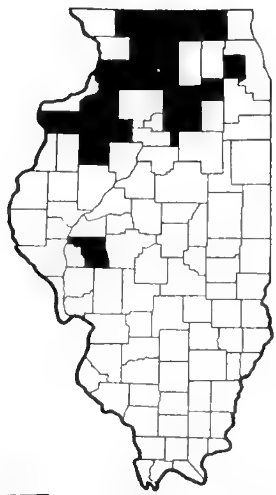


FIG. 35 *1924*

FIG. 36 *1925*

FIGS. 34–36. SOURCES OF STEM RUST DATA FOR BARLEY

The region from which data were taken in the years 1922, 1924, and 1925 are shown in black on these maps. In 1923, there was no stem rust infection. In 1926, 3 fields, one in Boone, one in DeKalb, and one in McHenry County, were examined. (See page 38.)

THE STEM RUST ON RYE

In spite of the wide distribution of rye in Illinois and the extensive use of it along newly placed hard roads, which might be expected to aid in distributing stem rust infection on the crop, it has been possible to secure but very little data on stem rust prevalence in rye fields. In 1922 only two fields, one in Mason and one in Grundy County, were found infected. No infection was recorded in 1923. In 1924 data were secured from 10 fields located in the seven counties shown in Figure 37. During the two subsequent years, 1925 and 1926, no instance of infection was seen in any of the fields examined, though

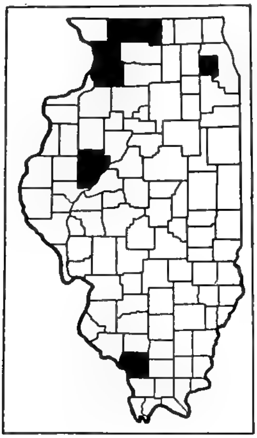


FIG. 37. SOURCES OF STEM RUST DATA FOR RYE IN 1924

In the seven counties shown in black, 10 fields containing a total of 70 acres furnished data on the stem rust attack of 1924.

infected rye plants were found occasionally in wheat fields and along roadsides. The data on the severity of stem rust on rye for the years covered by the survey are as follows:

Year	Acreage examined	Prevalence: Calculated percentages of stems infected with stem rust			Destructiveness: Calculated percentage of rye stem area occupied by stem rust		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	70	50.0	50	50	28.5	22.5	25.5
1923	217	0	0	0	0	0	0
1924	70	7.7	18.1	25.9	3.9	9.1	13.9
1925	230	0	0	0	0	0	0
1926	23	0	0	0	0	0	0

Comparison of stem rust infections on the cereal crops subject to its attack

With stem rust, as with leaf rust, both the degree of prevalence and the degree of destructiveness have varied from year to year. These variations, which have not been of the same relative amounts for each of the crops, are best shown graphically.

The indexes of prevalence on each of the cereals, for each year from 1922 through 1926, are shown in Figure 38. A common trend is shown by all except wheat. In 1922 stem rust was moderately prevalent on barley, rye, and oats, but only mildly so on wheat. The following year prevalence dropped practically to zero on the first three crops, but on wheat it increased considerably. The crop season of 1924 saw a marked increase on all the cereals except wheat, while in 1925 prevalence was less on oats and rye, but more on wheat and barley,

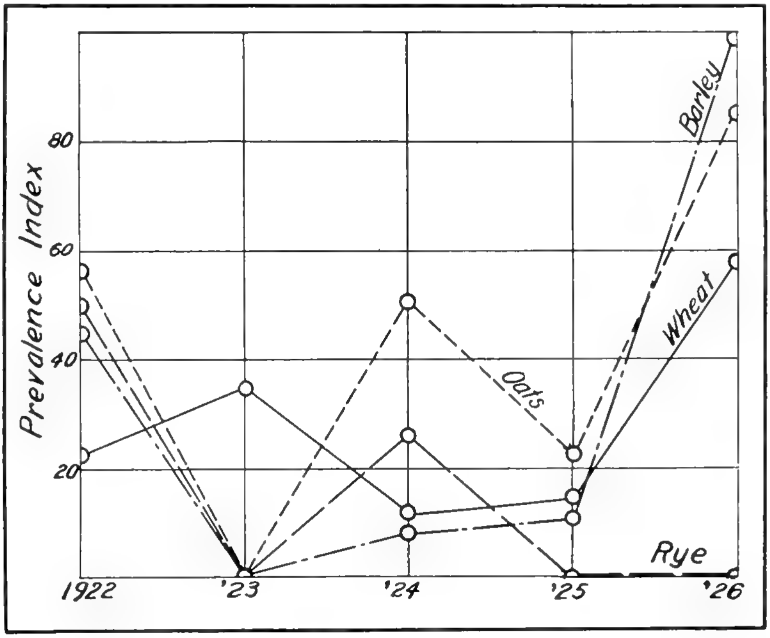


FIG. 38. PREVALENCE OF STEM RUST ON THE CEREAL CROPS, 1922–1926

The indexes of prevalence computed from field data and given in tables in the text are shown graphically here. There is a greater uniformity of prevalence trend from year to year on all crops than was true with the leaf rusts (compare with Fig. 23); but in contrast with the prevalence of the leaf rusts, stem rust reached its highest point in 1926.

than the year before. In 1926 it increased markedly on all except rye, reaching the greatest degree recorded during the survey. It is evident from an inspection of Figure 38 that the climatic conditions of any one year have not affected the prevalence of stem rust to the same extent, or in the same way, on every crop.

The intensities of attack, as indicated by the indexes of destructiveness calculated from the field data, are shown in Figure 39. Practically the same tendencies are exhibited on all the crops, wheat alone showing a marked divergence. In 1924, when the trend of destructiveness was upward on the three other crops, it declined very markedly on wheat.

There has been a distinct parallel between prevalence and destructiveness throughout the five seasons, the only break in it being the attack on wheat in 1923, in which year the increase in prevalence over the previous season was accompanied by a large decrease in destructiveness

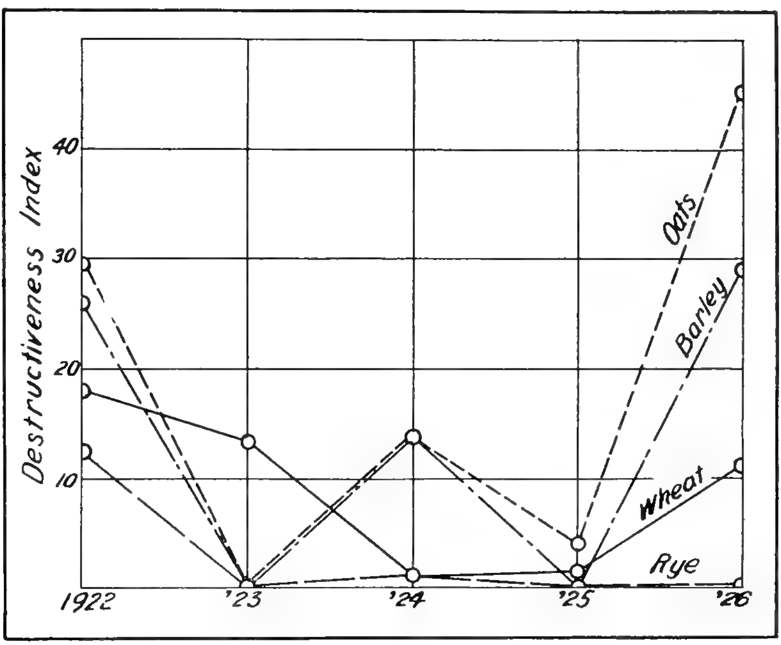


FIG. 39. DESTRUCTIVENESS OF STEM RUST ON THE CEREAL CROPS, 1922–1926

The indexes of destructiveness given in tables in the text are shown graphically here. The trend of destructiveness from year to year follows very closely the trend of prevalence (compare with Fig. 38), being greatest in 1926 and 1922, and generally very low in the other years.

CEREAL SMUTS

All of the cereal crops are subject to diseases classed under the general name, smut; but the smuts, like rusts, are different on the different crops, exhibiting different symptoms and being possessed of different means of spread and infection. On wheat there are three; on barley, two; on oats, two; on rye, two; and on corn, one. According to their appearance, they can be classed as "loose", "covered", and "stripe" smuts. In general, "covered" smuts are much less abundant than "loose" or "stripe" smuts. The covered smuts of oats and barley, because of their rarity, have not furnished sufficient data to deserve inclusion in this discussion; and the limited range of the "stripe", or "flag", smuts on wheat and rye precludes their inclusion.

The outstanding characteristic of all the smuts, except the one on corn, is that they nearly always destroy completely, either directly or indirectly, the head or the grain. The loose smuts replace the grain and the floral glumes with a mass of smutty powder, the covered smuts replace the grain and often the floral glumes as well, and the stripe smuts produce such malformations of the leaf and head that diseased stems rarely are productive. As a result, the prevalence of a smut is also a direct measure of its destructiveness.

WHEAT LOOSE SMUT

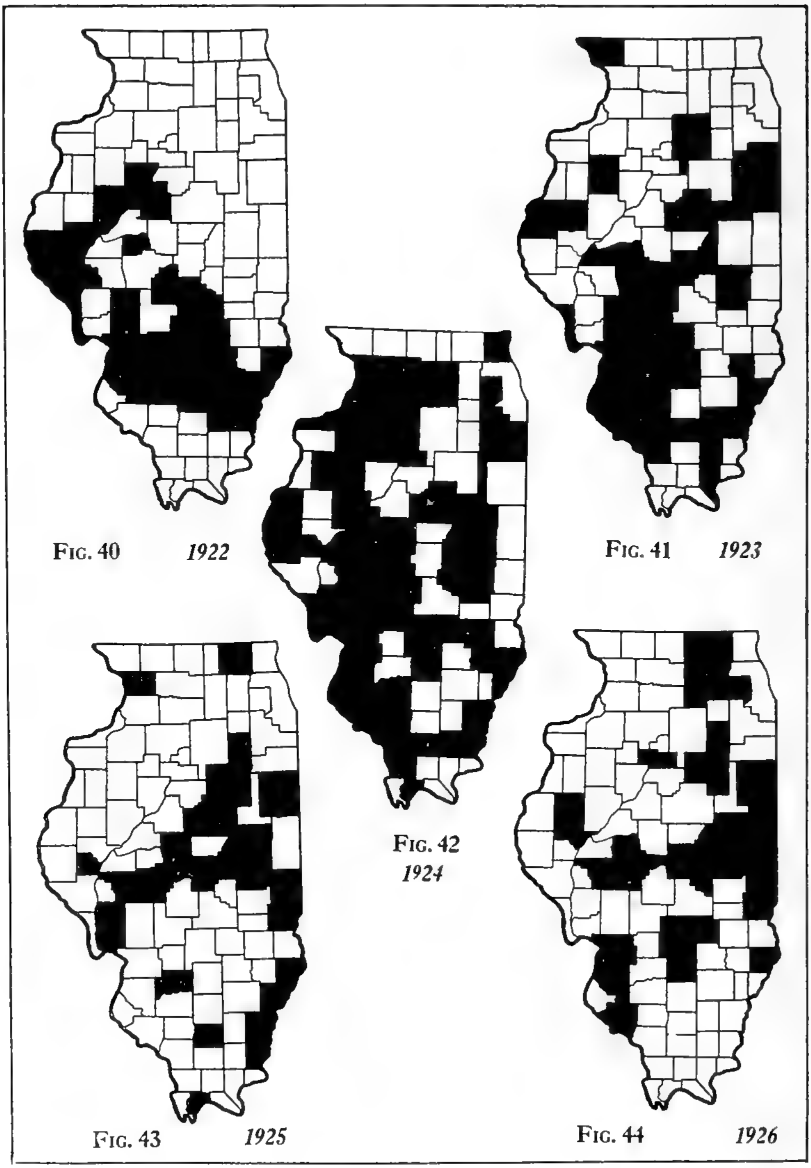
Caused by *Ustilago tritici* (Pers.) Rostr.

This is the least important of the common cereal smuts. Though distributed throughout the wheat fields of the State and conspicuous enough to be classed among the common diseases, its means of accomplishing infection, which is limited to the very short time the wheat flowers are open, prohibits it from becoming abundant, at least under Illinois conditions. For the same reason, the extreme fluctuations exhibited by other diseases will not be found with it.

During 1922, loose smut was seen in wheat fields located in the 29 counties shown in Figure 40. Wheat harvest was already so far advanced when the examinations were made that only the northern fields furnished data.

Data secured in 1923 from 81 fields located in the 38 counties shown in Figure 41 were representative of the loose smut infection of the season, not merely because of the large wheat-acreage from which they were taken but also because of their extensive distribution and their location in regions both of intensive and less intensive wheat culture.

The most abundant data obtained in any of the five years of the survey were procured in 1924. In the 58 counties shown in Figure 42, 145 wheat fields aggregating 5,661 acres were examined. The wheat grown in the counties represented by the field records aggregates 1,754,835



FIGS. 40–44. SOURCES OF DATA FOR THE LOOSE SMUT OF WHEAT, 1922–1926

The black areas on these maps show the regions from which data were taken in each year of the period. The fields examined in these five years contained a total of 16,425 acres. (See page 43.)

acres, which is slightly more than 76 per cent of the State's acreage for that year.

Data were obtained in 1925 from 51 fields located in the 26 counties shown in Figure 43. Although the acreage they contained was only about one third as great as in the previous year, the total county acreage of which they were representative constituted nearly 29 per cent of the State's acreage.

In 1926, data were obtained by examining 48 wheat fields located in the 29 counties shown in Figure 44. Though somewhat less representative with respect to size of acreage and wideness of distribution than the records of the previous two years, the increased care employed in obtaining them makes them the most dependable of all the estimates obtained.

During these five seasons, data have been taken from 349 wheat fields containing a total of 13,425 acres. The indexes of prevalence obtained from the analysis of the data compare as follows:

Year	Acreage examined	Prevalence: Calculated percentage of wheat heads infected with loose smut		
		In the acreage examined	In the county acreage represented	In the State's acreage
1922	433	1.37	1.28	89
1923	4,421	1.41	1.54	1 39
1924	5,661	.44	.44	.45
1925	1,725	.67	.69	70
1926	1,185	.94	....	....

WHEAT BUNT

Caused by *Tilletia laevis* Kuehn.

Wheat bunt, known more commonly as stinking smut, is much less prevalent than loose smut in the wheat fields in Illinois. Usually only a comparatively small number of wheat fields in a county are infested, and they often are grouped together in a small region. In the infested fields bunt may be the most costly disease, for it not only destroys the heads on infected stems but gives so bad an odor to the harvest from the field that large discounts, called dockage, from the market price are applied when the grain is sold.

The field prevalence of bunt is not easy to determine. The heads on diseased stems, though often very characteristically malformed and discolored, are yet so nearly like the normal heads that even a trained eye does not recognize them readily. Moreover, the characters by which they can be recognized do not develop fully until a field is nearly ripe. As a result, data on prevalence rarely is obtained earlier than a few days before harvest. The fields in which it is found are, therefore, both small in number and not representative in distribution, and the data obtained from them are, very probably, understatements of the amount of infection. The only means of supplementing the field counts is to obtain reports from wheat dealers on the marketing of smut infested wheat.

In analyzing data on bunt prevalence, the procedure is not quite the same as for other diseases. The smallness of the amount of data secured from fields, together with their limited distribution, renders them incapable of complete analysis. As a rule the only figure which can be computed is an index of prevalence in the acreage known to have been infested. It can be considered only as typifying the amount of infection prevailing in the crop found by other means to have been infected.

The most useful data on bunt prevalence have been obtained in reports from grain dealers. Circular letters were sent annually to the dealers in the State, requesting reports of the number of bushels purchased and offered that were smutted; and the replies received, which have been more numerous than is usual with circulars, are believed to be especially dependable because the dealers were asked to reply only when such lots had been offered them.

The data secured in this way, being in terms of bushels rather than acres, require a treatment somewhat different from that accorded acreage statistics. The following short section taken from the analysis of the 1922 reports shows the method.

Sheet	County	Bushels reported as infested	County yield	Percentage of the county yield infested
1	Adams	0	1,011,030	0
3	Champaign	0		
4	Champaign	2,000		
5	Champaign	0		
6	Champaign	622		
7	Champaign	0		
		2,622	518,315	.506
8	Douglas	1,500		
9	Douglas	0		
		1,500	392,632	.382
30	Piatt	2,000		
31	Piatt	500		
		2,500	581,600	.430
32	Putnam	2,000	203,381	.983
	Total	8,622	2,706,958	.318

The dealers' reports are assigned places in the permanent file with other disease records. These for each year are kept in separate folders, the sheets being assorted by counties as are the other reports, and the sheets of each folder numbered serially. In the calculations made with the data, only one tabulation is made. In the first column, the number of the report sheet is entered; in the second column, the county from which it came; and in the third column, the number of bushels of smut-infested wheat. When this is completed, the number of bushels infested is obtained for each county and for all the reports by summing the items in column 3. In column 4, opposite each county total, the county yield given in the agricultural statistical reports already mentioned is entered. The total yield of all the counties concerned in the report is the sum of these entries. By dividing the county yields by the county totals of infested wheat, a percentage, shown in column 5, is obtained which represents the proportion of smut infestation for each county; and by dividing the sum for column 3 by that for column 4 a percentage is obtained which represents the average proportion of smut infestation for all the counties in the tabulation. The percentages are carried to the third place beyond the decimal for the reason that the percentages dealt with in this disease are always very small and the maximum of accuracy is desirable.

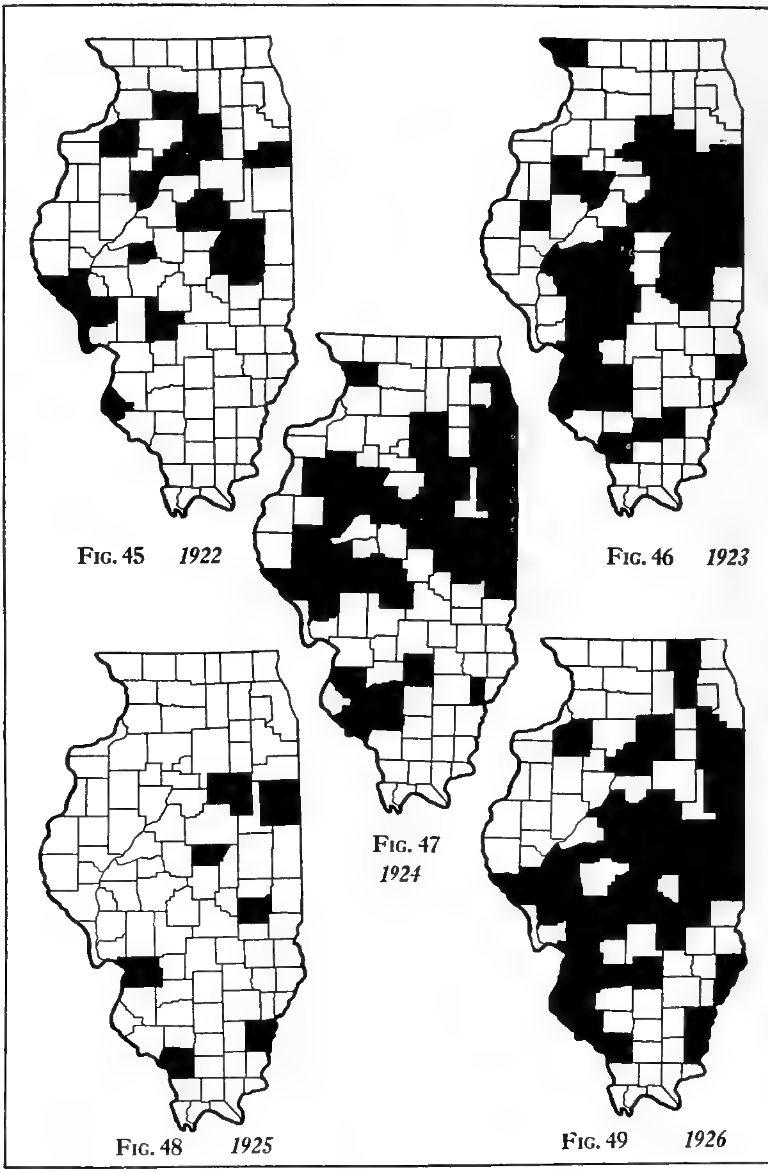
No further manipulation of these data is permissible. They must be considered as representative of the entire territory from which they came, and the complete lack of data from other territories prohibits further calculations.

The figures secured by this method are empirical in that they represent prevalence less directly than definite field data. A more definite conception of prevalence can be obtained if the results of field examinations and of dealers' reports are taken together. For example, dealers' reports show that, in 1922, .371 per cent of the State's yield was infested, the fields in which the infestation occurred having, according to the results of field examinations, 1.2 per cent of the heads bunt-infected.

During 1922 data on field prevalence were secured in six counties. These, together with dealers' reports, gave information from the 17 counties shown in Figure 45. The infestation present in 30.8 per cent of the State's yield of 55,432,000 bushels is represented.

The field data secured in 1923 are the most extensive obtained during the survey. Definite records were taken in 40 fields located in 24 widely distributed counties; but the acreage of these fields—2123 acres in all—is less than .2 per cent of the total acreage in the counties in which they were located, emphasizing again the lack of general prevalence. Grain dealers' reports received from 48 counties, give data on 64.7 per cent of the yield of the State. The counties in which bunt was shown to have occurred, by field examinations and dealers' reports, number 35 and have the distribution shown in Figure 46. From the two sets of data, it may be inferred that fields furnishing .317 per cent of the State's yield were bunt-infested to the average extent of 2.5 per cent.

Field examinations made in 1924 revealed the presence of bunt in 14 widely scattered counties Reports for this year were received from



FIGS. 45–49. SOURCES OF WHEAT BUNT DATA, 1922–1926

The black areas on these maps show the territory from which data were taken in each year of the period. The data for this disease are obtained in part by direct examinations of fields, and in part from the reports supplied by grain dealers. During the five years of survey, data were taken from fields aggregating 2,785 acres. The dealers' reports applied to from 30.8 per cent to 64.7 per cent of the State's annual yields. (See pp. 45-47.)

grain dealers in 46 counties. The total distribution of bunt included the 34 counties shown in Figure 47.

The lack of adequate assistance in the survey during the summer of 1925 made it inadvisable to circularize the grain dealers, but data were secured by carefully examining seven bunt-infested fields in the seven widely scattered counties indicated in Figure 48. Although the number of fields is small and their acreage almost negligible, their wide distribution and the variation in degree of infestation which they exhibited justify considering the data as representative.

Field examinations showing bunt prevalence in 1926 were limited, including five fields, all of which were in four centrally located counties. However, grain dealers' reports were abundant. Responses to inquiries were received from 193 purchasing stations, the crop directly represented by these reports constituting a very large percentage of the State's yield. The range of bunt infection for the year, compiled from dealers' reports and field examinations, is indicated in Figure 49, which shows this disease to have occurred in 44 counties.

Summaries of the data showing field prevalence and the infestation of harvested grain are given in the table below.

Year	Prevalence, as shown by:			
	Field examinations		Grain dealers' reports	
	Acres examined	Average percentage of heads diseased	Bushels of marketed wheat represented	Percentage of marketed wheat smut-infested
1922	107	1.20	17,085,896	.371
1923	2,123	2.50	128,104	.317
1924	310	4.03	25,150,705	1.043
1925	105	1.43	....	.....
1926	140	.45	....	.....

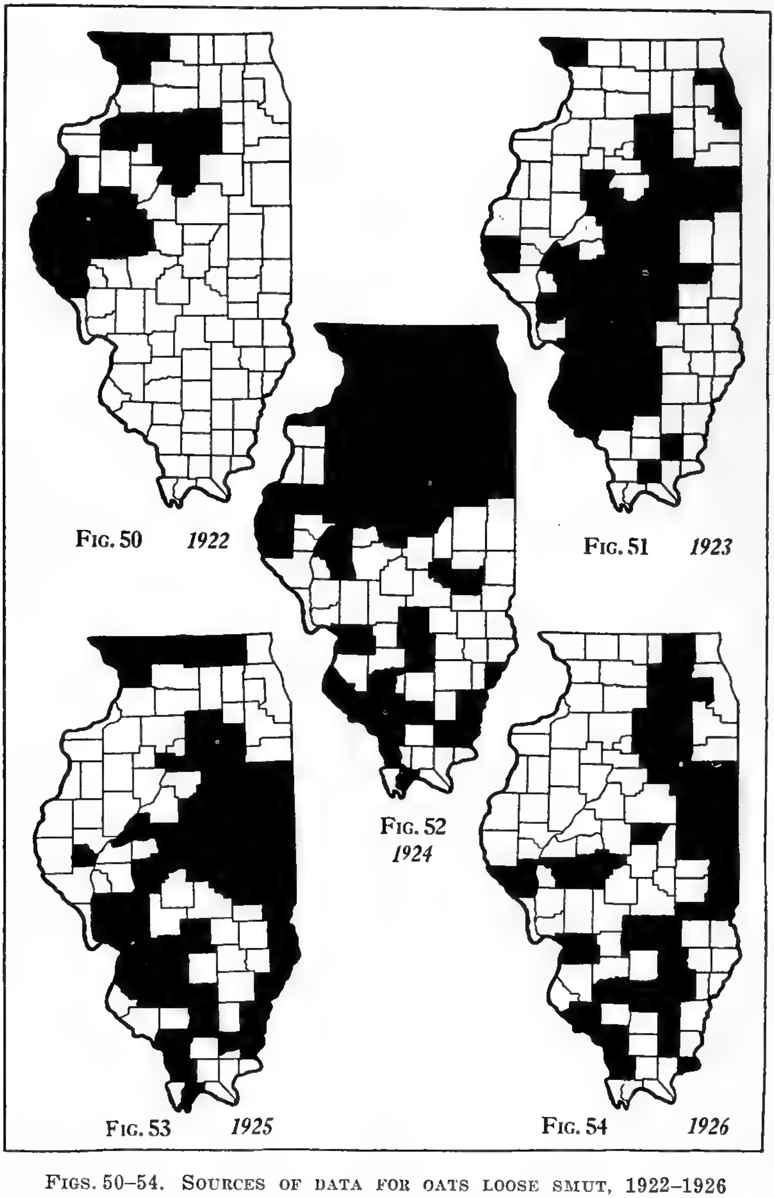
OATS LOOSE SMUT

Caused by *Ustilago avenae* (Pers.) Jens.

The loose smut of oats, though having a life history different from that of the loose smut of wheat, appears much the same in the field. It destroys the spikelets, leaving in their stead masses of smutty powder. Its abundance is measured simply as the percentage of smutted heads.

During 1922, dependable records of its prevalence were secured from 39 oat fields located in the 20 counties shown in Figure 50. It is unfortunate that all of these records should come from the northwest quarter of the State, but some dependence may be placed upon them because their number, distribution, and their varying acreages seem to indicate conditions typical of a very large part of the State.

Data showing loose smut prevalence in 1923 were secured from 88 fields aggregating 1,695 acres and distributed among the 36 counties



FIGS. 50–54. SOURCES OF DATA FOR OATS LOOSE SMUT, 1922–1926

The black areas on these maps show the territory from which data were taken in each year. In all, fields totaling 7,667 acres were examined, the smallest acreage (723) being examined in 1922, and the largest (2,412 acres) in 1924. (See page 49.)

shown in Figure 51. The extent of the regions from which the records were taken make them much more representative than those of 1922.

An acreage still larger than that of 1923 furnished data on oats smut prevalence in 1924. In all, 135 fields containing 2,412 acres were examined. They had the distribution shown in Figure 52, which includes 57 counties so widely scattered as to be typical of the entire state. The acreage in these counties constitutes 64.7 per cent of the State's acreage.

The acreage examined for smut in 1925, though less than that of 1924, was close to 2000. In the 48 counties shown in Figure 53, data were taken from 104 fields, which may be considered typical of the infection throughout the state even though a considerable territory in the northwest is not represented directly.

In 1926, 41 oats fields were examined for smut prevalence. Though their total acreage was small when compared with previous years, they were widely distributed and were directly representative of the oats crop grown in the 32 counties shown in Figure 54. These counties are so distributed as to be typical of the entire state.

The indexes of prevalence, which in these cases are also indexes of destructiveness, obtained from the field data are given below for each of the 5 years.

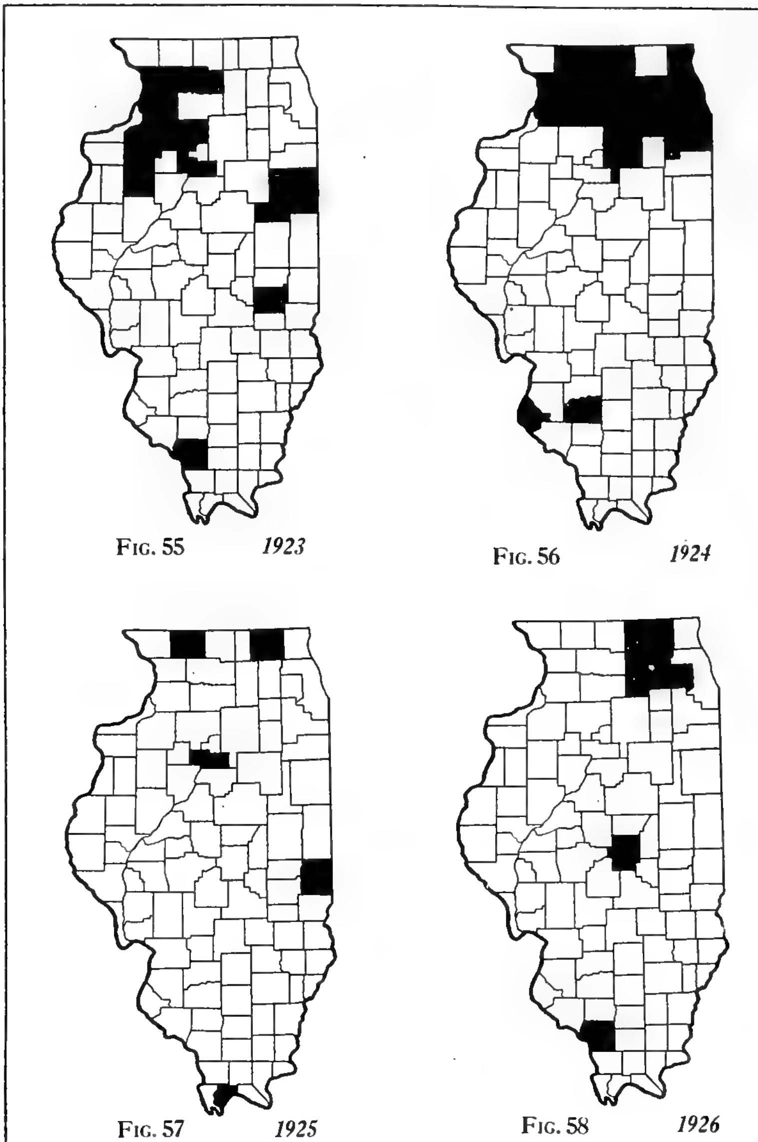
Year	Acreage examined	Prevalence: Calculated percentage of smut infected oats heads		
		For the acreage examined	For the county acreage represented	For the State's acreage
1922	723	6.94	4.44	5.62
1923	1,695	4.96	3.58	3.08
1924	2,412	5.43	5.21	5.20
1925	1,967	3.65	3.83	3.49
1926	870	3.40	....	....

BARLEY LOOSE SMUT

Caused by *Ustilago nuda* (Jens.) K. & S.

Although barley is subject to attack by both loose and covered smuts, the latter is found so rarely in Illinois and is recognized in the field with such difficulty that it has been impossible to secure adequate data bearing on its prevalence. As a consequence, only the data on loose smut will be presented.

In the first year of survey, 1922, no data were obtained, but in 1923 a considerable quantity of specific and general data was secured relating to infection in the 11 counties shown in Figure 55. Insofar as the field data are amenable to analysis, they indicate a prevalence of 6.3 per cent.



FIGS. 55–58. SOURCES OF DATA FOR BARLEY LOOSE SMUT, 1923–1926

The black areas on these maps show the territory from which data were taken in each of the four years. The acreage furnishing the records was not large, in comparison with other cereals, but the concentration of barley in the northern part of the State makes small acreages quite representative. (See page 16.)

More abundant data were secured in 1924. Barley fields—32 in number—scattered among the 17 counties shown in Figure 56 were given careful examination. All but two were located in the northern barley district, their wide distribution among the northern counties resulting in a typical sampling of smut prevalence.

In 1925, records were taken from only 5 fields. They were located in the five counties shown in Figure 57. The seven fields examined in 1926 were located in the seven counties shown in Figure 58. Although not so widely scattered as the fields examined in previous years, the uniformity of the data secured from them indicates a typical representation of the northern infection.

The prevalence of barley loose smut, as shown by calculations made from field data, is shown below, year by year.

Year	Acreage examined	Prevalence: Calculated percentage of smutted barley heads		
		For the acreage examined	For the county acreage represented	For the State's acreage
1923	49	5.30	....	....
1924	400	1.71	1.67	1.64
1925	60	3.07	3.86	4.11
1926	125	5.00	....	....

CORN SMUT

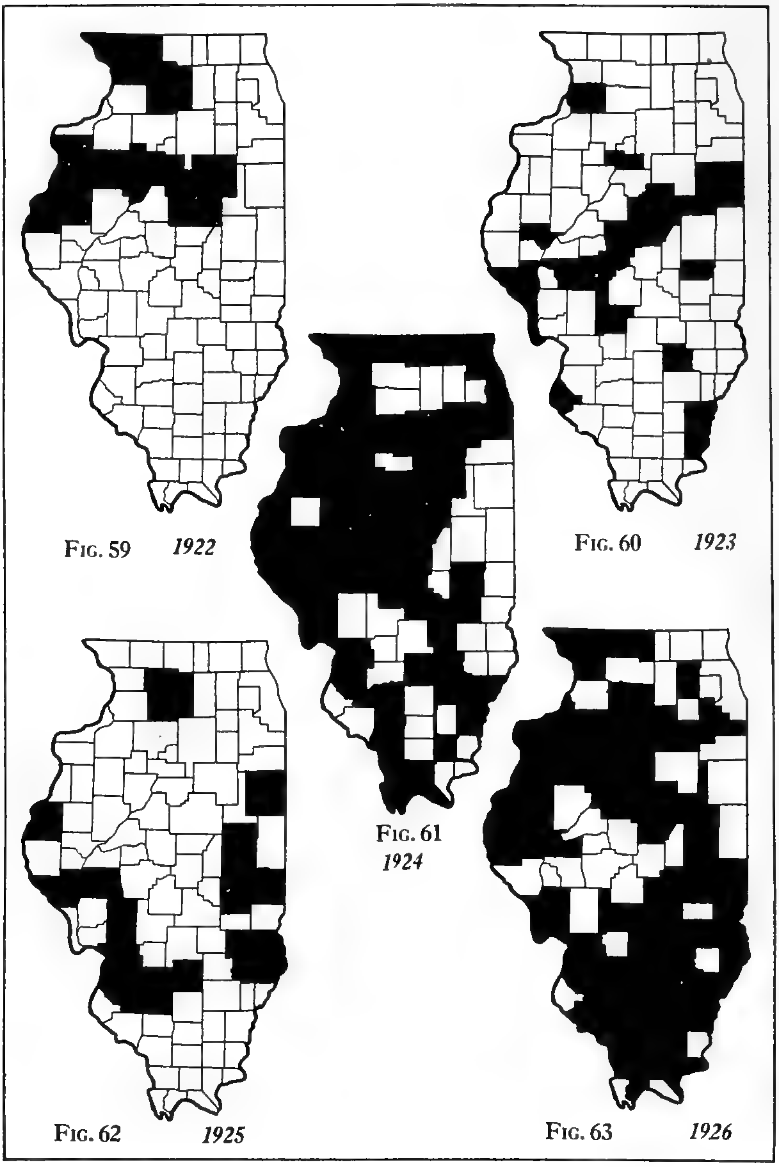
Caused by *Ustilago zeae* (Beckm.) Unger.

The smut of corn differs from the other cereal smuts in that when it attacks its host it affects localized regions, such as leaf bases, undeveloped buds in the axils of the low leaves, ears, and tassels. At least one, sometimes all, of these forms of attack may be seen on an infected stalk. Prevalence of smut, determined as for other cereals, alone is discussed in the paragraphs which follow. Destructiveness would have to be measured for each of the modes of attack; and it has not been possible, with the facilities at hand, to undertake these measurements.

In 1922, data on prevalence were obtained from 49 fields, aggregating 503 acres and representing the 17 counties shown in Figure 59. Though located entirely in the northern half of the state, and chiefly in the west, these counties are all heavy corn producers; hence, the fields examined may be considered typical of the corn fields of the state.

Data were taken in 1923 from 19 fields which were located in the 18 counties shown in Figure 60. Though fewer, these fields were more widely scattered than those examined in 1922 and contained a greater total acreage. The data secured from them are also more representative than those obtained in 1922.

The most abundant data were obtained in 1924. In the 68 counties shown in Figure 61, 141 fields were examined. The 5,546 acres which



FIGS. 59–63. SOURCES OF CORN SMUT DATA, 1922–1926

The black areas on these maps show the territory from which data were taken in each of the five years. The prevalence of smut was recorded, during these years, in 244 fields which contained a total of 8,866 acres. (See page 53.)

they contained represented directly 6,164,400 acres of corn—68.9 per cent of the State's acreage.

Twenty-four fields, distributed among the 21 counties shown in Figure 62, were examined in 1925. The data secured from them are not as typical as might be desired, for the reason that the large, centrally located corn region including McLean County is not represented. However, the universal occurrence of smut and the evident similarity of infections in widely separated regions both lend authenticity to the data.

Records of prevalence were taken in 1926 from 84 fields distributed among the 70 counties shown in Figure 63. The data secured are representative, not merely because of the extensiveness of the fields, which contained 1,574 acres, nor because of their very wide distribution, but especially because greater care was used than in previous years.

The indexes of prevalence for corn smut, determined from the field data, are as follows:

Year	Acreage examined	Prevalence: Calculated percentage of infected stalks		
		For the acreage examined	For the county acreage represented	For the State's acreage
1922	503	4.73	5.48	5.33
1923	678	5.91	9.40	11.56
1924	5,546	4.75	4.46	4.33
1925	565	3.00	3.53	3.16
1926	1,574	2.90	....	....

Summary of all data on cereal smut prevalence

The increase or decrease in prevalence from one year to another of the various cereal smuts is compared in Figure 64. There does not appear to be any definite agreement in the fluctuation exhibited by any two of these smuts throughout the period covered by the Survey's data. Neither is there any agreement in trend from one year to the next between smuts having either similar life histories or similar means of producing infection. The closest parallel is shown by the loose smut of oats and wheat bunt, both of which were moderately prevalent in 1923, increased greatly in 1924, fell off decidedly in 1925, and fell off still more in 1926. A less striking parallel existed between the loose smuts of barley and wheat, both showing in 1923 a high degree of prevalence which fell off very markedly in 1924, increased in 1925, and again in 1926; but in this case the very large variations exhibited by the barley smut stand in strong contrast with the lesser variation of the wheat smut.

The most remarkable fact illustrated is the directly opposed reactions of certain of the smuts in certain years. Oats smut showed very high prevalence, as opposed to the low prevalence of the two wheat smuts, in 1922; but in 1923 it decreased, while the wheat smuts increased. In 1924, the prevalence of wheat bunt and oat smut both increased, but that of wheat loose smut fell off, as did also that of barley smut. The high prevalence of the two first named is in very decided contrast with the low prevalence of the last two. A similar distinct contrast is exhibited in the years 1925 and 1926, the loose smuts of both wheat and barley showing decided increases in prevalence, the loose smut of oats and wheat bunt showing decreases. The curve for corn smut conforms to no other.

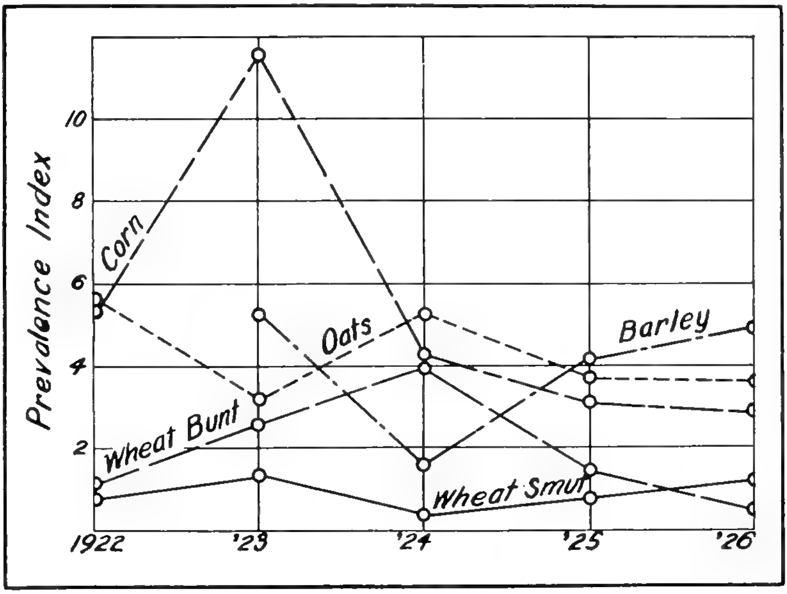


FIG. 64. PREVALENCE OF CEREAL SMUTS, 1922–1926

The year-to-year trend of prevalence for the entire period covered by the data is not the same for any two of these smuts. The closest similarity is exhibited by oats smut and wheat bunt, which followed the same trend in 1924, 1925, and 1926. Another similarity is shown by the trends of the loose smuts of wheat and barley from 1923 to 1926, but the large variations of the barley smut contrast sharply with the small variations of the wheat smut. Corn smut prevalence appears to be completely independent of the others.

SCAB OF CEREALS

Caused by *Gibberella saubinetii* (Mont.) Sacc.

As considered here, the disease commonly known as scab will be limited entirely to the effects its causal fungus produces upon the heads or spikes of the crops which it attacks. Measurement of its prevalence is accomplished in the same way as for other diseases of cereals, and its destructiveness, which might be termed severity with more propriety, is determined by exact counts of the diseased spikelets occurring on diseased heads; these heads, selected at random as the prevalence counts are made, are examined and counted later with care.

SCAB ON WHEAT

Though probably more widely distributed than our records show, scab infection of wheat had such limited prevalence in 1922 that records were taken from only 9 fields. Located in the 4 counties shown in Figure 65, they contained a total of 193 acres and, as sample fields, represented directly the scab prevalence in 212,000 acres of wheat. The data for this year show prevalence only, no special counts having been made to show destructiveness.

Records were taken from a much larger number of fields in 1923, and the territory represented by them was also much more extensive. In this year, as in 1922, the data obtained showed prevalence only. In all, 56 fields located in the 26 counties shown in Figure 66 and including a total of 2,164 acres were subjected to examination. The total county wheat acreage, of which they were samples, constituted 35.3 per cent of the State's acreage.

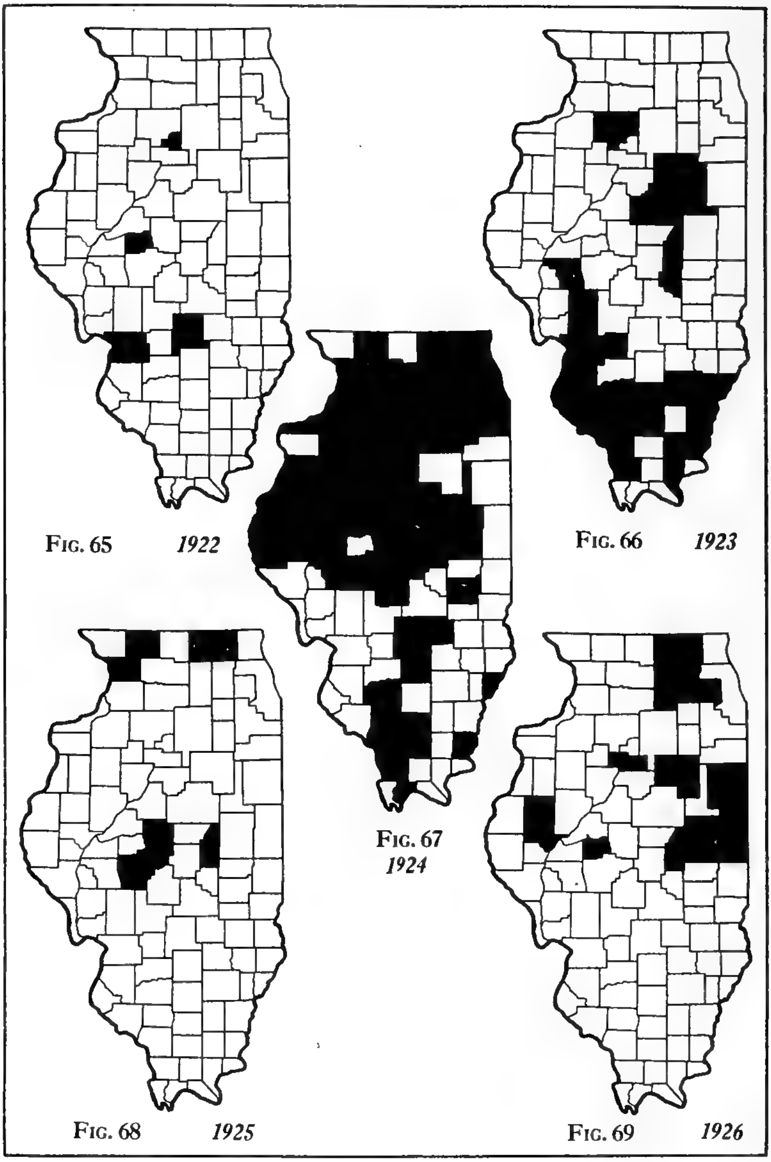
The season of 1924 gave the most abundant data, 146 fields located in the 59 counties shown in Figure 67 and containing a total of 3,166 acres being examined. It is unfortunate that, in this year of unusual prevalence, data bearing upon the destructiveness of the disease could not be secured. The 1,260,400 acres of wheat grown in the area shown in black in Figure 66, of which the sample fields were typical, constituted 54.6 per cent of the State's wheat acreage.

A very much smaller amount of data was secured in 1925, primarily because of the very late appearance of infections but also because the additional task of taking data on destructiveness required more time in each field. Only seven fields yielded data. They contained a total of 125 acres and were located in the 7 counties shown in Figure 68. A total of 173,010 acres of wheat—7.7 per cent of the State's acreage—was grown in these counties.

There was an increase in scab infection on wheat in 1926 which resulted in data being taken from 19 fields located in and representing the wheat acreage of the 14 counties shown in Figure 69. The data show both the prevalence of the disease and the destructiveness of the attack in a total of 435 acres.

The data taken from wheat fields to show the prevalence and destructiveness of scab are compared year by year in the following table:

Year	Acreage examined	Prevalence: Calculated percentages of wheat heads scab-infected			Destructiveness: Calculated percentages of wheat spikelets scab-infected		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	193	8.84	2.54	2.43	.....	.....	....
1923	2,164	4.22	5.65	8.82	.....	.....	....
1924	3,166	6.18	4.16	3.46	.....	.....	....
1925	125	16.36	34.74	21.20	14.51	34.34	20.5
1926	435	6.50	.....	.....	2.08	.....	....



FIGS. 65–69. SOURCES OF DATA FOR SCAB ON WHEAT, 1922–1926

The black areas on these maps show the regions from which scab data were taken by direct examination of wheat fields in each year. A very large number of fields were examined, data being taken directly from a total of 6,083 acres (see page 57.)

SCAB ON OATS

Although large acreages of oats have been examined in each of the years of the survey, but few data have been accumulated on scab infection. During 1922 one infested field was found in Stephenson County, and in 1923 an infested field was found in Logan County. In 1924 scab was sufficiently prevalent to show, on the basis of the data taken from 5 fields located in the four counties shown in Figure 70, an average prevalence of .75 per cent and a destructiveness too small to be determined. The fields furnishing these estimates contained an even hundred acres.

In both of the two seasons, 1925 and 1926, scab was so rare on oats that it was neither collected nor recorded.

The prevalence may be stated for the five years as follows:

Year	Acres examined	Percentage of panicles infected
1922	723	Trace
1923	1,695	Trace
1924	100	.75
1925	1,967	0
1926	870	0

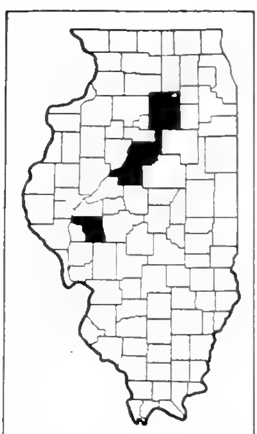


FIG. 70. SOURCE OF THE DATA FOR SCAB ON OATS, 1924

The black areas on this map show the regions from which scab data were taken by direct examination of oats fields in 1924. In the 5,355 acres of oats examined during the period 1922–1926, scab was practically absent, except in 1924.

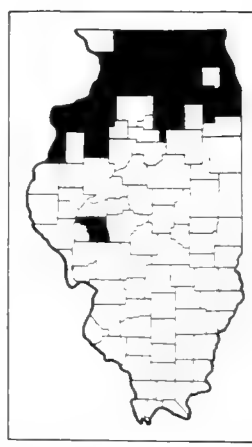


FIG. 71. SOURCE OF THE DATA FOR SCAB ON BARLEY, 1924

Although a considerable acreage of barley was examined in each year of the period 1922–1926, data on scab were obtained only in 1924. In the other years infection was practically absent.

SCAB ON BARLEY

As was the case with oats, infection has been very light on barley during the years of the survey. Only in 1924 was it possible to secure positive data on its prevalence. In this season, 30 fields were examined. They were located in the 20 counties shown in Figure 71 and contained a total of 392 acres. Their location in the northern counties of the State makes them typical of the barley region. In fact, the 209,780 acres of barley which they represented directly, were slightly more than 93 per cent of the State's acreage. In these fields, the data indicate a prevalence equal to 13.43 per cent; in the acreage directly represented, they indicate an average prevalence of 12.77 per cent; and in the State, of 12.86 per cent.

During 1925 and 1926 scab was so rare in barley fields that no records of it could be taken.

Scab on Rye

In contrast with the infections on oats and barley, scab on rye was most abundant in 1923, though the attack was too mild to measure. In the seasons of 1922, 1924, 1925, and 1926, infected rye was found only as mixtures in wheat fields.

Summary of data on cereal scab

The data obtained in field examinations, though much less voluminous than those for other cereal diseases, indicate the variations in prevalence among the individual crops from 1922 through 1926 and the intensity of the attacks in 1925 and 1926. The summaries of prevalence only, arrived at by methods previously outlined and given above for each of the crops, are compared in Figure 72.

Besides indicating that, of the four cereals commonly attacked by scab, wheat and barley alone have had serious epidemics, Figure 72

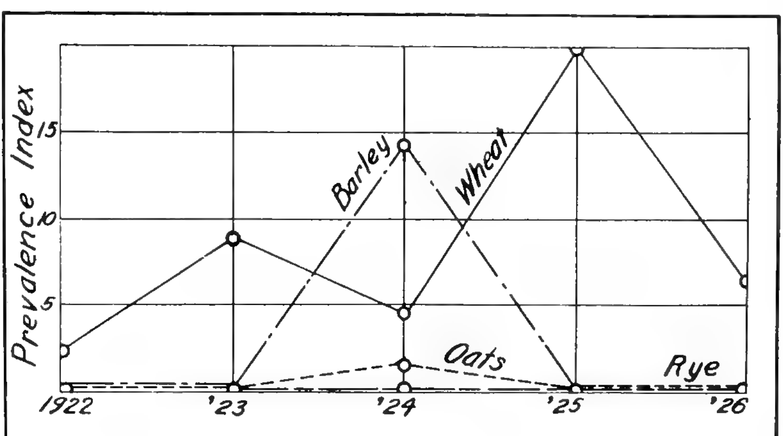


FIG. 72. PREVALENCE OF SCAB ON CEREALS, 1922–1926

The prevalence indexes for scab calculated from field data and given in the text are shown graphically here. Wheat and barley have had serious infections, and wheat alone is diseased every year.

shows that scab, like other diseases, finds conditions in a given year more favorable for spread on one crop than on another. Thus, in one season it may be very prevalent on wheat but practically absent from the other crops. Wheat appears to be the only crop consistently susceptible. There was an increase in prevalence on oats and barley in 1924; but, in contrast, the prevalence on wheat diminished. The slight rise in prevalence on rye in 1923 was accompanied by an increase on wheat. Except for these two coincidences, the tendency toward an increase in scab prevalence on one crop appears entirely independent of that tendency on another.

LEAF SPOT AND LEAF STRIPE DISEASES

Besides the common and conspicuous diseases just discussed, there is in Illinois at least one disease of each of the cereals, excepting corn, which attacks its host by entering the leaves, damaging the plants, and reducing yields by killing parts of the leaves. Barley is subject to a leaf stripe which not only results in a reduction in the amount of leaf but also generally kills the stem it attacks. Wheat is affected by "speckled" leaf blotch, which shows first as small spots but later kills large parts of the leaf. Rye is subject to a leaf spot much like the wheat leaf spot, but its occurrence in Illinois is very rare.

BARLEY STRIPE

Caused by *Helminthosporium gramineum* Rabh.

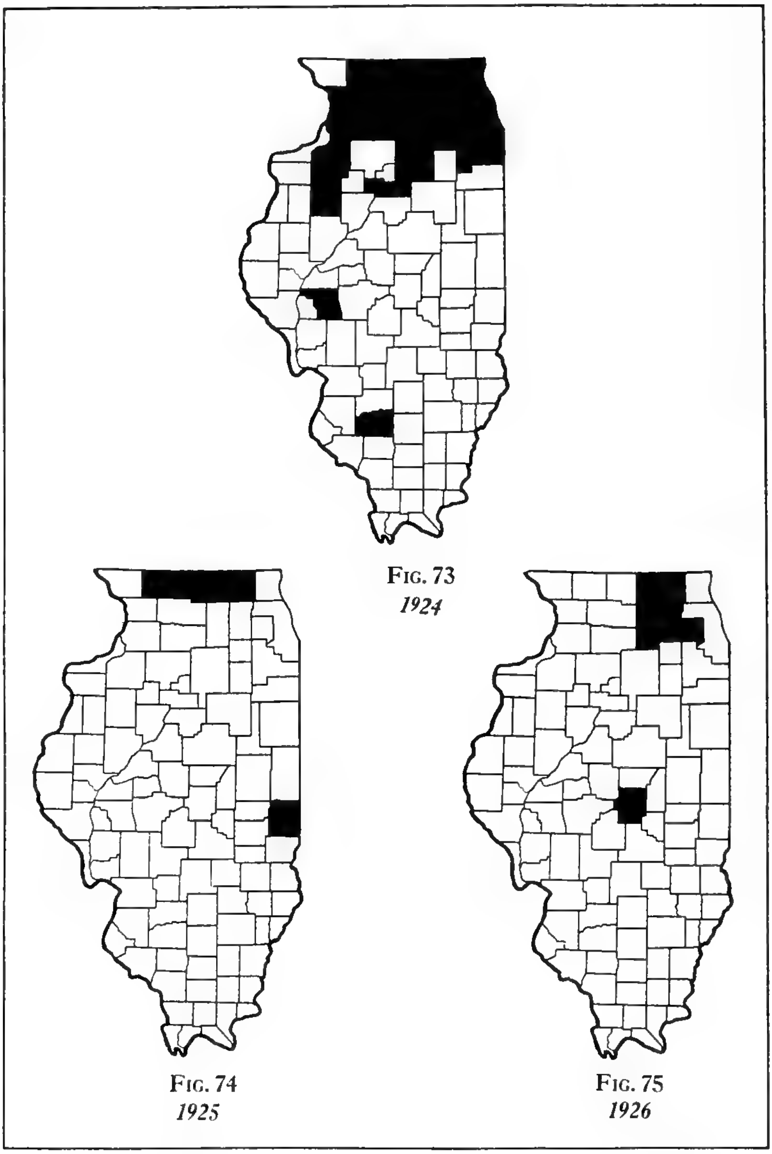
Stripe prevalence and stripe destructiveness are practically equivalent, for diseased stems die early, rarely maturing any grain. In obtaining data for this disease it is necessary, therefore, only to determine prevalence.

No data were taken in 1922 and 1923; but the lack of data from the many fields examined during these years should not be construed as showing the disease to have been absent.

In the summer of 1924 data were taken from 43 fields containing 683 acres. They were distributed among the 21 counties included in the black area of Figure 73 and, as samples of the 215,275 acres of barley grown in the area shown, were directly representative of 95.7 per cent of the State's acreage.

The records for 1925 were taken from five fields only, one in each of the five counties shown on Figure 74. Though containing a total of only 80 acres, they were representative of 56,320 acres of barley—46.2 per cent of the State's acreage.

In 1926 data were taken from 6 fields located in the 6 counties shown in Figure 75. These fields, which contained 120 acres, were located mainly in the northeast corner of the state, in a region devoted to barley production, and may be considered as typifying the prevalence of stripe infection.



FIGS. 73–75. SOURCES OF BARLEY STRIPE DATA, 1924–1926

The black areas on these maps show the regions from which data were taken by direct examination of barley fields in each year. No data were taken in 1922 and 1923, but the fields examined in 1924 were representative of 95 per cent, and in 1925 of 46 per cent of the State's acreage (see page 61).

The data accumulated show, when subjected to analysis, the following degrees of prevalence and destructiveness.

Year	Acreage examined	Prevalence and Destructiveness: Calculated percentages of stripe-infected barley culms		
		For the acreage examined	For the county acreage represented	For the State's acreage
1924	683	1.69	1.90	1.76
1925	80	4.49	4.21	4.16
1926	120	2.25	....	....

The indexes in this table are representative of stripe infection, except that the index for 1926 is somewhat low, being unduly lowered through the influence exerted in the calculations by a large field of 40 acres in Macon County. Were statistics available for 1926, this index would approximate 3.37 per cent in the two columns now vacant. This figure will be used in the summary to be made later.

SPECKLED LEAF SPOT OF WHEAT

Caused by *Septoria tritici* Desm.

Wheat plants are killed by the leaf spot only in rare instances; but in almost every season the disease is sufficiently abundant to cause serious damage to growing and maturing plants. Its prevalence is measured in terms of the number of stalks bearing spotted leaves; but since the spotting on the leaves varies in quantity, leaf by leaf and plant by plant, a special scale for determining destructiveness has been devised, a reduced replica of which is shown in Figure 76.

Such diagrams representing wheat leaves present, in a graded series, readily distinguishable degrees of leaf spot injury. Abundance of leaf spot infection, though in some measure correlated with the amount of injury, is not often the same, a fact explained through the ability of a spot located on the lower part of a leaf to cause the death of a large amount of leaf tissue extending upward beyond it. The examples in the scale indicate distinguishable degrees of injury as percentages of leaf area destroyed. They are also typical of types of injury commonly encountered in the field.

In making use of the device, the observer collects a generous leaf sample at random, while he is making prevalence counts. As the sample will contain leaves with no infection, with light infections, and with heavy infections, it should represent the average amount of leaf injury present on disease-bearing stalks. Either then, or later in the laboratory, the parts of the sample—fresh in the field, but pressed and dried in the laboratory—are compared individually with the standardized diagrams by fitting each part between the two standards which it most closely resembles. The intermediate value of the sample part is not determined, for to do so involves personal judgment to an extent certain to result in gross error. Instead, each part of the sample is considered as falling in the class represented by the scale diagram having the lower value of the two between which it falls. A record is made on the field data sheet of the number of parts of the sample falling in each class, and the average amount of leaf spot injury shown by the sample is determined in the manner described on page 19.

An analysis of the data on prevalence and destructiveness then is made in the manner described in the first part of this paper (see pages 8-14).

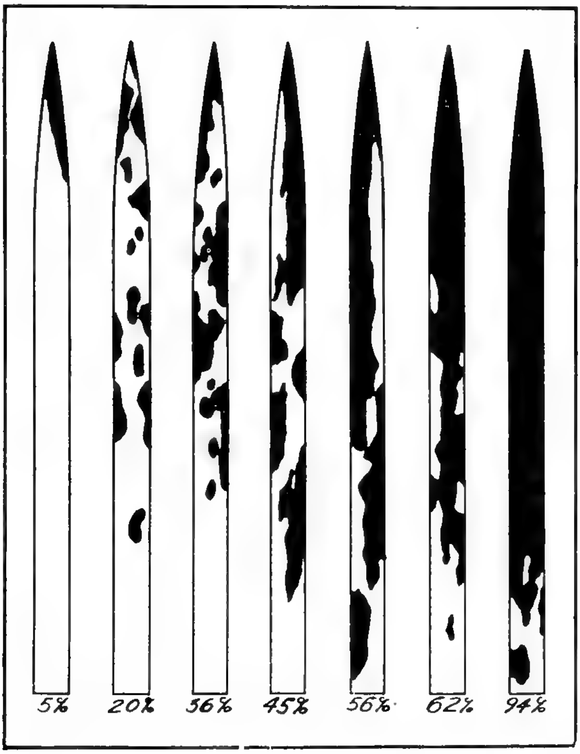
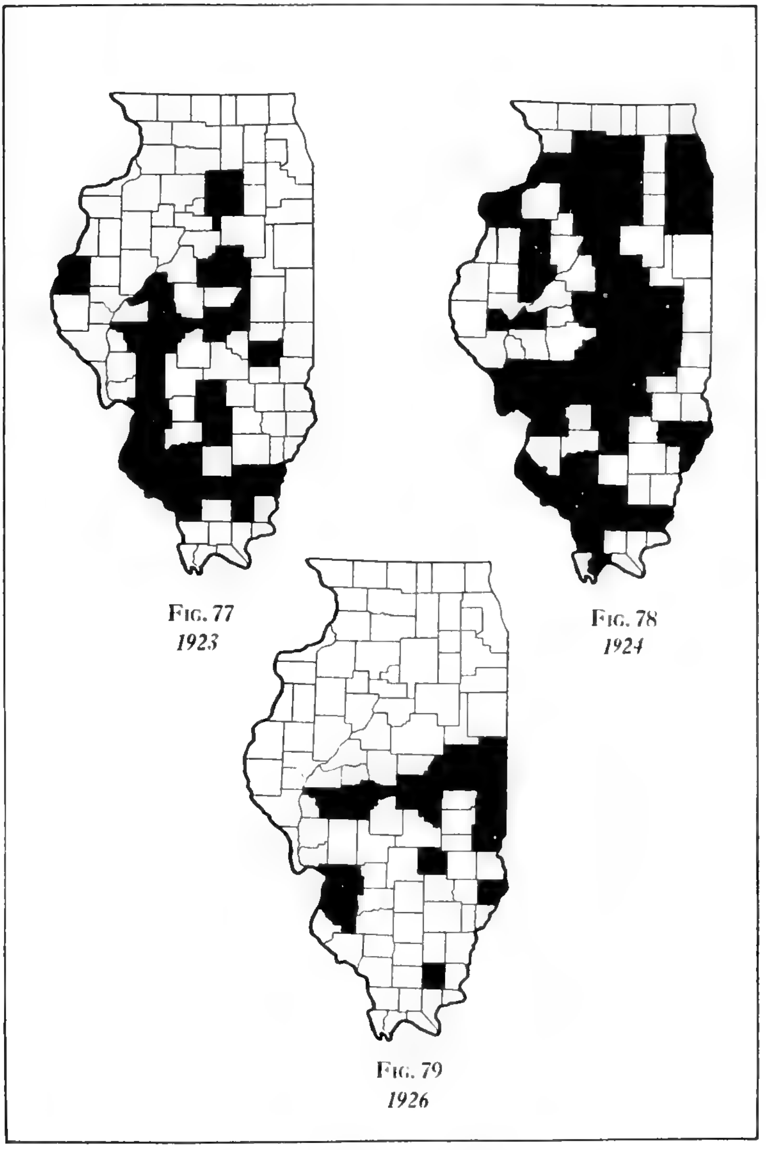


FIG. 76. STANDARD FOR MEASURING THE DESTRUCTIVENESS OF THE SPECKLED LEAF SPOT OF WHEAT

The black areas on each diagrammatic leaf represent the tissue killed by the leaf spot fungus. The area of the black spots has been measured and is given as a percentage of the entire leaf area for each diagram. Random samples taken in each field are compared with this scale, and the destructiveness of the disease is computed in terms of leaf area destroyed (see page 63).



FIGS. 77–79. SOURCES OF THE DATA FOR THE SPECKLED LEAF SPOT OF WHEAT IN 1923, 1924, AND 1926

The black areas on these maps show the regions from which data were taken by direct examination of wheat fields in each year. During the period 1922–1926 fields containing a total of 12,787 acres were examined for this disease, 862 acres showing none of it in 1922 and 3,225 acres having only a trace in 1925.

Due in a large measure, perhaps, to the exceedingly heavy attack of leaf rust in 1922, leaf spot appeared practically absent from wheat fields. No positive data on its prevalence were secured that year. In 1923, however, a considerable quantity was obtained from 41 fields located in the 24 counties shown in Figure 77. The fields examined contained 2,428 acres and were representative of 40.3 per cent the State's wheat acreage.

The season of 1924 furnished the largest accumulation of leaf spot data of any of the seasons covered by the survey. Examinations were made in 149 fields distributed in somewhat varying numbers among 53 counties. They furnished a representative sampling of leaf spot prevalence and intensity for the region shown in black in Figure 78. The fields themselves contained 5,667 acres, while the region which they represent grew 1,389,975 acres—60.3 per cent of the State's 2,307,000 acres of wheat.

Speckled leaf spot was rare in 1925. In 3,225 acres examined, only four instances of infection were found, one each in Clark, Crawford, Pulaski, and St. Clair counties. Though sufficient to give samples for laboratory diagnosis, they were so light that they could not be estimated, either in prevalence or severity. The infection for 1925 is to be considered, therefore, as only a trace.

In 1926, leaf spot was prevalent in fields throughout the central and southern parts of the state, but was not found in the northern third. Records of prevalence and severity were taken from 23 fields, which contained 605 acres and were located in the 14 counties shown in Figure 79. The data obtained were representative only of the infection in the southern half of the state, and the prevalence and intensity of the attack, expressed respectively by indexes of 11.0 and .39 calculated from these data, will be reduced considerably when 1926 acreage statistics become available for further calculations.

The fluctuations in prevalence and intensity of attack, as shown by the field data when subjected to analysis, are as follows:

Year	Acreage examined	Prevalence: Calculated percentage of wheat stalks with diseased leaves			Destructiveness: Calculated percentage of wheat leaf area destroyed		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	.....	0	0	0	0	0	0
1923	2,428	88.7	88.3	89.2	26.2	23.2	21.8
1924	5,667	58.3	53.2	54.2	9.06	8.03	9.5
1925	3,225	T	T	T	T	T	T
1926	605	11.0	....	....	.30	....	....

OATS HALO BLIGHT

Caused by *Pseudomonas coronafaciens* (Elliott) Stev.

Though the symptoms presented by the halo blight of oats are quite different from those shown by the leaf spot of wheat discussed above, the method of estimating its destructiveness is much the same. Its prevalence is determined, of course, as the percentage ratio of disease-bearing stalks. For estimating the intensity of the attack, a special scale, shown with considerable reduction in Figure 80, has been devised. The effect produced by halo blight in destroying leaf tissue appears to be considerably less than the similar effect of the wheat leaf spot. The degrees of destructiveness are more readily distinguishable, which permits the use

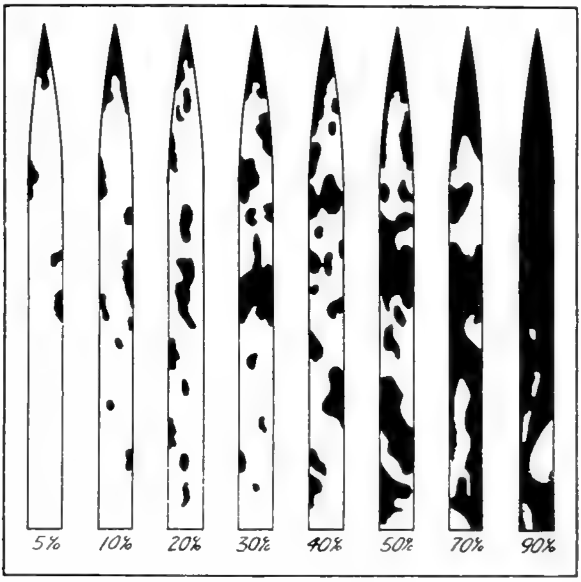
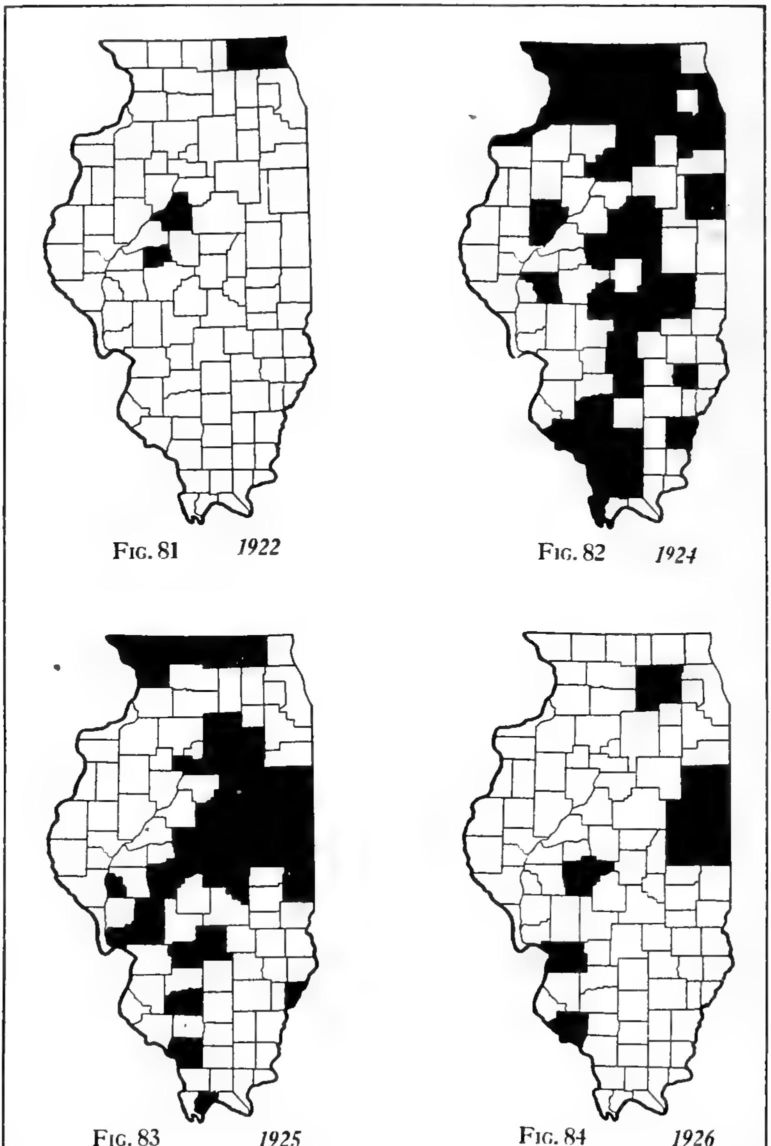


FIG. 80. STANDARD FOR MEASURING THE DESTRUCTIVENESS OF OATS HALO BLIGHT

The black spots on each diagrammatic leaf represent the tissue killed by the halo blight bacterium. The area of the spots has been measured and is given as a percentage of the entire leaf area for each diagram. Random samples taken in each field are compared with this scale, and the destructiveness of the disease is computed in terms of leaf area destroyed (see page 69).

of a larger number of individual standards in the scale and results in a considerably greater degree of accuracy in the estimates. Otherwise, the methods of obtaining field data are the same as those previously discussed.

During 1922, with halo blight of oats as with several other cereal diseases, data were recorded exclusively in the northern half of the State. Definite records were taken in 5 fields which contained a total of 97 acres and were located in the 4 counties shown in Figure 81. Although their combined acreage is not impressively large, their wide



FIGS. 81–84. SOURCES OF DATA ON THE HALO BLIGHT OF OATS, 1922 AND 1924–1926

The black areas on these maps show the regions from which data were secured by direct examination of oats fields in each year. Fields containing a total of 4,198 were examined for this disease during the period 1922–1926, the 1,306 acres seen in 1923 showing only a trace of infection.

separation together with the constancy of the data endows them with a certain degree of dependability.

In 1923 only two records of halo blight were obtained. A small field of 5 acres in Macoupin County, examined June 20, yielded the information that 65 per cent of the stems bore leaves having an average of 50 per cent of their area destroyed. In another small field of 3 acres in Fayette County, examined June 12, 3 per cent of the stalks bore leaves having 17.5 per cent of their area destroyed. In view of these facts, the prevalence and destructiveness of halo blight in 1923 were too light to be estimated.

In 1924 data were taken from 78 fields which contained a total of 1,291 acres. They were distributed among the 43 counties which make up the black areas of Figure 82. The oats grown in these areas, 1,906,500 acres, make up 43.5 per cent of the State's acreage.

Again in 1925 abundant data were obtained. The fields examined, 56 in number, contained 1,189 acres and represented the infection prevailing in the 31 counties shown in Figure 83. These counties contained 2,237,510 of the State's 4,724,000 acres devoted to oats production. The data, therefore, apply directly to 47.4 per cent of the State's acreage.

Much less abundant in 1926 than in the two preceding seasons, halo blight was, nevertheless, widely prevalent. Records were taken in the 9 counties included in the black areas of Figure 84.

Prevalence and destructiveness, as shown by data obtained by the survey, are given in the following table:

Year	Acreage examined	Prevalence: Calculated percentage of oats culms bearing blighted leaves			Destructiveness: Calculated percentages of oats leaf area destroyed by halo blight		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	97	77.90	78.30	67.70	14.20	14.80	13.60
1923	1,306	T	T	T	T	T	T
1924	1,291	61.33	46.45	47.87	8.27	8.27	7.30
1925	1,189	47.06	47.62	44.59	11.93	11.93	5.76
1926	315	3.00	.....	.....	T	.....	.....

Summary of leaf spot and stripe data

The variations in prevalence indicated for the individual diseases in the foregoing tables are brought into graphical comparison in Figure 85, while the differences in destructiveness are shown in Figure 86.

So far as available data show, the trends of both prevalence and destructiveness are the same for each disease; but there are marked differences in these trends for the different diseases. In 1922, both in prevalence and destructiveness, halo blight of oats stood high, while the speckled leaf spot of wheat was very low. In the succeeding year,

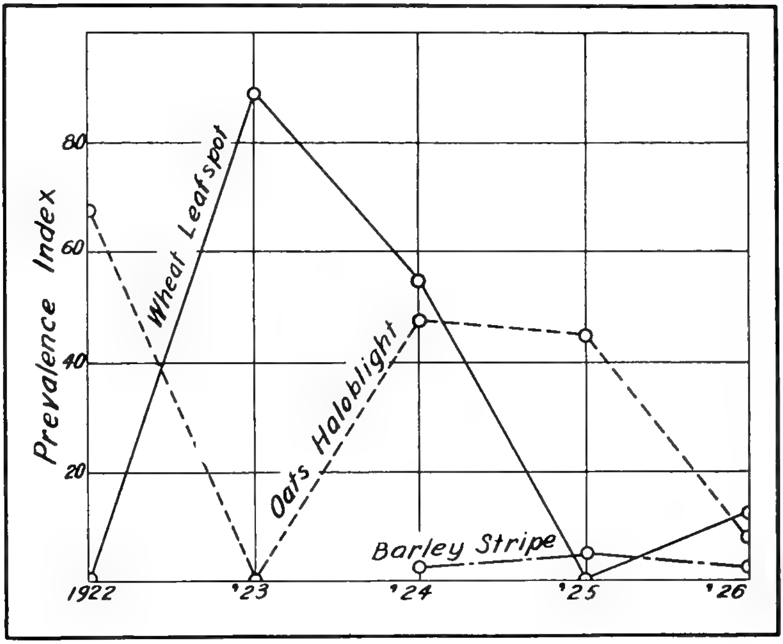


FIG. 85. PREVALENCE OF THE LEAF SPOT AND STRIPE DISEASES, 1922–1926

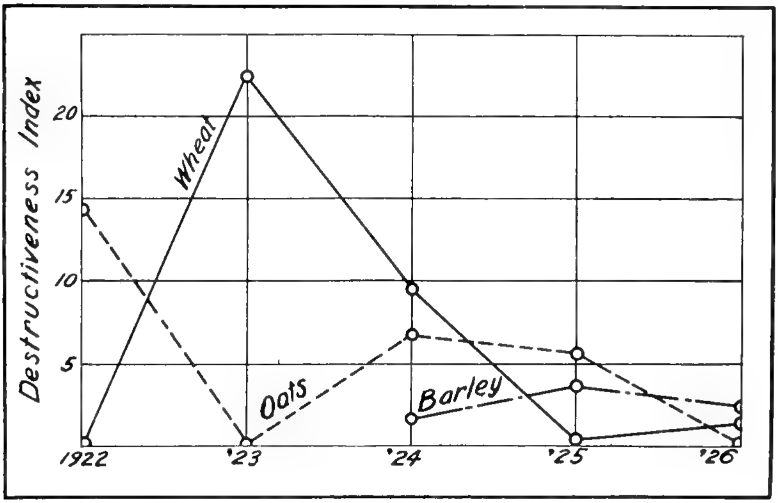


FIG. 86. DESTRUCTIVENESS OF THE LEAF SPOT AND STRIPE DISEASES, 1922–1926

1923, their positions were reversed, the former being low and the latter very high. The summer of 1924 was marked by a sharp decline of speckled leaf spot and a sharp rise of halo blight, the two being very nearly equal in prevalence and in destructiveness. In 1925 both diseases stood below their marks of the previous years, but the decline of halo blight was slight and that of leaf spot great, leaving the former still serious and the latter insignificant. In contrast to these two, there was a slight rise in the prevalence of barley stripe. Finally, in 1926, halo blight and barley stripe exhibited declines in both prevalence and destructiveness, which contrasted sharply with the increase shown by the speckled leaf spot of wheat.

SUMMARY OF ALL DATA SHOWING PREVALENCE AND DESTRUCTIVENESS

All of the diseases considered in the previous pages have been of a kind which attacks and destroys above-ground parts of the plant. When considered in relation to their effects, they are of three types: destroyers of stem tissue, of leaf tissue, and of heads. One only, the smut of maize, commonly attacks all parts of the plant. Data on at least one of each of these types of disease have been given for each of the cereal crops for nearly every one of the five seasons. In any season an individual plant of any of these crops may bear one, and is likely to bear two or even more, types of disease. This fact is not particularly significant with respect to the prevalence of the several diseases, but it is very important in determining the destructiveness resulting from disease attack.

The prevalence indexes previously given for the several types of disease are brought together in the following tables in closer relation to the individual crops. For each crop, the indexes of the several diseases are added together to give an index of total prevalence for each year; and averages are obtained for the entire priod of the survey. This gives a fairly exact comparison of the five seasons.

Disease	Prevalence: in 1922	in 1923	in 1924	in 1925	in 1926	Average
Leaf rust	94 10	89.70	68.30	52.60	57.24	72.38
Stem rust	22.06	35.70	11.10	14.90	57.80	28.31
Loose smut	89	1.39	.45	.70	.94	.88
Bunt	1.20	2.50	4.03	1.43	.45	1.92
Scab	2 43	8.82	3.46	21.20	6.50	8.48
Septoria	0	89 20	54.20	T	11.00	30.88
Total	120.68	227.31	141.54	90.83	133.89	142.85

On wheat, as shown in the first table, the total prevalence, as well as the prevalence of each disease, fluctuates from year to year. The season of 1925 ranks lowest, 1922 next, then 1926 and 1924, and finally 1923 at the peak with a total prevalence of 227.31.

The prevalence of oats diseases is given in the following table:

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Crown rust	67.00	83.10	64.3	27.00	70.40	62.36
Stem rust	56.90	0	45.5	21.60	85.50	41.90
Loose smut	5.62	3.08	5.2	3.49	3.40	4.58
Scab	T	T	.75	0	0	.15
Halo blight	67.70	T	47.87	44.50	3.00	32.63
Total	197.22	86.18	163.62	96.68	162.30	141.20

The average prevalence of disease for the survey period is 141.2, which, when compared with the index for wheat, 142.85, shows how similar in average prevalence the diseases of the two crops are. The variation in prevalence, season by season, is as evident as in the case of wheat diseases, and the differences in prevalence shown by the individual diseases are also evident.

The barley data, though in general much less abundant than those of wheat and oats, furnished indexes of prevalence which compare as follows:

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Leaf rust	25.0	100.0	100.0	34.6	76.10	67.14
Stem rust	45.5	0	8.0	11 1	100.00	32.92
Loose smut	....	5.30	1.64	4 11	5.00	4.01
Scab	....	.....	12.86	T	T	4.29
Stripe	....	.....	1.76	4.16	2.25	2.72
Total	70.5	105.3	124.26	53.97	183.35	107.47

The prevalence indexes of rye diseases, though computed like those for barley, from rather limited data, give the following comparison.

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Leaf rust	99.1	50 3	22.2	44.5	19 1	47.04
Stem rust	50.0	0	25.9	0	0	15.18
Scab	T	T	T	T	T	T
Total	149.1	50.3	48.1	44.5	19.1	62.22

Although only three diseases are considered, instead of the five or six diseases of the crops just discussed, similar seasonal variations in prevalence are evident.

For corn, the number of diseases treated is of necessity small, and the information secured concerning them, due to conditions imposed, has often been inadequate. Yet the indexes of prevalence obtained show the following comparisons:

Disease	Prevalence: in 1922	in 1923	in 1924	in 1925	in 1926	Average
Rust	34.6	3.0	62.6	33.3	11.4	28.98
Smut	5.33	11.56	4.33	3.16	2.9	5.46
Total	39.93	14.56	66.93	36.46	14.3	34.44

In order to show clearly the fluctuations from season to season of the total infections by the diseases discussed, the totals from the above tables are shown in Figure 87. The same lack of agreement is evident when the prevalence of the diseases attacking one crop is compared with those attacking another. Of the five years covered by our survey, there is not one in which disease prevalence was uniformly either

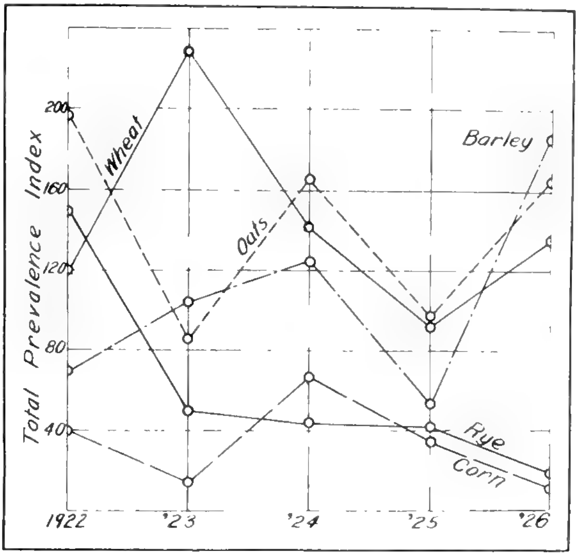


FIG. 87. TOTAL DISEASE PREVALENCE FOR EACH CROP, 1922–1926

There was not one year among the five in which disease prevalence was uniformly high or low on all the cereals, nor was prevalence constant in amount on even one crop throughout the period.

heavy or light on all of the five cereals. The closest approach to such a condition occurred in 1925, the total prevalence of disease in that year being, for each of the five crops, less than the year before. Beginning with the wide range of total prevalences displayed in the season of 1922, the trend was downward for rye, corn, and oats diseases, but upward for those of barley and wheat in 1923; down for wheat and rye diseases but up for those of oats, barley, and corn in 1924; down for the diseases of all five crops in 1925; and in 1926 down for corn and rye, but up to relatively high points for wheat, oats, and barley diseases.

The average total prevalence over the period of years covered by the survey is remarkably characteristic for each of the five crops. This fact is illustrated in Figure 88, in which the five-year index averages given in the foregoing five tables are shown graphically. The high prevalence of infection on wheat and oats is indicative of the fact that these crops suffer most from diseases of their above-ground parts. The

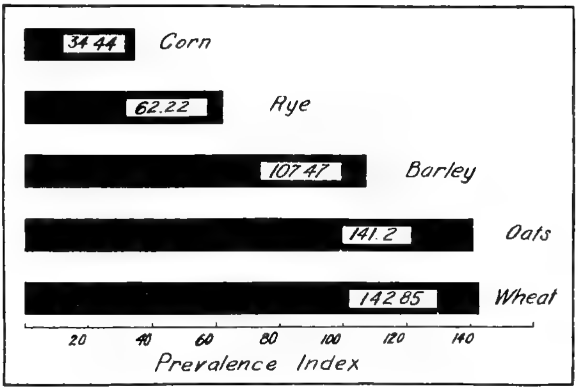


FIG. 88. AVERAGE DISEASE PREVALENCE FOR EACH CROP

The indexes of prevalence given in the text for the diseases of each crop have been added and averaged in order to show the normal prevalence of diseases on each crop in Illinois.

lesser prevalence shown for barley and rye result, in part at least, from the limited range of culture of the first crop and from the scattering cultivation accorded the latter. In the case of corn, however, the very low average prevalence may be considered as directly correlated with the relatively minor ranks held by smut and rust among corn diseases.

It is not possible to gain a clear-cut conception of the destructiveness of diseases through the simple process of adding the indexes, as has been done for prevalence. The types of injury caused by the various diseases are dissimilar and, therefore, require a more complicated treatment.

From the data previously given to show the comparative intensity of attack, those relating to wheat are selected and shown together in the following table:

Disease	Destructiveness: 1922 Stem injury	1922 Leaf injury	1922 Head injury	1923 Stem injury	1923 Leaf injury	1923 Head injury	1924 Stem injury	1924 Leaf injury	1924 Head injury	1925 Stem injury	1925 Leaf injury	1925 Head injury	1926 Stem injury	1926 Leaf injury	1926 Head injury
Leaf rust	....	50.3	....	....	31.3	....	....	19.1	....	....	17.1	....	....	11.2	....
Stem rust	17.8	....	....	8.0	....	....	.6	....	....	1.2	....	....	11.2	....	....
Loose smut	....	....	.89	....	....	1.39	....	....	.45	....	....	.70	....	....	.94
Bunt	....	....	1.20	....	....	2.50	....	....	4.30	....	....	1.43	....	....	.45
Scab	....	....	T	....	....	T	....	....	T	....	....	20.50	....	....	2.08
Leaf spot	....	0	....	....	21.8	....	....	9.5	....	....	T	....	....	.3	....
Total	17.8	50.3	2.09	8.0	53.1	3.89	.6	28.6	4.75	1.2	17.1	22.63	11.2	11.5	3.47

Disease attack injures or kills parts of the wheat stem, leaf, or head, thereby interfering with the ability of the plant to produce grain. The degrees of disease severity shown by the totals in the above have more or less commensurate effects upon the ability of the wheat to yield in each year; but a real understanding of the total destructiveness in one year with that in another is not readily attained by examining the table.

In order to gain a clearer picture of the meaning of the figures, one may imagine, first, a wheat stalk, unattacked by disease, with stature and proportions of leaf and spike such as those illustrated by the standard in Figure 89. The effect of disease attack upon such a stalk, through the injury it causes, would be to cut down the amount of stem, leaf, and spike in proportion to the severity of the attack, leaving only the healthy parts to produce the harvest. Yield from a diseased stalk might be expected to compare closely with the yield of a healthy stalk having the same proportions as those left healthy on the diseased stalk. The effect of disease attack may be appreciated, then, by imagining five wheat stalks, one for each of the years covered by our survey, reduced in the size of their parts, as shown in Figure 89, in the exact proportions (insofar as they can be depicted) indicated by the figures in the foregoing table.

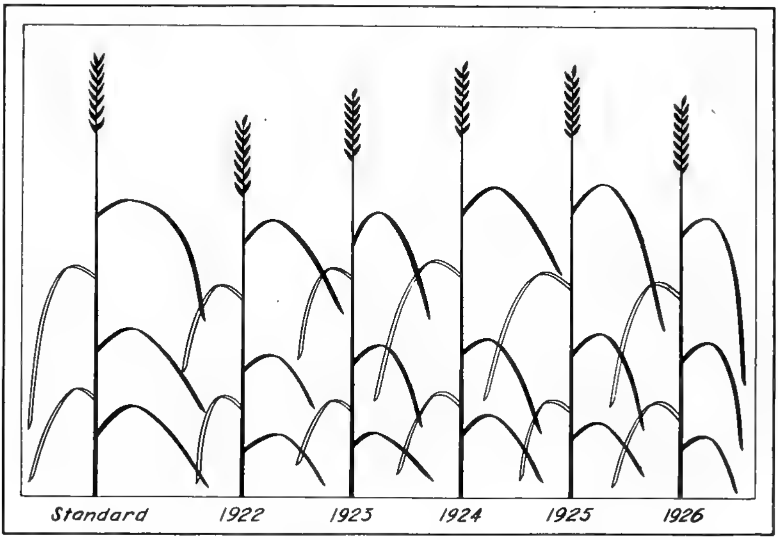


FIG. 89. DESTRUCTIVENESS OF WHEAT DISEASES, 1922–1926

The effect of disease attack upon the stems, leaves, and heads of wheat, as indicated by the indexes of destructiveness given in the text, is shown for each year of the period 1922-1926 in comparison with an average healthy stalk.

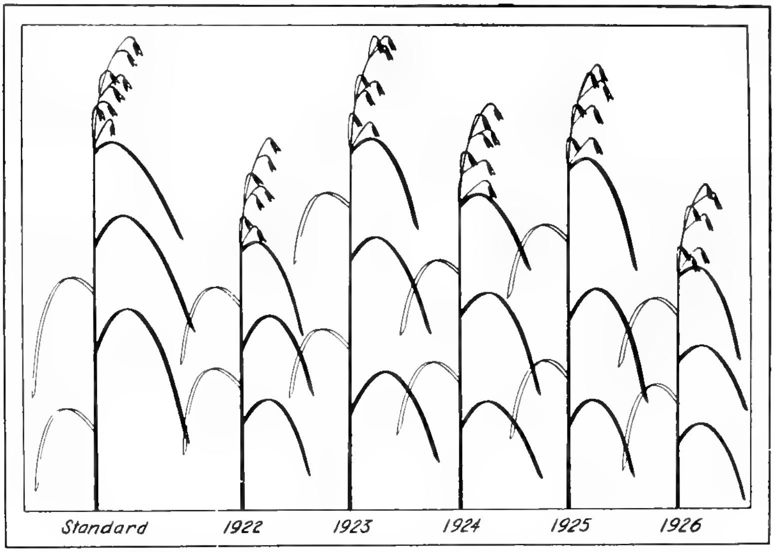


FIG. 90. DESTRUCTIVENESS OF OATS DISEASES, 1922–1926

The effect of disease attack upon the stems, leaves, and panicles of oats, as indicated by the indexes of destructiveness given in the text, is shown in comparison with an average healthy stalk. See the text on page 75 for further explanation.

The destructiveness of the diseases of oats, barley, and rye may be regarded in the same way as the diseases of wheat. A statement of their destructiveness may be made, consequently, by omitting summarizing tabulations like that given above for wheat diseases and using, in their stead, illustrations similar to Figure 89.

In Figure 90, the total effect of disease attack on oats, as indicated by the indexes of destructiveness given in previous pages, is illustrated for each year in comparison with an undiseased stalk of average proportions. The stature of the stalk is shown reduced 29 per cent by stem rust attack in 1922, not at all in 1923, 13.8 per cent in 1924, 4.5 per cent in 1925, and 42.7 per cent in 1926; the normal leaf complement is illustrated as being reduced 40.9 per cent by the combined attacks of crown rust and halo blight in 1922, 30.6 per cent in 1923, 19.2 per cent in 1924, 6.4 per cent in 1925, and 9.9 per cent in 1926; and the spikelets are depicted as reduced 5.62 per cent by scab and loose smut in 1922, 3.08 per cent in 1923, 5.95 per cent in 1924, 3.49 per cent in 1925, and 3.4 per cent in 1926.

The destructiveness indicated by the indexes given previously for barley diseases is shown in Figure 91. In comparison with a barley stalk

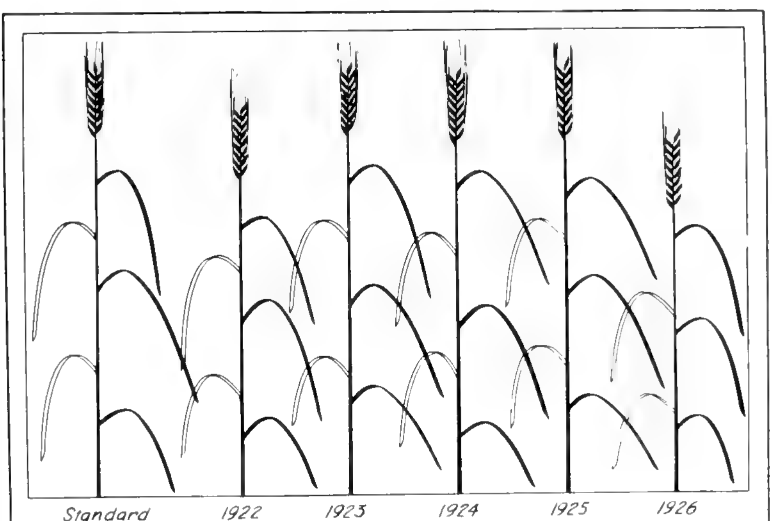


FIG. 91. DESTRUCTIVENESS OF BARLEY DISEASES, 1922–1926

The effect of disease attack upon the stems, leaves, and panicles of barley, as indicated by the indexes of destructiveness given in the text, is shown in comparison with an average healthy stalk. See the text on pages 75-77 for further explanation.

of normal proportions, stem rust is shown to have reduced the stature 12.4 per cent in 1922, not at all in 1923, .6 per cent in 1924, .2 per cent in 1925, and 28.7 per cent in 1926; the normal leaf complement is reduced 5 per cent by the combined attacks of leaf rust and stripe in 1922, 5 per cent in 1923, 6.16 per cent in 1924, 9.16 per cent in 1925, and 9.25 per cent in 1926; and the heads are reduced 5.3 per cent by loose smut in 1923, 1.64 per cent in 1924, 4.11 per cent in 1925, and 5.0 per cent in 1926.

The destructiveness effect of rye diseases is illustrated in Figure 92. In comparison with an undiseased stem of average proportions, the diagram illustrating the disease injury of 1922 has 25.5 per cent less stem and 55.1 per cent less foliage; for 1923 the stem is normal and the foliage 8.2 per cent smaller for 1924 the amount of stem of 13.9 per cent less, and the foliage 2 per cent less; for 1925 the stem is normal, the foliage .9 per cent less; and for 1926 the stem is normal but the foliage is 19.1 per cent less. In every season, the heads are drawn at normal size, as the data accumulated for head smut, scab and ergot showed no appreciable general reductions from their attack.

No similar depiction can be given of the effect of smut and rust on corn, for no satisfactory method of estimating their destructiveness has been devised.

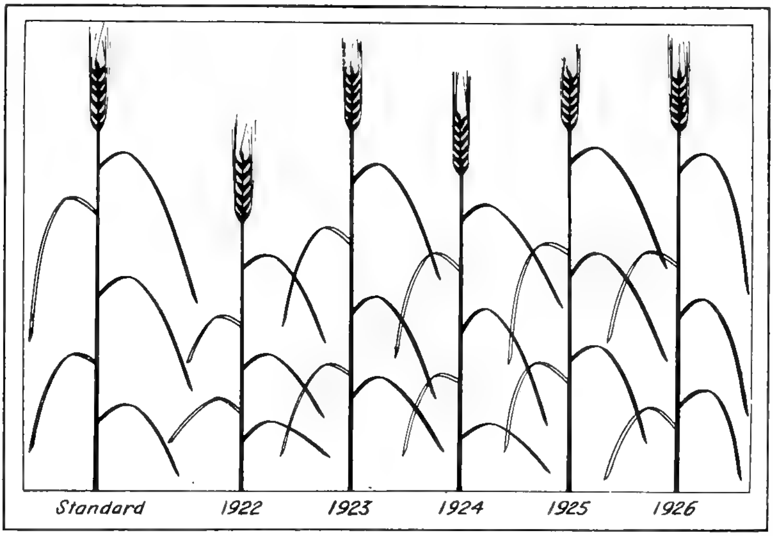


FIG. 92. DESTRUCTIVENESS OF RYE DISEASES, 1922–1926

The effect of disease attack upon the stems, leaves, and panicles of rye, as indicated by the indexes of destructiveness given in the text, is shown in comparison with an average healthy stalk.

SOME RELATIONS OF DISEASE TO WEATHER AND CLIMATE

There is abundant evidence in the experience of the farmer and the disease specialist that a vital relation exists between the occurrence of disease epidemics such as those described in the preceding pages and the accompanying weather conditions. Particular combinations of temperature and rainfall have been observed to accompany—even to condition—severe attacks, and the absence of them generally is attributed to a corresponding absence of favorable weather. The climate of a region, also, appears to determine to a very large extent what the relative importance of particular diseases shall be, or whether any disease shall be important.

In the main, these interrelations have not been defined. With respect to weather, they have been generalized into the four categories, hot and wet, hot and dry, cold and wet, and cold and dry, each combination being reported to have a particular influence over particular diseases. Since they refer, almost without exception, to departures from the average conditions of localities or limited regions familiar to the observers who make the statements, it is not surprising that a list of their reported effects contain incongruous diversities of opinions, among which the only apparent agreement often is that weather has had a dominating influence. This applies particularly to diseases which attack plants above the ground; for a number of diseases that are soil borne or attack the parts of plants that are in the soil have been subjected to extensive investigation in the laboratories of the Wisconsin Agricultural Experiment Station*, where many of their relations to temperature and soil moisture have been ascertained. But, with diseases attacking as well as spreading to and from aerial plant parts, the conditions which govern infection are chiefly those of the atmosphere, though it must be recognized that concurrent soil conditions may so hasten or delay the plant's growth that even under ideal atmospheric conditions heavy infection does not occur.

The difficulties which attend the artificial duplication of out-of-door weather in the limited space of a laboratory demand that the main facts of the disease-and-weather relation shall be determined by observing the two as they occur naturally. The conclusions arrived at may be subjected later to experimental verification and refinement; but the principles worthy of practical application to the problems of the farm certainly will be those derived by observing natural phenomena.

It is not within the scope of this paper to define exactly any of these principles, for the chief intention has been to describe ways of measuring disease phenomena; but a small contribution may be made by showing some of the ways in which disease data may be correlated

* Jones, L. R., James Johnson, and James G. Dickson. Wisconsin studies upon the relation of soil temperature to plant disease. Wis. Agr. Exp. Sta. Research Bull. 71. 1926.

with weather. As this material is presented mainly by way of example, it will be limited to the leaf rust of wheat, leaving the fuller treatment of it and other diseases to later papers.

RELATION TO MEAN ANNUAL TEMPERATURE AND TOTAL ANNUAL RAINFALL

The yearly history of wheat leaf rust may be considered to extend from about the first of July to the end of the following June. During this time, there are various periods of rest and active growth, the sum of which is expressed in the degree both of prevalence and destructiveness reached by the rust at harvest. There is, first, a period of meagre existence in shocks, on stubble, in straw stacks, and on volunteer plants. Following it there often is a short period of very rapid multiplication upon the young, fall-sown wheat, which is terminated by the arrival of the winter months with their low temperatures. Finally, there is the spring and early summer, when the rust that was overwintered, aided by an accretion of wind-blown infection from the south, develops with exceeding swiftness, step by step with the wheat, to harvest.

The success with which the rust-producing organism passes these various periods is determined by many factors, including temperature, rainfall, humidity, wind, and light, each of which is changing continually and independently. While varying greatly in individual seasons, the most important of these factors—temperature and rainfall—vary remarkably little, as a rule, from year to year. The normal yearly mean temperature for Illinois, according to weather records extending back to 1878, is 52°, and the average yearly rainfall is 36.42 inches. During the years covered by the disease survey reported here (1922-1926), the mean temperature of a year has never been more than 2.3° above nor more than 1.4° below the normal mean, and the rainfall of a year has never been more than 1.57 inches above nor more than 3.59 inches below the normal total.

Striking correlations ought to exist, therefore, between very small annual departures and the large annual variations in rust attack. The indexes of wheat leaf rust are given in comparison with the mean temperature and total rainfall for each rust year, that is for the period July through June rather than January through December, in the following table:

Year	Prevalence index	Destructiveness index	Mean temperature of the rust years	Total rainfall of the rust years
1922	94.1	50.3	54.8	41.73
1923	89.7	31.3	53.1	32.69
1924	68.3	19.1	51.9	38.74
1925	52.6	17.1	53.0	31.15
1926	57.2	11.2	51.3	35.15

No complete parallels exist between either phase of the rust attack and mean temperature or total rainfall for year-long periods, but they are observable when temperature and rainfall are considered together. In 1922, when the rust indexes were highest, both mean temperature and total rainfall were highest; while in 1923 the rust indexes, the mean temperature, and the total rainfall were distinctly lower. The destructiveness index was greater in 1925 than in 1926, and the combinations of mean temperature and total rainfall for these two years stood in the same relation.

These facts, and the deductions to be drawn from them, are shown more clearly by diagram in Figure 93. The horizontal scale represents inches of total annual rainfall; the vertical scale, degrees of mean annual temperature. The heavily-lined axes are drawn from the points of average mean annual temperature and average total annual rainfall for Illinois. The points labeled A, B, C, D, and E are the combinations of temperature and rainfall listed in the preceding table for the consecutive years 1922-1926. In the upper half of the diagram, a trend of rust increase from points B and D to point A is indicated by a dotted line; and in the lower half a similar trend is indicated by the dotted line drawn through points E and C. These two lines are nearly parallel.

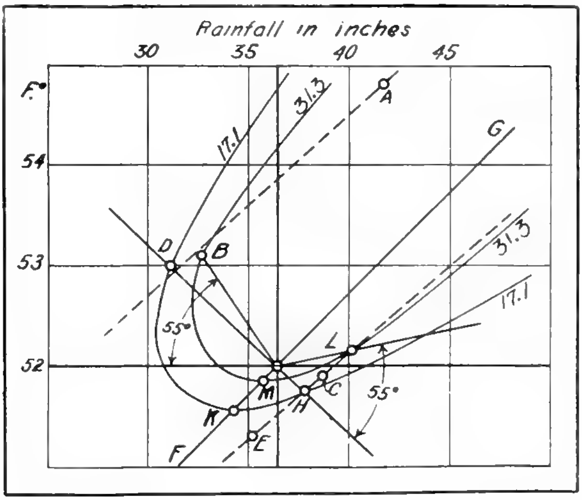


Fig. 93. Relation of combinations of mean annual temperature and total annual rainfall to destructiveness of the leaf rust of wheat

The hyperbolic lines, drawn as explained in the text, pass through all the combinations of mean annual temperature and total annual rainfall capable of producing rust attacks with destructiveness indexes of 17.1 and 31.3. When enough data have been obtained, hyperbolas can be determined for every degree of rust attack, and the facts so learned can be used in predicting the intensity of attack in a given season.

running upward at an angle very close to 45°. The trends which they indicate suggest strongly that rust destructiveness increases when both the mean annual temperature and the total annual rainfall increase. Although these lines are determined by a very small number of points, the fact that they run upward at an angle so close to 45° is strongly indicative of a certainty of correlation between increasingly heavy rust attacks and combinations of increasingly high mean annual temperatures and totals of annual rainfall.

If it is assumed that this correlation is perfect, the line F-G may be drawn at a 45° angle through the intersection of the temperature and rainfall axes. Starting at the lower end, it should pass through points representing combinations of temperature and rainfall which would result in rust attacks with indexes rising steadily from 0 to 100.

Certain of the indexes theoretically included in this line are shown, however, actually to have been produced by temperature-rainfall combinations not crossed by the line, thus suggesting that rust attacks measured by a given index may result from an infinite number of such combinations. To determine them exactly requires data for a period of years much greater than is now available; but a method for determining them approximately is suggested in the following:

Point D is so situated that a line drawn from it to the intersection of the axes stands nearly at a right angle to the line F-G and, when continued, cuts the dotted line E-C at H. The point H lies about at the place between E and C where an index of 17.1 would be expected from inspection, and it may be given that value. By rotating either point D or point H about the intersection of the axes in conformity with the known values indicated by points already placed, a hyperbolic line may be drawn through the points D, K, and H, which theoretically runs through all the possible combinations of temperature and rainfall resulting in a rust attack having an index of 17.1.

A line drawn from point B to the axis intersection departs at an angle of 55° from the temperature axis. If a line is drawn from the intersection, departing from the line F-G at the same angle, to cross the line E-C, it will determine the point L, to which may be assigned the index of point B, 31.3. By rotating either point B or point L as directed above for D, the hyperbola L, M, B is obtained, which runs through all of the combinations of temperature and rainfall capable of producing a rust attack of the index 31.3.

From so small a number of points, the proper location of the hyperbolic lines can be only suggested; but with the accumulation of data year after year, it will be possible to determine them with great precision for every magnitude of rust attack. Practically, the delineation of a set of hyperbolic bands for predetermined ranges of rust indexes will be more serviceable than hyperbolic lines in predicting intensity of rust attack, for the absolute regularity of the line, which is determined only by temperature-rainfall combinations, will be shattered by the occurrence of varied atmospheric saturation deficits, light intensities, and other minor factors not readily subjected to quantitative measurement.

RELATIONS OF DISEASE TO SEASONAL TEMPERATURE AND RAINFALL

It has been pointed out that the leaf rust of wheat exists under quite diverse conditions during different periods of its year. Since these periods correspond to a certain extent, but not wholly, with the seasons of the year, it is necessary to visualize the points of difference and similitude among various years in order to determine the extent and characteristics of the rust seasons.

Making use of diagrams constructed according to the method suggested by Taylor[1], the mean temperature and total rainfall for each month of the years included in the survey may be so represented as to be compared easily, year with year and month with month. This is done in Figures 94-99, in which the vertical scale represents Fahrenheit degrees of mean monthly temperature and the horizontal scale, inches of total monthly rainfall. The combination of mean temperature and total rainfall occurring in any month is shown by a point placed at the intersection of the proper temperature and rainfall lines, and the month is designated by an arabic numeral (1 = January, etc.). Figure 94 shows the progress of a "normal" year in Illinois, beginning with July and ending with the following June, the normal mean annual temperature and the normal total monthly rainfall for the state being indicated by the heavy, dotted lines. Figures 95-99 are diagrams of the years 1922-1926, in which, to facilitate comparison, the mean annual temperature and total monthly rainfall of a normal year are indicated as in Figure 94.

These diagrams show that no one of the years with which we are dealing approaches a normal year very closely. The outstanding fact illustrated by all of them is that the rust year is divided roughly into halves, the first of which is characterized by falling, and the second by rising, temperatures. This we may take to be a characteristic of every rust year, to which we should attach only this very broad and obvious significance: From July through December the rust organism is being subjected to increasingly rigorous temperatures and is decidedly on the down-grade, while from January through June the general upward trend of temperature has an increasingly favorable influence upon its rate of propagation. Lacking definite names, the terms "fall trend" and "spring trend" may be given to these periods.

When a fall trend or a spring trend in any one of these years is compared by means of these diagrams with its counterpart in any other year, distinct differences are evident. Keeping in mind the variations in rust attack stated previously, the observable differences suggest at once that

[1] The settlement of tropical Australia. By G. Taylor *in* Geog. Rev. Vol. 8, pp. 84-115. 1918.

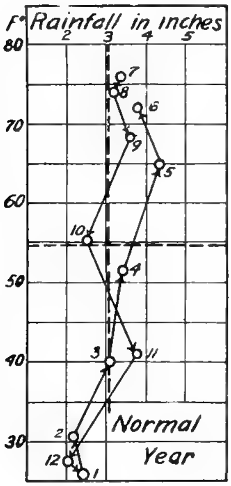


Fig. 94

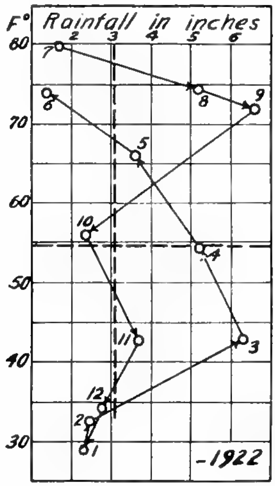


Fig. 95

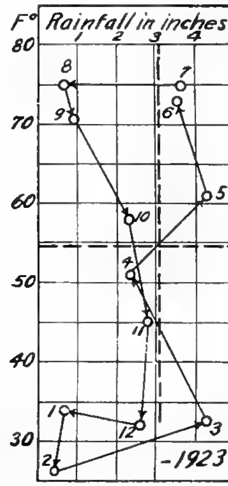


Fig. 96

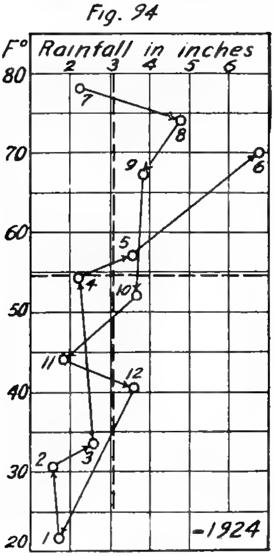


Fig. 97

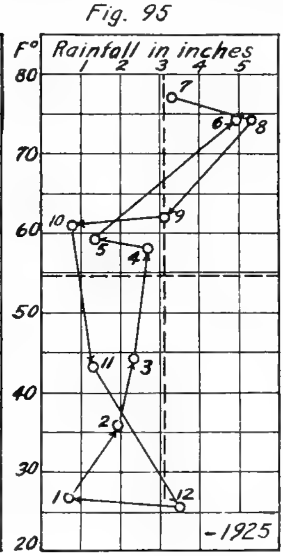


Fig. 98

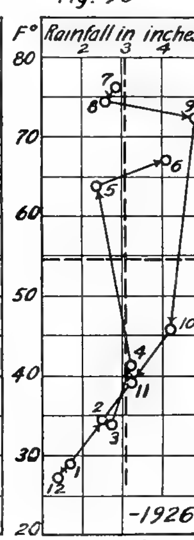


Fig. 99

FIGS. 94–99. TEMPERATURE-RAINFALL DIAGRAMS OF A NORMAL WHEAT LEAF RUST YEAR AND OF THE RUST YEARS 1922–1926 IN ILLINOIS

The rust year begins with July, after the previous crop has been harvested, and extends through the following June. The trends of temperature and rainfall, given as monthly means and totals, respectively, are shown for a normal year and for each year for which rust data were procured. These diagrams show that each rust year consists of two parts, the first of which has falling, rust abundance is related to the mean temperature of the fall trend and the total rainfall of the spring trend rather than to the rainfall of the fall trend and the temperature of the spring trend or combinations of the two.

The following table emphasizes these points.

Year	Destructiveness index	Mean temperature		Total rainfall	
		Fall trend	Spring trend	Fall trend	Spring trend
1922	50.3	59.8	49.3	22.59	19.14
1923	31.3	59.3	47.0	15.01	17.78
1924	19.1	59.0	44.9	20.24	18.52
1925	17.1	56.1	49.9	17.27	13.91
1926	11.2	56.2	46.4	18.97	16.19

No parallel can be found between the variations in rust destructiveness and either the spring temperatures or the amounts of fall rain given in this table, or between combinations of the two, whether the years be taken successively or grouped according to high and low rust indexes. Variation in the mean temperature of the fall trends and in the total rainfall of the spring trends, however, follows very closely the rise and fall of the rust indexes. How closely they follow one another is shown better by Figure 100.

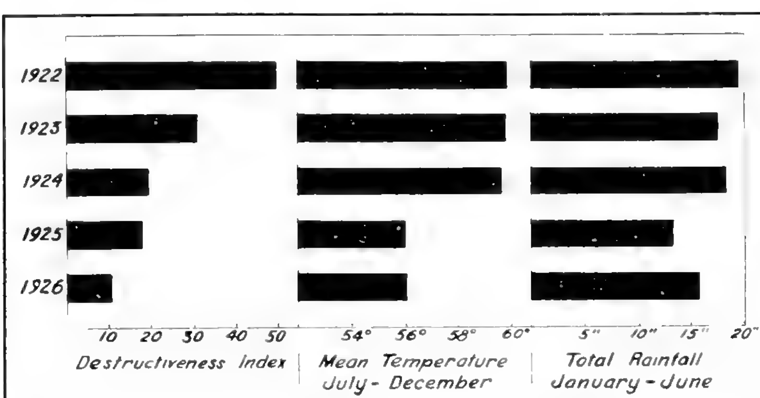


FIG. 100. COMPARISON OF RUST INTENSITY WITH JULY–DECEMBER TEMPERATURE AND JANUARY-JUNE RAINFALL, 1922–1926

and the second rising, temperatures (see page 83). The rust year may be divided also into three parts: an autumnal season, July–September; an hibernal season, October–March; and a vernal season, April–June (see page 83).

Practically, we are lead to believe that, whenever a fall trend has rain exceeding 15 inches in amount, abundant rust is probable the following spring, if the mean temperature of the fall is 59°F. or more; but if the temperature is around 56°, light rust is to be expected. A spring trend with a mean temperature of 45° or more may be expected to be productive of a heavy rust epidemic when it follows a fall trend of 59°, if its rainfall is in excess of 17.5 inches, and of a light rust attack when it follows a fall period of 56°, if its rainfall is less than 16.2 inches.

Records of the weather in Illinois are available since 1878, making it possible to estimate the frequency with which years favorable and unfavorable to leaf rust may be expected to occur in the future, on the basis of their occurrence during the past 48 years. Favorable, intermediate, and unfavorable fall and spring trends, alone and in various combinations, have occurred the number of times shown in the following table:

Combinations of temperature and rainfall, classified with respect to rust development	Number of times occurring in 48 years	Comparative frequency of occurrence
Fall trend alone		
favorable	7	1/6.857
intermediate	23	1/1.086
unfavorable	18	1/2.666
Spring trend alone		
favorable	32	1/1.500
intermediate	6	1/8.000
unfavorable	10	1/4.800
Both fall and spring trends		
favorable	4	1/12.000
intermediate	3	1/16.000
unfavorable	6	1/8.000
Fall trend favorable		
spring trend intermediate	0	0/48.000
spring trend unfavorable	3	1/16.000
Fall trend intermediate		
spring trend favorable	19	1/2.526
spring trend unfavorable	1	1/48.000
Fall trend unfavorable		
spring trend favorable	9	1/5.333
spring trend intermediate	3	1/16.000

Stated more concretely, the expectation with respect to any fall is only 1 in 7 that it will be favorable to rust, nearly 1 to 1 (even chances) that it will be intermediate, and only 3 in 8 that it will be unfavorable; and with respect to any spring the chances are 2 in 3 that it will be favorable, 1 in 8 that it will be intermediate, and 1 in 4 that it will be unfavorable. The probability of a favorable spring following a favorable fall is only 1 in 12, and of an unfavorable spring following an unfavorable fall only 1 in 8; but the likelihood of intermediate falls and springs occurring together is approximately 4 in 5. Stated in terms of leaf rust attack, it is probable that on an average only one year in twelve will be productive of a severe epidemic and only one year in eight of a very light epidemic, while four years in every five should have moderate rust attacks. This statement, however, should not be expected to apply rigidly to any small number of years; it is significant only for a period of half a century or more.

Referring again to Figures 94-99, three divisions of the year may be distinguished, including first the months July, August, and September, next the months October through March, and finally the months April, May, and June. For convenience, these periods may be designated respectively as aestival, hibernal, and vernal, these terms applying not only to periods of the year but also to distinct phases in the rust organism's history. The mean temperatures and total precipitation of each of these periods for the years during which rust observations were made are compared in the following table, with the indexes of rust destructiveness.

Year	Destructiveness index	Aestival period		Hibernal period		Vernal period	
		Mean temperature	Total precipitation in inches	Mean temperature	Total precipitation in inches	Mean temperature	Total precipitation in inches
1922	50.3	75.5°	13.58	39.0°	18.02	64.7°	10 13
1923	31.3	73.4	7.33	38.7	15.19	61 7	10 27
1924	19.1	72.5	11.02	37.5	15.21	60.3	12.53
1925	17.1	69.3	11.60	39.3	10 50	64 2	9.08
1926	11.2	74.5	10.47	35.4	15.18	59.8	9.51

The variations of the rust indexes is not correlated throughout the five years with either the temperature or precipitation of any season; but the heavy and light rust years, as groups, find striking counterparts in the heavy and light precipitations of their corresponding vernal seasons. It is evident, also, that the effect of precipitation in these seasons is intimately related to that of temperature. The 15.18 inches of rainfall in the hibernal season and the 9.51 inches in the vernal season of the light rust year of 1926 approach very closely the corresponding amounts in the heavy rust year of 1923, but the expectation of heavy rust from this cause is counterbalanced by low mean temperatures in both seasons. An illustration of the opposite relation occurred in the light rust year of 1925, when the mean temperatures of both the hibernal and the vernal periods, which were almost as favorable as those of the heavy rust year of 1922, were offset by very low precipitation totals.

The relative effects of various mean temperatures and totals of precipitation upon the amount of rust infection could be determined by making numerous comparisons like the foregoing; but at the present stage of our inquiry the details in our possession are not sufficiently abundant to furnish satisfactory conclusions. We might assume, for example, that the influences of temperature and rainfall are cumulative and that their total effect is expressed in the amount of rust eventually produced. On this basis, we could develop a linear equation for each year and, by comparing the equations, arrive at average effects to be assigned to each degree of mean temperature and each inch of rainfall for each of these seasons.

Actual tests of this process with the data at hand have yielded results which, though very suggestive, are still too indefinite to be presented, except in generalizations. They suggest that there is a well defined minimum temperature below which rust infection can not occur, and that above this threshold the amount of rust produced increases more and more rapidly as the temperature increases.

The months of May and June should be regarded as the most critical of the year in the development of a leaf rust epidemic, for at this time the infections that have survived the rigors of the previous months begin to grow anew, producing new spores and starting the new epidemic. As the days pass, infection is increased not only from the local sources of spore supply but also by spores blown in on the wind from fields to the southward. Even under the most adverse circumstances, sufficient infective material is present in the fields of this State to produce a very destructive epidemic. Whether it remains mild, as it did in 1925 and 1926, or becomes serious, as in 1922, 1923, and 1924, depends very largely upon the spring temperature and rainfall. A comparison of rust indexes and the weather of May and June is given below.

Year	Destructiveness index	Weather conditions of May and June	
		Mean temperature	Total rainfall
1922	50 3	70.2	5.08
1923	31.3	67.0	7.88
1924	19.1	63 4	10.35
1925	17.1	67.0	6.42
1926	11 2	66.5	6.39

It is evident that neither temperature alone nor rainfall alone in these months is related to heavy or light infections. The mean temperature in 1925, the year of lightest rust, was the same as in 1923, when there was a rather heavy rust attack; and the rainfall of 1922, the year of heaviest rust, was less than in either of the two light rust years, 1925 and 1926. The degree of rust attack must be determined, consequently, by the condition produced by the mean temperature and total rainfall combined. It is not possible to see, in the foregoing table, what interrelations such combinations may have, but if a diagram, as in Figure 101, is drawn and the different years properly plotted upon it, they may be made clear. The normal mean temperature for the May-June period in Illinois, 67.1°, is shown by the heavy horizontal line, and the normal total rainfall, 8.08 inches, by the heavy vertical line. The point at which these lines cross represents the normal mean temperature and total rainfall condition for the May-June period. The actual combinations for the years in question are shown on the diagram, circled dots marking years of heavy rust and circled crosses years of light rust.

It is remarkable that the points representing heavy rust lie in a nearly straight, diagonal line running from the upper left to the lower right corner of the diagram, while those for light rust lie close together near the middle of the upper part of the cold, dry quarter.

The number of seasons for which there are records are far too few to permit complete acceptance of the relations the diagram suggests; but in view of the principles underlying mathematical correlation, it is quite probable that the general trend, at least, of the May-June mean temperature-total rainfall combinations likely to produce heavy rust attacks is indicated.

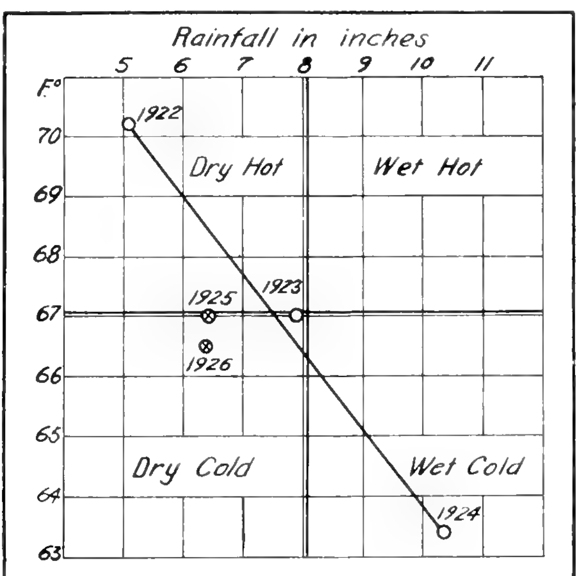


FIG. 101. CORRELATION BETWEEN THE DESTRUCTIVENESS OF WHEAT LEAF RUST AND THE MEAN TEMPERATURE AND TOTAL RAINFALL OF THE MAY–JUNE PERIOD

Circles mark the May–June weather in years of destructive rust and circled crosses in years of light rust. The line connecting the circles suggests that, contrary to the usual opinion, dry, hot weather will produce the heaviest attacks. Damp, cool weather produces moderately serious disease, and rather dry weather with usual temperatures results in mild attacks.

The geographical occurrence of dates of first spring infection, and the temperature relations governing the subsequent development of an epidemic

It has been said that there is always sufficient infective material present to produce a destructive epidemic if conditions are favorable. Although, as has just been shown, several distinguishable parts of the year, as well as the year as a whole, influence very definitely the intensity of disease attack, the fact remains that each year's epidemic is independent, in a measure, of all the seasons of the year except the spring, for then spores of the rust organism blown from distant places by strong winds serve to introduce new infection. For this reason, it is worth while to inquire into the time when spring infection is likely to occur and the conditions under which various grades of intensity are developed.

The earliest appearance of rust in Illinois, as shown by our survey records, varies considerably according to locality. The late start on field work in 1922 failed to furnish any such records for that year, but in the years 1923, 1924, and 1925 a number of dates of earliest infections were secured. In 1923, five such observations were made; in 1924, 8; and in 1925, 11. Arranged roughly from south to north, they are given by counties in the following table under the "observed date."

County	Observed Date	Theoretical date	County	Observed Date	Theoretical date
1923			1925		
Bond	June 5		Madison	June 4	
Coles	June 8	June 7- 8	Greene	June 4	June 4- 5
Macon	June 9	June 9	Clark	June 9	June 8- 9
LaSalle	June 15	June 14-15	Coles	June 10	June 9-10
Cook	June 30	June 18	Edgar	June 10	June 10-11
			Macon	June 12	June 9-10
1924			Piatt	June 11	June 10-11
Calhoun	June 6	June 4- 5	Champaign	June 11	June 11-12
Jersey	June 6	June 4- 5	Logan	June 12	June 10-11
Macoupin	June 4	June 4- 6	McLean	June 13	June 12-13
Champaign	June 15	June 11	Iroquois	June 19	June 15-17
Moultrie	June 17	June 11-12			
Piatt	June 17	June 12			
Kankakee	June 25	June 18-19			
Will	June 25	June 19-20			

Upon inspection of this list, it is apparent that, though the dates for comparable localities differ year by year, the first rust infection is always earlier in the south than in the north and for, the same latitude, earlier in the west than in the east. This suggests that rust infection occurs in close conformity in the spring with Hopkins' Bioclimatic Law[1], which

[1] Hopkins, A. D. Periodical events and natural laws as guides to agricultural research and practice. U. S. Dept. Agr. Weather Bureau, Monthly Weather Review. Supplement 9, 1918.

states, essentially, that "other conditions being equal, the variation in the time of occurrence of a given periodical event . . . is at the general average rate of 4 days to each 1 degree of latitude, 5 degrees of longitude and 400 feet of altitude, later northward, eastward, and upward in the spring and early summer, and the reverse in late summer and autumn.'

In accordance with this view, the State of Illinois has been divided into the sections shown in Figure 102, which represent theoretical time variates of periodical events in harmony with adjacent states. The slanting longitudinal lines represent a difference of approximately four-fifths

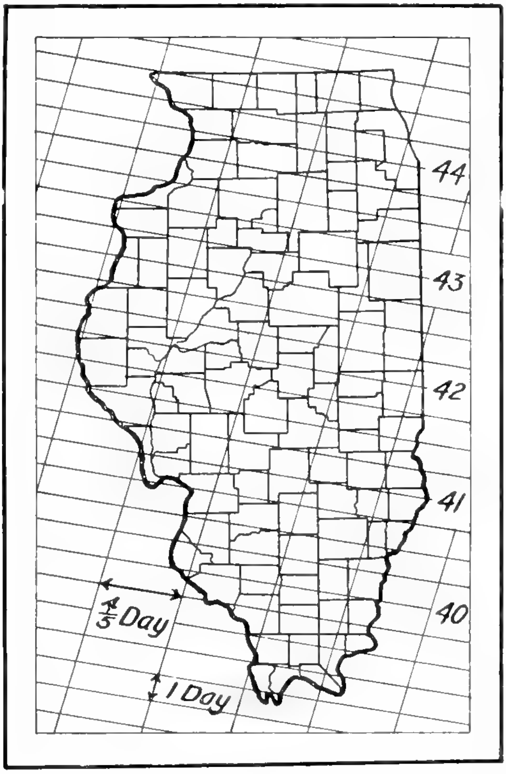


FIG. 102. THEORETICAL TIME-VARIATE LINES FOR ILLINOIS, ACCORDING TO HOPKIN'S BIOCLIMATIC LAW

The earliest wheat leaf rust infection occurs in the south, and at a given latitude infection occurs earlier in the west than in the east. The seasonal progress of infection is in the northeasterly direction taken by the longitudinal lines. The horizontal lines represent, from south to north, a difference of one day, and the longitudinal lines a difference of four-fifths of a day, from west to east, in the appearance of first rust infections. When the first infection is observed in the south, the date of its appearance in any more northern region can be predicted accurately.

of a day, and the somewhat slanted horizontal lines a difference of approximately one day in the occurrence of a given event.

Selecting the first date given in the foregoing table for each year, it is possible to compute from Figure 102 a theoretical date of first infection for the other counties listed. As an example, in 1923 rust was first seen in Bond County June fifth, but it was not seen in Coles County until June eighth. Referring to Figure 102, it is readily determined that, by the provisions of the law just stated, rust should have appeared through the southern part of Coles County June seventh and through the northern part June eighth. There is a practical coincidence of observed date (June 8) and theoretical date (June 7 and 8). Theoretical dates so determined are given in the preceding table for each of the observed dates.

A comparison of the observed and theoretical dates shows in all cases a very close agreement. The statement seems warranted that, when the appearance of rust has been observed in the southern part of the State, an accurate prediction can be made of the date on which initial infections will occur in any part further north.

The dates of spring infection influence the total amount of disease subsequently produced. If they are early, there are longer periods of multiplication; but if they are late, the periods of multiplication are shorter. This, however, is probably much less important than the temperature and rainfall of the multiplication period, for it is commonly observed that low temperatures inhibit the development of infection, though prolonging somewhat the growing period of wheat, while high temperatures not only inhibit infection but greatly curtail the growing season of the crop and consequently the multiplication period of the disease.

As temperature appears to be the controlling factor, it is to be expected that certain average temperatures occurring through periods of given extent should result, other conditions being equal, in definite amounts of infection. These other conditions will not be equal, of course; but when a large territory is included, the variations they cause should fluctuate about the general trend of the temperature effects.

The amount of rust observed at a certain time in a certain field may be considered, therefore, to be in the main an expression, somewhat modified by other factors, of the effect of the temperatures accumulated from the time of the initial infection to the time of examination. A statement of the accumulated temperatures may be obtained by adding the daily mean temperatures recorded by the nearest Weather Bureau station. In the following table, these totals as well as the average mean daily temperature during rust development are given in connection with amounts of rust observed in 1926.

It should be stated that the first infection was observed June 2 at Paris. From it, theoretical dates of first infection were determined, by the prediction method just described, for instances not definitely observed.

OBSERVED RUST INFECTIONS, COINCIDENTALLY ACCUMULATED TOTAL MEAN DAILY DEGREES, AND AVERAGE MEAN DAILY TEMPERATURES FROM FIRST INFECTION TO DATE OF EXAMINATION

County	Destructiveness index	Mean daily degrees accumulated	Average mean daily temperature during rust development	County	Destructiveness index	Mean daily degrees accumulated	Average mean daily temperature during rust development
Boone	14.0	4,105.0°	66.2	Macon	2.0	453.5°	64.8
Champaign	33.6	2,051.5	70.7	Madison	6.0	2,040.0	68.0
Champaign	20.0	2,209.5	71.3	Marion	trace	1,529.5	72.8
Champaign	25.0	2,478.0	70.8	Marion	trace	573.5	71.6
Clark	10.0	1,019.5	67.9	Marion	1.0	1,529.5	72.8
DeKalb	15.0	3,373.5	68.8	Marshall	30.0	3,589.0	70.3
DeKalb	10.0	2,934.5	68.2	McDonough	35.0	3,379.0	71.8
Douglas	32.0	2,012.5	67.1	McHenry	15.0	3,355.5	68.4
DuPage	11.0	3,149.0	68.4	Menard	30.0	3,407.5	72.5
DuPage	17.0	3,512.0	67.5	Monroe	trace	1,007.5	71.9
Edgar	32.0	2,055.5	70.8	Morgan	trace	826.0	68.8
Edgar	32.0	2,115.5	70.5	Moultrie	trace	1,499.5	68.1
Effingham	5.0	846.0	70.5	Moultrie	16.6	1,499.5	68.1
Fayette	6.2	544.5	68.1	Piatt	35.0	439.5	73.2
Grundy	16.0	3,758.0	70.9	Randolph	10.0	2,362.5	73.8
Iroquois	17.0	2,373.5	71.9	Saline	17.0	2,778.5	75.1
Iroquois	17.0	2,373.5	71.9	Sangamon	trace	676.5	67.6
Kane	15.0	3,272.5	66.7	St. Clair	trace	1,231.5	72.4
Kane	29.0	3,200.5	66.6	St. Clair	4.1	1,231.5	72.4
Lawrence	4.5	372.5	74.5	Schuyler	20.0	3,712.0	71.4
Livingston	30.0	3,653.0	70.0	Vermilion	25.0	1,783.5	71.3
Livingston	60.0	4,154.5	72.8				

Upon examining this table, many wide discrepancies may be observed between the amounts of rust developed and the accompanying accumulated temperatures. For example, the development of a 32 per cent infection in Edgar County required from 2,055° to 2,115°, while southward, in Saline County, a much greater accumulation, 2,778°, was required for a 17 per cent infection; and northward, in McHenry County, 3,355° were required for a 15 per cent infection. In Edgar County, however, the average mean daily temperature was 70.5° to 70.8°, in Saline County it was 75.1°; and in McHenry County, 68.4°. This indicates that, in the field, there is a certain mean daily temperature, apparently between 70° and 71°, which may be termed the optimum, at which the rust organism can develop and spread most rapidly, and that if the mean daily temperature for any considerable number of days either falls much below or greatly exceeds this optimum the development and spread of the rust will be correspondingly inhibited.

The items in the preceding table fall into three groups, corresponding in the main to geographic sections of the state. In the south and in the north large accumulations of temperature are required for small percentages of infection because the mean daily temperatures are in excess of and less than the optimum, respectively; but through the central part of the state mean daily temperatures are close to the optimum. For convenience, these parts of the state may be designated as lying south of the line numbered 41 in Figure 102, between lines 41 and 43, and north of line 43. The relation between the rapidity of rust development and accumulated temperatures in these districts is illustrated in Figure 103.

These differences in rapidity of rust development may be explained further, in view of their geographic locations, on the seasonal characteristics of the region in which they occur. Spring and summer come earlier and endure longer in the south. There, optimum temperatures for rust development may occur before the wheat can be infected readily and may be succeeded by temperatures above the optimum before the epidemic has progressed appreciably. In the central section, optimum temperatures appear somewhat later and endure through much of the growing season. Northward, unfavorably low temperatures, characteristic of

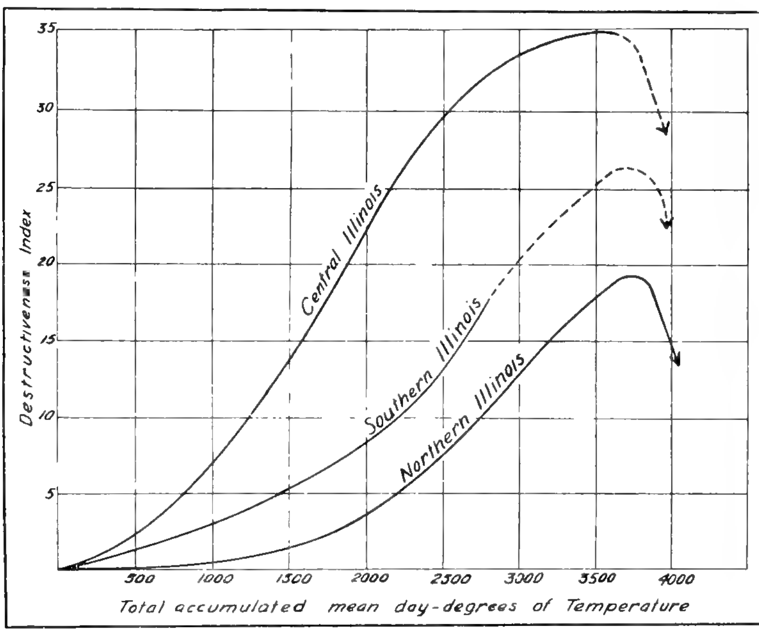


FIG. 103. EFFECT OF TEMPERATURE UPON THE DEVELOPMENT OF A WHEAT LEAF RUST EPIDEMIC, FOLLOWING THE OCCURRENCE OF FIRST INFECTION

The destructiveness indexes given in the table on page 93 are shown graphically here with their corresponding accumulations of mean daily degrees of temperature. They fall into the three rather distinct groups indicated by the three curved lines. The line of greatest rustiness is obtained from observations made in central Illinois; the intermediate line, by observations in southern localities; and the line of least rustiness, in northern localities.

the early growing season, are succeeded for a short period by optimum temperatures as the crop nears maturity, and immediately are followed by the high temperatures of summer.

The curves shown in Figure 103 suggest that a more complete analysis (not possible with the data we now possess) would show that temperatures could be classed as effective or non-effective in the development of an epidemic and that exact values could be assigned, in terms of velocity of disease development, to effective temperatures, which would make it possible to predict with a high degree of accuracy the ultimate intensity of attack in any season. This problem, however, requires data much more extensive, detailed, and complete than have been obtained thus far.

SUMMARY AND CONCLUSION

With strikingly few exceptions, attempts made heretofore to estimate variations in disease attack have resulted, with respect to commercial crops, in statements so patently generalized, both as to prevalence and damage, as to be far from convincing. Based on inexact observations and evaluated from memory or from too brief and inadequate notes, they have dealt too much with reductions in yield and money losses, neither of which can be estimated fairly with our present knowledge. While such estimates have been, as a rule, far too conservative, placing losses inordinately low, the fact remains that an abundant yield is determined chiefly by soil, weather, and proper cultivation. It is only in the exceptional season that yield is determined by disease attack alone.

The methods for collecting data on disease outlined in the preceding pages take into account the effect of disease upon the individual plant and its parts rather than upon yield. Disease prevalence and disease destructiveness have been observed directly, in accordance with definite rules, in fields selected at random, in order that representative samples might be secured; statistical methods of a relatively simple nature have been devised and used in evaluating the data thus secured; and indexes have been computed which represent the disease attack as it actually occurred. Because they do not involve the necessity of comparing or evaluating indirectly estimated reductions in yield or money losses, these indexes furnish the most satisfactory means now available for comparing disease attacks, year with year, or region with region. They also provide a means of visualizing the effect of disease upon the crop subjected to attack, as was illustrated in Figures 89-92.

The use that is to be made of exact data collected by studying and measuring epidemics under natural conditions has been exemplified, though briefly, with some of the wheat leaf rust data. It has been shown that there is a well defined relation between intensity of attack and annual mean temperatures and yearly totals of rainfall; that in the July-December period of the year temperature has a greater influence than rainfall, while in the January-June period rain is the more important, in determining the destructiveness of a year's rust attack; that there is a possibility of predicting with reasonable accuracy the date upon which the first spring infection will occur in any part of the State in any year; that during the months of May and June the correlation between disease development and weather conditions lies mainly with temperature; and that the degree of destructiveness which an epidemic, once started, is likely to attain may be predicted from the rapidity with which degrees of mean daily temperature accumulate.

Such results as these outline only the broadest of the principles which underlie the yearly development of disease epidemics on the crops grown on the farms of Illinois. Although they have no immediate application to the problems of the farm, they are the general laws from which the rules of practice must be drawn. What has been learned in the case of wheat leaf rust must be learned also for the other diseases of wheat, and for the diseases of other crops; the laws pertaining to all must be refined by further observations and analyses; and the practical rules at last determined must be subjected to final tests, before the task is finished.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, *Chief*

Vol. XVII. BULLETIN Article II.

A Manual of Woodlot Management

BY

C. J. TELFORD

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After Threshing Comes Sawmilling

A MANUAL OF WOODLOT MANAGEMENT

C. J. TELFORD

This manual is addressed to those landowners who have woodlots or idle land. It is assumed that they appreciate the intangible benefits accruing from the woodlot as a refuge for wild life, as a local modifier of dry and cold winds, as a protection to the sources of local water supply, as a means of enhancing the beauty of the landscape, and as a place for recreation; and that they also appreciate the service to the nation rendered by productive forests. Our purpose is to define the true forest lands in Illinois, to outline the methods for the proper management of the woodlot, and to give the general returns to be derived from the managed production of wood. The point of view throughout is the growing of a wood crop as a producer of revenue. The broad essentials of woodlot management are outlined briefly, the methods which are adapted to the growing of timber under different conditions of site and market are discussed at some length, and the methods of measuring and marketing the product are described in detail.

SUMMARY OF GENERAL MEASURES IN THE MANAGEMENT OF NATURAL WOODLOTS

The broad essentials of woodlot management may be summarized as follows:

(1) Put the soil in condition to support the best growth by developing and maintaining a good leaf mulch. Since fire, grazing, wind, and sunshine destroy this mulch, keep out fire by eternal vigilance, stock by fencing, wind by leaving a dense wall of bushes on the borders and small trees within the woods, and sunshine by growing enough trees to provide a complete shade.

(2) Stock the area with the most rapidly growing species suited to the products in view. In Table VIII (page 118) are listed the species recommended for the specified products under definite soil conditions. Work out the worthless trees, such as decayed, broken-topped, crooked- or short-boled, very limby ones of all species, and all trees of those species classed as weed trees and listed on page 118. Observe the seed bed conditions which favor the seeding in of trees of the species desired—shade or sunlight, leaf litter, humus or mineral soil—and create such

conditions at the time when the desired species promises to bear good seed crops. If suitable restocking can not be attained naturally, plant seeds or small trees where reenforcement is necessary.

(3) Develop and maintain light conditions favoring the rapid growth of trees of good form. Enough trees should be grown so that tall clear-boled trees are produced. This type is secured when the trees during their early stages of development get direct sunlight only from overhead and none on the lower branches. This crowding, intended to force the tree to discard the lower limbs, must be done when the trees are young. The naturally pruned tree should be so developed as to show a tall straight stem, with the crown bunched at the top when it has attained a diameter of 6 to 10 inches and is passing the period of most rapid height growth. After this period, there will be progressively less stem added to the top from which branches can grow, and continued crowding cramps the crown. At this stage, therefore, thinnings should be initiated to supply space for lateral crown expansion. Such thinnings should be light, removing just enough live trees to give the select trees the space which they will fill up in five or six years. When crowding again occurs, another thinning is made. In even-aged stands, these thinnings can be done somewhat systematically at regular intervals. In an all-aged stand containing trees of different sizes, the process of regeneration, the crowding of immature trees to improve their form, thinnings to give additional space to the crowns of select trees, and cuttings incident to harvesting the crop, are carried on simultaneously.

Very frequently one operation can be carried out only by sacrificing some of the rules outlined. If a raw mineral soil is necessary for seedling regeneration, obviously the heavy leaf mulch can not be retained; if undesirable trees have usurped a large part of the area, these can not be removed without letting in sunlight; if the underbrush consists of weed trees, its removal gives access to the wind. In forest management, judgment rather than rules must be followed.

LAND CLASSIFICATION

Land is classified according to its suitability for certain uses. The guiding principle usually is that lands should be put into the most productive group to which they lend themselves. Permanent classification is impossible—the swamp of yesterday, if drained, becomes productive cropland to-day, and may be the site of a town to-morrow—but at present almost nine-tenths of the area of Illinois is given over to the business of farming, so that a classification based upon the use of land for farming applies to practically all of the State.

The farm owner generally classifies his land by answering two questions: (1) Does the land lie so that cropping is possible? (2) Is the quality of the soil good enough to raise paying crops? Any part of the farm which seems unlikely to produce crops at a profit is left in forest or is considered waste land. Some areas are undeveloped because they do not lie so that cropping is possible. The slopes may be too steep for tillage or they may be badly gullied. Similarly, rock-strewn fields discourage cultivation. Other areas are not farmed because the quality of the soil is not good enough to raise paying crops. This class includes extremely compact hardpan soils, extremely loose sandy soils, worn-out croplands, and soggy bottomlands. Some of this non-cropped land is potential cropland in the sense that by terracing, by draining, or by soil treatment it can be developed to produce crops, but there is no reason to believe that the economic conditions which have forced a decrease in the cropland area in Illinois during the past 15 years will improve enough to make profitable the immediate redemption of these marginal lands. The steep hillsides, gullied, rocky, or worn-out fields, sands, hardpan soils, swamps, and flood bottoms, it is generally agreed, should be in forests.

From the viewpoint of the production of wood at a profit, this definition of the true forest lands is inaccurate. There are lands in the above list which can not produce any kind of wood crops at a profit, and there are certain lands now returning a profit in crops which would show a higher profit from forests. The farmer can not get a profitable wood crop from all lands too poor for general crops, nor does he need to confine his woodlot to areas unsuited to other crops.

Considering, first, the lands listed above as unsuited to ordinary farm crops, we find that the revenue to be derived from either natural or planted forests on the hardpan soils (post oak flats) is less than the cost of management; that sands can usually produce acceptable timber crops only when planted to conifers; that the loams on steep slopes and on gullied, rocky, or worn-out fields usually prove acceptable for either native hardwoods or conifers; and that the floodlands are well suited to hardwoods.

Considering, next, the arable lands which are commonly considered as true croplands, we find that wood production is financially justifiable on such lands only when the sustained net returns from wood crops equal or exceed those from other crops which can be produced on them. There is very little conflict between wood crops and other farm crops on high-grade arable land. Aside from very limited areas devoted to fence post or Christmas tree plantations, such land can not produce returns from wood crops comparable to those from the ordinary farm crops, and it should not be in woods. Low-grade arable land and unimproved pasture return net revenues comparable to those from productive forests. The net returns from the rough hillside pasture averages about $1.25 per acre annually. The same kind of land in well-stocked hardwood forests yields a net return up to $1.60 per acre annually. Certainly, there is no economic justification for developing a pasture or low-grade cropland where woods are already well established and will give a better return, but, if they are once cleared, the very considerable cost of forest restoration more than offsets the higher revenue accruing from the forest. Keep such forested land in forest. The time has not yet come in Illinois when land already cleared, suitable for and devoted to untilled pasture, will give sufficiently greater returns if restored to forest to justify the change; and such land, therefore, should be kept in pasture.

The detailed classification of farm land to determine the area of true forest land is most important and often difficult. Very steep hillsides or frequently flooded bottomland can readily be classified as forest land, just as well-located, fertile prairie loams fall into the division of true arable soils. The need of information which can be used in classifying the marginal soils between these extremes becomes apparent in the survey of the farm.

Should any of the improved lands be given over to forest? A proper system of accounting will show if the field in question is giving a net return. Lacking such records the classification becomes a matter of guesswork and is seriously liable to error.

What slopes are too steep for cultivation? The erosion of a given area is dependent upon the volume of water passing over it, the velocity which the water attains, and the character of the soil. The amount of water is influenced by the area drained and by the structure of the soil and soil cover, and the velocity is determined by the gradient. Heavy, compact clays absorb but little water and, when stripped of cover, readily wash at gradients as low as 6° in Hardin County. The open, absorbent, deep loess soils in parts of Jackson County produce alfalfa on slopes greater than 20° without eroding; yet the open mixed sand and loess soils in parts of Whiteside County gully seriously when cleared.

These instances are advanced to show that no fixed ruling about degree of slope can be given*. If erosion has developed to such an extreme stage that gullies are forming, the land is true forest land; but areas may be in this class where erosion has not reached the gully phase. Actually less loss to farm soils results from gullying than from a general surface washing resulting in the steady removal of the surface soil particles, the consequent impoverishment of the soil, and the relegation of the area to the worn-out crop-land class. The effect on the soil of this surface washing is much more ruinous than is generally appreciated and reduces the fertility of soils to a greater degree than the demands of the crops for plant food. Thus arable slopes which do not gully may become true forest areas because they no longer produce profitable crops, and the classification is dependent upon crop records and costs.

Total Area of Woodlot

Careful classification of the land on a given farm may show both wooded areas and cleared areas which should be forested. The total of these areas of true forest land naturally varies for individual farms. If the woodlot comprises all non-arable parts of the farm, it is evident that its size may bear little relation to the needs of the farm. The first aim in woodlot management, however, should be to supply the farm with those products which can be grown in the woodlot. In many instances the woodlots will also produce a surplus, and they must be managed with a view to marketing this surplus in the most profitable form.

THE WOODLOT AS A SOURCE OF SUPPLY FOR THE FARM

The wood consumed on farms in Illinois consists largely of fuelwood, posts, and lumber; it averages, as standing timber, 704.8 cubic feet per farm annually. The average rate of growth for fully-stocked stands is estimated at 41.1 cubic feet per acre annually, and the area of the woodlot required to supply this wood to an average farm is 17.1 acres.

Considering these three major forms of wood used, the woodlot should in all cases supply the posts used on the farm; it should in most cases furnish the lumber; and it should supply the fuelwood only when this can be secured by utilizing tops and other materials which can serve no higher purpose. White oak fence posts cost on an average $0.24 each, and an average acre should produce 38 posts annually, a total value of $9.12. The farm woodlot can usually supply all the rough lumber used on the farm. The operator will be dependent upon outside sources for the bulk of the surfaced lumber; for, although the woodlands of Illinois will produce crops of pine and other woods suitable for

* For a discussion of erosion see Circular No. 290, "Saving Soil by Use of Mangum Terraces", and Bulletin No. 207, "Washing of Soils and Methods of Prevention", University of Illinois Agricultural College and Experiment Station.

finished lumber, the process of manufacturing into siding, flooring, ceiling and similar finished products requires equipment not available to the woodlot owner. The fully-stocked average acre in Illinois should produce an average of 180 board feet of hardwoods annually, having a gross value of $8.10. The production of fuelwood as the chief crop is not an economical use of forests. To supply annually wood equivalent to one ton of coal requires nearly 2½ acres of average woodland. With an average cost of coal of $6.60 per ton, the gross returns from such woodland devoted to cordwood are but $2.71 per acre annually. No greater mistake is commonly made than converting into cordwood the timber which is suitable for higher uses.

The following information is given for the benefit of the woodlot owner who wishes to compute the woodlot area required to supply his farm. He may calculate from Table I the number of posts which will be needed annually to keep up his fences.

TABLE I

REQUIRED RENEWALS OF UNTREATED POSTS *

Species	Number of untreated posts that must be renewed annually in each 100 posts in fence	Species	Number of untreated posts that must be renewed annually in each 100 posts in fence
Osage orange ..	2½	White oak	10
Mulberry	5	Sassafras	11
Black locust	5	Elm	16⅔
Catalpa	6⅔	Black or red oak	20
Cedar	6⅔	Ash	20
Burr oak	8	Maple	22⅕
Post oak	9	Cottonwood	28½
Walnut	9	Willow	28½

* From *Second Report on a Forest Survey of Illinois.* State Natural History Survey Bulletin Vol XV, Art. III (1924).

Each post is equivalent to 1.08 cubic feet in the standing tree. To get the total cubic feet required for posts, find from Table I the number required annually and multiply by 1.08. To get the total cubic feet required for rough lumber,divide the annual board feet requirements by 4.4. There will be approximately one cord of fuelwood in the tops for each 1000 B. F. of lumber taken out.

If additional fuel wood is cut, the amount in cubic feet is found by multiplying by 80 the number of additional cords required.

The average annual growth in peeled stems for fully-stocked woodlots is as follows:

	Cubic feet per acre
Upland	
Hardpan	15.8
Sands	28.6
Loams	36.4
Bottomland	
Oak, hickory, elm, ash	45.0
Sycamore, soft maple, cottonwood, sweet gum, locust	100.0

To find the approximate number of acres required to supply the farm, first find the total number of cubic feet required and then divide by the average annual growth per acre of the type in question.

Example: Assume that the farm has 135 acres with a total of 844 posts. If the posts are white oak, there are required for renewals 10 posts for each 100 in service (Table I), or 85 posts yearly. Each post is equivalent to 1.08 cubic feet of standing timber, so that the annual drain on the woodlot *for post material* is 85 × 1.08, or 92 cubit feet.

Assuming that the consumption of rough lumber on the farm is 1000 B. F. annually, and that there are 4.4 B. F. in each cubic foot of the standing tree, then the drain on the woodlot *for lumber* is 1,000 divided by 4.4 or 228 cubic feet.

Assume that, in addition to the cord of fuelwood in the tops of the trees cut for sawlogs, there are cut 4 more cords per year. Each cord is equivalent to 80 cubic feet; hence, this drain *for fuelwood* equals 4 times 80, or 320 cubic feet.

The total annual drain is then to be calculated thus:

Lumber	228 cubic feet
Fuel	320 " "
Posts	92 " "
Total	640 " "

If the woodlot is entirely on the hardpan soils, only fuel and posts can be produced. To supply the 412 cubic feet needed for these, requires $\frac{412}{15.8}$, or 26.1 acres.

If the woodlot is on sands, the fuel, lumber, and post requirements of 640 cubic feet can be supplied by $\frac{640}{28.6} = 22.4$ acres.

Similarly, on the upland loams the requirements will be met by using $\frac{640}{36.4} = 17.6$ acres; the oak, hickory, elm, ash bottomland type, by using $\frac{640}{45} =$ 14.2 acres; the sycamore, soft maple, cottonwood, locust, sweet gum, type, by using $\frac{640}{100} = 6.4$ acres. The gross value of the 1,000 B. F. of lumber, 5 cords of wood, and 85 posts is approximately $92, so that the woodlot on sand gives a gross return of $4.10 per acre annually, the upland loam type $5.23, the slow-growing bottomland type $6.48, the rapidly-growing bottomland type $14.38.

GRAZED WOODLOT.

Young trees cleaned out, ground covered with turf.
Natural replacement impossible.

WOODLOT PROTECTION

The method of establishing and of harvesting a stand usually differ in even-aged and all-aged forests, but the same degree of protection must be given to each against grazing, fire, and attacks of insects and diseases.

Grazing. The injury done to the Illinois woodlots by using them for pasture is greater than injury from all other sources. Throughout central and northern Illinois, woodland is not only being injured; it is being converted to cleared land by grazing.

To appreciate the damage resulting from grazing, we must understand that grasses and trees are conflicting kinds of vegetation. A very slight agency in this region is able to upset the balance between them and determine whether a forest or a sod shall hold the contested site. The forest's defenses against grass consist in shade and in a leaf mulch completely covering the earth. This blanket of leaves and partly-decayed vegetable matter serves the very vital purpose of readily absorbing moisture and checking evaporation; in addition, it serves to cultivate and fertilize the ground, as it supports bacteria which are the agents for chemical reactions of the greatest importance in building up the soil fertility. The first effect of grazing is the injury to the small trees. A grazed woodlot is strikingly free from underbrush. More sunlight reaches the ground, and sunlight is as effective as fire in destroying the leaf mulch. Its destruction, coupled with the increased sunlight striking the forest floor, paves the way for the occupation of the site by grasses; and the formation of a sod, in addition to effectively preventing tree seedlings from becoming established, uses up the moisture. The effect of the very variable moisture conditions which result from the destruction of the mulch of humus and the compacting of the soil by the trampling of stock, is shown as the larger trees begin to die at the top and eventually drop out. First, the grazed woodlot becomes clear of underbrush, then grasses appear and a sod forms, the tops of the large trees die, eventually these trees drop out, and the area is cleared. If you wish to retain any area wooded, you must keep out live-stock. Grazing and wood production can not be practiced on the same area except to the material disadvantage of each and the lessening of total returns received from the area.

Fire. It is universally understood that fire is very destructive to our forests. The ordinary farm woodlot in Illinois is relatively small, usually isolated from extensive woodland, and can readily be protected by the owner. The reasons why fire protection is imperative are much the same as those given under grazing. The smaller trees are usually killed outright, and the larger trees suffer wounds which offer ingress to rot fungi, but the greatest injury comes in the destruction of the leaf mulch. A single burning may destroy the accretion of years, and repeated burnings, like grazing, result in the formation of a sod.

Insects and fungous diseases. The application of insecticides and fungicides and other measures feasible for the protection of valued ornamental and fruit trees are not ordinarily practicable in the woodlot. If a disease or insect attack takes on the proportions of an epidemic, the woodlot owner as an individual usually can not successfully combat it. Such epidemic conditions occur throughout the country both as disease infections and insect infestations. The attacks of a particular disease or insect are generally limited to a certain tree species or genus; they vary in intensity, and in an extreme form they may affect every tree of the species in the region. Disease epidemics on native chestnut are spreading throughout the range of this species so completely that native chestnut seems sure to disappear from our forests. No successful method has been found to combat it. In sections of the Northeast, Lake States, and Northwest where the white pine blister rust has caused serious loss, organized protective measures have been adopted. Insect epidemic conditions are also common and often destructive. In the Northeastern States losses through infestations of the brown-tail and gypsy moths have reached millions of dollars; throughout the range of eastern larch, periodic epidemics of the larch sawfly eliminate this species from the forest; in the West and South, the devastation of bark beetles destroys immense acreages of pines. In Illinois diseases have not reached such destructive intensity as to eliminate completely any important species. Insect damage, however, has been serious enough to restrict the use of certain affected species. The black locust borer is so universally destructive that the use of black locust for post production is advisable only under exceptional conditions. Trees of the black oak group are being killed by a flat-headed borer. Ash and cottonwood are dying in large numbers as a result of the attacks of scale and bark-boring insects. Where marked disease and insect injury are present in our woodlots, it is usually a result of poor forest conditions. The remedies lie in practicing forest hygiene and in destroying diseased trees and those which harbor borers. It should be the rule to remove trees as soon as they show evidences of weakness and stagnation. If bark borers are present in a living tree, it should be cut and peeled, and the bark and tops burned.

Identification of diseases and recommendation of remedial measures will be made upon receipt of a specimen by the pathologist of the Natural History Survey, Room 219, Natural History Building, Urbana, and of insects by the entomologist at the same address.

ADAPTATION OF TREES TO SOIL

To get the highest production from the woodlot, it is essential not only that the trees should be given protection so that they can be carried to harvesting maturity but also that they should be suited to the site and market demands. The average growth rates of different species of trees vary greatly, even when they are growing under similar conditions. Once the choice has been made as to what form the output of the woodlot should take, the woodlot should be managed with the object of favoring those most rapidly growing species which are suitable for the manufacture of these products. Studies of growth rates correlated with soil types made by the Natural History Survey,* show the relative values of the commoner soil types for tree growth and the relative growth rates of the species commonly found on each soil type.

The best soils for timber production in this region are the bottomland sandy loams, followed by the bottomland heavy loams, the upland loams, the sands, and finally the very compact loams or hardpan soils. If we give the least productive—hardpan soils—a rating of 1, the relative productiveness of the other soils for unmanaged tree growth characteristic of each soil type is in about the following ratio: sands, 1.8; upland loams, 2.3; bottomland clay loams, 2.8; bottomland sandy loams 6.3. The above ratings, representative of unmanaged forests stocked with species whose presence in the stand is the result of natural forces, are probably very conservative for stands under management. In the latter, only the more rapidly growing species will be permitted to grow. The growth rates on the poorer soils are uniformly low, but with improved soil conditions not only do the growth rates increase, but there is also an increased number of the more rapidly growing species from which to choose. The prospects of raising the production on the hardpan soils through management of the woodlot are not encouraging, but on all other soils the managed woodlot is clearly capable of producing much better returns than the unmanaged.

Tables II, III, IV, V, VI and VII show the average growth rates on these five general soil groups at 20-year periods in Illinois. The growth rates are indicated by the diameter inside the bark on the stump, by the height, and by the cubic feet of stem exclusive of bark. In a managed woodlot the growth rates should be more comparable to the even-aged figures as shown in these tables than to the all-aged figures.

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* Bulletin Vol. XVI, Art. I, *Third Report on a Forest Survey of Illinois.* (1926.)

TABLE II.

AVERAGE GROWTH RATES ON UPLAND SANDY LOAMS IN ILLINOIS

A and E indicate all-aged and even-aged stands, respectively

Species		20 years			40 years			60 years			80 years			100 years		
		D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.
Black walnut	A	4.8	31	1.3	11.2	71	17.4	16.8	87	51.5						
Tulip	A	7.4	19	2.1	13.4	39	13.2	17.8	62	37.5	21.9	83	78.8	25.4	94	120.1
Black oak	E	4.4	26	1.1	9.3	50	9.9	13.8	67	26.7	18.1	81	57.5	20.9	90	74.6
	A	2.2	25	.4	4.6	45	2.1	7.8	62	8.0	11.6	73	21.6	16.4	80	46.6
White oak	E	5.5	22	1.1	10.5	44	8.7	14.0	60	23.5	17.2	70	43.6			
	A	2.6	24	.6	6.2	48	3.4	10.2	69	15.0	13.4	86	33.6	17.0	91	64.5
Red oak	A	2.2	24	.3	4.4	45	1.9	8.6	61	9.8	14.2	74	32.8	18.6	84	63.2
Basswood	A	2.4	19	.4	5.7	37	2.1	10.0	55	11.2	15.0	68	32.9	20.0	80	70.6
Ash	A	1.9	21	.4	4.6	43	2.0	8.2	65	9.4	12.3	83	27.4	15.0	95	45.1
Hard maple	A	2.1	17	.2	5.1	35	1.8	7.6	55	6.4	10.6	70	20.3	15.1	81	40.1
Hickory	A	1.4	25	.2	3.4	48	1.6	6.2	66	5.6	9.0	78	14.0	12.2	86	27.9
Elm	A	1.9	24	.4	4.0	44	1.7	6.5	60	5.4	8.8	72	13.0	12.0	82	25.9
Beech	A	1.6	15	.1	3.2	29	.8	5.3	42	2.4	8.4	56	8.0	11.6	69	21.3

TABLE III.

AVERAGE GROWTH RATES ON UPLAND YELLOW AND YELLOW-GRAY SILT LOAMS IN ILLINOIS

A and E indicate all-aged and even-aged stands, respectively

Species		20 years			40 years			60 years			80 years			100 years		
		D. i. b., In.	Height, Ft.	Volume. Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.
White pine	E	8.6	29	4.6	18.0	64	40.1	22.3	85	79.7	24.4	97	10.76			
Tulip	A	5.6	30	1.8	10.4	57	11.3	14.0	63	23.3	18.0	85	55.0	21.4	91	82.8
Red oak	E	2.6	22	.33	6.8	42	4.2	11.4	60	16.8	15.6	70	38.2			
	A	2.8	24	.38	6.6	45	4.3	11.9	61	18.7	17.2	73	47.0	21.6	82	83.6
Black oak	E	3.2	25	.7	7.4	47	4.9	11.6	63	17.8	14.6	72	33.0			
	A	2.8	24	.5	6.6	45	3.7	10.2	61	13.4	13.0	72	30.3	17.2	76	48.9
Shingle oak	E	3.0	19	.5	6.6	41	3.3	10.2	58	12.5	13.8	68	28.0			
Ash	E	3.9	25	.9	7.9	44	5.1	11.6	58	15.9	14.7	68	31.5			
	A	1.5	15	.1	3.7	33	1.1	7.3	52	5.5	10.2	68	15.3	12.8	80	28.8
Hickory	E	2.4	12	.1	5.4	27	1.4	8.5	42	5.6						
	A	1.7	22	.1	4.2	40	1.6	6.8	52	4.8	9.6	63	12.0	12.3	72	23.8
Hard maple	A	1.8	18	.1	3.6	38	1.2	6.1	52	3.8	8.7	63	10.1	10.8	72	18.2
White oak	E	3.4	20	.5	7.2	40	3.8	10.8	55	12.2	13.8	65	25.5			
	A	2.4	20	.4	4.8	34	1.6	7.0	45	4.1	9.8	53	9.6	12.2	60	17.8

TABLE IV.

AVERAGE GROWTH RATES ON SAND IN ILLINOIS

A and E indicate all-aged and even-aged stands, respectively

Species	20 years			40 years			60 years			80 years		
	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.
White pine ....E	4.1	26	1.2	8.3	47	7.3	11.0	62	16.6			
Black locust ....E	5.5	38	2.2	11.4	60	16.1	17.1	73	46.5			
Black oak ....E	3.4	25	.7	7.6	46	5.1	10.8	54	13.6	14.0	57	22.7

TABLE V.

AVERAGE GROWTH RATES ON HARDPAN IN ILLINOIS

A and E indicate all-aged and even-aged stands, respectively

Species		20 years			40 years			60 years			80 years			100 years		
		D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.
Black oak	E	3.2	25	.7	6.8	41	3.5	10.8	49	11.0						
Post oak...........	E	2.8	15	.3	5.8	32	2.0	9.0	42	6.1	12.0	54	18.8			
	A	2.4	14	.2	5.2	30	1.6	7.2	42	4.0	9.8	56	10.4	11.8	57	15.4

TABLE VI.

AVERAGE GROWTH RATES ON BOTTOMLAND LIGHT SOILS IN ILLINOIS

A and E indicate all-aged and even-aged stands, respectively

Species	20 years			40 years			60 years			80 years			100 years		
	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.
Cottonwood ....E	17.2	96	56.2	24.2	108	122.9									
Sycamore ....A	8.8	67	10.0	17.2	96	56.2	21.8	100	94.3	25.8	101	132.6			
Soft maple ....E	.....	43	.....	.....	78	53.0									
Elm ....A	2.2	24	.4	4.0	44	1.7	5.2	60	3.6	6.4	70	6.5	9.1	74	13.4

TABLE VII.

AVERAGE GROWTH RATES ON BOTTOMLAND HEAVY SOILS IN ILLINOIS

A and E indicate all-aged and even-aged stands, respectively

Species		20 years			40 years			60 years			80 years			100 years		
		D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.	D. i. b., In.	Height, Ft.	Volume, Cu. Ft.
Water locust	A	7.5	47	5.0	14.6	65	25.2	18.0	80	47.9						
Honey locust	A	5.6	33	2.0	13.4	65	21.2	20.0	82	61.1	26.6	87	116.3			
Sofe maple	A	5.0	34	1.7	11.2	63	16.6	17.8	80	55.0	22.4	90	98.1			
Pin oak	E	5.8	34	2.2	13.8	62	21.4	19.8	83	60.6	24.2	88	97.6			
	A	4.0	27	.9	10.0	53	10.2	16.0	80	38.0	21.6	86	75.5	23.8	95	103.5
Ash	A	3.8	25	.8	8.8	48	7.3	12.4	69	23.2	16.2	82	46.9	16.8	91	54.6
Schneck's oaks	E	3.1	24	.4	8.3	47	6.1	15.0	68	28.0	21.4	82	70.2			
Swamp	E	3.4	23	.7	7.6	46	5.1	11.2	61	15.9	14.2	67	29.0			
Spanish oak	A	3.0	24	.6	6.2	45	3.3	9.0	60	10.1	14.0	70	30.0			
Hackberry	A	2.3	26	.4	6.0	48	3.3	9.6	61	11.8	13.6	70	28.4	16.2	86	48.6
Elm	A	2.8	22	.5	6.6	41	3.3	10.0	58	11.9	13.1	68	25.2	15.8	73	39.9
Tupelo	A	3.0	19	.3	6.0	35	2.5	8.6	47	6.5	12.0	58	15.7	13.4	65	21.2
Hickory	A	1.8	18	.1	3.8	35	1.2	6.6	53	4.6	9.8	67	13.9	12.0	75	23.8

An inspection of these growth measurements emphasizes the importance of eliminating the slow-growing species. The following list contains those slow-growing or otherwise undesirable species which are least suited to a place in the Illinois woodlot.

WEED TREES

Box elder	Hackberry	Black gum	Elm
Hard maple	Redbud	Hop hornbeam	Ailanthus
Buckeye	Dogwood	Shortleaf pine	Jack pine
Shadbush	Persimmon	Aspens	Crabapple
Pawpaw	Beech	Scrub oak	Tupelo gum
Birch	Butternut	Cypress	
Hickory	Red cedar	Arbor vitae	

Table VIII is a compilation of those species which are recommended because they have high growth rates and have the mechanical properties necessary for the production of the given product. The fastest growing species are listed first.

TABLE VIII

LIST OF SPECIES RECOMMENDED FOR SPECIFIC SOIL CONDITIONS AND PRODUCTS

FOR BOTTOMLAND			
Flooded for long periods		Not flooded for long periods	
Light Soils	Heavy soils	Heavy soils	Light soils
For Production of High-Grade Veneer Logs			
Red Oaks White oaks	Red oaks White oaks	Black walnut Red oaks White oaks	White oaks Red oaks
For Production of Posts			
Catalpa White oaks	Catalpa White oaks	Catalpa Mulberry Black walnut White oaks Sassafras	Catalpa Mulberry White oaks

FOR BOTTOMLAND—Continued.

Flooded for long periods		Not flooded for long periods	
Light Soils	Heavy soils	Light soils	Heavy soils
For Production of Piling			
Pin oak	Pin oak	Pin oak	Pin oak
Red gum	Red gum	Sycamore	Sycamore
Sycamore	Sycamore	Red oak	Red oak
Red oak	Red oak	White oak	White oak
White oak	White oak	Black oak	Black oak
Black oak	Black oak	Shingle oak	Shingle oak
Shingle oak	Shingle oak	Ash	Ash
Ash	Ash		
For Production of Ties			
Sycamore	Sycamore	Sycamore	Sycamore
Ky. Coffee tree	Ky. Coffee tree	Black walnut	Ky. Coffee tree
Honey locust	Honey locust	Ky. Coffee tree	Honey locust
Pin oak	Pin oak	Honey locust	Pin oak
Red oak	Red oak	Pin oak	Red oak
White oaks	White oaks	Red oak	White oak
Black oak	Black oak	White oak	Black oak
Shingle oak	Shingle oak	Black oak	Shingle oak
Ash	Ash	Sassafras	Sassafras
		Shingle oak	Mulberry
		Mulberry	Ash
		Ash	
For Production of Lumber			
Cottonwood	Water locust	Cottonwood	Sycamore
Water locust	Sycamore	Sycamore	Soft maple
Sycamore	Soft maple	Black walnut	Coffee tree
Soft maple	Coffee tree	Soft maple	Honey locust
Ky. Coffee tree	Honey locust	Coffee tree	Pin oak
Honey locust	Red gum	Honey locust	Red oak
Red Gum	Pin oak	Tulip	White oak
Pin oak	Red oak	Pin oak	Black oak
Red oak	White oak	Red oak	Ash
White oak	Black oak	White oak	Shingle oak
Black oak	Ash	Basswood	
Ash	Shingle oak	Black oak	
Shingle oak		Ash	
		Shingle oak	

FOR BOTTOMLAND—Concluded.

Flooded for long periods		Not flooded for long periods	
Light Soils	Heavy soils	Light soils	Heavy soils
For Production of Mine Timbers			
Sycamore	Sycamore	Sycamore	Sycamore
Coffee tree	Coffee tree	Coffee tree	Coffee tree
Catalpa	Catalpa	Catalpa	Catalpa
Honey locust	Honey locust	Honey locust	Honey locust
Red gum	Red gum	Red gum	Red gum
Pin oak	Pin oak	Black walnut	Pin oak
Red oak	Red oak	Pin oak	Red oak
Black oak	Black oak	Red oak	Black oak
White oaks	White oaks	Mulberry	White oak
Shingle oak	Shingle oak	Black oak	Shingle oak
Ash	Ash	White oak	Ash
		Shingle oak	
		Ash	
For Production of Slack Cooperage and Average Veneer Logs			
Cottonwood	Sycamore	Cottonwood	Sycamore
Sycamore	Water locust	Sycamore	Soft maple
Water locust	Soft maple	Soft maple	Coffee tree
Soft maple	Red gum	Coffee tree	Honey locust
Coffee tree	Honey locust	Honey locust	Ash
Honey locust	Coffee tree	Willow	
Red gum	Ash	Tulip	
Willow		Basswood	
Ash		Ash	
For Production of Cordwood			
Cottonwood	Sycamore	Cottonwood	Sycamore
Sycamore	Water locust	Sycamore	Soft maple
Water locust	Soft maple	Soft maple	Coffee tree
Soft maple	Coffee tree	Coffee tree	Honey locust
Coffee tree	Honey locust	Honey locust	Pin oak
Honey locust	Red gum	Black walnut	Red oak
Red gum	Pin oak	Pin oak	White oak
Pin oak	Red oak	Red oak	Black oak
Red oak	White oak	Willow	Shingle oak
Willow	Black oak	Tulip	Ash
White oak	Ash	Magnolia	
Black oak	Shingle oak	Basswood	
Ash		Black oak	
Shingle oak		White oak	
		Shingle oak	
		Ash	

Table VIII—(Continued)

List of Species Recommended for Specific Soil Conditions and Products

FOR UPLAND

Sandy Loams	Silt Loams	Sand	Hardpan
	For Production of High-Grade Veneer Logs		
Black walnut	Black walnut		
Black cherry	Red oaks		
Red oaks	White oaks		
White oaks	Black cherry		
	For Production of Posts		
Catalpa	Catalpa	Sassafras	Post oak
Mulberry	Mulberry	Black locust	
Black walnut	Black walnut	Osage orange	
White oaks	White oaks		
Sassafras	Sassafras		
Black locust	Black locust		
	For Production of Piling		
White oak	White oak		
	For Production of Ties		
Black walnut	Black walnut	Red oak	
Ky. Coffee tree	Ky. Coffee tree	Black oak	
Honey locust	Honey locust	Black locust	
Cherry	Cherry		
Red oak	Red oak		
Black oak	Black oak		
Shingle oak	Shingle oak		
White oak	White oak		
Sassafras	Sassafras		
Mulberry	Mulberry		
Black locust	Black locust		
Ash	Ash		
	For Production of Lumber		
White pine	White pine	White pine	
Black walnut	Black walnut	Red oak	
Tulip	Tulip	Black oak	
Magnolia	Magnolia		
Black cherry	Black cherry		
Coffee tree	Coffee tree		
Honey locust	Honey locust		
Red oak	Red oak		
White oaks	White oaks		
Black oaks	Black oaks		
Basswood	Basswood		
Ash	Ash		
Shingle oak	Shingle oak		

FOR UPLAND—Concluded.

Sandy Loams	Silt Loams	Sand	Hardpan
For Production of Mine Timbers			
Black walnut	Black walnut	Red oak	Red oak
Coffee tree	Coffee tree	Black oak	Black oak
Honey locust	Honey locust	Sassafras	Post oak
Catalpa	Catalpa	Black locust	
Sassafras	Sassafras		
Red oak	Red oak		
Black oak	Black oak		
White oaks	White oaks		
Mulberry	Mulberry		
Ash	Ash		
Black locust	Black locust		
For Production of Slack Cooperage and Average Veneer Logs			
Coffee tree	Coffee tree		
Honey locust	Honey locust		
Tulip	Tulip		
Magnolia	Magnolia		
Basswood	Basswood		
Ash	Ash		
For Production of Cordwood			
Black walnut	Black walnut	Sassafras	Red oak
Coffee tree	Coffee tree	Red oak	Black oak
Honey locust	Honey locust	Black oak	Post oak
Tulip	Tulip	Black locust	
Magnolia	Magnolia		
Black cherry	Black cherry		
Sassafras	Sassafras		
Red oak	Red oak		
Black oak	Black oak		
White oak	White oak		
Mulberry	Mulberry		
Basswood	Basswood		
Ash	Ash		
Black locust	Black locust		

EVEN-AGED SYSTEM OF SILVICULTURE

A silvicultural system is a broad plan of management under which a forest is reproduced and developed. The two general types of forests which can be developed are even-aged and all-aged. Even-aged forests contain trees of approximately uniform size, all of which reach harvesting maturity and are cut at approximately the same period; all-aged forests, as the name implies, contain trees of varying ages and sizes. No system based upon the idea of clear cutting is well suited to our Illinois woodlots. One important function of the woodlot is to supply the farm requirements for certain wood products. A clear-cutting system results in the formation of an even-aged stand, incapable of yielding any products until it has passed through the sapling stage. The returns from the even-aged stands are periodic, and the interval between periods of returns is so long that the interest compounded on the maintenance costs—protection, taxes, cleanings—may completely absorb all proceeds. To illustrate the influence of compound interest where returns are deferred: if taxes of $0.50 per acre per year are paid for 30 years while the stand is going through the sapling stage, the actual outlay for taxes totals $15, but the interest on these payments compounded at the rate of 5 per cent totals $18.44. On the average upland soils, at least 60 years are required to produce hardwood trees large enough for ties or small sawlogs. At $0.50 a year, the total outlay for taxes is $30 per acre, but the interest on this amount, when compounded over this period at 5 per cent totals $146.79. On this basis of calculation, only trees of exceptionally rapid growth and high value can show a profit when grown in even-aged stands. A discussion of the even-aged system follows.

Even-aged woodlots are common throughout central and northern Illinois. The economic conditions by virtue of which such stands originated and developed are rapidly altering and should force the complete clearing of these stands on the high-grade agricultural land and should lead to their alteration to all-aged stands on the true forest lands. During the three decades prior to rail transportation when the tide of immigrants settled the prairies, there was a tremendous drain upon the local forests, amounting almost to clear cutting. The plow at the same time stopped the sweep of destructive fires, and the removal of the old forest and the cessation of fire was closely followed by the natural reestablishment of young trees. With the advent of the railroad, these young trees were permitted to grow, since construction materials and fuel requirements were supplied from other regions. Pressure for cleared land has subsequently resulted in clearing arable areas occupied by this second growth, thus incidentally supplying the farm with certain wood products, but very little cutting has been done in the stands which remain. The majority of these even-aged stands grow on upland sites and are between 60 and 90 years in age, and the diameters fall between 8 and 18 inches.

EVEN-AGED STAND OF YOUNG WHITE OAK.

Ground carpeted with leaves and well shaded by heavy stand of trees.

As the timber famine becomes more acute, the farmer will draw upon these woodlots for his requirements, gradually changing them to all-aged woodlots. But since the even-aged type usually follows clear cutting or the natural and planted reforestation of abandoned fields, there will always be stands of this character.

The practice of growing wood crops in even-aged stands is more applicable to bottomland than to upland regions. On the bottomlands subject to inundation, natural regeneration after a clear cutting is a certainty, although it is very difficult to control the kinds which seed in, because the floodwaters deposit seeds from outside sources and carry away seed from local sources. Plant growth on such bottomlands is usually rank—weeds, vines, and worthless trees are very aggressive—and under an all-aged, or selection, system constant work is necessary to prevent the useless species from suppressing the useful. The unbroken canopy of the even-aged stand offers less favorable conditions for climbing vines. Certain useful bottomland species have very rapid growth rates; yet these trees are often intolerant of shade, developing better in even-aged stands. Finally, tall straight stems suitable for piling can best be developed in even-aged bottomland stands. Under these conditions it may be expedient to use an even-aged system.

The management of even-aged stands is less complex in many respects than that of all-aged stands. The process may be divided into (1) development of the crop, (2) harvesting, and (3) reestablishing of a new crop. The proper development of the crop is attained through protecting the area so that an abundance of trees may grow and through the judicious use of the axe so that the maximum growth may be concentrated on the trees which are carried to the final harvest. The natural reestablishment of a new crop can usually be secured by observing a few rules at the time of harvesting the old crop.

Development of an Even-aged Stand

The stand on the well-stocked acre starts with several thousand small trees. In a few years these become a thicket of saplings. The struggle for light at this stage is very intense, as each tree races upward in the effort to overtop its neighbor. When the polewood stage is reached, there are approximately 400 trees per acre, ranging in diameter from 2 to 10 inches. The increasing height brings added difficulty in transporting supplies from root to crown, and the height growth slows down. At this stage, trees must have room to expand laterally in order to make the best growth; hence, thinnings should be made. This is the opportunity to insure the representation of desirable trees in the final crop by cutting into the following classes: (1) undesirable species (see p. 118), and (2) trees of desirable species but poor form. The forest tree should be tall and straight with a relatively short crown and a long stem. The thriftier trees of the desirable species which should be carried to maturity are less than half the number present, but the rule should be to thin lightly, cutting only those trees which are directly interfering with the development of the select trees. In general, not more than a quarter of the trees should be taken out in any thinning, and the crowns of the trees left should close the canopy in 5 or 6 years. All material which can not be utilized should be left on the ground to decay. It should not be burned except in the emergency of insect or disease attacks. When it is evident that the trees are again suffering from crowding, other thinnings should be made. The average numbers of trees per acre on unmanaged even-aged stands at different decades are shown in Table IX.

The heavy mulch of leaves and humus, a characteristic of good forest conditions, can not be maintained if excessive thinnings occur. The appearance of grass and weeds in abundance after a thinning is evidence that it was excessive. Even-aged stands are often free from an understory of bushes and shrubs, and if not, the owner considers it good practice to clear them out. *Such an understory should not be cleaned out.* It protects the forest floor by its shade and retards the movements of drying air. Indeed, it is advisable to provide a thicket of bushes along the southern and western borders of the woodlot exposed to dry winds prevailing from these points.

Harvesting the Crop

Under the even-aged system a stand may be harvested in a single operation or by a series of cuttings. Such cuttings should not be extended over too long an interval—more than 20 years—since young trees usually appear after each cutting and the succeeding stand loses its even-aged character.

Reestablishment

Following the removal of an even-aged stand, the area may be restocked by sprouts or seedlings or both, or restocking may fail completely; therefore, a knowledge of conditions favorable to regeneration is essential to intelligent management.

regeneration from sprouts

Common Illinois hardwoods show a capacity to send out sprouts when trees are cut under certain conditions. These sprouts grow rapidly for several years, but trees developing from them do not eventually attain the dimensions of trees grown from seedlings, and rot commonly enters the sprout through the decay of the stump to which it is attached. The sprouting capacity weakens and is lost as the tree matures. For these reasons, stands of sprout origin are not well suited to the development of trees for the larger logs, nor can stands be renewed through sprouts from these larger stumps.

This method of regeneration is, however, silviculturally suited to stands handled on a short rotation for the production of posts, cordwood, and mine timbers. The trees should be cut during the dormant season;

Table IX. Average Yields from Even-aged Stands in Illinois

Age Years	No. of trees per acre	Height of dominant trees Feet	D. B. H. of average trees Inches	Basal area per acre Sq. Ft.	Yields per acre in peeled stems Cu. Ft.	Average annual increment Cu. Ft.
	(Upland) Post Oak Type. (Based on 14 Plots)					
20	1,025	22	2.8	45	250	12.5
30	775	29	3.6	56	420	14.0
40	605	35	4.4	63	610	15.2
50	470	40	5.1	67	775	15.5
60	360	43	5.9	69	950	15.8
70	285	46	6.8	71	1,150	16.4
80	235	49	7.5	73	1,360	17.0
90	195	51	8.4	75	1,550	17.2
100	170	52	9.1	77	1,780	17.4
	(Upland) Scrub Oak Type. (Based on 23 Plots)					
20	1,035	25	2.9	47	450	22.5
30	670	36	4.0	59	775	25.8
40	400	46	5.6	68	1,075	26.9
50	260	54	7.3	75	1,400	28.0
60	180	61	9.1	81	1,750	29.2
70	120	67	11.6	88	2,075	29.7
80	90	72	13.8	93	2,375	29.7
90	75	74	....	...	2,650	29.4
100	65	77	....	...	2,920	29.2
	(Upland) Upland Hardwood Type. (Based on 34 Plots)					
20	1,010	36	3.6	72	810	40.5
30	630	47	4.8	79	1,175	39.2
40	400	55	6.5	84	1,520	38.0
50	250	61	8.1	89	1,870	37.4
60	185	66	9.5	94	2,175	36.2
70	155	70	11.0	99	2,500	35.7
80	130	73	12.5	103	2,825	35.3
90	110	75	13.9	106	3,125	34.7
100	100	78	15.6	109	3,425	34.2
	(Bottomland) Rapidly-Growing Species. (Based on 8 Plots) Cottonwood, Sycamore, Soft Maple, Honey Locust, Sweet Gum					
20	450	75	6.0	87	2,450	122
30	290	82	8.6	118	3,400	113
40	230	87	10.2	130	4,180	104
50	205	90	10.9	137	4,930	99
60	190	92	11.7	143	5,600	93
70	165	94	12.7	146	6,150	88
	(Bottomland) Slow-Growing Species. (Based on 11 Plots) Oak, Elm, Ash, Hickory					
20	1,100	42	3.5	74	1,075	54
30	530	53	5.4	84	1,560	52
40	330	62	7.1	92	2,000	50
50	250	69	8.5	98	2,375	47.5
60	200	76	9.7	104	2,675	45
70	170	81	10.8	109	2,950	42
80	145	85	12.0	113	3,225	40
90	125	88	13.0	116	3,500	39
100	110	91	14.0	118	3,750	37.5

the stumps should be low, and it is preferable to cut the top of the stump on a slant to allow water to drain off. Trees cut during the growing season exhibit a weakened sprouting capacity, and the sprouts are frequently killed by the autumn frosts before the tender tissues harden. Sprouts from low stumps are usually more vigorous, and conditions are less favorable to the decay of stems than in trees growing from high stumps. The sprouting capacity varies for different species, but, in general, stumps should not be more than a foot in diameter for good results. It usually happens that too many sprouts develop and a thinning becomes necessary. This should be made in the early sapling stage when the crowns are closing and crowding each other. The object is to leave plenty of thrifty stems to form the stand but to cut out the less desirable ones which are crowding the others. Frequently the thinning is cheapened by lopping off the tops of undesirables with a machéte or a bush hook sufficiently to check them and permit the desirables to get above them.

REGENERATION FROM SEED

In case the stand is carried past the period of vigorous sprouting—about 60 years for most species—, provision should be made for seedling reproduction or for replanting. The two different methods of securing natural seedling regeneration are as follows:

1. When the old crop is removed in a single cutting, the operation should take place after the trees have matured a heavy seed crop. Since heavy seed years vary somewhat for different species, best results are attained by selecting the species which is sufficiently well represented to insure the proper amount of seed production and which is the most desirable tree to grow, and then by clear cutting the area immediately after this species has matured a heavy seed crop. The layer of leaves which covers the ground under normal forest conditions is very favorable to the establishment of heavy-seeded trees, such as the oaks and other nut trees; it is unfavorable to the seeding in of elm, ash, tulip, and other light-seeded trees. In logging the area, the ground will be torn up somewhat, making spots favorable for the establishment of seedlings. The device of burning this leaf carpet will secure excellent results for light-seeded species *if a favorable seed year is followed by a moist growing season;* but this combination can not be assured. Therefore, as a failure to re-establish the forest under natural seeding is irrevocable after the seed trees have been cut, *a burning is not recommended.*

2. In order to positively insure the satisfactory restocking from the trees of the crop to be harvested, the stand can be harvested in two operations. The first cutting removes about 40 per cent of the total number of trees and, by opening up the stand, creates light and heat conditions favorable to the establishment of seedlings. The trees removed in this first cutting are those of undesirable species or form; the 60 per cent left should give character to the succeeding stand. When seedlings appear abundantly in the openings, these remaining trees are removed. Since

all seed trees are not cut until seedlings are established, this is the safest method of securing seedling regeneration from an even-aged stand. Under this system a light burning previous to the falling of the seed crop is justified where the leaf litter is heavy and where it is desired to secure seedlings from light-seeded species.

Application of the Even-aged System

Species suitable for production of piling

Temporary piling includes any sound timber that will stand driving, such as ash, beech, birch, cherry, sap cypress, sap white oak, red oaks, maple, black gum, and sycamore. In the application of the even-aged system to the production of piling, the object is to grow tall straight trees. Trees of this form can best be produced on fertile bottomland sites. Red gum, pin oak, and sycamore, especially in youth, develop a long narrow crown, and the main stem continues to the top. A great number of trees of this form can be grown per acre; consequently, for piling production these species rate high.

Planting, or artificial regeneration, is not economically justifiable; hence, dependence must be placed upon natural regeneration. An abundance of seedlings can be secured on cleared bottomlands if light and soil conditions are favorable; a full stand is assured on all cleared, unsodded floodlands, but usually the stand is a mixture of many species. To produce tall straight stems, the trees should crowd each other during the sapling and polewood stage, so that no heavy side branches are formed. Thinnings can usually begin when the larger trees of the stand are a foot in diameter breast high (12 inches D. B. H.).

Pin oak on fertile bottomlands produces a 30′ to 35′ pile in forty years, and unmanged stands contain as many as 60 trees to the acre suitable for piling.

Intolerant species, exemplified by cottonwood

Those tree species which are not shade-enduring are classed as "intolerant". Sycamore and soft maple belong in this class, but the Carolina poplar, or cottonwood, is the outstanding example of a rapidly-growing intolerant tree which should be grown in even-aged stands. Cottonwood trees make phenomonal growth on all but the heaviest bottomland soils, the logs find a ready market at excellent prices at mills specializing in fruit and egg containers, and the cordwood furnishes 50 per cent of the pulpwood grown in Illinois. Cottonwood has been successfully grown in plantations by the prairie farmer, has been developed into a profitable commercial project in South America, and is being developed commercially on Illinois bottomlands. There is no wood crop in Illinois which promises better returns than this species.

Cottonwood seeds in naturally on bottomlands where the moist mineral soil is exposed to full sunlight. It does not seed in on ground covered with a layer of leaves or a heavy growth of weeds, nor will it survive if planted under the shade of other trees. Pure stands have come in naturally on river bars and similar deposits and on patches of abandoned plowland. The embankments of levees and drainage ditches are quickly marked by a line of cottonwoods. This species grows best on the alluvial sandy-silt loams; it grows well on alluvial sands and loams, but poorly on ill-drained alluvial clays. Although well able to grow on the floodlands subjected to repeated inundations, cottonwood does not grow in swamps where water stands continually or on the very poorly drained clays otherwise well above water level.

Cottonwood matures an abundant crop of seed practically every year during the latter part of May and the early part of June, but these seeds must find favorable seed-bed conditions immediately, for they begin to lose their vitality within a week and are dead within a month. The pistillate, or seed-producing, flowers are borne on different trees from the staminate flowers. At maturity the pods open and liberate immense quantities of tiny brown seeds. Each seed is provided with a tuft of long silky hairs which enables it to be readily carried long distances by the wind. Ripening at a period when the larger rivers are at flood, the seeds are also transported long distances by water; but floods may also submerge an area past the germinating period of the seed, thus effectually keeping cottonwood out. This, together with the aggressiveness of weeds on open bottomland areas, has led to the practice of *planting* such areas to cottonwood rather than depending upon a natural seeding. The methods of planting are outlined on pp. 152-154.

When light and soil conditions have chanced to be just right, cottonwood has come in on bottomland sites in immense numbers; but since it is a tree which requires abundant sunlight throughout its life, only a very few of the most vigorous trees survive the sapling stage; the stand then opens up, and less valuable but more tolerant trees grow as an understory. A bad cutting practice of harvesting all trees above a merchantable diameter has been developed to conform with market conditions. A few years later some of the survivors have reached a merchantable size and are cut. Meanwhile, the shade has been sufficient to keep out cottonwood seedlings, but insufficient to keep out elm, soft maple, hackberry, and other less valuable trees. This cutting practice should be changed to a single clear cutting followed by a fire which thoroughly cleans off the ground cover in order to create seed bed conditions favorable for another crop of cottonwood.

SELECTION SYSTEM OF SILVICULTURE

The system generally best suited to the woodlot is termed the selection system. It consists in harvesting trees singly or in small groups and in regulating the cuttings so as to bring the stand to produce about the same number of mature trees in each cutting period. In the fully-stocked woodlot the total amount cut at any time should balance the total amount grown since the previous cutting was made. Under intensive management the mature trees are harvested annually; hence, the total amount of wood per acre removed should equal the annual growth of the acre. The usual practice is to fix a minimum diameter limit and to cut each year all trees which attain this limit, carrying on at the same time such cuttings in the lower-diameter classes as may be necessary to facilitate the growth of the trees to be carried to maturity and to free the stand from undesirable trees. Under this method the woodlot contains trees of many sizes; thus the diverse requirements of the farm can at all times be supplied. Since some trees are harvested annually, the value of these can be balanced against the annual maintenance costs—protection, taxes, cleanings—, and there is no compounding of interest over long periods.

General Cultural Measures

Whether the woodlot be managed for the production of the small products, such as cordwood, posts and mine timbers, the intermediate products, such as ties, piling, ordinary sawlogs, or the large products, such as veneer logs, the general cultural measures are similar. The first concern should be to insure proper conditions for regeneration. This means, first of all, the absolute protection of the area from fire and grazing. Under natural forest conditions, where fires and live-stock are kept out, the layer of leaves gives place to a rich, moist layer of partly-decayed organic matter, under which is the mineral soil. Small seeds to some extent sift through the layer of leaves; the sprouting acorn or nut can push through to the rich humus and finally to the mineral soil. The removal of this layer of leaves and the exposure of the humus or bare mineral soil is usually highly conducive to the establishment of seedlings, but the leaves should not be removed, because satisfactory regeneration can usually be established with the leaves present and because the injury to the soil through the destruction of leaves and humus outweighs all benefits.

Where fires have repeatedly run through the woodland or cattle have freely grazed, the conditions are quite different. Instead of a mellow moist soil, there is hard dry surface or, if sufficient sunlight, a sod. Keeping fire and cattle out will usually bring back the forest trees if there is no sod; but, if a sod has formed, more intensive measures are

ALL-AGED, OR SELECTION, TYPE.

Ground carpeted with leaves. Abundance of trees.

necessary to restore the forest, as germinating seeds can not establish themselves under such conditions. Any agency which breaks up the sod, be it harrow or hogs, is useful; but the best means and often the only sure method of securing regeneration is to plant seed or seedlings in spots from which the sod has been removed. Where the woodlot is managed for the production of small products, satisfactory regeneration can be secured largely from sprouts. When managed for the production of medium and large products, this method can not be depended on, as the larger stumps do not sprout vigorously and the trees which develop from sprouts, although growing rapidly until the polewood stage is reached, do not develop into mature trees as large as those from seedlings.

After the woodlot has been managed under the selection system for a period long enough to secure good forest conditions, abundant natural reproduction is a practical certainty, and management will consist largely in trying to insure the establishment in sufficient numbers of the most desirable species. The rather common practice of marketing the valuable species from the woodlot without taking any positive steps to reestablish a valuable successor has resulted in a two-fold evil. The unmerchantable or low-grade species practically dominate the mature classes and deluge the area with seed. Thus the trees remaining in the woodlot have a low value, and these inferior species will perpetuate themselves and make up the succeeding stands. Management aims to correct this condition by weeding out the inferior species, thus lessening the seed supply and decreasing their representation in the reproduction, and by securing the establishment of desirable species, even resorting to planting when natural reproduction is not wholly successful.

Since, under the selection system, the aim is to manage the woodlot so as to bring about the same number of trees to cutting maturity each year, the area occupied by each age class should be approximately the same. If the average time required to grow trees suitable for mine timbers, cordwood and posts is 40 years, then each age class would occupy one-fortieth of the area. In actual practice this exact adjustment of age classes can not be attained, because of irregularity in regeneration and variation in growth rates, and because the annual yields from small areas often are insufficient to justify an annual cut. Although in theory the area occupied by each age class is the same, the number of trees in each age class is not. On average upland loams there will be something like 42 one-year-old trees and but 10 forty-year-old trees on the acre. In the case of such small products as mine timbers, cordwood, and posts requiring 40 years, only 400 out of 1000 trees are brought to maturity. In the case of sawlogs requiring 80 years, there are 600 trees per acre, 130 of which are carried to maturity. In the case of veneer logs requiring up to 150 years, only 80 would be carried to maturity out of a total of 367 trees. Since from 60 to 80 per cent of the total number of trees fail to reach maturity, it is not necessary to have more than half the reproduction of desirable species. Thus, for small products, it would be considered satisfactory regeneration if 20 trees per acre of a desirable species were established annually; for logs, 4 trees; and for high-grade veneer, one tree of a desirable species per acre properly located will suffice. The young trees of the desirable species should, of course, be located in the openings formed by the removal of the older trees. Frequently, well-located young trees, which have become established before the older trees are removed, provide satisfactory successors to the matured trees. Commonly, young trees in abundance will appear in any opening; but if these are wholly of undesirable species or if, as in rare cases, reproduction fails, it is advisable to plant seed or seedlings. Methods of planting seed and young trees are described on pages 138-142.

The establishment of desirable trees in sufficient numbers is half of silviculture; the other half consists in creating light conditions such that the trees to be carried to maturity will require the shortest time consistent with the production of trees of good form. Openings will always be made in the forest by the removal of mature trees and of other trees of undesirable species, but one of the cardinal principles of cuttings should be to make as few openings as possible where the direct sunlight can reach the forest floor. Although from 60 to 80 per cent of the trees which start will not be carried to maturity, these trees perform the useful service of shading the forest floor and preserving moisture conditions decidedly beneficial to soil enrichment as well as to tree growth; and, in addition, by lateral crowding of the select trees during their immaturity, these others force them to rapid height growth and development into trees of good form. On the other hand, the competition for growing space between all trees is keen, and, if unaided by thinnings, many of the desirable species will be crowded out by less desirable ones. Hence it is advisable to let all trees grow until such a time that the proper development of the select trees can not continue because of lack of crown space, and then to cut the undesirable trees which are competing with the select ones. The number of trees per acre or the regularity of spacing of the trees does not indicate whether the stand should be thinned, but rather the growing space available to the crown is the factor determining the necessity of a thinning. The critical examination is overhead. The rule should be to make light cuttings often rather than to depend upon heavy thinnings at longer intervals. Only through experience can the individual develop the skill and judgment by which he determines when crowding ceases to be a stimulus to height growth and becomes a check to proper development. Unutilized tops of felled trees should not be piled and burned, unless burning must be resorted to in order to check insects and fungous diseases. The brush should be scattered to lie close to the ground in order to facilitate decay. In woodlots managed for the production of cordwood, posts, and mine timbers, such thinnings would give products of little value; but in woodlots managed for the production of ties and logs, these thinnings should provide posts, cordwood and mine timbers.

Fixing the Diameter Limit

The diameter of a standing tree is customarily taken outside the bark and at a point 4½ feet from the ground. This is known as the diameter breast high, or D.B.H, and affords a convenient basis of classification. If the stand is kept fully stocked in the smaller-diameter classes, and if the area occupied by each class is approximately the same, then, by fixing a diameter to which the select trees must grow before they are harvested, equal quantities can be harvested each year, yet the cut is automatically balanced by growth.

Not only are there certain products which give higher returns than others, but also the returns per acre, even for a given product, vary with the diameters of the trees harvested. The individual tree is unmerchantable for a definite period of its immaturity; after it attains merchantable dimensions, the value increases rapidly as the tree increases in size. The higher value is due to the added growth and to the higher quality of growth. This increase in value continues as long as the tree remains sound and continues growth. Offsetting this increase in value as the individual tree gains in size is the fact that fewer large trees can be grown per acre. A refinement of management consists in fixing the diameter limit at the size which gives the greatest returns per acre.

The accurate defining of the correct diameter limit for any given product and region requires a knowledge of the average time required to grow a tree to each diameter, the number of trees of any given diameter which can be grown on an acre, the quantities of the product which are produced per tree and per acre for each diameter class, and, finally, the net value of the product. The problem is further complicated by the constant increase in the value of forest products, an increase which often justifies holding trees beyond the time dictated by factors of natural growth. The local influence of market conditions, together with the variation in the composition of different stands, permits the application of only very general statements to individual woodlots. It is a fact, however, that the smallest diameter at which a tree becomes merchantable almost never corresponds to the diameter at which the tree would give the best returns. It is not wise to cut thrifty trees of the lower-diameter classes which may be merchantable.

ADVANTAGE OF LARGER DIAMETERS

The rapid increase in value of the individual tree after it enters the merchantable class is brought out in studies of black oak on upland loam in Illinois Such a tree having a D. B. H. of 10″ averages one tie worth $0.50; a 12″ tree averages two ties worth $1.60; a 14″ tree, four ties worth $3.80; a 16″ tree, four ties worth $4.90; an 18″ tree, five ties worth $5.70. It takes 52 years to grow the tree producing the $0.50 tie, and 103 years for the tree producing the $5.70 value. If the 10-inch tree is cut, the gross annual returns per tree approximate one cent; if the tree is allowed to grow to 18 inches, these returns are approximately 5½ cents per tree.

No information exists as to the number of trees per acre which can be grown to 10" D. B. H. in 52 years under the selection system, or to 18" D. B. H. in 103 years. In the absence of reliable data on the average number of trees per acre of a given diameter which can be matured yearly where the selection system has been practiced, recourse must be had to the data collected from fully-stocked even-aged plots. Table X gives data for such plots on upland loams in this State, the tabulation being in terms of the average D. B. H. of the stand. The average D. B. H., made up from all trees on the plot, includes trees of several diameters, and the yields assume that all trees which have attained a merchantable diameter will be cut, whereas in the selection system only those trees which reach the diameter limit chosen as the most desirable will be harvested. In order to make the data from even-aged stands directly applicable to a selection cutting, the rather doubtful assumption must be made that the number of trees on the even-aged plot of a given age and average D. B. H. is equal to the number of trees actually brought to this diameter in a selection forest over the same period.

The number of ties which can be harvested from the larger tree until the 15-inch class is reached more than makes up for the decrease in the number of trees per acre. Above this diameter the increase in the number of ties per tree is not enough to offset completely the decrease in the number of trees per acre, and the total tie yield per acre decreases. Converted to gross returns, however, it often happens that the increase in value due to the higher quality of ties which can be secured from the larger-diameter classes may carry optimum gross returns into a larger-diameter class than that for the maximum number of ties. The interplay of quantities and quality, as measured by gross annual returns per acre for ties shown in column 6, indicates that under average conditions of growth the upland woodlots give the highest gross returns on a 15-inch diameter limit. At this diameter these returns per acre are 1.65 times those when a 10-inch diameter limit is used.

The same general principle, that it is not profitable to cut the low-diameter classes merely because there happens to be a market for them, holds for other products. Rather limited studies of black walnut on sandy loams in this State indicate that 1.58 trees averaging 14 inches on the stump can be matured per acre annually. Such trees average 50 years in age, and the average annual yield per acre is 63 B. F. of lumber logs worth $3.15 at the mill. If trees are carried until they attain a 26-inch diameter, only .57 trees per acre can be matured annually, and such trees average 140 years in age, but the average annual yield *per acre* is increased to 214 B. F. of veneer logs and 16 B. F. of lumber logs, totaling $23.54 at the mill. Thus the acre managed on the 26-inch diameter limit gives a gross return of 7.47 times that from the acre on the 14-inch diameter limit.

Table X.

Yield of Ties per Acre on Upland Loam under Various Diameter Limits

Diameter Limit	Height of Dominant Tree	Age	No. of trees annually reaching diam. limit per A.	No. of ties annually harvested per A.	Av. annual gross return per A.	Av. annual gross return per tree
Inches	Feet	Years				
10	67	63	2.78	2.78	$2.28	$.013
11	70	70	2.21	3.24	2.89	.018
12	72	77	1.75	3.64	3.29	.024
13	74	84	1.43	3.83	3.55	.030
14	76	91	1.21	3.98	3.73	.034
15	77	97	1.06	4.02	3.76	.036
16	78	104	0.95	3.92	3.70	.039
17	78	111	0.86	3.80	3.60	.042
18	79	117	0.80	3.73	3.50	.044

PLANTING TO REENFORCE HARDWOOD STANDS

Up to this point in the discussion of woodlot management, it has been assumed that natural reproduction is possible and advantageous, but there are conditions where planting must be resorted to. Tree planting on the farm may be divided into two classes: (1) reenforcement planting within the woodlot, and (2) planting of cleared areas. The first of these will be discussed here, and the second on pages 143-163.

The principle to be followed in reenforcement planting within the woodlot is to use those species which are not only adjusted to local soil and climatic conditions but which are also able to compete successfully with the associated native trees and to reproduce naturally under forest conditions. The conifers do not qualify for reenforcement planting among all-aged hardwoods in Illinois, because those having a sufficiently high rate of growth and value are intolerant of shade and are not well suited to woodlot conditions, nor will they reproduce and hold their place in a hardwood mixture. Black walnut, basswood, and red oak are recommended for woodlot reenforcement on those soils and sites adapted to these species as shown in Table VIII, p. 118. To these may be added tulip poplar in the southern part of the State.

Black Walnut

Black walnut is by far the best native hardwood for reenforcement planting. The tree can easily be grown from nuts, the wood is suitable for farm requirements, and the growth rate is relatively rapid. Logs of black walnut command a price virtually double that of any other native hardwood, and good markets are accessible. A large percentage of the walnut now being marketed is coming from open-grown trees, and the practice is general of leaving seedlings which spring up in vacant places along fences or in pastures. Farm owners have found that walnut trees set out in plantations on high-grade arable land do not give returns at all comparable to those from ordinary crops, but that trees standing individually or in groups along roads, fences, streams, and hollows, or scattered about in the permanent pasture, are a source of revenue and warrant the slight positive effort necessary to increase their representation in such waste places. A walnut takes up no more room than an elm or hackberry and has a much higher market value.

Black walnut is rather exacting as to soil requirements. It grows best on deep, fertile, well-drained loams with a stable moisture supply, such as are found along the flood-plains of the smaller streams, or in hollows and sheltered coves receiving the wash from adjacent uplands. It makes exceptionally rapid growth on sandy loams. It grows well on the moderately fertile, yellow and yellow-gray, silt loams characteristic of the rolling uplands of the timbered regions, and on well-drained, dark, prairie loams. It does not grow on sands or hardpan soils where acidity is high and moisture conditions are variable, nor on swampy areas.

This species is also somewhat exacting as to light requirements. The seedling can persist under an overwood but requires full overhead light to develop; therefore, in reenforcement planting in a hardwood stand, walnut should be started in openings large enough to insure such light. This species should be used to supplant other trees which are removed, but there is a limit to the number which should be grown on an acre. It is a space-demanding tree, for the long branches extend almost at right angles to the axis. The canopy is also relatively open, so much so that in pure walnut stands enough light comes through to support grass. It can be grown in groups, but not more than half of the stand should be of walnut if proper forest conditions are retained.

When grown in the open, the tree has a short trunk and wide-spreading crown. A tree developing a long clear bole can be produced by pruning off the lateral branches close to the trunk while the tree is in the sapling stage, or by pinching off the new lateral shoots as they develop during spring.

Tulip Poplar and Basswood

Tulip poplar and basswood are not valuable for ordinary farm requirements but are special-purpose woods, and should be grown in those woodlots tributary to a market. Good markets for tulip logs exist in southern Illinois and for basswood logs in both southern and northern Illinois. The natural range of tulip is limited to the southern part of the state, while basswood is of state-wide occurrence. Tulip is slightly more exacting as to soil and light requirements, but both species occur on all but extremes of sands and hardpan soils, and each can naturally establish itself and grow in hardwood mixtures. Tulip must have direct overhead light, being very similar to walnut in this respect. Basswood is rather shade-enduring, and can grow on heavier clays and wetter situations than tulip or walnut, commonly being found on the stream banks as well as on the uplands.

It is not advisable to plant basswood or tulip seed directly in the woodlot, because the germination of the former is often delayed until the second year and the germination of the latter is uncertain. Other less desirable seedlings meanwhile establish themselves. Seeds should be planted in a seed bed as described on pp. 141-142. The proper time for sowing is in the fall. The proper number of seeds per foot of row is shown in Table XI (p. 142). In order to produce sturdy stock well able to compete in the woodlot, it is advisable to let the young trees grow two seasons in the seedbed, after which they can be transplanted to the woodlot.

Oaks

Red oak, although it is a wood of only medium value for either farm or market purposes, is recommended as a sort of general-purpose tree, because it is one of the most rapidly growing oaks, because it can be easily grown on a wide range of soil conditions, and because its wood has so many uses that markets exist everywhere in the State. It is subject to destruction through the attacks of a flat-headed borer and should not be used in those localities where this insect is killing the black and red oaks. Reenforcement can be made by planting acorns during the spring.

METHODS OF PLANTING

The term reenforcement planting has been used for planting done in openings where natural reproduction is not assured. On such blanks, once the desirable species is planted, there is but little danger that reproduction of undesirables will crowd it out. But woodlot improvement does not stop with the operation of filling up the blanks with seedlings of valuable species. Such seedlings can be established where an abundance of reproduction of an undesirable kind exists. In this case the undesirable reproduction must be cleaned away from the valuable in order that the latter may properly develop. Such a cleaning should occur at the time when the planting is made and be repeated at any stage of the competition when the undesirables overtop the planted trees.

When the nut trees and oaks are used, the better method consists in planting the seed where the trees are needed. For basswood, tulip, and other light-seeded trees, the better method is to transplant seedlings where trees are needed.

The acorns of the white oaks germinate in the fall and must be planted at this season; spring is the best time to plant acorns or nuts of the other oaks and nut-bearing trees, as fall-planted seeds are subject to rodent destruction. The seed should be collected in the fall. It is a good plan to place acorns in a vessel of water and discard those which float buoyantly, as this minimizes the number ruined by insects. To store nuts or acorns over winter, place them outdoors in a small heap on a slight elevation where water will not stand, and preferably on well-drained sandy soil. Place a layer of straw or leaves over them and then throw dirt on this, but leave places where the straw ends project out at the side of the mound to insure ventilation. Freezing does not injure them, but as soon as the frost leaves the ground in the spring they must be planted, because acorns especially will quickly sprout at this time. Most of the black walnuts sprout the first year, but some walnuts will carry over and sprout the second year. In planting, two or three nuts are placed in a slight excavation where the tree is to be grown, and about 2 inches of soil packed over them. If squirrels are troublesome, it is advisable to make several seed spots where ultimately but a single tree may stand, or to protect the nuts by covering each one with a tin can from which the lid has been removed. A crisscross incision in the bottom of the can is made with an axe, the can is placed upside down over the planted nut, and the tree grows through the hole punched in the bottom. The can rots away before the tree attains a large diameter.

GROWING HARDWOOD PLANTING STOCK

Customarily those trees which have small seeds are raised in a seedbed during the first year and transplanted to the woodlot as seedlings. Elm, soft maples, willows, and cottonwoods ripen their seeds between April and June, and since these seeds are relatively perishable they should be planted immediately. The seeds of virtually all other native hardwoods can be planted in the fall. The ideal soil is a well-drained, mellow, sandy-loam, garden soil. It should be tilled until the soil is thoroughly pulverized, then raked level, and the seeds should be sown in rows to a depth two or three times the thickness of the individual seed. The rows should be about one foot apart for hand cultivation or three feet if horse cultivation is used. The object is to secure a seedling for every four-fifths of an inch of the row, and to do this requires a knowledge of the germinating capacities of seeds of the species used. See Table XI.

For fall-sowed seed, a mulch consisting of two or three inches of leaves is advisable, but this should be removed before the seeds germinate

TABLE XI.

NUMBER OF SEEDS TO SOW TO SECURE 15 SEEDLINGS TO THE FOOT

Hardwoods

*Species	No. of seed to sow per foot of row	Species	No. of seed to sow per foot of row
Yellow poplar	150	Honey locust	23
Sycamore	50	Catalpa	20
Basswood	30	Black locust	23
Maple	30	Elm	23
Mulberry	30	Cherry	20
Ash	25	Hackberry	20
Coffee Tree	25	Osage orange	20
Red gum	25		

* Based on Table 8, U. S. Dept. Agr. Bulletin 1123.

in spring. The same weeding and cultivation should be given as is practiced to insure the success of garden crops. One growing season in the seed bed produces stock of the size most convenient to handle. Stock can be left in the seed bed over winter without mulching. Transplanting should be done in spring as early as possible after the frost is out of the ground. In lifting seedlings from the bed, care must be taken to minimize root injury; the trees should never be pulled up but should be turned out by a spade. They should be transplanted immediately and the roots kept moist while out of ground by covering with wet sacking, moss, or other moisture—retaining matter.

GULLIED, WORN-OUT, LOW-GRADE SOILS SHOULD BE PLANTED TO TREE CROPS.

PLANTING CLEARED AREAS

Two disturbing consequences of forest and land exploitation are forcing a consideration of tree planting on cleared areas. As the forests diminish, the prices of forest products go up until eventually they reach such a height that wood can be grown as a crop at a profit. This is the commercial aspect of reforesting cleared areas. But also, following the development of a region into farm lands, soils from the upland fields wash and are deposited over the choice bottomlands, or sands are blown over adjacent fields, so that the protective aspect of reforesting becomes important. In most instances where protective forests are needed, it is possible to use species which promise commercial returns as well.

COMMERCIAL ASPECTS OF REFORESTING CLEARED LAND

The chief deterrent to landowners undertaking the project of planting their waste lands to forests is the long interval which must elapse between planting and harvesting the crop. In an analysis of the project of tree plantations as profitable crops, it is necessary to recognize the tremendous accumulative effect of compound interest when carried over a long period, and to draw a general comparison between the trend in lumber prices as compared to all other commodities.

In computing returns from forest plantations as an investment, the practice is to regard all money spent for land purchase and plantation development as entitled to a rate of interest which the owner can readily secure by investing in other common phases of business, and, since the period between disbursement and realization extends over several years, to compound the interest. The use of interest calculations permits the owner to establish the value of an acre of land for growing timber and to compare this with the value of other crops which could be secured from the same land. It also enables him to measure the present value of a sum to be received in the future. The rate customarily used in computing farm values is 5 per cent. At this interest rate and with average yields and stumpage values, upland soils of average fertility in Illinois have a value of $13.25 an acre when devoted to pine plantations. Land in annual crops needs to net but $0.66 per acre yearly to give this soil value. But the forest plantation is in the nature of a savings account which draws 5 per cent interest and which is permitted to run for a long period, say 50 years, at compound rates. In such an account, the sum of the "deposits" consists of $13.25 an acre for land, $12.00 for planting, and $20.00 for taxes paid at the rate of $0.40 yearly. These deposits are considered to earn 5 per cent interest compounded annually, so that at the end of 50 years when the deposits total $45.25, the accumulated interest is $314.75, and the account amounts to $360.00.

It should be pointed out that while such an accounting is a fair basis for planting projects where land must be purchased and where capital has the choice of other fields of investment, the case of the farm owner is somewhat different. Farms are acquired as units, embracing both good and poor areas. The owner can not separate out and dispose of the waste areas, since no market exists for disconnected fragments of land of this type. He is committed to owning the waste-land and carrying the taxes on it in order to possess that part of the farm from which he gets his revenue. He is already two-thirds in the business, and the decision left for his judgment is whether the cost of the other third of the project—establishing and carrying the trees—will be amply rewarded. When he considers that plantations in 50 years repay the cost of establishing approximately 30 fold, amounting to an average of $7.00 per acre yearly, he is more likely to decide in favor of planting than if he considers compound interest on the land values and taxes.

In approaching the problem of the practicality of devoting areas now cleared to growing wood, it is important, also, to thoroughly appreciate the fact that the present is a period intermediate between a former period of abundant and cheap supplies of high-grade virgin timber and a future period of inadequate supplies of wholly second-growth origin, and that forest crops have increased and should continue to increase in value more rapidly than other commodities. Since 1865 the average price of lumber in the United States has risen 300 per cent while the average prices of other commodities have risen but 40 per cent. The use of current stumpage values in computing the value of a crop which matures in 50 years injects a very conservative element into the computation. The prices of wood products have now reached a level where with certain species the Illinois plantation can return a profit on all but the poorest soil.

Plantations for Production of Saw-logs

Plantations for the production of saw-logs offer a profitable use for low-grade lands, but only those species can yet be profitably used which have an exceptionally high growth-rate and value. The native hardwoods are not profitably used for restocking denuded upland areas. Even under natural seeding to hardwood and with no planting cost incurred, the long period required to produce hardwood saw-logs and the small yields per acre result in decidedly low returns. Recent studies of growth rates in this State place the average yield of well-stocked even-aged stands of native hardwoods on upland loams at 60 years as 6,144 B. F. to the acre. The stumpage value scarcely totals $75 an acre. Pine plantations on similar sites produce 30,000 B. F. in 50 years, or a stumpage value of $360 per acre. If planting is necessary in each case, the cash outlay on an acre of hardwood is $12 planting cost and $24 taxes; on pine, $12 planting cost and $20 taxes. The hardwood pays an average of $0.65 per year over money spent for taxes and planting; the pine returns ten times as much, or $6.50. The interest rates earned on these costs properly compounded over the period represent slightly better than 1½ per cent for hardwood and slightly better than 6 per cent for pine.

GROWING CONIFEROUS PLANTING STOCK

In those States which have developed tree nurseries, suitable planting stock can usually be secured cheaper than it can be raised. This State is just developing such nurseries, and the supply from private concerns is uncertain and expensive; consequently, the Illinois landowner must grow his own. (Tree seeds can be purchased from concerns listed on p. 183.)

The seedbed should preferably be located at a point convenient to work and where water can readily be supplied in dry periods. A sandy loam is best, and almost any fertile soil is acceptable, but the land should not be fertilized with fresh manure or lime. The seedbed should be thoroughly tilled and the soil pulverized and leveled off in beds. A convenient width of the beds is about 4 ft. This allows access from the margin and is suitable for the adjustment of shading frames. About 500 trees per running foot of bed can be raised in beds of this width.

Fall sowing is preferable to spring sowing, because the germination of seeds which have been in moist soil over winter is higher. If, however, planting is done in spring, germination can be increased by soaking the seeds in water for about a week before sowing. The seeds can be sowed in rows spaced about 5 inches apart and running crosswise of the bed. The drills should be about one-half inch deep, and the number of fresh seed to be sowed per linear foot of drill is shown in Table XII.

Table XII.

Number of Seeds to Sow to Secure 100 Seedlings per Square Foot

Conifers

Species*	No. of seeds per lb.	No. of seedlings 1 lb. of seed will produce	No. of seed per running foot of drill to produce 100 seedlings per sq. ft.
Eastern red cedar........	17,000	6,000	120
European larch	60,000	5,000—10,000	331
Jack pine	150,000	15,000—35,000	276
Red pine	54,000	20,000—30,000	83
Eastern white pine.......	26,000	8,000—14,000	98
Norway spruce	60,000	14,000—35,000	103

* Based on Table 2, Farmers Bulletin 1453, U. S. Dept. Agr.

PLANTATION FOR THE PRODUCTION OF SAW LOGS.

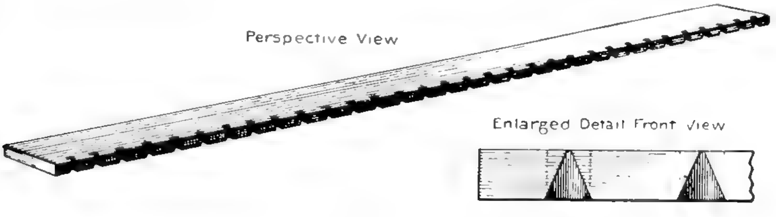
White pine on dune sand. Age 20 years.

The seeds should be covered with one-fourth to one-half inch of pulverized soil and this in turn with a mulch of straw leaves, or burlap. The mulch must be removed in spring as soon as seedlings appear, and shade should be provided for most coniferous seedlings at this stage. A good framework to support the shading material consists of two-by-fours driven into the ground at the corners of the bed, so that about 20 inches projects above ground, and connected by one-by-four strips nailed near the top of each stake. This forms a support across which can be placed the brush, boards, or lath used to supply shade. By this arrangement the layer of shading material will be about 20 inches above the seed bed. Shading is essential from the time the seedling emerges until well into the first summer. Complete shading, however, should never be supplied, but the material should shut off only about half of the sunlight. After the first year the trees should stand full sunlight. The beds should be kept free from weeds, and during dry periods they must be watered, although the ground should never be kept water-soaked.

TRANSPLANTING

The trees can be left in the seed bed during two growing seasons, then either planted directly in the plantation or set out in transplant beds. Spruce develops so slowly that it is usually advisable to set it in transplant beds for one or two growing seasons. On such adverse sites as pure sands, loams where a rank weed and grass growth prevails, or gullied uplands where bare soil is exposed to the drying effects of sun and wind, pine *transplants* should be used; but on the ordinary upland loamy cleared fields pine *seedlings* can be successfully used.

Transplanting from seedling bed to transplant bed may be done after either the first or second season's growth. The soil of the transplant beds should be well tilled. The beds can be 6 feet wide, the trees are spaced 2 inches apart in a row, and the rows are 6 inches apart. Such a bed contains 72 plants for each linear foot of bed. Transplanting is facilitated by using an inch board 6 inches wide and 6 feet long, with notches cut two inches apart along one edge to hold the seedlings. (See figure.) A row of holes one-fourth inch in diameter is bored one-half



Transplant board *

* From U. S. Dept. Agr. Bull. 1453.

inch from the edge, two inches apart. Wedge-shaped slots are cut from the edge to the holes, the base of the wedge at the underside of the board being three-fourths of an inch and the apex on the top side having a width about the same as the one-fourth inch hole.

Transplanting may be done either in fall or spring. If dry, both seed bed and transplant bed should be well soaked in order to soften the soil. Carefully lift plants by inserting a spade fork between the rows, thrusting it deeply under the roots, and, as the handle is forced back, pulling gently on the tops. If too much force is used, the roots will be so damaged that the seedlings will die. The roots should be kept constantly moist until replanted. The trees can be placed in a basket and the roots well wrapped with wet burlap or moss. It is not advisable to place the roots in water, as it should be the aim to retain as fully as possible the soil particles which surround roots when the trees are lifted from the bed. Poor specimens should be discarded, and the rest immediately transplanted. The transplanting board is placed across the bed, the unnotched edge serving as a marker. The trench is dug along this edge to a depth of at least 6 inches, the spade being thrust vertically down along the edge of the board and the excavated earth placed directly in front of the trench. The board is now reversed so that the notched edge is over the trench and the back of the notch is flush with the vertical side of the trench. The seedlings are then placed one to a notch in a vertical position. The lower leaves hold the crown above the board and the trench is now filled with earth which is tramped firmly about the roots. To remove the board, grasp the unnotched edge and pivot it forward on the notched edge and draw it slowly backward. Repeat the process for each row. Before finishing for the day, water the plants set out that day. The beds should be kept free from weeds and in periods of unusual drought should be watered. Trees carried over the winter in transplant beds do not need to be mulched.

The trees may be removed from the seed bed or transplant bed to the plantation either in fall after the conclusion of the season's growing period or in spring before growth starts. On sandy sites there is a slight advantage in fall planting; but on heavy soils fall-planted stock is often heaved by frost, so that spring planting is preferable. On the ordinary upland loams it becomes more a matter of convenience. If the site is so unfavorable as to require transplants, it is advisable to use stock which has been in the seed bed one year and in the transplant bed two years, that is, stock about 6 inches high, but it is rarely economical to use stock which is a foot or more high.

A discussion of the methods of establishing plantations and the kinds of trees which are recommended for the different soils follows.

CONIFER PLANTATIONS ON SANDS

Red pine *(P. resinosa)* and white pine *(P. strobus)* will grow well on most Illinois sands; but if the site is exceptionally dry and exposed, Jack pine *(P. banksiana)* should be used. Either red or white pine produces very excellent lumber. Probably preference should be given to red pine on sandy sites as it grows naturally under these conditions and is not susceptible to insect and disease damage to the same degree as white pine. Yet there is no reason why white pine should not be used, as it has demonstrated its ability to produce good yields on Illinois dune sand, and effective control can readily be secured if the white pine blister rust becomes established in Illinois. Spruce and tamarack are not adapted to sand.

On areas where the sand drifts, it is advisable to establish a windbreak on the windward side of the area to be planted. The ordinary cottonwood, or Carolina poplar, has the required adaptability, as it sends out roots from the parts of the tree which become buried by sand drift. This species also grows with relative vigor on dune sands. A windbreak of three rows of poplar with the trees spaced 8 by 8 feet usually suffices to stop the sand particles. Rooted cuttings (described on p. 154) may be used. On sandy areas the sparse grass cover is not an impossible barrier to transplants. If the plow can be used, a single furrow should be plowed, and the planters should follow this immediately and plant the trees in the furrow. The soil should not have time to dry between the plowing and planting. Transplants rather than seedlings should be used, and the proper safeguards should be taken to prevent root drying when the plants are out of the ground.

The furrows should parallel each other at 6-foot intervals, and the trees should be planted at 6-foot intervals in the furrow. This spacing of 6 feet by 6 feet makes a total of 1,210 trees required for an acre. Spacing can be measured by pacing. In planting, the tree is held in one hand in a vertical position and the roots properly spread; then with the other hand the most fertile soil is spread about the roots and packed firmly, care being taken to remove all leaves and sticks from contact with the roots. The tree should be planted fully as deep as it stood in the nursery. Lastly, some loose sand or litter should be thrown over the topsoil as a protective mulch. If the sand is liable to drift, the furrow should not be deep, as the tree will be covered and die. If the plow can not be used, planting is usually done by two-man teams, one man digging the hole with a grub hoe or mattock, the other following closely and planting the trees. The man digging holes maintains an even spacing between lines (if necessary, by placing a stick to serve as a foresight at the end of the row and 6 feet from the last row planted) and maintains even spacing between trees within the line by pacing. The earth is scooped out and deposited in a heap at the edge of the hole. If a sod interferes, it should be torn up, making a bare spot about 16 inches square. The planter places the trees properly, as in furrow-planting. Two men in this way plant an acre in a day. Trees respond to cultivation, but usually no further treatment after planting is given the young plantation on sand excepting the replanting necessary in the following year to replace trees which die.

CONIFER PLANTATIONS ON LOAMS

Practically all of the common conifers used in plantations in this region are suited to loams, but the pines are most satisfactory for lumber production, and white pine should probably be given preference over red pine on the heavier loams. Larch and spruce grow well, and a special discussion of spruce for Christmas trees will be given. The loams in Illinois are comparatively fertile, and a plantation can easily be established on unsodded fields. Two-year-old seedlings can safely be used. When a sod occupies the site to be planted, special measures are necessary, as small conifers can not compete with the heavy grass which covers loams in this region. If the area can be plowed, the sod should be broken up by plowing a couple of furrows for each row of trees. On heavy soils it is preferable to do this in the fall, leaving the upturned soil exposed to frost and air over winter, and planting the following spring by plowing a single furrow in the center of the double furrow. In this method transplants should be used. The planter should be particularly careful to work the more fertile topsoil against the roots. If the area can not be plowed, the man digging holes should clear a spot about 16 inches square and dig the hole in the center of this. Once the trees become established and the canopy closed—about 10 years after planting —the sod is shaded out and a carpet of needles soon furnishes typical forest conditions.

Conifer plantations for profit should not be attempted under other trees, nor in spots where shade from brush or weeds is dense, nor on heavy, sour, light-colored hardpan soils locally known as post-oak flats, nor on bottomlands subject to inundation.

CHRISTMAS TREE PLANTATIONS

The species most used for Christmas trees are spruce and fir. Of these, Norway spruce is best adapted to handling in plantations. A sandy loam is best, but the ordinary yellow and yellow-gray silt loams of the rolling uplands are entirely satisfactory. The brown prairie loams can be used if well drained. The soil should not be pure sand or a heavy hardpan. A north or east slope not too steep for tillage is preferred, but trees can be grown even on dry southwest exposures which have suitable soils. Cultivation hastens the early growth of all kinds of trees in plantations, and the business of growing Christmas trees warrants the use of land which can be cultivated, although it need not be high-grade crop land. To secure the best returns, the soil should be put in good tilth by plowing and harrowing. Sodded areas should be thoroughly broken, and it is a good plan to raise a crop on such land before planting trees in order to thoroughly work and disintegrate the sod. However, Christmas trees can be raised on land too rough for cultivation.

Trees may be planted either in autumn or spring on light soils; on heavy soils it is preferable to plant in spring. Four-year-old spruce transplants are recommended. Such trees will be from 10 to 18 inches high and will be ready to develop rapidly. Younger transplants and even seedlings can be used, but such trees require from one to three additional years before good height growth begins. The trees are spaced in the formation of a triangle three feet on a side, and regular spacing is desirable where later cultivation is applied. This spacing is attained by plowing parallel furrows spaced 31 inches apart, planting the trees every three feet in the furrow and at a point half-way between the trees of the adjacent furrow. For such a three-foot triangular spacing, there are required 5600 trees per acre.

In all planting operations, precautions are essential to prevent the drying of roots when trees are out of the ground. As each tree is put in place, the roots must be well spread and in contact with moist fertile soil. The soil must be firmly packed about the roots, and loose soil finally scattered over it to serve as a mulch. The plantation should be cultivated during the first two years.

The variation in height growth is very pronounced in young spruce. The heights commonly in demand are from 4 to 8 feet, and the time required to grow spruce to such sizes runs from 4 to 10 years. The usual system is to cut out the larger trees as they become merchantable rather than to attempt to carry the entire plantation until most trees are merchantable and then clear the area. A small per cent will attain 4 feet or more after four growing seasons, and 90 per cent should reach this height before the eighth growing season. No special irrigation or fertilization is desirable, as trees growing more than one foot a year do not have the compact form desired in Christmas trees.

Christmas tree plantations should prove profitable when located near a market, especially when the production is carried on with sufficient regularity to assure dealers a sustained supply.

The cost of vigorous four-year-old transplants when purchased from private nurseries is prohibitive for plantation stocking, and since Illinois has not yet perfected a state-owned nursery, the planter must grow his own stock from seed. The methods are described on pp. 145-148. The trees should be left two years in the seedbed and two years in the transplant bed. Seed costs approximately $2.50 per pound, and one pound should produce 25,000 seedlings—at least enough transplants for 3 acres of plantation. The disadvantage is that eight years are required to produce marketable trees from seed. In most States suitable transplants can be secured from the state nurseries at rates up to $15 per thousand, and at such rates this stock is profitably used. The returns begin after four growing seasons, and at an average price of $0.50 per tree the acre shows the following gross returns:

Year*	No. of trees harvested	Gross value
4th	1000	500
5th	1000	500
6th	2000	1000
7th	940	470
Total	4940	$2470

* An allowance of 12 per cent, or 660 trees, is made to cover loss in growing stock and trees which fail to attain a merchantable size in 7 years.

These returns of $2470 per acre are based on the wholesale price to the retailer, on the assumption that the owner of the plantation will deliver his trees direct to the retailer. Trees can be cut, bundled, and delivered within a reasonable distance, for 15 cents each, netting $1729 per acre. Against these receipts must be balanced the costs of plowing and subsequent cultivation, which average $12; of transplants, $84; of planting, $35; and taxes at $1.50 annually carried seven years to the maturity of the project. Where a 5 per cent interest rate is used in all computations, the entire project gives an annual return of $208.80 per acre for the use of the land.

Cottonwood Plantations on Bottomland

As stated above (p. 130), cottonwood grown in plantations on bottomlands yields larger quantities of wood in a shorter period than any other native tree. The area to be planted must be as completely cleared of brush and weeds as for field crops. Planting stock is of three kinds: (1) direct cuttings, (2) seedlings, and (3) rooted cuttings.

Direct cuttings are used on the more fertile, mellow, bottomland soils where a good supply of moisture is available. Cuttings are taken from vigorous trees growing in the neighborhood, preferably from the top of the tree. The growth of the preceding year is best, and that of the second year is acceptable, but good results can not be secured by using wood older than two years. The branches are cut during the dormant season and should be subdivided into lengths averaging about 18 inches by cuts made at a 45° angle with a sharp knife. These cuttings are tied in bundles of 50 or 100, with the tops all one way. Care should be exercised to avoid breaking off the buds. If made in autumn, these cuttings should be buried over winter below the frost line in moist sand, and they should not be allowed to dry out whether cut in spring or fall. It is also advisable to bury spring-cut stock for 2 or 3 weeks in moist sand, with the large end but an inch or two from surface. This process facilitates the callousing of the cut surface from which roots are sent out.

The method of planting consists merely in sticking the larger end of these cuttings into the ground to a depth of about a foot. No preliminary plowing or digging is done as the cuttings can usually be pushed directly into the soil. When the soil is not loose, it may be necessary to make a hole with a stick or iron rod. This is the cheapest planting method commonly employed and is well suited to fertile, mellow, moist soils free from weeds and brush. The cuttings should be planted as soon as the frost leaves the ground in spring. When this is done in a wet period, excellent stocking results.

Seedlings are recommended for intermediate sites, where soil or moisture conditions are neither exceptionally favorable nor adverse. Wild stock can be collected, or seedlings can be grown. In collecting wild stock, one-year-old seedlings average 12″ to 18″ in height should be lifted in spring before growth starts. In favorable circumstances this stock can be turned out with a plow, but ordinarily a spade can be used to advantage. Collecting should be done while the ground is soft and moist, and precautions must be taken to keep the roots moist until replanted.

If seedlings are to be grown, a seed bed of rich loam should be selected and the soil thoroughly worked, pulverized, and then rolled smooth. Small branches heavily laden with seed catkins are cut from the seed tree just before the pods open. At this time it may be necessary to cover the beds with paper or any material which will hold the buoyant seed on the plot. When the pods open, shake seed out on a calm day. The bed should be evenly covered with a very thin layer of cottony seed, then just enough dry soil sifted over this to hide the cotton from view. Next, thoroughly saturate the seedbed, using a spray. Cover the moistened surface with paper until the seedlings appear. After this the paper should be removed, but the bed should be kept moistened, as the surface soil must not become dry before the tiny seedlings have developed deep taproots. If the stock seeds in thicker than 20 trees to the square foot, it should be thinned. This stock should be taken up and planted the following spring before growth begins. It will then be about 2 feet tall. It is important to keep the roots moist during the interval between lifting from the bed and replanting.

Seedlings are planted as follows: a hole about 6 inches wide and fully a foot deep is dug with a narrow spade, the roots of the seedling are well spread, and the loose earth is packed firmly about them. The seedling should be set fully as deep as it stood in the bed.

Rooted cuttings are recommended for sites where soil and moisture conditions are not well suited to the establishment of cottonwood. This stock is bulky, costing more to handle than either calloused cuttings or seedlings. On sandy or gravelly soils where the water table is not close to the surface, or on fertile sites where vigorous weed growth is not controlled, rooted cuttings are necessary to insure the establishment of a fully-stocked plantation. For growing this stock, branches should be cut into lengths of about 1 foot and set in a well-tilled sandy-loam bed to a depth of 9 inches. At least one good bud should project above ground. Space 6 inches in a row with a foot between rows. Keep free from weeds and well moistened during the growing season. Plant the following spring before growth begins. Planting requires digging the hole for each tree as for seedlings, but the process can be cheapened by the use of a plowed furrow on those areas where a plow can be used. The spacing for all forms of planting stock should be 10 feet by 10 feet when logs are to be produced, and 8 feet by 8 feet for pulpwood. This is 440 and 680 trees per acre, respectively.

The exceptional growth and unusual intolerance of cottonwood results in an early struggle for light and the early suppression of all but the most vigorous trees. Pure stands of cottonwood open up at an early age, creating light conditions favorable for less-exacting trees and weeds. Cottonwood responds to increased light conditions resulting from a thinning, but after the sapling stage the canopy of a pure stand opens up so much naturally that the benefits of increased growth on the trees left in a thinned stand are somewhat nullified by the increase in weeds and brush which follows such a thinning. When thinnings are made they should be light. The main crop should be harvested in a single cutting, all brush and under-growth being cleaned out at the same time, and the area should be immediately restocked with cottonwood before a heavy growth of other species makes clearing costs prohibitive. An idea of the number of trees naturally found at different ages on fully-stocked cottonwood stands can be had from an inspection of column 2 in Table XIII (p. 155).

Planting an understory of soft maple and elm has been practiced as a means for utilizing all the light for tree growth and for keeping out the weeds. On floodlands a well-shaded forest floor is not essential to the maintenance of soil fertility, since such fertility is renewed by repeated soil deposits rather than by the decay of forest litter. The growth of the understory must be cleared off at the time that the overwood is harvested if a new stand of cottonwood is to be established; and since such growth is relatively slow and is not of merchantable size, growing an understory is a questionable practice in managed cottonwood stands on floodlands. Weeds and trees which seed in naturally, do not greatly influence the development of a crop of cottonwood on fertile bottomlands after it is well started.

The yields given in Table XIII can be secured from cottonwood plantations on the floodlands of the Wabash, Ohio, and Cache, and on the Mississippi up to about Alton. On Mississippi bottomland in Union County a yield of 5,174 B. F. per acre harvested for veneer logs from 18-year-old trees compares very favorably with the 4,100 B. F. yield in the table. Yields on the Kaskaskia, Illinois, and upper Mississippi bottomlands are somewhat lower.

Logs delivered at the mills average about $25 per thousand (Doyle Rule). The 1924 price for logs delivered on the river bank at a landing in southern Illinois was $17 per thousand. The trees are grown on the floodlands outside the levees; consequently, the haul is short and $5 per thousand is a fair logging cost. Table XIII shows the yields and the returns received at these values.

TABLE XIII

YIELD PER ACRE FOR FULLY-STOCKED COTTONWOOD STANDS AT AGES FROM 12 TO 50 YEARS IN ILLINOIS

Age Yrs.	No. of trees per A.*	B. F. yield per A. (Doyle Rule)*	Gross value of logs per A. at $17 per M.	Cost of logging per A. at $5 per M.	Accumulated tax and planting cost per A. An. Tax $0.40. Planting $9.08. Interest 5% compounded	Returns per A. above logging, planting, and tax costs	Maximum to be spent for buying and clearing lands at 5% compound interest
1	2	3	4	5	6	7	8
12	452	200	3.40	1.00	22.68	—20.28	.....
13	375	700	11.90	3.50	24.20	—15.80	.....
14	320	1,300	22.10	6.50	25.82	—10.22	.....
15	276	1,900	32.30	9.50	27.51	—4.71	.....
16	243	2,600	44.20	13.00	29.28	1.92	1.62
17	217	3,300	56.10	16.50	31.15	8.45	6.54
18	195	4,100	69.70	20.50	33.10	16.10	11.44
19	178	4,900	83.30	24.50	35.16	23.64	15.48
20	163	5,700	96.90	28.50	37.32	31.08	18.80
21	150	6,500	110.50	32.50	39.59	38.41	21.50
22	140	7,500	127.50	37.50	41.96	48.04	24.95
23	130	8,400	142.80	42.00	44.46	56.34	27.20
24	121	9,500	161.50	47.50	47.08	66.92	30.07
25	114	10,700	181.90	53.50	49.84	78.56	32.92
26	106	12,000	204.00	60.00	52.72	91.28	35.72
27	99	13,400	227.80	66.00	55.77	106.03	38.80
28	92	15,100	256.70	75.50	58.95	122.25	41.86
29	86	17,100	290.70	85.50	62.30	132.90	42.65
30	80	19,200	326.40	96.00	65.81	169.59	49.59
31	75	21,400	363.80	107.00	69.50	187.30	52.94
32	70	23,500	399.50	117.50	73.38	208.62	55.41
33	66	25,300	430.10	126.50	77.45	226.15	56.49
34	62	26,600	452.20	133.00	81.73	237.47	55.83
35	59	27,500	467.50	137.50	86.21	243.79	53.98
36	57	28,200	479.40	141.00	90.92	247.48	51.64
37	53	28,700	487.90	143.50	95.87	248.53	48.91
38	51	29,100	494.70	145.50	101.06	248.14	46.07
39	50	29,300	498.10	146.50	106.52	245.08	42.96
40	49	29,300	498.10	146.50	112.24	239.36	39.63
50	32	29,400	499.80	147.00	187.86	164.94	15.75

* From U. S. Dept. of Agr. Bulletin No. 24, "Cottonwood in the Mississippi Valley".

Period for Most Profitable Harvest

Table XIII has been worked out in detail in order to show the importance of the time element on both the amount of wood grown and the net returns received. The annual tax of $0.40 per acre and the planting cost of $9.08 both approach maximum costs for the unprotected floodlands used for this purpose in Illinois. Where money is spent for taxes and planting costs and when returns are deferred for a period of years, compound interest at 5 per cent has been charged.

The stand first contains trees of a merchantable size at the age of 12 years, when the yield is 200 B. F. per acre, as shown in column 3. The merchantable contents added thereafter increase yearly until the amount of merchantable contents grown in the 31st year (2200 B. F.) is more than four times that grown in the 13th year (500 B. F.); after the 31st year the rate of increment decreases rapidly, and virtually no increase in yields occurs after 40 years. The folly of cutting a stand of 20-year-old cottonwood for a yield of 5,700 B. F. per acre becomes apparent when it is seen that an additional growth of 13,500 B. F. can be secured if the stand is allowed to grow another ten years. Expressed in money the wood grown in the first 20 years has an average gross value of $4.84 per acre annually, but in the next ten years the wood grown has an average gross value of $22.95 per acre annually.

The rapid increase in carrying costs, due to compounding the interest on money actually expended, is apparent in column 6. At 18 years approximately half of these costs, or $16.28, is actual disbursement, and the rest, or $16.82, is interest; at 33 years the interest amounts to 71 per cent ($55.17) of the carrying costs ($77.45); and at 39 years, the interest has climbed to $82.02, or 77 per cent of the carrying costs. This rapid increase fixes the period for most profitable harvest well in advance of the time when the volume of wood in the stand reaches its maximum amount. Thus, according to column 8, in which land cost, planting cost, and tax cost are calculated, with 5 per cent compound interest, the most profitable time at which to cut the stand is at 33 years, although the maximum merchantable content of the stand does not occur before 39 years, as shown in column 3. In other words, under the approximately average yields and costs shown in this table, cottonwood reaches its financial maturity at 33 years, paying 5 per cent interest compounded on a total investment of $78.77 per acre for land, planting, and taxes.

Plantations for Post Production

The farm owner who is considering the advisability of establishing a plantation of trees to supply his posts is confronted with this problem: he can consider one of the five durable species each of which has at least one serious limitation, or he can decide to treat his posts with a preservative and grow any of a half-dozen species well suited to this purpose because of rapid growth rates, insect immunity, and ease of culture.

The five durable species commonly used are catalpa, black locust, Osage orange, mulberry, and red cedar. Although very rapid growth produces posts of low durability, yet posts from these species have an average durability of 15 years or more. Red cedar, although it will grow on thin sterile soils, is scarcely to be considered because of its slow growth*. Mulberry requires a fertile soil, freezes back in winter, and develops a bushy form not suited to post production. Osage orange is very durable and has been freely planted as a hedge, but develops both poorly and slowly when planted in groves. Black locust has all the qualities of durability, rapid growth rate, adaptability to a wide range of soils, and proper form, but it has two insect enemies which have discounted its usefulness. Catalpa has a rapid growth rate, durability, and suitable form, but requires a fertile soil, and has one serious insect enemy.

CATALPA

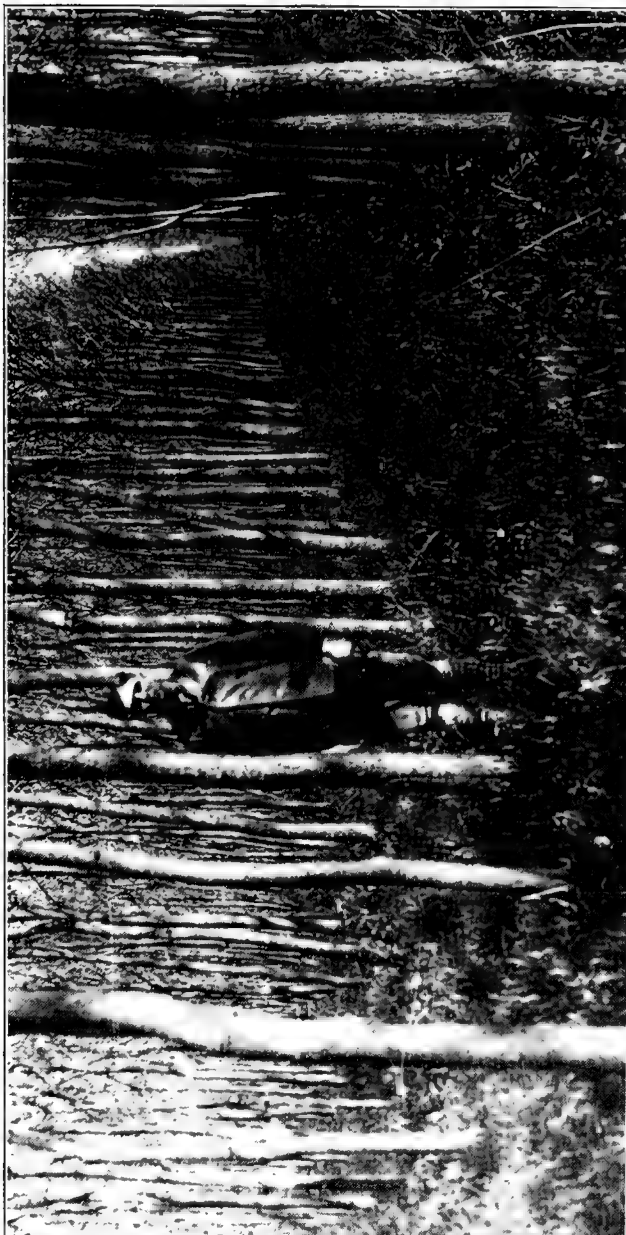
Most failures in catalpa plantations in Illinois can be traced either to planting the trees on soils not suited to the species, to the use of the wrong species, or to insect attacks. Catalpa plantations show excellent returns, but only on high-grade fertile soils. The upland locations where catalpa will succeed are limited to deep, well-drained, fertile soils. It grows well on fertile prairie loams, but it is not recommended for ordinary light-colored soils of the upland, and it should never be planted on extreme types, such as sands or clays. On bottomlands the tree grows well over a wider range of soils, and can be used on both heavy and light loams, but not on extremes of sands or clays. It is not injured by flooding but is susceptible to frost injury on bottomland sites in the northern part of the State. When grown in pure plantations, it is also defoliated from 2 to 3 years out of 5 by larvae of the catalpa sphinx moth.

In spite of its exacting soil requirements, liability to frost injury, and probability of insect damage, this tree is recommended because in Illinois under proper conditions it produces more high-grade posts in a given period than any other species. It should not be considered for pole or tie products, as it tends to rot freely after the post size is passed. The average service of posts is 16 years. From 12 to 15 years are usually required to produce posts in plantations, and the average yearly yield approximates 100 per acre.

The use of a hybrid of the native catalpa *(Catalpa speciosa)* and the southern catalpa *(Catalpa bignonoides)* has invariably resulted in trees of unsatisfactory form. In ordering nursery stock, insist upon *Catalpa speciosa.*

It is preferable to select a spot protected from the prevailing winds, because in exposed plantations the trees on the south and west sides are usually distorted and less thrifty. Catalpa should not be planted

* Studies based on 200 trees in southern Illinois indicate that approximately 50 years are required for cedar to grow to post size.



FIFTEEN-YEAR-OLD CATALPA PLANTATION FOR PRODUCTION OF POSTS under other trees nor in small openings in native hardwood forest. The cleared area should be plowed, as catalpa planted in a sod develops very slowly. After plowing, furrows should be run every six feet, and the trees planted three feet apart in these furrows. The roots should be well spread in the bottom, loose moist earth placed over them and packed firmly with the foot. After the furrows have been planted, they should be plowed full of earth. This spacing requires 2420 trees per acre.

The plantation should be cultivated and kept clean of weeds until the trees attain a size sufficient to form a closed canopy—at least two years. Proper tillage shortens by several years the time required to grow posts.

Catalpa does not naturally develop the straight smooth stem suited to post material. The terminal bud is frequently winter-killed or injured by insects, resulting in a crook in the stem as a lateral branch replaces the terminal. Also, the dead side branches hang to the tree long after they have been shaded out. In order to correct these conditions, the young trees frequently are cut back to the ground during the dormant season after their second year's growth. As sprouts develop, only the most vigorous one on each stump is permitted to grow. This sprout often grows nearly to the same height the first year as the seedling attained in the previous two years, and it forms a straight stem. There is a very good chance, however, that the vigorous sprouts bearing their large leaves will be ruined by storms or distorted by sheer weight. The same injury also follows a pruning off of the live lateral branches for the purpose of forcing the stem to vigorous height growth, and this practice is not recommended. The trees should be planted close together to insure active height growth, and on fertile land to support such growth; *as the lateral branches are shaded out and die*, they should be pruned off as close to the stem as possible.

At about eight or ten years after the plantation has been set out, it will need thinning. The smaller trees should be cut, taking out between one-fifth and one-third of the total number. The plantation on good soil should produce posts after 12 years. The higher yields are secured between 12 and 18 years, and an acre should average 100 posts per year since planting. Because catalpa posts are not easily split from larger diameters but must be sawed, it is usually preferable to cut the trees before they develop large diameters. Some success in reestablishing a new plantation from sprouts is secured if the rows are cut clean in the dormant season. In order to minimize wind injury, it is a good plan to cut rows on the north or east side first and to work south or west in successive years as posts are needed. The old plantation then forms a windbreak. Only one sprout to each stump is usually allowed to grow, but as this practice often results in a very tall shoot unable to support its heavy crown of leaves, it may be advisable to let all sprouts grow during the first season and to knock off all but the best one the following winter.

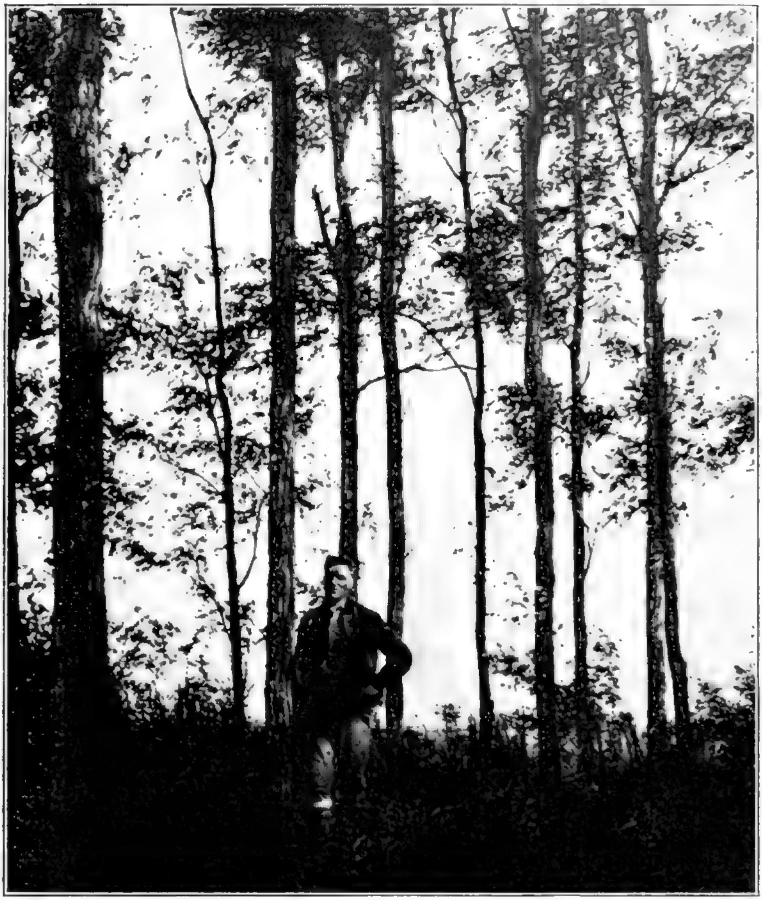
The plan of management of a catalpa plantation must include control of the catalpa sphinx. This is practical, as an arsenical spray can be applied to the crowns with a hand pump in those years when the worms are abundant. The normal defoliations of three years out of five will utterly kill an unsprayed plantation. The effective mixture consists of 4 pounds of lead arsenate to 50 gallons of water, and it should be applied upon the first evidence of the larvae in the plantation.

BLACK LOCUST

Black locust stock can be purchased cheaply, is easily transplanted, makes rapid growth, and produces very durable posts. The tree develops a very fibrous root system capable of producing new trees from root sprouts. Black locust is one of the legume family and has the nitrifying merits of this family. Perhaps its best quality, however, is its ability to grow on thin, sandy, or eroded soils; as an agent in the reclamation of sterile gullied hillsides or loose sand, it is superior to any other tree. Even though the borers distort or kill the stem, the roots grow vigorously and bind the soil, sending out sucker shoots freely and developing a soil cover as well as enriching the soil with nitrogen.

There are conditions under which black locust plantations are not destroyed by attacks of the borer. Trees which are growing with pronounced vigor seem not to offer suitable conditions for borer infestation in epidemic intensity. Although such trees are usually attacked, the infestation does not gain such momentum as to destroy them. It is possible for entire plantations to be brought to profitable yields of posts in spite of the locust borer. Pure locust plantations are successfully grown on fertile, well-drained loams, but they are generally destroyed when located on sterile sands or thin loams. On such intermediate sites as gullied uplands or crop-worn fields, special measures will often result in a growth vigorous enough to enable the plantation to resist a borer attack. Alternate the locust with another species, and cultivate the plantation as long as it is possible to drive between the rows.

Black locust should never be planted under an overwood, but it will grow as groups in openings of the forest. It produces posts in about 15 years. A good mixture for the reclamation of gullied uplands or of sand hills and for the production of posts consists of sassafras and locust, planted alternately, as the sassafras offers a certainty of some posts even if the locusts are destroyed. Spacing should be about 6 feet by 6 feet, thus requiring 1210 trees per acre.



PLANTATION FOR THE PRODUCTION OF POSTS.

Twenty-year-old black locust on gullied land.

OSAGE ORANGE

Osage orange is less exacting in soil requirements than catalpa and more exacting than locust. It will produce posts on sandy and loamy soils which are deep and well-drained, but it is not suited to extremely heavy, thin, or sterile soils, and it suffers winter injury on bottomlands.

Although Osage Orange posts excell in durability, the growth rate is less than that of either locust or catalpa, and the trees have a pronounced habit of forking close to the ground and producting much-branched and crooked stems. This defect can be corrected by pruning, but the tree has too slow a growth rate to recommend it for extensive plantation work. Osage orange can grow well in situations exposed to drying winds, and the very qualities which bar it from use in plantations make it a very excellent hedge tree. The much-branched form is trimmed to make a living fence, or the trees are allowed to develop full height growth, making a tall hedge which serves as a windbreak. Leaders from the trimmed hedge may be permitted to grow and provide posts at intervals of about three feet.

This species was formerly freely planted about the fields, not only because it served as an excellent fence and provided excess post material, but also because a windbreak was considered a necessity for high crop yields in all sections of the prairie regions. The influence of windbreaks upon crops in adjoining fields is injurious within the zone reached by the shade of the trees and may be injurious over a somewhat wider zone because their roots compete with crops for moisture; for a distance beyond this the influence is generally beneficial. The balance measured in crop yields is entirely in favor of windbreaks in more arid regions but not enough so in Illinois to justify decisively their general use. The past decade has witnessed a transformation in farm management involving the general use of tractors, organized campaigns against weeds and insects, and the effort to utilize fully the crop-producing areas. As a consequence, hedges are in disrepute and during the past few years their removal has been actively carried on; yet many landowners are still interested in growing such hedges.

Seedlings can be easily grown on the farm. Gather the hedge apples in fall and place them in water until the pulp becomes rotten, and then wash out the seeds. Plant the seeds in spring in well-tilled garden soil and, when the seedlings appear, thin so that they stand about three inches apart. Keep free from weeds and transplant to the field in fall or early the following spring. One growing season in the seed bed is ample. For hedges, a two-foot spacing is recommended; for windbreaks, three-foot. If a plantation is the object, plow the area and set the seedlings in rows seven feet apart and five feet in the row. The area should be cultivated until the growth of the branches impedes this work—about two years. The trees should also be pruned, as this species has a habit of developing forks and persistent side branches. If pruning is properly done between the second and fifth years, post production is materially increased. The trees require at least 15 years to grow to post size.

Summary of Points on Seed and Tree Planting

Reenforcement planting in under-stocked natural stands.—Use rapidly-growing native hardwoods rather than conifers. For oaks and other large-seeded species, plant the seeds where trees are needed. Trees having small seeds are customarily first started in a seed bed and the young trees transplanted where needed after the first growing season in the bed. Transplant during spring before the leaves appear and in spots cleared of bushes and sod, packing fine, moist soil about roots and mulching with litter.

Planting cleared areas.—For saw timber, conifers should be used on upland sites and broadleaved species on bottomlands. Conifers are grown from 2 to 4 years in the nursery before transplanting in the field. If such trees can not be bought for a cent a piece, they should be grown on the farm. Plant thickly—6 feet by 6 feet—to develop trees of good form, and begin thinnings when the lower branches have been shaded out and the plantation reaches the polewood stage—trees from 3 to 8 inches in diameter and 20 years or older.

In plantations for posts, the relatively durable species recommended are: catalpa for fertile uplands, or for bottomlands except in the northern quarter of the State, and black locust mixed with larch or sassafras on the less fertile soils. For hedge fencing, nothing equals Osage orange.

MEASURING AND MARKETING WOODLOT PRODUCTS

In general, the woodlot owner should undertake the marketing of his own products. In so doing, in addition to providing employment for teams and men at a season when farm work is slack, he gets for himself a knowledge of timber values and woodlot management, which is the best guarantee for a permanent and profitable woodlot. Woodlot owners are usually ignorant of the products and grades into which trees can be cut, do not know of the many markets for woodlot products, and are unable to estimate standing timber. For these reasons they frequently sell standing timber for a lump sum below its real value, or turn into cheap products much timber which is suitable for high-grade products. It is a good plan to investigate the markets and estimate the contents of standing timber, even if it is to be sold for a lump sum. Selling by the piece or by board-foot unit rather than for a lump sum is generally more satisfactory, especially if it is possible to get a reliable check on the amount taken.

While it is usually desirable to harvest systematically at regular intervals, as previously explained, yet this practice should be modified when necessary to take advantage of periods of favorable market conditions. Timber holds a unique position as a crop, inasmuch as, within certain limits, it increases in volume and value if not harvested. When market conditions are poor, it should be allowed to grow.

Choice of Products

There are eight principal products grown on Illinois woodlots: cordwood, mine timbers, cross ties, lumber, cooperage and veneer logs, piling, and posts. All forest soils in the State can produce at least three of these products, and most forest soils are generally fit for the production of all eight. Since some of them are much more profitable than others, it is best to choose those from which the highest returns may be had.

Before any comparison of returns can be made, these different products must be reduced to a common unit, for different products are measured by different units: cordwood, by the cord; mine timber, cross ties, piling, and posts, by the piece; logs and lumber, by board feet. These may all be reduced to cubic feet. The average cord contains 80 cubic feet of wood; the average mine timber, 0.606; cross tie, 3.0; pile, 22.3; post, 0.8; and 1,000 B. F. in the log is equivalent to 166.7 cubic feet; 1000 B. F. of lumber to 83.3 cubic feet. Again, in converting the tree into the different products, the owner should consider what portion of it is usable in each case. The amount of stem which appears in the product varies from 32.5 per cent in lumber to 100 per cent in cordwood. The amount of wood to the acre is best expressed as total cubic feet in the entire stems, and the annual growth, or accretion, as the number of cubic feet annually added. Therefore, in order to express the money value of the annual growth worked up into the different products, their value must be computed per cubic foot of total stem rather than per cubic foot of manufactured product. This has been done in Table XV (p. 167).

The choice of the product or combination of products, in any given case, depends upon the following considerations: (1) per cent of the tree which enters into the salable product, (2) relative costs of converting the tree into different products, (3) relative cost of shipping products to market, and (4) relative sale values at market.

(1) The per cent of the total amount of wood in the bole of a tree which enters into the salable product averages as follows: cordwood 100, piling 85, mine timber and posts 74, cooperage and veneer logs 65, cross ties 49, and lumber 32.5. It is evident that, if the sale price is similar, the greater returns will come from those forms of product which utilize the greater part of the tree.

(2) The average costs of converting a tree into the different products, *in terms of cubic feet of wood in the bole or stem*, are as follows: veneer or cooperage logs $0.0509 per cubic foot, cordwood $0.0518, piling $0.0794, cross ties $0.0796, mine timbers $0.0808, posts $0.0932, and lumber $0.0996. Thus the greatest cost of conversion (into lumber) is 95 per cent greater than the lowest cost (into veneer logs), both being measured in cubic feet of the entire stem.

(3) The freight rates vary with the product and the distance. Customarily, cordwood pays the least per hundred pounds, mine timbers slightly more, while rates on piling, logs, posts, and lumber are yet higher. The effect of these transportation costs is to limit definitely the area within which forest products can be shipped. When the costs of manufacture and transportation equal the sale price, the operator has given his product away. At the average sale price of $5.06 per cord, cordwood can not be shipped at all. The other products can be shipped distances varying from 100 miles for ordinary logs up to 500 miles for average lumber produced in Illinois. (See Table XIV.)

(4) Rates of growth per acre and per cents of possible utilization determine the quantities of the different products which can be produced; the respective manufacturing and shipping costs determine the expense of putting the various products from tree to market; and, finally, the respective sale values determine the choice of the product. The average cost of manufacturing, the average sale price, and the margin left for profit *per cubic foot of product* are shown in Table XIV, and from these elements can be computed the shipping zones; but the determination of the *relative profit* in growing these different products is not based solely upon the cubic feet of product, but involves also relative per cents of the total growth which can be utilized in making these products. In Table XV this variable degree of utilization has been taken into account by converting all values per cubic foot of the different products into values *per cubic foot of the total contents of the standing tree*, and the data are tabulated to show stumpage values per cubic foot of the standing tree for timber which is marketed at average prices (1) with no freight cost, (2) with a 25-mile haul, and (3) with a 100-mile haul. This table, giving weight to degree of utilization as well as costs, more nearly expresses the ratings of the different products from the viewpoint of the producer.

TABLE XIV

SHIPPING DISTANCES DETERMINED BY THE MARGIN BETWEEN AVERAGE SALE PRICE AND AVERAGE MANUFACTURING COST

Product	Unit	No. of cu. ft. per unit	Sale price per cu. ft. of product	Cost of mfg. per cu. ft. of product	Margin left for transportation and profit	Freight rates per cu. ft.		Shipping zone
						25 Mi.	100 Mi.	Miles
Mine timber..	Props	.83						
	Bars & legs..	1.91						
	Mine ties....	.70						
	Average..	.85	$.183	$.1092	$.0738	$.018	$.0301	250
Cross ties.....	Tie	3.0	.300	.1611	.1389	.0337	.0585	250
Piling.........	Pile	22.3	.230	.0934	.1366	.0337	.0585	250
Cooperage.....	M. B. F.....	166⅔	.150	.0783	.0717	.0337	.0585	150
Veneer								
Average.....	M. B. F.....	166⅔	.150	.0783	.0717	.0337	.0585	150
Highgrade..	M. B. F.....	166⅔	.300	.0783	.2217	.0337	.0585	400
Lumber.......	M. B. F.....	83⅓	.504	.3061	.1979	.0337	.0585	500
Posts.........	Post	.8	.300	.1260	.174	.0337	.0585	300
Cordwood.....	Cord	80.	.0633	.0518	.0112	.0146	.0225	...

TABLE XV

NET RETURNS PER ACRE AS INFLUENCED BY KIND OF PRODUCT AND SHIPPING DISTANCE

Product	Sale price per cu.ft. of stem	Cost of mfg. per cu. ft. of stem	Freight rates per cu. ft. of stem		Value of stumpage per cu. ft. of tree at specified shipping distances			Net returns per acre from upland loam woodlots averaging 36.4 cu. ft. growth annually, at specified shipping distances		
			25 mi.	100 mi.	0 mi.	25 mi.	100 mi.	0 mi.	25 mi.	100 mi.
Mine timber	$.1345	$.0808	$.0133	$.0223	$.0546	$.0413	$.0323	$1.99	$1.50	$1.18
Cross ties	.1482	.0796	.0165	.0289	.0686	.0521	.0397	2.50	1.90	1.45
Piling	.1955	.0794	.0287	.0497	.1161	.0874	.0664	4.23	3.18	2.42
Cooperage	.0975	.0509	.0219	.0380	.0466	.0247	.0086	1.70	.90	.31
Veneer										
Average	.0975	.0509	.0219	.0380	.0466	.0247	.0086	1.70	.90	.31
High-grade	.1950	.0509	.0219	.0380	.1441	.1222	.1061	5.25	4.45	3.86
Lumber*	.1638	.0996	.0219	.0380	.0642	.0423	.0262	2.34	1.54	.95
Posts	.2220	.0932	.0250	.0433	.1288	.1038	.0855	4.69	3.78	3.11
Cordwood	.0633	.0518	.0146	.0225	.0115	......	......	.42		

* Cost of sawmilling averages $7 per M. B. F. and sale prices at destination average $42 per M. B. F.

Thus Table XIV, in terms of *cubic feet of product*, shows the margin left for profit and transportation of the different products in the following order: (1) high-grade veneer logs, (2) lumber, (3) posts, (4) ties, (5) piling, (6) mine timber, (7) cooperage and average veneer logs, and (8) cordwood. Table XV, containing the same data but also including the quantity utilized, rates the different products as follows: (1) high-grade veneer logs, (2) posts, (3) piling, (4) ties, (5) lumber, (6) mine timber, (7) cooperage and average veneer logs, and (8) cordwood. This is the more accurate index of the relative average value of the different products from the producer's viewpoint.

High-grade veneer, posts and piling, are in general the most profitable products; the average net returns from woodlots yielding these are roughly twice as great as for those yielding ties, lumber, mine timber, or average veneer and cooperage logs, and ten times as great as those yielding cordwood. It is necessary to emphasize the fact that, while these are average statewide figures, yet the presence of local markets will modify these ratings, and the woodlot owner producing for the market must know the market conditions locally. For instance, cordwood sells for $8.00 a cord in Chicago and $3.00 in Johnson County. These are sale prices of $0.10 and $0.0375 per cubic foot, respectively. The cost of manufacturing is $0.0518 per cubic foot. Woodlot owners near Chicago supplying this market find cordwood giving higher returns than either mine timbers or cooperage and average veneer logs, while those in Johnson County fail by $0.0143 per cubic foot, or $1.14 per cord, to get the average labor cost for producing it.

SAWLOGS

Estimating standing timber

Logs for veneer, cooperage, and lumber are measured by the thousand board feet (M. B. F.). The amount of lumber in a standing tree is estimated by judging the number of logs which would be cut from the given tree and estimating the length and top diameter inside the bark of each log. The estimator requires a stick of lumberman's crayon (red) for marking trees, calipers for getting the diameter of the tree, a pencil, and a notebook. A convenient form for recording log lengths and diameters by species is shown on the following page.

Calipers may be purchased from a dealer in instruments of precision, or may be made from an ordinary carpenter's square by attaching an arm sliding along the beam and at right angles to it (see figure). If large timber is to be measured, the beam should be 36 inches long; in second growth, an 18- or 24-inch beam suffices. The sliding arm is made by cutting a half-inch strip about two inches wide, two inches longer than the short arm of the square. Next, get a strip of tongue-and-groove material six inches long and an inch and a half wide, shave off the tongue and mortise the first strip at right angles through the center of this 6-inch strip in such a way that when the beam of the carpenter's square is placed in the groove the mortised arm will be parallel to the fixed arm of the square. A brace, as shown in the figure, is necessary to strengthen the movable arm. When in use, the movable arm must be parallel to the fixed arm of the square.

Species	Log length	Diameter inside the bark at small end of log																				
		10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Ash	8																					
	10																					
	12																					
	14																					
	16																					
Basswood	8																					
	10																					
	12																					
	14																					
	16																					
Elm	8																					
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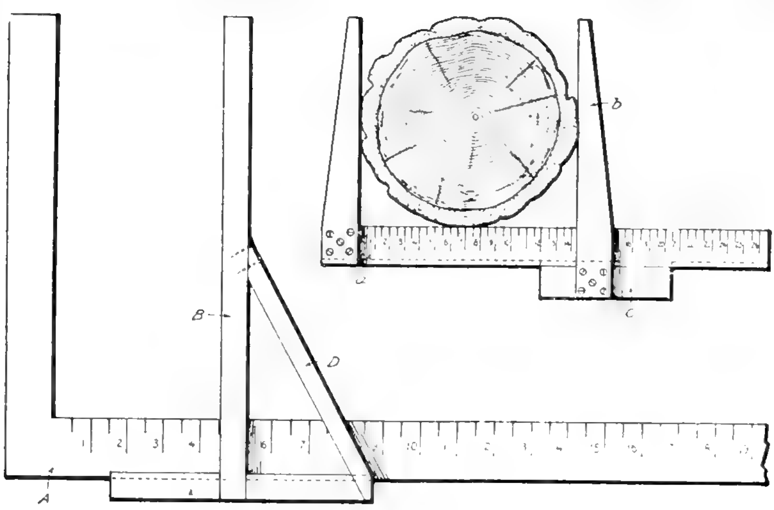
	16																					



A simple homemade instrument, or calipers, for measuring the diameters of trees *

* Taken from U. S. Dept. Agr. Farmers' Bulletin No. 1210.

The contents of large timber tracts are frequently estimated by measuring a percentage of a tract and applying the results to the entire tract. In ordinary woodlot work involving small areas, the contents of each tree should be estimated.

Usually two work together. The estimator begins at a convenient side of the tract and estimates the trees in a strip 50 or 100 feet in width extending across the woodlot. He first measures the average diameter of the tree outside the bark at a point 4½ feet from the ground. This is usually called the "diameter breast-high" (D. B. H.). This serves as a check and helps to estimate correctly the diameters of the logs into which he mentally divides the tree. He also marks the tree with the crayon at a given place where it will be visible as he works on the next strip. He then steps back to where he can get a clear view of the bole and lays off with his eye a log length (8, 10, 12, 14, or 16 feet from the assumed stump) and estimates the diameter *outside the bark* at the upper end of the log. With a knowledge of average bark thicknesses for trees of a given species and size, he mentally deducts the double bark thickness (D. B. T.), so as to get the diameter inside the bark (D. i. b.). See Table XVI for bark thickness of oaks, which can be used for most species. He then calls the record to his companion; for example, "white oak, 14 feet, 18 inches." The tallyman places a single dot in the proper place on the form shown on page 83, to indicate a white oak log 14 feet long and 18 inches in diameter inside the bark at the small end. Succeeding logs are recorded by dots and lines until ten complete the figure, as follows:

The estimator continues, mentally, to divide up the bole and estimate the log lengths and diameter of each log inside the bark at the small end, until he reaches a point in the crown where the material is unmerchantable. A ten-inch top is commonly taken as the minimum diameter for a log, but in large hardwoods the heavy limbs may prevent the economical use of logs of a diameter as small as this. Thus, in turn, all trees in the strip are estimated, and with succeeding strips the entire woodlot is covered.

The next step consists of computing the board-feet contained in the logs. For this, it is necessary to have a log rule. A log rule is a statement of the number of board feet contained in logs of different lengths and diameters. It may be marked on a stick or printed as a table.

Add up the total number of logs of each species having the same diameter and length, and multiply by the board-foot contents as shown for a log of this given length and top diameter inside the bark (D. i. b.). The summation for all logs gives the total for the woodlot.

The many different log rules in use give quite different readings. The theory has been to construct a rule giving the number of board feet which could be sawed out of logs of a given region and under rather fixed marketing conditions. The early rules were made to fit conditions then in force, such as an abundance of large, defective trees and a demand for high-quality material, and such rules do not give the quantity which is now cut from second-growth logs for a market using material formerly unmerchantable. Since they give a decided advantage to the buyer, these old rules have been retained in many instances. Thus, in Illinois practically all logs are scaled with the Doyle Rule. A comparison of the values for the Doyle and the International Rules, Table XVII, shows that the latter gives fully one-third greater amounts for 12-inch logs. In general, it may safely be said that there is sawed from ordinary-size timber 20 per cent more material than is scaled under the Doyle Rule.

If logs are to be sold, the buyer usually insists upon using the Doyle Rule; if the logs are to be sawed by the owner, a closer approximation of the yield can be secured by using the International Rule.

Table XVI

Average Thickness of Bark for Black Oak Trees of Diameters up to 30 Inches

Diameter breast-high (D. B. H.)	Double bark thickness (D. B. T.)	D. B. H.	D. B. T.	D. B. H.	D. B. T.
1	.1	10	.9	21	1.8
2	.1	11	1.0	22	1.9
3	.2	12	1.1	23	2.0
4	.3	13	1.2	24	2.0
5	.4	14	1.2	25	2.1
6	.5	15	1.3	26	2.2
7	.6	16	1.4	27	2.3
8	.7	17	1.5	28	2.4
9	.8	18	1.6	29	2.5
		19	1.6	30	2.6
		20	1.7		

Scaling logs

The process of scaling cut logs consists in measuring the average diameter inside the bark at the small end, noting the log length, and looking up in a log rule the board-foot contents for a log of this diameter and length. The record can be kept in a form as shown on p. 169. Where much scaling is done, a stick is used from which can be read the contents of a log of specified length and diameter. When the average diameter does not fall on the even inch, it is rounded off to the nearest inch class; thus, 10.5 to 10 inches, 10.6 to 11 inches, etc. The values are for sound, straight logs, and if defects are present, a certain per cent is usually discounted. This rarely runs beyond 10 per cent, even for old-growth hardwood.

Markets, Specifications, and Quotations

Logs are valued according to species, size, and freedom from defects. Large, sound logs of a species suitable for high-grade veneer bring twice as much as those used for ordinary lumber, cooperage, or low-grade veneer such as goes into fruit containers and egg crating.

The leading species used in high-grade veneers are black walnut, white oak, and red oak; and to a lesser extent tulip poplar, black cherry, and basswood are used. Sound logs of these species, with a D. i. b. of 16 inches and up, bring $50 or more per M. B. F. at the points of consumption.

TABLE XVII

BOARD-FOOT CONTENTS FOR LOGS OF GIVEN DIAMETERS AND LENGTHS AS SCALED BY THE INTERNATIONAL RULE (I) AND BY THE DOYLE RULE (D)

Top diameter Inches	Length of the log in feet									
	8		10		12		14		16	
	I	D	I	D	I	D	I	D	I	D
6	10	2.0	10	2.5	15	3.0	15	3.5	20	4.0
7	10	4.5	15	5.0	20	7.0	25	8.0	30	9.0
8	15	8.0	20	10.0	25	12.0	35	14.0	40	16.0
9	20	12.0	30	16.0	35	19.0	45	22.0	50	25.0
10	30	18.0	35	22.0	45	27.0	55	31.0	65	36.0
11	35	24.0	45	31.0	55	37.0	70	43.0	80	49.0
12	45	32.0	55	40.0	70	48.0	85	56.0	95	64.0
13	55	40.0	70	51.0	85	61.0	100	71.0	115	81.0
14	65	50.0	80	62.0	100	75.0	115	87.0	135	100.0
15	75	60.0	95	76.0	115	91.0	135	106.0	160	121.0
16	85	72.0	110	90.0	130	108.0	155	126.0	180	144.0
17	95	84.0	125	106.0	150	127.0	180	148.0	205	169.0
18	110	98.0	140	122.0	170	147.0	200	171.0	230	196.0
19	125	112.0	155	141.0	190	169.0	225	197.0	260	225.0
20	140	128.0	175	160.0	210	192.0	250	224.0	290	256.0
21	155	144.0	195	181.0	235	217.0	280	253.0	320	289.0
22	170	162.0	215	202.0	260	243.0	305	283.0	355	324.0
23	185	180.0	235	226.0	285	271.0	335	316.0	390	361.0
24	205	200.0	255	250.0	310	300.0	370	360.0	425	400.0
25	220	220.0	280	276.0	340	331.0	400	386.0	460	441.0
26	240	242.0	305	302.0	370	363.0	435	423.0	500	484.0
27	260	264.0	330	331.0	400	397.0	470	463.0	540	529.0
28	280	288.0	355	360.0	430	432.0	510	504.0	585	576.0
29	305	312.0	385	391.0	465	469.0	545	547.0	630	625.0
30	325	338.0	410	422.0	495	507.0	585	591.0	675	676.0
31	350	364.0	440	456.0	530	547.0	625	638.0	720	729.0
32	375	392.0	470	490.0	570	588.0	670	686.0	770	784.0
33	400	420.0	500	526.0	605	631.0	715	736.0	820	841.0
34	425	450.0	535	562.0	645	674.0	760	787.0	876	900.0
35	450	480.0	565	601.0	686	721.0	805	841.0	925	961.0
36	475	512.0	600	640.0	725	768.0	855	896.0	980	1024.0

Where local markets do not exist, it pays to market such logs at distant points. The prospective returns can be approximated by getting specifications and quotations from buyers of the kind of logs in question. A list of dealers and consumers is given in appendix C. Get from the local freight agent the rates per 100 pounds on logs in carload lots to the markets in question. The number of pounds per M. B. F. of logs for various species is given in Table XVIII. The transportation cost per M. B. F. is found by multiplying the rate per 100 pounds by the number of hundred-weights shown in the table, and thus the best market may be determined. Full carload lots should be shipped to minimize the freight charge. Frequently it is advisable for several woodlot owners to cooperate in making carload shipments. From 4,000 to 7,000 B. F. (Doyle Rule) can be shipped per average car of 60,000-pound capacity.

Logs should be cut in lengths of 8, 10, 12, 14, and 16 feet, and an allowance of from 3 to 6 inches should be made for irregular saw-cut in working the tree up into logs. It is advisable to make long logs where possible, but the aim should be to get the most from the tree by making cuts so as to get the maximum amount of high-grade material.

Logs suitable for low-grade veneers used in the manufacture of containers for fruit, eggs, and vegetables, or for ordinary lumber, bring from $15 to $30 per M. B. F. at points of consumption. Specifications vary, but logs with a minimum diameter of 12 inches are usually accepted. The manufacturers of fruit and vegetable containers use tulip poplar, sweet gum, tupelo gum, black gum, sycamore, cottonwood, willow, elm, cypress, birch, cucumber, hackberry, soft and hard maples. Egg crates are made chiefly from tupelo gum, sweet gum, and cottonwood. Local sawmills or wood-using industries in many regions offer a market for logs of practically all species listed above, as well as for ordinary oak and hickory. Prices paid usually range between $15 and $30 per M. B. F.

LUMBER

The efficient manufacture of lumber for special industries requires knowledge, experience, and capital not ordinarily at the command of the woodlot owner; consequently, he finds it difficult to manufacture to special sizes, grades, and quantities to meet the requirements of wood-using industries. The woodlot owner who decides to operate a sawmill will usually find a local market for oak and hickory bridge plank and for limited amounts of mill-run rough lumber and dimension stock. This, with the tie market, usually furnishes the chief outlet for such mills, but a better market can be developed for sound timber of the larger diameters. Markets should be investigated even before the trees are cut, in order to determine the lengths and diameters required; and, if possible, contracts should be secured for the product before cutting a stick.

TABLE XVIII

APPROXIMATE WEIGHTS OF VARIOUS WOOD PRODUCTS*

Species	Lumber (per 1,000 board feet).			Logs (per 1,000 board feet) (Doyle Rule)						Cordwood bolts, butts, etc., per cord	
				12 inches diameter		18 inches diameter		24 inches diameter			
	Air-dry	Green	Rough (classed as 1 inch thick) "shipping dry"	Green	Dry	Green	Dry	Green	Dry	Green	Dry
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Ash, white	3,500	4,000	3,800	11,100	9,700	7,700	6,800	6,600	5,700	4,300	3,800
Basswood	2,100	3,400	2,500	9,500	5,900	6,600	4,100	5,600	3,500	3,700	2,300
Beech	3,600	4,600	4,000	12,700	10,100	8,900	7,000	7,500	6,000	5,000	3,900
Cherry, black	3,000	3,800	3,800	10,500	8,300	7,300	5,800	6,200	4,900	4,100	3,200
Cottonwood	2,200	3,600	2,800	10,700	6,300	7,500	4,400	6,300	3,700	4,200	2,500
Elm, white	2,900	4,000	3,100	11,300	7,800	7,900	5,500	6,700	4,600	4,400	3,100
Elm, slippery	3,300	4,600	4,000	12,600	9,200	8,800	6,400	7,400	5,500	4,900	3,600
Gum, black	3,000	3,700	2,800	10,400	8,300	7,200	5,800	6,100	4,900	4,000	3,200
Gum, red (sweet)	2,800	3,900	3,300	10,600	8,100	7,400	5,600	6,300	4,800	4,200	3,100
Hackberry	3,500	4,400	3,200	11,300	8,900	7,900	6,200	6,700	5,200	4,400	3,500
Hickory	4,300	5,200	4,500	14,700	11,900	10,300	8,300	8,700	7,000	5,700	4,600
Locust, black	4,100	4,800	.....	13,400	11,300	9,300	7,900	7,900	6,700	5,200	4,400
Maple, sugar	3,600	4,700	3,900	12,900	10,000	9,000	7,000	7,600	5,900	5,000	3,900
Maple, red	3,000	4,300	3,300	11,900	8,200	8,300	5,700	7,100	4,900	4,700	3,200
Maple, silver	2,800	3,800	3,300	10,500	7,800	7,300	5,400	6,200	4,600	4,100	3,000
Oak, red	3,600	5,400	4,000	14,800	10,400	10,300	7,300	8,800	6,200	5,800	3,900
Oak, white	4,000	5,200	4,000	14,400	10,900	10,000	7,600	8,500	6,500	5,600	4,300
Poplar, yellow (tulip)	2,400	3,200	2,800	8,800	6,500	6,100	4,500	5,200	3,800	3,400	2,500
Sycamore	3,000	4,300	3,000	12,000	8,300	8,400	5,800	7,100	4,900	4,700	3,200
Walnut, black	3,000	4,300	3,800	11,900	8,200	8,300	5,700	7,100	4,900	4,700	3,200
Willow	2,100	4,300	2,800	11,800	6,000	8,200	4,200	7,000	3,500	4,600	2,300

* Table taken from U. S. Dept. of Agr. Farmers' Bulletin No. 1210.

Grading hardwoods requires experience. The number of grades into which a given species is divided varies with different manufacturers, ranging from six to twenty or more grades for a single species. A description of the more standardized grades is given in grading rules which can be secured from the National Hardwood Lumber Association, McCormick Building, Chicago.

The weight of lumber per M. B. F. is given in Table XVIII. From 15 to 20 M. B. F. can be loaded to the car.

POSTS

A great many posts are marketed locally to farmers or to retail lumber dealers. The steam and electric lines also use large numbers and will furnish the specifications and quotations upon request. Some consumers limit purchases to the few so-called durable woods; others use a greater variety. Ordinarily the specifications call for straight, sound, round posts having a top diameter ranging between 4 and 6 inches D. i. b. and a length of 7 feet, cut square on both ends.

TIES

To estimate the number of ties in a tract of standing timber, there are required calipers, chalk, notebook, and pencil, as for estimating saw-logs. The following form is convenient.

D.B.H. inches	Black Oak Height in feet				White Oak Height in feet				Maple Height in feet				Elm Height in feet			
	50	60	70	80	50	60	70	80	50	60	70	80	50	60	70	80
10																
11																
12																
13																
14																
15																
16																
17																
18																

When two work together, the estimator calipers each tree about $4\frac{1}{2}$ feet from the ground, marks it, and estimates the total height, calling out, for instance, "white oak, 14 inches, 70 feet." His companion places a dot or line in the proper place on the form to record a white oak D. B. H. 14 inches, total height 70 feet. The usual system of placing dots and lines as shown on p. 170, so that the closed figure records ten, is followed.

The total height can be estimated with the eye after a little practice, but at first the eye should be checked by measuring standing trees. A fairly accurate and simple method consists in using a straight stick having a length of about five feet. The estimator takes a position at a point he judges to be distant from the tree about the total height of the tree and on approximately the same level as the tree. He grasps the stick in the right hand and standing with his right side toward the tree holds the stick vertically at arm's length between his body and the tree and pivots it until the tip comes to his right eye. The stick is pivoted back again and held vertically at a full arm's length toward the tree, so that a line from the eye to the pivotal point of the stick cuts the base of the tree. He then advances or retreats until the tip of the stick and the tip of the tree are in line with his right eye, while the line from eye to hand cuts the base. The distance to the tree from the point where he now stands, equals the total height of the tree. With practice, this distance can be measured by pacing.

Heights should be recorded in the nearest height class, i. e., 55 feet in the 50 feet class, and 56 feet in the 60 feet class. When the field work is completed, the number and grades of ties can be approximated by reference to Table XIX.

TABLE XIX

YIELD IN TIES OF VARIOUS GRADES (NO. 1-5) FOR TREES OF GIVEN DIAMETER AND HEIGHT

Based on studies of black oak

D.B.H. inches	Total height in feet																			
	50					60					70					80				
	No. 1	2	3	4	5	No. 1	2	3	4	5	No. 1	2	3	4	5	No. 1	2	3	4	5
10	.....	..	..	..	..	1	..	..	..	..	1	..	..	..	..	1				
11	1	..	..	..	..	2	..	..	..	..	1	1	..	..	..	1	1			
12	1	..	1	..	..	.....	1	1	..	..	1	1	1	..	..	2	1			
13	.....	1	..	1	..	1	..	1	1	..	.....	1	1	1	..	1	1	..	2	
14	....	1	..	..	1	.....	1	..	1	1	.....	1	1	1	1	1	1	..	1	2
15	1	..	..	1	1	.....	..	1	1	1	.....	1	..	1	2	1	..	1	1	2
16	1	..	..	..	2	1	..	..	1	2	.....	..	..	1	3	.....	1	..	1	3
17	.....	..	..	..	2	1	..	..	..	3	1	..	..	1	3	.....	..	1	..	4
18	.....	..	1	..	2	.....	1	..	..	3	.....	1	..	..	4	1	..	..	1	4

Ties are graded according to species and size. There is a slight variation in required length, some specifications calling for 8½ feet, others for 8 feet. Also, some roads use a wider range of species than others, or have special rules governing the cutting period and methods of delivery. For these reasons, it is advisable to get specifications and quotations from the railroad where ties are to be marketed. This information can be secured through the local agent or by writing to the general purchasing agent. The quotations in Table XX give a general idea of the relative values of the different species and grades.

TABLE XX

VALUES OF TIES (BASED ON AVERAGE QUOTATIONS)

Grade No.	Thickness In.	Width In.	"U A" Black locust, White oaks, Black walnut	"U D" Catalpa, Red mulberry, Sassafras	"T A" Ashes, Hickories, Honey locust, Red oaks	"T C" Beech, Birch, Cherry, Hackberry, Hard maple	"T D" Gums, Soft maples, Sycamore, White walnut
1	6	6	$0.55	$0.20	$0.45	$0.30	$0.20
2	6	7	0.75	0.30	0.65	0.50	0.40
3	{ 7	7	} 1.00	0.50	0.90	0.75	0.55
	{ 6	8					
4	7	8	1.25	0.65	1.15	1.00	0.65
5	7	9	1.35	0.75	1.25	1.10	0.75

The steam railroads readily absorb grades 4 and 5 but frequently local traction companies provide a better market for the smaller ties.

PILING

Trees suitable for piling must be straight and must carry a long clear bole with relatively little taper. The woodlot owner who has tall straight trees ranging in diameter between 14 and 22 inches D. B. H. should investigate the possibilities of this market. Dealers in piling are given in the list in Appendix C, but in many cases the owner can market directly to consumers, such as railroad companies or contractors along the water front. Specifications vary, depending on the conditions under which the pile is to be used. The common sizes are 30, 40, and 50 feet in length with a minimum top diameter of 9, 8, and 7 inches, respectively, and with a maximum butt diameter of 20 inches and a minimum of 12 inches. Prices depend not only upon the size but also upon the species, the more durable kinds, such as white oak, bringing a higher price. Species generally used are: black locust, white oaks, red gum, ash, beech, birch, cherry, elm, hickory, honey locust, maple, red oaks, and black gum. The approximate weights are given in Table XXI.

To estimate the number of piles in a woodlot, there are required calipers, crayon, pencil, and notebook. A convenient form for recording material is given below:

Species	Length of pile in feet						
	30	35	40	45	50	55	60
White oak...							
Red oak.....							
Ash							
Elm							

The estimator first determines if the tree has the required form, straightness, and size. Trees which have a D. B. H. between 14 and 22 inches are commonly acceptable. He then marks the tree and estimates the maximum length which can be secured conforming with the top diameter requirements. The rule is to allow two inches for bark thickness. Consequently, for piling with a 7-inch top, a point in the stem must be selected which has a diameter of 9 inches outside the bark. The estimator then judges the distance from the stump to this point as the length of pile which can be cut. Some experience in estimating diameters and lengths is essential to accurate work. The tree is recorded by the dot-and-line system as for sawlogs.

TABLE XXI

APPROXIMATE WEIGHTS OF PILING OF DIFFERENT SIZES, GREEN AND DRY, FOR DIFFERENT KINDS OF WOOD*

Length	White Oak		Black Oak		Sugar Maple		White Elm		Black Gum	
	Green	Air dry	Green	Air dry	Green	Air dry	Green	Air dry	Green	Air dry
Feet	Weight in pounds									
20	610	470	610	440	550	430	480	340	440	350
25	770	590	770	550	690	530	600	430	550	450
30	920	700	920	660	820	640	710	510	660	530
35	1080	820	1080	770	960	750	840	600	770	620
40	1580	1200	1590	1140	1410	1100	1230	880	1130	920
45	1780	1360	1790	1280	1590	1240	1390	990	1270	1030
50	1980	1500	1980	1420	1770	1370	1540	1090	1410	1140

* From Farmers' Bulletin 1210, U. S. Dept. Agr., Washington, D. C.

MINE TIMBERS

The Illinois coal mines provide a market for large quantities of both rough and sawed wood. Wood in the round is used for props, legs, and bars. For ties, a face is hewed or sawed on one or more sides. For caps, inch boards about one foot square are used, and large quantities of sawed material are used in the buildings at the surface. The requirements in sizes and lengths vary for the different seams mined, so that a list of specifications should be obtained from accessible markets before cutting such timber. The latest coal report can be secured upon request at the Department of Mines and Minerals, Springfield, Illinois, which shows the location and tonnage produced from the operating mines. The list in appendix C contains the addresses of most mine timber dealers and consumers.

Sticks, either split or round, such as are used for supporting the roof in temporary openings, are termed props. They are cut square at the ends from any hardwood, and the bark is left on. The minimum top diameter accepted usually varies between 4 and 7 inches. The mines in the LaSalle region require lengths from 3½ to 7 feet; in Fulton County, 5 feet; in Sangamon County, 6 to 7 feet; and in Williamson County, 7½ to 10 feet.

Legs are the upright posts used, together with the bar across the top, to support the roof and walls in more permanent openings. For this work, white oak is usually demanded in lengths from 8 to 16 feet and in diameters from 6 to 9 inches.

Main-line, or motor, ties are usually oak from 4 to 6 feet long with a face of 4 inches and a thickness of 5 inches. Room ties are usually lighter, having a face and diameter an inch less. Prices for props at the mine range from 2 to 3 cents per running foot, legs average 4 cents, and bars from 4 to 10 cents. Motor ties bring about 25 cents each, and room ties from 8 to 16 cents. Mine timbers at these prices and under average costs of production (see Table XIV, p. 166) can be shipped up to 250 miles before all profit vanishes. Approximately 1200 mine ties constitute a carload, or from 800 to 1200 props, legs, or bars, depending upon the sizes. This market offers a very satisfactory outlet for the utilization of small materials such as usually come from thinnings or remain in the tops after a sawlog or railroad tie operation. The estimating of the amounts of mine timber per acre is complicated by the variety of products and specifications. No tables have been made to cover this material, but the general statement can be made that usually from one-fourth to one-half carload is cut per acre and that its requires an exceptionally well-stocked stand of thrifty polewood growth to produce a carload to the acre.

CORDWOOD

Fuelwood and pulpwood are measured and marketed by the cord. Ordinarily the market price of cordwood does not justify any rail shipment. Local markets may be found among neighboring farmers, fuel dealers, bakers, and consumers of open-fireplace fuel. The meat packers offer a somewhat limited market for good hardwood at excellent prices, as they consume more than 5,000 cords annually. Charcoal plants in Johnson, Pulaski, Alexander, and Jersey counties furnish markets for cordwood located within short hauling distances. Limited amounts of pulpwood are also marketed from Illinois to Ohio.

The standard cord is a stack which measures 8 by 4 by 4 feet and contains 128 cubic feet. Usually the stack of green wood is piled 3 inches higher than 4 feet to allow for shrinkage in drying. An approximate estimate of the amount of cordwood in standing timber can be secured by calipering each tree in the plot and referring to Table XXII for the number of trees of each diameter required to yield one cord.

TABLE XXII

NUMBER OF TREES REQUIRED TO YIELD ONE CORD*

Diameter of tree breast-high	Number of trees	Diameter of tree breast-high	Number of trees
2	170	13	3.4
3	90	14	3.0
4	50	15	2.5
5	25	16	2.2
6	17	17	2.0
7	13	18	1.8
8	9	19	1.5
9	7	20	1.3
10	6	21	1.2
11	5	22	1.1
12	4	23	1.0
		24	.9

* Taken from Farmers' Bulletin No. 1210, United States Department of Agriculture.

The markets should be investigated before cutting. The requirements of the meat packers vary, but such species as oak and hickory in diameters between 4 and 8 inches are generally preferred. Quotations fall between $6 and $16 per cord for wood f. o. b. destination. For wood pulp, the sticks must be 54 inches in length, peeled, and of cottonwood, soft maple, or box elder. Sticks down to a 3-inch diameter are accepted, and the prices approximate $6.50 per cord f. o. b. shipping point. Wood used in stoves and open fireplaces is usually cut into 16-inch lengths and marketed locally by the short cord or by the pound, retailing in cities for about $7 per short cord. A cord of air-dried hardwood weighs 4,000 pounds, and a box car holds from 15 to 18 cords.

Appendix A

PRESERVATIVE TREATMENT OF FENCE POSTS

The practice of treating fence posts with preservatives permits the use of virtually all species. Posts which ordinarily would give service of from 3 to 10 years can be treated so as to serve 20 years or more, so that species which have rapid growth rates and immunity from destructive insect attacks may be chosen for post production. Cottonwood, silver maple, willow, and honey locust are very satisfactory post trees. Cottonwood will produce posts in five years on good bottomland soils, is a very suitable tree on upland prairie loams, makes growth acceptable for posts on upland sands, but does not make acceptable growth on hardpan soils. The cost of treatment increases with increase in the size of the post, and for this reason posts having a diameter under five inches are preferable to larger ones. Split posts when properly treated have practically the same durability as round posts. The cost of treatment runs up to 20 cents per post.

Posts with a high percentage of sapwood, such as usually require preservative treatment, often check if cut in the summer, and for this reason it is preferable, although not essential, to cut them in the dormant season. They should be peeled, and it is important to carefully remove the inner as well as the outer bark. The posts should then be piled off the ground in such a manner as to give free air circulation. They should be left in this condition two or three months in order to season properly before being treated.

The application of preservatives to the surface is not effective; hence, the slight increase in durability secured by brush or dipping treatments of tars and paints does not warrant the expense. An effective treatment, practical for farm use, is called the open-tank process.

The simplest equipment for this process is a single tank set over a fire pit. The tank should be deep enough to insure submergence of fully half the length of the post at a dipping. A large oil drum* has a capacity of 25 posts per day. Care should be exercised in selecting a location away from buildings. The pit should be partly below ground level in order to keep the top of the tank as low as possible. It can be walled in with brick, hollow tile, or rock, leaving an aperture for the flue and an opening to stoke the fire. In a temporary

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* A tank with a 3-foot diameter and 4-foot depth made from 20 gauge iron with angle iron reinforcements, all joints riveted and rivet holes soldered.

set-up where cement is not used, earth should be banked about the outside of the foundation. Three or four lengths of ordinary stove pipe can be used for a flue. Four iron bars are laid across the top of the foundation as a support for the tank. Earth placed against the sides of the tank serves to hold the heat in the pit, while the opening in front and the flue furnish ample draft. Enough coal-tar creosote is placed in the tank so that with its charge of posts the tank is full. The creosote is heated to a temperature of at least 180° F. but should not be heated above 200° F., as there is then a loss of the oils through evaporation. The posts are placed in position with the larger end down, with at least 3 to 3½ feet submerged, and held in creosote at the above temperatures, as follows: Soft maple and cottonwood, 2 hours; willow, 4 hours. The butt treatment of yellow poplar and sycamore requires about the same time as cottonwood, while fully 6 hours are required for good impregnation of white ash, elm, hackberry, hickory, hard maple, and black oak. The preservative should go into the wood at least a half-inch. The amount of creosote absorbed averages half a gallon per post. Keep the creosote at a uniform level by adding more as posts absorb it. The posts should be left in the tank until the creosote cools, and the creosote should be kept at a uniform depth for this time also.

The tops should next be treated by inverting the posts so that all wood not previously reached is submerged, and leaving them in the tank while the creosote is being heated up to 180° F. The posts should then be put in open piles. The excess creosote in the tank can be put back into a barrel and stored until needed again. It is important, in setting posts thus treated, that the top line of the butt treatment should be at least 6 inches *above* the ground line.

Where the number of posts to be treated justifies the installation of more elaborate equipment, a second tank* of cold creosote is used. After the butt treatment in the hot creosote, the posts are immediately transferred to the tank of cold creosote. These are held in the cold creosote until the posts are thoroughly cooled, and by this process the preservative is drawn into the heated portion of the butt. The coating which the top receives is enough to safeguard it against ordinary decay.

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* The best type of tank for the cold creosote is a 2½ x 2½ x 8 foot stock tank. It should have ample capacity to hold completely submerged all posts from the hot tank.

Appendix B

Concerns Dealing in Tree Seedlings and Transplants*

D. Hill Nursery, Dundee, Illinois.
Onarga Nursery Company, Onarga, Illinois.
Naperville Nurseries, Naperville, Illinois.
Betsie River Nursery, Thompsonville, Michigan.
Northeastern Nursery Company, Cheshire, Connecticut.
F. W. Kelsey Nursery Co., 50 Church Street, New York City.
Evergreen Nursery Company, Sturgeon Bay, Wisconsin.
Forest Nursery Co., Inc., McMinnville, Tennessee.

Tree Seed Dealers*

T. Meehan Sons, Dresher, Pennsylvania.
Thomas J. Lane, Dresher, Pennsylvania.
Conyers B. Fleu, Jr., Germantown, Pennsylvania.
Otto Katzenstein, 6 Cone St., Atlanta, Georgia.
J. M. Thorburn, 32 Barclay Avenue, New York City.
The Barteldes Seed Co., Lawrence, Kansas.
L. E. Williams, Exeter, New Hampshire.
The American Forestry Co., Pembine, Wisconsin.
Frank N. Graass, Sturgeon Bay, Wisconsin.

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* These lists have been carefully prepared for the convenience of woodlot owners, but the State Natural History Survey does not vouch for their completeness nor guarantee the responsibility of the concerns here named.

Appendix C

LIST OF CONSUMERS AND DEALERS*

ADAMS COUNTY

Lumber

Electric Wheel Co., Quincy. Buy graded oak and hickory cut to special sizes.

Collins Plow Co., Quincy. Buy graded elm and oak.

Henry Knapsheide Wagon Co., Quincy. Buy graded oak.

Quincy Show Case Works, Quincy. Buy black walnut, oak and rough local lumber.

ALEXANDER COUNTY

Logs

Peterson-Miller Box Co., Cairo. Buy cottonwood, sycamore, willow, and red gum.

Singer Mfg. Co., Cairo. Buy black walnut, white and red oak, and red gum.

Lumber

Vehicle Supply Co., Cairo. Buy oak and hickory cut to special sizes.

Ties

Solomon Tie & Timber Co., Cairo. Buy ties.

Piling

Solomon Tie & Timber Co., Cairo. Buy piling.

Cordwood

Solomon Tie & Timber Co., Cairo. Buy cordwood at Tamms.

Alabama Charcoal Co., Kansas City, Mo. Buy cordwood at Cache and Olive Branch.

Sawdust

E. Bucher Packing Co., Cairo. Buy hardwood sawdust.

Standing timber

Solomon Tie & Timber Co., Cairo.

BOONE COUNTY

Logs

National Sewing Machine Co., Belvidere. Buy walnut.

BUREAU COUNTY

Mine timbers

Spring Valley Coal Co., No. 3. Springvalley.

Saint Paul Coal Co., No. 2, Cherry.

CHRISTIAN COUNTY

Mine timbers

Penwell Coal Mining Co., Pana.

Springside Coal Co., Pana.

Pana Coal Co., No. 1 and 2, Pana.

Peabody Coal Co., No. 7, Kincaid.

Peabody Coal Co., No. 8, Tovey.

Peabody Coal Co., No. 9, Taylorville.

Peabody Coal Co., No. 21, Stonington.

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* The Natural History Survey does not vouch for the completeness of this list nor guarantee the responsibility of the concerns named here.

Clinton County

Mine timbers

Breese-Trenton Mining Co., Beckemeyer.
W. W. Smith, Keyesport.

Cook County

Logs

R. S. Bacon Veneer Co., 213 N. Ann st., Chicago. Buy walnut.
Adolph Sturm Co., 542-44 W. Washington St., Chicago. Buy dogwood and persimmon.

Lumber

Pullman Car & Mfg. Corp., Pullman. Buy graded car stock.
Yellow Cab Mfg. Co., Chicago. Buy graded ash.
Marsh & Truman Lumber Co., 332 S. Mich. Ave., Chicago. Buy car stock crossing plank, etc.
L. D. Leach & Co., 5 N. Wabash, Chicago. Buy locally sawed lumber.
Chicago Mill & Lumber Co., Conway Bldg., Chicago. Buy locally sawed lumber.
Frank B. Stone, Maller's Bldg., Chicago. Buy local lumber.
Anguera Lumber & Tie Co., 111 W. Washington, Chicago. Buy local lumber.

Posts, Ties, and Piling

L. D. Leach & Co., 5 N. Wabash, Chicago. Buy piling and ties.
Chicago Mill & Lumber Co., Conway Bldg., Chicago. Buy piling poles and posts.
W. W. and A. J. Schultz, 1235 Colony Bldg., 37 W. Van Buren St., Chicago. Buy piling.
Ozark Timber Co., 833 W. Washington, Chicago. Buy ties.
Frank B. Stone, Maller's Bldg., Chicago. Buy piling and ties.
Anguera Lumber & Tie Co., 111 W. Washington, Chicago. Buy ties.
Bay, DeNouquet Co., 80 E. Jackson Bldv., Chicago. Buy ties.
W. B. Crane Co., 22nd and Sangamon Sts., Chicago. Buy ties.
Marsh & Truman Lumber Co., 332 S. Michigan Ave., Chicago. Buy ties.
Lake Superior Piling Co., 22nd and Morgan St., Chicago. Buy piling.
C. B. & Q. R. R. Co., Burlington Bldg., Chicago. Buy ties and piling.
C. M. & St. Paul Ry., Exchange Bldg. Chicago Buy piling, ties, and posts.

Cordwood and Sawdust

Swift & Co., Union Stock Yards, Chicago. Buy cordwood and sawdust.
Armold Bros., Inc., 660 W. Randolph St., Chicago. Buy hardwood sawdust.
Jourdan Packing Co., Chicago. Buy hardwood sawdust.
Cudahy Packing Co., 111 W. Monroe St., Chicago. Buy oak hickory cordwood and sawdust.
Omaha Packing Co., 2320 W. Halsted St., Chicago. Buy oak hickory cordwood and sawdust.
Roberts & Oaks, 45th and Racine Ave., Chicago. Buy oak hickory cordwood and sawdust.
Hately Bros. Co., 37th and Halsted Sts., Chicago. Birch, maple, oak, hickory cordwood and sawdust.
William Daviess Co., Inc., Union Stock Yards, Chicago. Birch, maple, oak, hickory cordwood and sawdust.
Armour & Morris, Union Stock Yards, Chicago. Oak wood, oak and maple sawdust.
Libby, McNeil & Libby, Union Stock Yards, Chicago. Oak and hickory wood and sawdust.
Beiersdorf & Bros., 932 W. 38th Place, Chicago. Buy oak, hickory, wood and sawdust.

COOK COUNTY—(Continued)

Covey Durham Co., 431 S. Dearborn St., Chicago. Buy cordwood and standing timber.

Illinois Fuel Co., 39 S. LaSalle St., Chicago. Fuelwood retailer.

Northern Wood Fuel Co., 310 S. Mich. Ave., Chicago. Fuelwood retailer.

W. A. Davis Hardwood Co., 122 S. Mich. Ave., Chicago. Fuelwood retailer.

Buesing Homan Coal Co., 2151 N. Lincoln St., Chicago. Fuelwood retailer.

Chicago Wood & Coal Co., 4900 W. Chicago Ave., Chicago. Fuelwood retailer.

Wilson & Co., 4100 S. Ashland Ave., Chicago. Maple and hickory wood and sawdust.

Chicago Butchers Packing Co., 216-222 N. Peoria St., Chicago. Buy maple and hickory wood and sawdust.

G. H. Hammond Co., Union Stock Yards, Chicago. Buy elm, maple, oak, hickory wood and sawdust.

Reliable Packing Co., 1446-1452 W. 47th St., Chicago. Buy hardwood sawdust.

Miscellaneous

Hartwell Handle Co., 146th and Lincoln Ave., Harvey. Use sapling hickory.

H. R. Mosnat, 10, 910 Prospect Ave., Morgan Park, Chicago. Buy walnut kernels.

DEWITT COUNTY

Cordwood

Clinton Coal Co., Clinton.

C. E. Crang, Clinton.

EDGAR COUNTY

Logs

T. A. Foley, Paris. Buys black walnut, cherry and high grade logs.

Lumber

Cummings Car & Coach Co., Paris. Buys car stock.

EFFINGHAM COUNTY

Lumber

John Boos, Effingham. Buys specially sawed soft maple.

Mine timbers

C. E. Hershey & Co., Effingham.

FAYETTE COUNTY

Mine timbers

Sholmier Timber Co., Vandalia.

FRANKLIN COUNTY

Mine timbers

Valier Coal Co., Valier.
Franklin County Coal Co. No. 7, Royalton.
Franklin County Coal Co., No. 5, Herrin.
Franklin County Mining Co., Benton.
Old Ben Coal Corp. Nos. 8, 9, 19, West Frankfort.
Old Ben Coal Corp. Nos. 10, 11, 12, Christopher.
Old Ben Coal Corp. No. 14, Buckner.
Old Ben Coal Corp. No. 15, Ezra.
Old Ben Coal Corp. No. 16, Sesser.
C. W. & F. Orient No. 2, West Frankfort.
C. W. & F. Orient No. 1, Orient.
Peabody Coal Co., No. 18, West Frankfort.
Bell & Zoller Mining Co., No. 2, Zeigler.

Fulton County

Mine timbers

Canton Coal Co., Canton.
Buckheart Coal Co., Canton.
Rawal Coal Co., Canton.
Murphy & Loftus, Canton.

Grundy County

Mine timbers

Wilmington Star M. Co., Coal City.

Henry County

Mine timbers

Shuler Coal Co., Alpha.

Jackson County

Logs

Merchants Basket & Box Co., Grand Tower. Buy elm, gum, etc., logs 16" and up.

Ties

Ayer & Lord Tie Co., Carbondale.

Mine timbers

DeSoto-Peacock Coal Co., DeSoto.
Harsha & Floyd, Vergennes.
Rector Bros., Murphysboro.
H. M. Sellers, 800 S. Forest St., Carbondale.

Jersey County

Cordwood

Equitable Powder Mfg. Co., E. Alton. Use bottomland and hardwoods in charcoal plant at Grafton.

Johnson County

Cordwood

Berger Bros., 1176 Cherry Ave., Chicago. Charcoal plant at Belknap.

Kane County

Logs

Westgate Walnut Co., Aurora. Buy black walnut.

Lumber

Appleton Mfg. Co., Batavia. Buy graded oak.

LaSalle County

Lumber

King & Hamilton Co., Ottawa. Graded oak.

Ties

Northwestern Timber Co., Mendota. Also buy standing timber.

Mine timbers

LaSalle County Carbon Coal Co., Union.

McLean County

Logs

J. O. Wheadon, Bloomington. Buys walnut logs, standing timber, ties, lumber, mine props and cordwood.

Lumber

Paul O. Moratz, Bloomington. Buys log run oak and hard maple lumber.

Macon County

Cordwood

Danzeisen Packing Co., Decatur. Buy oak hickory wood.

MACOUPIN COUNTY

Mine timbers

Madison Coal Corp. No. 5, Mt. Olive.

MADISON COUNTY

Lumber

American Car Foundry Co., Madison. Buy car stock.

Illinois Glass Co., Alton. Buy cottonwood lumber.

MARION COUNTY

Mine timbers

L. S. Gray, Centralia.

MARSHALL COUNTY

Mine timbers

F. A. Barr, Lacon.

MASON COUNTY

Lumber

Havana Metal Wheel Co., Havana. Buy graded oak, ash, hickory.

MASSAC COUNTY

Logs

E. C. Artman Lumber Co., Metropolis.

Roberts Liggett Co., Metropolis.

Ties

E. C. Artman Lumber Co., Metropolis.

Bennett-Field Tie Co., Tie plant at Brookport.

Mine timbers

Bennett-Field Tie Co., Brookport (main office 1406 Fisher Bldg., Chicago).

MONTGOMERY COUNTY

Mine timbers

Hillsboro Coal Co., Hillsboro.

MORGAN COUNTY

Cordwood and sawdust

Powers Begg & Co., Packers, Jacksonville. Buy hardwood and sawdust.

Walton & Co., Jacksonville, cordwood retailers.

Rogerson & Co., Jacksonville, cordwood retailers.

J. A. Paschall, Jacksonville, cordwood retailers.

PEORIA COUNTY

Logs

National Cooperage & Woodenware Co., Peoria. Buy red and white oak.

Moschell & Whitfield, Marshall Block, Pekin. Buy black cherry and walnut logs.

Mine timbers

Crescent Coal Co., No. 6, Peoria.

Neusau Bros. Coal Co., Glasford.

Crescent Coal Co., No. 1, Peoria.

Hanna City Mining Co., Hanna City.

Bartonville Coal Co., Peoria.

Cordwood and sawdust

Wilson Provision Co., Peoria. Buy maple, oak, hickory wood and sawdust.

Godel & Sons, Peoria. Buy oak, hickory wood.

Perry County

Mine timbers

Crear Clinch Coal Co., DuQuoin.
Willis Coal & Mining Co., No. 7. Sparta.

Pulaski County

Logs

O. L. Bartlett, Mound City. Buys elm, gum, hackberry, maple, ash, and sycamore.
Geo. L. Kannapell, Mound City Veneer Mills. Buys tulip and gum.
Portsmouth Veneer & Panel Co., Mound City. Buy oak, poplar and gum.
Inman Veneer & Panel Co., Mound City. Buy poplar, gum, and oak.
Main Bros. Box & Lumber Co., Karnak. Buy softwood logs locally.

Cordwood

B. E. Moses, Perks.
J. E. Black Charcoal Co., Ullin.

Putnam County

Mine timbers

Barney Ernst, Granville.
A. Hecht, Magnolia.

Randolph County

Mine timbers

Madison Coal Corp., Tilden.

Rock Island County

Lumber

Strombeck-Becker Mfg. Co., Box 74, Moline. Buy locally sawed basswood.

St. Clair County

Logs

W. L. Fletcher, Ill. Walnut Co., E. St. Louis. Buys walnut.

Mine timbers

B. B. Coal Co., Belleville.
Prairie Coal Co., O'Fallon.
Mulberry Hill Coal Co., Freeburg.
Southern Coal, Coke & M. Co., Nos. 1, 6, 7, 8. Belleville.
Aluminum Ore Co., E. St. Louis.
Groom Coal Co., Belleville.
Lou Nash Coal Co., Freeburg.

Cordwood and sawdust

Armour and Co., E. St. Louis. Buy hickory wood, hardwood sawdust.
Swift and Co., E. St. Louis. Buy hickory wood, hardwood sawdust.

Saline County

Mine timbers

Dodds Coal Co., Carriers Mills.
Harrisburg Coal M. Co. B. B., Harrisburg.

Sangamon County

Mine timbers

Madison Coal Corp., Divernon.
West End Coal Co., Springfield.
Sangamon Coal Co., No. 2, Springfield.
New Staunton Coal Co., Livingston.
C. W. & F. Coal Co., No. 1, Thayer.

SANGAMON COUNTY—(Continued)

Peabody Coal Co., No. 6, Sherman.
Peabody Coal Co., No. 51, Auburn.
Peabody Coal Co., No. 52, Riverton.
Peabody Coal Co., No. 53, Springfield.
Peabody Coal Co., No. 54, Auburn.
Peabody Coal Co., No. 55, Springfield.
Castleman Bros. Timber Co., 401 Ridgley, Springfield. Buys ties, standing timber, mine timber.
Standard Tie & Timber Co., Reisch Bldg., Springfield.

SHELBY COUNTY

Mine timbers

Moweaqua Coal M. Co., Moweaqua.
J. J. Patterson, Trowbridge, R. R. 1

TAZEWELL COUNTY

Mine timbers

Groveland Coal M. Co., Pekin.
Ubben Coal Co., Pekin.

UNION COUNTY

Logs

H. A. DuBois, Cobden. Buys gum, sycamore, maple, poplar, cottonwood, willow, elm, and hackberry.
Julius Rendelman, Alto Pass. Buys poplar, gum, beech, sycamore, etc.
Ed. Karraker, Jonesboro. Buys poplar, gum, beech, sycamore, etc.
C. M. Sampson, Jonesboro. Buys oak and poplar veneer logs.
R. L. Lawrence, Cobden. Buys basket veneer logs.
Dongola Box Factory, Dongola. Buy softwood and oak logs.
Fruit Growers Package Co., Jonesboro. Buy maple, beech, sycamore, etc.

Ties

C. M. Sampson, Jonesboro.

VERMILION COUNTY

Logs

Pierson-Hollowell Walnut Co., 520 Section St., Danville. Buy walnut.

Mine timbers

Peabody Coal Co., No. 24, Danville.

WARREN COUNTY

Lumber

Western Stoneware Co., Monmouth. Buy rough local lumber.

Mine timbers

Dennis Howard, Monmouth.

WASHINGTON COUNTY

Logs

J. J. Pool, Richview. Buy cooperage stock.

WHITE COUNTY

Mine timbers

C. A. Fitch, Norris City.

WHITESIDE COUNTY

Logs

Illinois Refrigerator Co., Morrison. Buy ash, basswood, elm, maple logs and lumber.

Will County

Logs

Federal Match Corp., Joliet. Basswood logs.

Williamson County

Mine timbers

Sincerity Coal Co., Marion.
Crear Clinch Coal Co., Herrin.
Sincerity Coal Co., Carterville.
Crear Clinch Coal Co., Johnson City.
St. Louis Coal & Iron Co., No. 1, Johnson City.
Consolidated Coal Co., No. 7, Herrin.
Freeman Coal M. Co., Herrin.
Old Ben Coal Corp. No. 18, Johnson City.
Old Ben Coal Corp. No. 20, Herrin.
C. W. & F. Mining Co., Mine A, Herrin.
Peabody Coal Co., No. 3, Marion.
Southern Timber Co., Marion.

Winnebago County

Logs

Litton Veneer Co., Rockford. Buy walnut, basswood, and elm.
Illinois Veneer Co., Rockford. Buy walnut, basswood, and elm.

Lumber

Rockford Furniture Co., Rockford. Buy walnut and basswood.
Illinois Sewing Machine Co., Rockford. Buy walnut and basswood.
Old Colony Chair Co., Rockford. Buy walnut.
Continental Desk Co., Rockford. Buy cedar.
Rockford Eagle Furniture Co., Inc., Rockford. Buy red cedar.
Rockford Reed & Fibre Co., Rockford. Buy rock elm.
Rockford Cedar Furniture Co., Rockford. Buy red cedar.

Woodford County

Mine timbers

Banta Bros., Lowpoint.
Rudolph Durst., Metamora.

Appendix D

UNITED STATES DEPARTMENT OF AGRICULTURE

PUBLICATIONS RELATING TO WOODLOT MANAGEMENT AND ORNAMENTAL TREE CULTURE

For the following publications, address the U. S. Department of Agriculture, Washington, D. C.

Trees for shade and ornament

- Planting and care of street trees. (Farmers' Bulletin 1209) 5 cents.
- Street trees—kinds, description, culture, and care. (Department Bulletin 816) 15 cents.
- Tree Surgery. (Farmers' Bulletin 1178) 5 cents.
- Trees for town and city streets. (Farmers' Bulletin 1208) 5 cents.
- Planting the roadside. (Farmers' Bulletin 1481).
- Trees for roadside planting. (Farmers' Bulletin 1482).
- Beautifying the farmstead. (Farmers' Bulletin 1087).
- Insects injurious to deciduous shade trees and their control. (Farmers' Bulletin 1169) 15 cents.

Trees for wood production

- Cottonwood in the Mississippi Valley. (Department Bulletin 24) 10 cents.
- Protection from the locust borer. (Department Bulletin 787) 5 cents.
- White pine under forest management. (Department Bulletin 13) 15 cents.
- Black walnut for timber and nuts. (Farmers' Bulletin 1392) 5 cents.
- Black walnut, its growth and management. (Department Bulletin 933) 20 cents.
- Selling black walnut timber. (Farmers'Bulletin 1459.)
- Basket willow culture. (Farmers' Bulletin 622) 5 cents.
- Basket willow, with chapter on insects injurious to basket willow. (Forest Bulletin 46) 15 cents.

Farm forestry

- Care and improvement of the farm woods. (Farmers' Bulletin 1177) 5 cents.
- Cooperative marketing of woodland products. (Farmers' Bulletin 1100) 5 cents.

Forestry and farm income. (Farmers' Bulletin 1117) 5 cents.

Forestry lessons on home woodlands. (Department Bulletin 863) 15 cents.

Measuring and marketing farm timber. (Farmers' Bulletin 1210) 5 cents.

Preserving treatment of farm timbers. (Farmers' Bulletin 744) 5 cents.

Machinery for cutting firewood. (Farmers' Bulletin 1023) 5 cents.

Use of wood for fuel. (Department Bulletin 753) 10 cents.

Wasteland and wasted land on farms. (Farmers' Bulletin 745).

Second-growth hardwoods in Connecticut. (Forest Service Bulletin 96) 15 cents.

Growing and planting hardwood seedlings on the farm. (Farmers' Bulletin 1123).

Growing and planting coniferous trees on the farm. (Farmers' Bulletin 1453).

Appendix E

ILLINOIS STATE NATURAL HISTORY SURVEY PUBLICATIONS ON FORESTRY

Sent free upon request

Hall, R. C., and Ingall, O. D.
1911. Forest conditions in Illinois. Vol. IX, Art. 4.

Forbes, S. A.
1920. Concerning a forestry survey and a forester for Illinois. Forestry Circular No. 1.

Miller, Robt. B.
1920. Fire prevention in Illinois forests. Forestry Circular No. 2.
1923. First report on a forestry survey of Illinois. Vol. XIV, Art. 8.

Chapman, Herman H., and Miller, Robert B.
1924. Second report on a forest survey of Illinois. The economics of forestry in the state. Vol. XV, Art. 3.

Telford, C. J.
1926. Third report on a forest survey of Illinois. (A woodland inventory, including growth and yield studies). Vol. XVI, Art. 1.
1926. Brownfield Woods: a remnant of the original Illinois forest. Forestry Circular No. 3.
1926. Wood as a crop in Illinois. Forestry Circular No. 4.

Appendix F

SERVICES OFFERED TO WOODLAND OWNERS IN ILLINOIS

The Natural History Survey, as a branch of the State Government, is prepared to help farmers and other woodland owners in the following ways:

(1) Instruction through correspondence, or by personal visit if necessary, in proper methods of thinning and developing natural woodlands to their highest productive capacity.

(2) Advice as to cutting trees to the best advantage for various purposes.

(3) Information on means of marketing wood products from any point in the State to such users as furniture factories, veneer plants, railroads, mines, car shops, pulpwood factories, companies using piling, dealers in cordwood, and others.

(4) Estimation of costs of manufacturing various wood products and costs of transportation to various markets.

(5) Identification of tree diseases and insect enemies, when specimens are sent to the Natural History Survey, and advice on methods of eradicating pests.

(6) Advice through correspondence, or by personal visit if necessary, to those who desire to plant waste lands, as to the proper species of trees suited to the soils and to the special purposes of the plantations.

(7) Suggestions for solving problems in the protection of woodlands against fire.

(8) Co-operation with other State agencies in all matters related to forestry.

In this connection, the Natural History Survey also pursues the following aims:

(a) To take account of the value of woodlands, existing or proposed, for recreational uses, not only by the inhabitants of the larger cities of the State, but also by the country people and the inhabitants of the smaller towns, whose home surroundings are often oppressively monotonous.

(b) To consider the uses of forests as preserves of the primitive life of the State, of great interest and value to the student of science and his teacher and to the lovers of wild life.

(c) To co-ordinate the forest policy of the State with the movement for the establishment of a system of State parks.

Address inquiries to: Forester,
State Natural History Survey,
Urbana, Illinois.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, *Chief*

Vol. XVII. BULLETIN Article III.

An Epidemic of Leeches on Fishes in Rock River

BY

DAVID H. THOMPSON

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
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DEPARTMENT OF REGISTRATION AND EDUCATION

A. M. SHELTON, *Director*

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AN EPIDEMIC OF LEECHES ON FISHES IN ROCK RIVER

DAVID H. THOMPSON

IN the course of field work in aquatic biology on Rock River it was noticed in the winter of 1925-1926 that almost every red-mouth buffalo (*Ictiobus cyprinella* Cuv. & Val.) was heavily infested with the leech, *Piscicola punctata* Verrill.* This leech had not been taken during the two preceding years of almost continuous work on this river, which included the collecting of hundreds of samples of the bottom fauna and the handling of many thousands of red-mouth buffalo at all seasons of the year. Moreover, fishermen at many points on the river reported that no such infestation had occurred in the last half-century and that the only time they had ever seen any such leeches on the buffalo was about ten years ago when a few were noticed during some early spring fishing. The first appearance of *Piscicola punctata* in epidemic proportions was on February 25, 1926, about four miles above Rockford. The river's winter covering of ice having "gone out" of most of the channel the previous day, the remaining ice was moved off an eddy, and a seine haul was made which included, among a number of other fishes, 45 red-mouth buffalo weighing one to two pounds each, 38 of which were infested with this leech. The number of leeches on each of the infested fishes ranged from 1 or 2 up to 50 or more with an average of about 20.

The point of attack was most often in the axils of the fins and about the anus, where the cuticle is relatively thin; however, clusters of leeches were often found attached to other parts of the body, especially in places where the cuticle had been broken by injuries. A missing scale or a cut usually offered a place of attachment for several leeches. Those which had penetrated the cuticle or had found an opening in it were usually well filled with blood and mucus; others contained mucus only or were quite empty.

Extent of the Epidemic

During the remainder of February and throughout March, leeches were found on the red-mouth buffalo in much the same numbers and proportions as just described for the first haul. Seine hauls made in this period over a 20-mile stretch of Rock River in the vicinity of Rockford netted 2831 red-mouth buffalo, averaging about 2 pounds in weight. The leeches were so numerous that the bottom of a boat in which fishermen had handled a few hundred pounds of fishes was almost completely covered with them.

* Preserved specimens of this leech were identified by Professor J. Percy Moore.

"Thin" fishes usually bore more leeches than "fat" ones. Whether the leeches made the fishes thin, or whether thin fishes were predisposed to leeches, is uncertain. The fishermen picked off the leeches before the fishes were sold on the retail market. When the leeches were removed, the place of attachment was raw and bleeding and was surrounded by a halo of inflamed flesh. Fishes infested with leeches were less desirable for market, partly because the wounds and blood-shot flesh injured their appearance and partly because the mere thought of leeches was repulsive to buyers. Many thin, infested buffalo were thrown back by the fishermen while sorting the marketable fishes out of the seine.

At this same time fishermen seining farther down the river near Oregon also found the red-mouth buffalo very heavily infested with leeches. Those taken in the channel of the river were reported to have about the same number of leeches as described for the Rockford region, but those taken in sloughs and backwaters were much more heavily infested, individual fishes often bearing more than a hundred leeches.

Fishermen at other points on Rock River found leeches on the buffalo during the same winter, but there is no evidence that the epidemic extended into other streams of the State. One commercial fisherman, of many years experience in catching buffalo at all seasons of the year on the lower Illinois River near Meredosia and on the Mississippi River near Savanna, reported that he had never seen leeches in any considerable numbers on the fishes. The most that he had ever seen were on some red-mouthed buffalo taken on the Mississippi during some early spring fishing five years ago, but they numbered only two or three to a fish. Fishermen on the Wabash River at Lafayette, Indiana, saw no such epidemic.

During the epidemic on the red-mouth buffalo, other fishes were occasionally found infested with small numbers of the same leech. The small-mouth buffalo *(Ictiobus bubalus)* was thus attacked, most often in the axils of the fins and about the anus. The common red-horse *(Moxostoma aureolum)*, which is somewhat more abundant in Rock River than the small-mouth buffalo, was affected even less; on it, no leeches were seen which were filled with blood, although many were well filled with mucus. The mongrel buffalo, the European carp, the common river carp (or quillback), and the common (or black) sucker were found with small numbers of leeches on them. It is possible that the leeches attached themselves to these other fishes after having been dislodged from red-mouth buffalo in the seine.

Seasonal Habits of the Leeches

The epidemic began while the river was covered with ice and ended soon after the ice had gone and the water temperature had risen a few degrees above freezing. There were no leeches on any of the 1481 red-mouth buffalo taken by the writer during November, 1925, in the same locality. Fishing was continued by the commercial fishermen in the same locality until late in December, when the river froze over for the winter, but no leeches were noticed. It seems probable, therefore, that the red-mouth buffalo became infested with the leeches sometime during the month of January.

At the end of March, a decline in the number of leeches was evident. This was preceded by a sharp rise in the water temperature (see Table I). Since the river was covered with ice, water temperatures between 0° C.

TABLE I

ROCK RIVER WATER TEMPERATURES* (C.) ABOVE ROCKFORD DAM, 1926

Day of month	February	March	April	May
1			1.3	13.55
2			1.3	
3		0.5	1.35	14.65
4		0.25		
5		0.0	4.4	
6		0.15		15.05
7		0.0		
8		0.1	3.45	
9		0.65	4.75	
10		0.15		
11		0.4	7.0	
12				
13				
14				
15				
16				
17		1.1		
18	0.1	2.85		
19	0.15		7.15	
20	—0.05	2.3		
21	0.05	2.9	12.2	
22	0.1	2.55	12.5	
23	0.1	3.25		
24	0.45	6.65		
25	0.6	6.2		
26	1.2	4.55	9.45	
27				
28			9.2	
29			10.9	
30				
31		0.05		

* Each temperature is an average of two readings:
(a) 1 foot below surface, and (b) 1 foot above bottom.

and 1° C. must have obtained throughout January and February. On March 18, a rise in temperature began which reached a maximum of 6.7° C. on March 24. During the last days of March the temperature fell again to freezing and then rose steadily through the first three weeks of April, reaching a maximum for the month of 12.5° C. on April 22. The number of leeches declined through the first half of April, until on April

17 only 2 leeches were seen on 51 red-mouth buffalo, and the last leech was seen on a buffalo on April 30, although several hundred red-mouth buffalo were examined for them during the summer.

An effort was made to find out what became of these leeches after they left the fishes. The bottom of the river was sampled in many places where the leech-infested buffalo had been abundant. A number of them were found on April 29 among the fauna living on the vegetation in Long Slough above Rockford. There, on clumps of Elodea, they appeared empty and quite active, in contrast to their well-filled and sluggish condition when found on fishes. Earlier in the spring the fishermen had taken many leech-infested buffalo from this slough. Late in April in the same place, red-mouth buffalo were seen with fungous infections in wounds evidently made by the leeches.

Since the leeches had not been found until late in February, it is not known exactly when they first attacked the buffalo, there having been no fishing since December, when the river had frozen over. It was with considerable interest, therefore, that the buffalo were examined in the fall and early winter of 1926. Leeches first reappeared on them at Rockford and Sterling on November 30, which was after the temperature of the water had dropped to less than 1° C. and the more quiet parts of the river had frozen over. They were also taken by the writer on December 5 and on following days, near Sterling and Oregon, from buffalo in seine hauls made where the ice had been moved away.

The leeches at this time were very small and active, translucent and apparently empty. They measured 8-10 mm. in length, as contrasted with those measuring 20-30 mm. which were taken the preceding spring. They grew rapidly and reached adult size during January. While young, they apparently fed on mucus alone, but as they became larger they were seen to be filled with blood as well as mucus. The number found during this winter was only a small fraction of the number found the preceding winter. Counts made at Sterling in December showed that about one-fourth of the buffalo were infested, and that the average number of leeches per fish was 2. Just as in the preceding spring, they left their hosts as soon as the water temperature had risen a few degrees above freezing. The river remained at or near the freezing point and the leeches remained on the fishes up to March 19, when a three-day rain melted the ice and raised the temperature of the water. On March 22, when the temperature was 40° F. (4.4° C.), very few leeches were left on the fishes, and a few days later there were none.

Since that time, a very thorough search has been made for *Piscicola punctata*, including more than 100 collections taken in all sorts of situations in the river and adjacent waters, but not a single individual has been found.

Moore[1] sums up what is known of the habits of this leech, as follows: "This is our commonest fresh water fish leech. It is common in the ponds

[1] Moore, J. Percy. Classification of the Leeches of Minnesota. Geological and Natural History Survey of Minnesota, Zoological Series, No. V, Part III, p. 105 (1912.)

and lakes of the northern states and the Mississippi Valley and is especially abundant along the Ohio shore of Lake Erie. It lives upon the exterior of the body of various species of small fishes, feeding upon the mucus which covers the surface as well as upon their blood. It appears to be in no way injurious to its hosts. Many examples may also be found living among water plants, to the stems of which there is good reason to believe its stalked cocoons are attached."

DESCRIPTION

The following description, which is based in all particulars on examination of specimens taken on the red mouth buffalo in Rock River, includes the external characteristics only, and in a few items, where there is no disagreement, uses language earlier employed by Moore.

Usual size 15 to 25 mm., but extensible to a greater length; greatest diameter 2 or 3 mm. A narrow neck-like constriction embracing the first few somites behind the anterior sucker; the posterior two-thirds much flattened when the animal is contracted. The posterior sucker when expanded is wider than the widest portion of the body, and normally three or four times the diameter of the anterior sucker. One pair of eyes, with conspicuous bar-like pigment cups, which are place obliquely, converging anteriorly, and which in length are each equal to more than a fourth of the breadth of the anterior sucker. Behind these are two smaller pigment spots, also somewhat bar-like, and easily mistaken for a second pair of eyes.

Living specimens had a translucent greenish ground-color, as described by Verrill, when containing little or no blood; both the upper and lower surfaces of both body and suckers were densely covered nearly everywhere with minute black specks, irregularly arranged. Along each side are eight or more sub-equally spaced pale spots which are partly visible from above, and which are connected with each other lengthwise by narrower pale areas, forming a continuous pale lateral stripe for most of the animal's length. The pale dorsal stripe found by Verrill is only faintly developed or wholly absent in a majority of the specimens which were closely examined. When filled with blood the greenish groundcolor is largely submerged, except on the two suckers, and the general appearance is speckled brownish.

COLOR VARIANT

During this epidemic on the red-mouth buffalo, a different-appearing leech, provisionally identified as a color variant of *P. punctata*, was found on the small-mouth black bass and the wall-eyed pike. It is smaller than the buffalo leech and is dark brown instead of an iridescent pale green. It occurred almost exclusively on the head of its host; fifty were once found about the mouth and branchial region of a small-mouth black bass weighing 1½ pounds. These leeches moved about rather actively and were closely applied to the host throughout their length, while the buffalo leech was usually seen hanging by its caudal sucker, the remainder of the body dangling in the water. These smaller brown leeches apparently fed upon mucus alone, since none were seen filled with blood and no injuries were found on the host which could be attributed to them. They curl up tightly when killed in formalin while the buffalo leech dies straight or but slightly bent. These leeches disappeared from the small-mouth black bass at the same time as did those on the buffalo, and they reappeared in reduced numbers in the following winter.

OTHER SPECIES OF *Piscicola*

Another leech of this genus, *P. milneri* Verrill, is reported by Milner[2] to have been taken in large numbers on fishes in Lake Michigan: "The Ichthyobdellan, a leech of three-fourths of an inch long, grayish white in color, with brown tesselated markings, was seen in great numbers in the month of April, while the fishermen were lifting their nets from about fifty fathoms some fifteen miles out from Kenosha, Wis. They covered the nets and fishes of all species, and fell in such numbers on the deck that it became slippery, and an old coat was thrown down for the man who was lifting the gang to sand upon. They were very tenacious of life, living for a long time on the deck, and for several days in the bilge-water of the fish-boats. They were in such numbers that it was difficult to decide whether they had a preference for any species, and were found filled with blood both in the gills and while attached to the body, though it was difficult to imagine that they could fill themselves with blood from the epidermal sheath of the scales. They were thought to be most numerous on the white-fishes, as they were in greater numbers on them than on the trout, the lawyer, or the cisco, the only other fishes taken. A prevailing but mistaken opinion in the vicinity was that the white-fish fed upon the leech. Dr. Hoy's investigations disproved the notion, and all examinations of stomach-contents confirmed this fact."

Dr. F. B. Adamstone is quoted by Moore[3] in regard to *P. milneri* in Lake Nipigon as follows: "this leech *(piscicola)* is found by hundreds on whitefish, and the decks of the tugs are strewn with them when the nets are lifted." This species is parasitic on whitefish throughout the year, although it is also found free-living (presumably in summer) on floating vegetation and in the more shallow waters. In view of the fact that *P. punctata* infests the red-mouth buffalo only when the water is cold, it may be of some significance that the whitefish spends the warmer months in the deep waters of the lakes where the temperature is close to 4° C.

The European species, *P. geometra* L., is a common pest and well known to fish culturists. According to Plehn,[4] it not only seriously dam-

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[2] Milner, James W. Report on the Fisheries of the Great Lakes; the Results of Inquiries Prosecuted in 1871 and 1872. Rept. U. S. Comm. Fish & Fisheries, Part II, for 1872 and 1873, p. 64.

[3] Moore, J. Percy. The Leeches (Hirudinea) of Lake Nipigon. University of Toronto Studies, Biological Series, No. 25: Publications of the Ontario Fisheries Research Laboratory, XXII-XXVI, page 18. (1924.)

[4] Plehn, Marianne. Praktikum der Fischkrankheiten. Handbuch der Binnenfischerei Mitteleuropas. Band I. Page 339. (1924.)

ages its hosts but also transmits the blood parasite *Trypanoplasma cyprini*. This leech apparently attacks the fishes at all seasons and does not have its parasitic habit restricted to a narrow temperature range.

No evidence of any special seasonal relationship to the host has been found in the literature on other species of this genus occurring in various parts of the world.

EFFECT ON FISH YIELD

The epidemic of *Piscicola punctata* appreciably affected the fish yield of Rock River for the spring of 1926, and the possibility of its continuing to do so should be considered, since the red-mouth buffalo is second only to the carp in commercial importance. While other species of this genus regularly appear in large numbers on fishes in other waters, this is the only known instance where this species assumed the proportions of a pest with which it would be necessary to reckon. Within the memory of the oldest fishermen of Rock River, it has never been seen except in small numbers and at long intervals. During the winter of 1926-1927, it was present in only about one-tenth of the numbers found the previous winter. There were no unusual conditions known to be prevalent in Rock River during these years which could obviously predispose to such an epidemic. Considering these things, it seems likely that *Piscicola punctata* will not continue to occur in sufficient numbers to affect the fish yield and that it may again be relegated to the rarer species of the river fauna.

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DEPARTMENT OF REGISTRATION AND EDUCATION

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STEPHEN A. FORBES, *Chief*

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The Plankton of Lake Michigan

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SAMUEL EDDY

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ERRATA

ges 208, 211, 214, 219—for **Bacellariaceae** read **Bacillariaceae.**

ge 209, middle of table—for **oligactus** read **oligactis.**

ge 211, fifth line in table—for **Aphanotheca** read **Aphanothece.**

ge 213, first line in table—for **oligactus** read **oligactis.**

ge 215, fourth line in table—for **acuminata Ehr.** read **acuminatum (Kutz.) Cl.**

ge 218, sixth paragraph—for **Aphanotheca** read **Aphanothece.**

e 220, fifth paragraph—for **acuminata** read **acuminatum.**

e 224, fourth line from bottom—for **Pandorin** read **Pandorina.**

Omit last line and read **Traverse Bay region.**

e 228, fifth line from bottom—for **Antario** read **Ontario.**

THE PLANKTON OF LAKE MICHIGAN

SAMUEL EDDY

The minute organisms constituting the plankton of the Great Lakes have been studied previously more in connection with investigations of their inter-biotic relations rather than from the primary aspect of the plankton. Perhaps the largest amount of work has been done by investigators who were interested chiefly in the relation of the plankton to the white-fish industry. This is one of the most important phases of plankton work, because the white-fish as well as other fishes of the Great Lakes is dependent upon the plankton for food in its early life (Forbes, 1883)—a fact which has made the study of plankton and plankton production most valuable. Other investigators have made fragmentary studies of the plankton of the Great Lakes for taxonomic purposes; Kellicott, Jennings, and others, for example, devoted their attention to the occurrence of certain groups of organisms and to the number and description of species in those groups as found in the Great Lakes.

The chief purposes of this paper are: (1) to present a general picture of the plankton of Lake Michigan, (2) to determine the relative abundance of its constituent organisms, and (3) to incorporate and summarize the facts now known relating to the plankton of the Great Lakes.

Very little work of a quantitative nature has been published on this subject within the last twenty years. Previous to this period a number of qualitative investigations were made on the plankton of Lake Erie, Lake St. Clair, Lake Michigan, and Lake Superior; and a very important work of both quantitative and qualitative character was done on Lake Michigan in the Traverse Bay region by the Michigan Fish Commission (Ward, 1896). In the latter investigations, which covered both bottom and plankton organisms, the gross quantity of the plankton was estimated from silk-net tows, and some idea of the general character of the plankton was obtained from the relative abundance of the constituent organisms.

METHODS AND MATERIALS

The data for the present paper were obtained from two series of collections made from Lake Michigan in 1887-1888 and 1926-1927. Fifty silk-net tows (Table I) were made by the Illinois State Laboratory of Natural History from November, 1887 to November, 1888 from the breakwater at Chicago. Quantitative silk-net and filter-paper collections (Table II) were made October 16-17, 1926 at Indiana State Dunes Park and Michigan City, Indiana, and near Sawyer, Michigan. Quantitative collections (Table III) were also made May 14-15, 1927 at Dunes Park and Gary, Indiana, and July 10, 1927 at Chicago, Illinois. All of these were surface tows near the shore, so that the material in this paper relates only to surface and in-shore conditions. No investigation has been reported on the plankton or the conditions in the central area of the lake.

The material of the older series of collections, which had been preserved in formalin and glycerin, was found to be in excellent condition. Unfortunately, the accession numbers on some of these collections had become illegible, so that it was impossible to secure definite information in regard to the months of January, February, and March of the year 1888. The collections which were assumed to cover these months showed very little variation in the constituent organisms from those of the other months.

Physical Conditions

Lake Michigan offers a very stable habitat for the production of plankton. Because of its large size and the lack of strong currents, the physical conditions of the water vary but slightly from year to year; therefore, the same constituent organisms may be expected in the plankton over a long period of time. Forbes (1883) found that the conditions of life in Lake Michigan were remarkably uniform throughout the seasons and from year to year and that both plant and animal life exhibited there a regularity and stability in remarkable contrast to their fluctuations in smaller bodies of water and on the surrounding land. There was little change, he found, in the relative number of individuals of the various species or in the absolute number of each. Shelford (Ward and Whipple, 1918) pointed out that Lake Michigan, being a large and deep lake, had none of the seasonal temperature changes extending to the deeper parts. Consequently, as only the surface temperature fluctuates, one would expect the deeper portions to exert a more stabilizing influence on the surface waters than would be found in the waters of more shallow lakes. The stability of the lake as a biotic factor is strikingly demonstrated by our comparisons of data covering a period of forty years, for little or no change has occurred in the composition of the plankton over this long period. Many of the constituent species, though showing slight seasonal variations, are rather constantly abundant throughout the year.

The south end of Lake Michigan is composed of gently-sloping sand beaches exposed to considerable wave action. In the northern portion of the lake there is some rocky shore line. Areas of mud flats and aquatic vegetation are rare. All these conditions are characteristic of a primitive lake. There is little variation in water level or shore line from year to year, and overflow conditions are practically unknown. Cooley (1913) gives the following figures covering the water level for the years 1860-1913:

Greatest yearly range of Lake Michigan........	1.94 ft.
Least " " " " "	.59 ft.
Average " " " " "	1.21 ft.

At the south end the sandy character of the beaches and the strong wave action prevent the growth of vegetation with its consequent influence on the conditions and life of the water. Practically all the plankton, therefore, must originate within the limnetic area. Shallow breeding areas such as Kofoid (1908) found in the backwaters of Illinois River are practically unknown. Adventitious species so common in the plankton of the shore and bottom areas of rivers and shallow lakes are rare.

Stable conditions are insured still further by the extremely slow removal and renewal of the water in the lake. Speaking generally, Ward (Ward and Whipple, 1918) stated that great depth in a body of water and a large inflow in proportion are unfavorable to the abundant production of plankton, and Ward (1896) computed that there is a change of about one-eightieth of the entire volume of Lake Michigan in one year. In other words, there are no extensive outflows to upset the conditions of life in this lake.

The suspended organic matter and silt so common during overflows in rivers and other plankton-bearing waters—and so detrimental to the production of plankton organisms—seem to be at a minimum in Lake Michigan. (The turbidity was not recorded when the collections were made, but it never seemed to be very high.) All things considered, the conditions for plankton production in Lake Michigan approach those of the sea as near as do those of any body of freshwater.

GENERAL CHARACTER

The gross bulk of the plankton in the water, determined from the collections made in 1926-1927, is quite large. Ward (1896) reported that the plankton in the upper two meters in the Traverse Bay region ranged from 8.9 to 14.12 c. c. per cubic meter, and that the abundance of the plankton gradually diminished in the lower levels. His data were obtained by allowing the silk-net collections to settle in a graduated cylinder and computing the volume of the plankton per cubic meter. The same method when used on the recent collections showed an even greater bulk for the surface plankton. The collections of October, 1926, averaged 10 c. c., and those of May, 1927, 40 c. c. per cubic meter. Some differences in bulk may be due to time, locality, and seasonal variations. The heavy bulk of the May, 1927, plankton may be due to a spring condition, as Ward's collections were made in summer.

In general, the plankton of Lake Michigan is that which characterizes large and deep lakes. Its specific character consists principally of diatoms of the genera *Asterionella*, *Striatella (Tabellaria)*, and *Fragilaria*. Limnetic algae are not very conspicuous. Zooplanktonts are generally scarce in numbers, but always present to some extent. In the 1887-1888 collections the zooplanktonts, particularly those of the larger sort, were much more abundant than in the recent collections and sometimes comprised nearly half the total number of organisms present. The absence of the smaller organisms in the older series makes it reasonable to assume that a coarser net must have been used, which would account for the loss of many of the smaller organisms and for the relative abundance of the larger forms.

As quantitative methods were not used in making the 1887-1888 collections, it was impossible to calculate the total volume of plankton at any time during that period. Qualitatively, however, the older series was very similar to the recent series.

At all times in the silk-net collections, the phytoplanktonts greatly outnumbered the zooplanktonts; the latter, however, made up for their smallness in numbers by their much larger individual size. Because of their spines and other peculiarities of shape, the plant species actually occupied a great deal less space than they seemed to at first glance, or than their numbers would indicate. Careful measurements, with an ocular micrometer, of the average actual bulk of the various silk-net organisms showed that the zooplanktonts, although present in much smaller numbers than the plant species, often comprised nearly one-half the total bulk. Considerable variation of this ratio between the animal and plant constituents was shown in different collections, depending on seasonal and other factors. This ratio would not apply to the total plankton of the lake, because not enough data were obtained in regard to the smaller organisms (nannoplankton), some of which escaped through the net but were found in the few filter-paper collections.

In all, 119 species were found, most of which were typical plankton species. More data on the nannoplankton would undoubtedly greatly increase this number. Sixty of these species were phytoplanktonts and fifty-nine were zooplanktonts. This is only about one-fifth of the total number of the species listed in the various reports of previous investigators as occurring in the waters of the Great Lakes. Of the 66 species occurring in our 1887-1888 collections, 17 (at least three of which were adventitious) did not occur in our recent collections; most of these were never abundant and could have been easily lost in the later collections. Of the 102 species occurring in our 1926-1927 collections, 53 were not observed in the earlier collections; these were either rare or, as previously mentioned, were so small as to escape through the meshes of the net. Many species of algae which were not noted in the earlier series showed up in the recent series, though none of them were abundant. There is no evidence that any of the missing species did not exist in both periods. Anyone familiar with the methods of plankton study can easily understand how some of the smaller organisms by their scanty distribution can easily escape collection and observation. The 49 species which were common to both periods were usually the larger and most abundant organisms.

A rich diatom flora predominated in all the collections, the same species occurring in both periods with few exceptions. Those species which were most abundant in the recent series appeared in the same proportions in the earlier series.

The same species of copepods occurred in both periods with the notable exception of *Epischura lacustris* Forbes, which was abundant in the early collections but did not appear at all in the recent ones. The same species of cladocerans were scattered throughout both series. The Protozoa and Rotifera, never abundant, were limited to a few common species occurring in most of the collections, and as they are hard to preserve for identification not enough good determinations could be made of most of them to establish their distribution.

SEASONAL ASPECT

The data are not extensive enough to justify any definite statement of seasonal variations in the bulk of the plankton, although the fall collections of 1926 showed only one-fourth the bulk of the spring collections of 1927. Seasonal variations in constituent species were noticeably lacking, the dominant diatoms running almost uniformly through the collections of 1887-1888. *Asterionella gracillima*, reported as a spring species in the Illinois River by Kofoid (1908), was abundant throughout the different months, as also were *Lysigonium (Melosira)*, *Striatella (Tabellaria)*, *Synedra*, and *Fragilaria*. Other less abundant diatoms generally appeared irregularly in the collections. Forbes (1883) concluded, from his own observations and those of B. W. Thomas over a period of sixteen years, that there was little change in the constituent organisms in Lake Michigan from one season to another, although he noted a slight increase in number of species in the spring and summer months. In the 1887-1888 collections, the zooplanktonts showed a decided decrease in the colder months, being almost entirely absent in the collections of December and in those attributed to January, February, and March.

GENERAL DISTRIBUTION

A fairly uniform distribution of the plankton of Lake Michigan is to be expected, and very little difference has been noticed in the specific character of the plankton at different points. The off-shore waters of Lake Michigan are fairly well mixed by circulation; currents sweep southward on the west side, turn at the south end, and flow northward on the east side (Harrington, 1895), so that the water bearing the plankton at Chicago is, a few days later, off Michigan City, Indiana.

In all the collections examined, the exact number of organisms was never the same, and absolute uniformity has never been reported in plankton investigations. A tendency to swarm is indicated by the variations in abundance in all collections. Reighard (1894) found evidence of plankton swarming in Lake St. Clair. Forbes (1883) found that the plankton was not equally distributed throughout the water and was more dense off the mouths of rivers. These variations, however, were not usually as great as those between different habitats or seasons.

TABLE I.—AVERAGE MONTHLY RELATIVE ABUNDANCE OF PLANKTON ORGANISMS IN LAKE MICHIGAN, 1887-1888, AT CHICAGO

Organisms	1887		1888						
	Nov.	Dec.	Apr.	May	June	July	Aug.	Sept.	Oct.
Cyanophyceae									
Merismopedia glauca (Ehr.) Nag.*	......	......	......	......	rare	......	......	......	......
Coeleosphaerium kutzingianum Nag.*	occ.	......	......	......	......	......	rare	rare	......
Anabaena sp.	......	rare	......	......	......	......	......	rare	occ.
Lyngbia sp.	......	......	......	......	......	......	......	......	rare
Oscillatoria princeps Vaucher*	......	......	......	......	......	......	......	......	rare
Bacellariaceae									
Lysigonium varians Ag.	occ.	occ.	occ.	occ.	occ.	occ.	com.	abd.	com.
Lysigonium granulata (Ehr.) Ralfs.	com.	......	occ.	abd.	......	......	occ.	abd.	com.
Cyclotella sp.	com.	rare	......	com.	......	rare	occ.	occ.	......
Stephanodiscus niagarae Ehr.	occ.	......	......	com.	rare	rare	occ.	occ.	......
Striatella fenestrata (Kütz.) Kuntze	abd.	v. abd.	abd.	abd.	v. abd.	v. abd.	abd.	abd.	v. abd.
Striatella flocculosa (Roth.) Kuntze	com.	occ.	com.	occ.	......	......	......	occ.	com.
Fragilaria crotonensis (Edw.) Kitton	abd.	abd.	com.	abd.	occ.	com.	abd.	abd.	abd.
Fragilaria virescens Ralfs.	occ.	occ.	com.	com.	com.	occ.	com.	com.	occ.
Synedra tenuissima Kütz.	occ.	occ.	......	abd.	......	......	......	occ.	......
Synedra ulna (Nitz.) Ehr.	abd.	com.	abd.	abd.	com.	com.	abd.	abd.	abd.
Asterionella gracillima (Hantz.) Heib.	abd.	v. abd.	com.	abd.	......	......	occ.	com.	com.
Navicula sp.	......	......	......	occ.	......	......	......	......	......
Cocconeis placentula Ehr.	......	......	......	occ.	......	......	......	......	......
Gomphonema acuminatum Ehr.	abd.	......	com.	rare	......	......	rare	occ.	occ.
Encyonema prostratum Berk.	occ.	......	......	......	......	......	......	......	com.
Sphinctocystis librilis (Ehr.) Hass.	rare	......	......	......	rare	rare	rare	rare	......
Sphinctocystis eliptica (Kütz.) Kuntze	......	......	......	......	......	rare	......	......	......
Chlorophyceae									
Spirogyra sp.	......	......	occ.	occ.	occ.	......	......	......	......
Dictyosphaerium pulchellum Wood	......	......	......	......	......	......	rare	......	......
Coelastrum reticulatum (Dangeard.) Senn.*	......	......	......	......	......	......	......	rare	......
Pediastrum boryanum (Turpin) Menegh.*	rare	......	......	......	......	rare	rare	......	......

Protozoa									
Centropyxis aculeata Stein						rare			
Difflugia globulosa Duj.					rare	occ.	abd.	rare	occ.
Difflugia lebes Penard								rare	occ.
Trachelomonas hispida Stein								occ.	
Dinobryon sertularia Ehr.							rare		
Peridinium tabulatum Ehr.							occ.		
Ceratium hirundinella Müll.				rare			occ.	rare	
Codonella cratera (Leidy)						rare	rare	occ.	
Vorticella sp.								rare	
Thuricola sp.								rare	
Podophrya sp.								rare	
Acineta sp.								rare	
Coelenterata									
Hydra oligactus Pallas		rare						rare	
Rotatoria									
Polyarthra trigla Ehr.				rare		rare		rare	
Trichocera cylindrica (Imhof.)								rare	
Lepadella oblonga (Ehr.)						rare			
Trichotria tetractis (Ehr.)						rare			
Keratella cochlearis (Gosse)				rare		occ.	occ.	occ.	occ.
Keratella quadrata (Müll.)						rare			
Notholca longispina Kellicott				rare	occ.	com.	occ.	occ.	occ.
Notholca striata Müll.						rare			
Brachionus capsuliflorus Pallas							rare		
Asplanchna priodonta Gosse							occ.		
Conochiloides dossuaris (Hudson)							rare		

* Filaments or colonies.

TABLE I—Concluded

Organisms	1887		1888						
	Nov.	Dec.	Apr.	May	June	July	Aug.	Sept.	Oct.
Cladocera									
Sida crystallina (Müll.)	......	......	......	......	......	......	......	rare	......
Diaphanosoma leuchtenbergianum Fischer	......	......	......	......	......	......	......	rare	com.
Daphnia retrocurva Forbes	com.	......	com.	com.	......	rare	occ.	occ.	rare
Daphnia longispina (Leydig)	rare	......	......	com.	......	rare	......	occ.	......
Bosmina longirostris (Müll.)	......	......	rare	......	rare	rare	rare	occ.	rare
Bosmina longispina Leydig	com.	......	com.	abd.	com.	com.	rare	com.	occ.
Alona sp.	......	......	......	......	......	rare	......	......	......
Chydorus sphaericus (Müll.)	......	......	......	......	......	occ.	rare	......	......
Leptodora kindtii (Focke)	......	......	......	......	......	......	......	......	occ.
Copepoda									
Epischura lacustris Forbes	abd.	......	abd.	abd.	......	occ.	abd.	abd.	occ.
Diaptomus sicilis Forbes	......	......	......	......	occ.	......	occ.	occ.	......
Diaptomus minutus Lillj.	com.	......	......	occ.	......	abd.	com.	abd.	occ.
Limnocalanus macrurus Sars	......	......	......	......	......	......	......	occ.	......
Cyclops bicuspidatus Claus	com.	......	com.	com.	......	abd.	com.	com.	occ.
Cyclops prasinus Fischer	rare	......	abd.	......	......	......	rare	occ.	occ.
Cyclops fimbriatus Fischer	......	......	......	......	......	occ.	occ.	com.	occ.
Young Copepods	......	......	......	......	......	......	......	rare	......

TABLE II.—ABUNDANCE OF PLANKTON ORGANISMS (PER CUBIC METER) IN COLLECTIONS FROM LAKE MICHIGAN, OCTOBER, 1926

Organisms	Dunes Park, Ind. 10/17/1926 (2 silk-net collections)	Michigan City 10/17/1926 (3 silk-net collections)	Sawyer, Mich. 10/18/1926 (2 silk-net collections)	Michigan City 10/17/1926 (2 filter-paper collections)
Cyanophyceae				
Merismopedia glauca (Ehr.) Nag.*	3,750	200	250	....
Coelosphaerium kutzingianum Nag.*	52,500	90,000	25,000	....
Aphanocapsa elachista W. & G. S. West*	11,350	16,000	10,000	....
Aphanocapsa delicatissima W. & G. S. West*	3,750	8,000	1,250	....
Aphanotheca sp.*	18,750	12,000	7,500	....
Chroococcus limneticus Lemm.*	3,750	....	1,200	....
Chroococcus dispersus (v. Keiss) Lemm.*	300	....	100	....
Anabaena sp.	....	....	20,000	....
Bacellariaceae				
Lysigonium varians Ag.	7,000	400,000	10,000	1,350,000
Lysigonium granulata (Ehr.) Ralfs.	....	....	37,500	900,000
Stephanodiscus niagarae Ehr.	11,250	8,000	5,000	200,000
Cyclotella sp.	18,750	20,000	2,500	42,000
Striatella fenestrata (Kütz.) Kuntze	3,750,000	6,000,000	2,000,000	30,060,000
Striatella flocculosa (Roth.) Kuntze	2,310,000	1,000,000	400,000	28,000,000
Fragilaria crotonensis (Edw.) Kitton	60,600,000	48,000,000	12,500,000	16,000,000
Fragilaria virescens Ralfs.	37,500	....	20,000	40,000,000
Synedra tenuissima Kütz.	562,500	800,000	100,000	7,200,000
Synedra ulna (Nitz.) Ehr.	300,000	800,000	300,000	9,500,000
Asterionella gracillima (Hantz.) Heib.	3,750,000	2,520,000	2,500,000	15,000,000
Amphiprora alata (Ehr.) Kütz.	375	200	250	....
Sphinctocystis eliptica (Kütz.) Kuntze	1,875	8,000	2,500	4,000
Sphinctocystis librilis (Ehr.) Hass.	3,750	4,000	250	....

* Per filaments or colonies.

TABLE II—Concluded

Organisms	Dunes Park, Ind. 10/17/1926 (2 silk-net collections)	Michigan City 10/17/1926 (3 silk-net collections)	Sawyer, Mich. 10/18/1926 (2 silk-net collections)	Michigan City 10/17/1926 (2 filter-paper collections)
Chlorophyceae				
Closterium gracile Brèb.	....	200	25,000	....
Chrysosphaerella longispina Lauter.*	....	36,000	5,000	....
Rhizochrysis limneticus G. M. Smith*	....	4,000	....	....
Dictyosphaerium pulchellum Wood*	48,750	5,000	20,000	....
Botryococcus sudeticus Lemm.*	1,875	4,000	2,500	....
Kirchneriella obesa Schmidle	....	200	....	....
Oocystis sp.*	....	....	200	....
Coelastrum reticulatum (Dangeard.) Senn.*	7,500	2,000	7,500	....
Tetrastrum sp.	....	....	200	....
Scenedesmus quadricauda (Turpin) Brèb.	....	....	200	....
Pediastrum duplex Meyen.*	187	40	2,500	....
Pediastrum simplex (Bail.)*	350	200	....	....
Pediastrum boryanum (Turpin) Menegh.	7,000	100	1,200	....
Protozoa				
Centropyxis aculeata Stein	....	....	200	....
Difflugia globulosa Duj.	11,250	6,000	25,000	....
Difflugia pyriformis Perty	....	100	100	....
Eudorina elegans Ehr.*	....	100	....	4,500
Uroglena americana Calkins*	....	....	250	....
Dinobryon sertularia Ehr.	....	900,000	250,000	860,000
Ceratium hirundinella Müll.	18,750	14,000	7,500	10,300
Codonella cratera (Leidy)	....	100	2,500	18,000

Coelenterata				
Hydra oligactus Pallas	...	100	...	...
Rotatoria				
Synchaeta stylata Wierz.	23,100	200	1,000	...
Polyarthra trigla Ehr.	3,750	200	100	...
Diurella sp.	...	400	...	...
Keratella cochlearis (Gosse)	7,500	2,000	200	18,000
Notholca longispina Kellicott	...	100	100	...
Schizocerca diversicornis Daday	...	50	...	...
Cladocera				
Sida Crystallina (Müll.)	370	...	...	...
Daphnia retrocurva Forbes	300	100	...	...
Ceriodaphnia lacustris Birge	...	...	100	...
Bosmina obtusirostris Sars	...	100	...	...
Bosmina longispina Leydig	3,750	4,000	5,000	...
Copepoda				
Diaptomus ashlandi Marsh	...	500	...	...
Diaptomus minutus Lillj.	...	500	500	...
Cyclops bicuspidatus Claus	50	50	100	...
Cyclops prasinus Fischer	400	2,000	1,200	...

* Per filaments or colonies.

TABLE III.—ABUNDANCE OF PLANKTON ORGANISMS (PER CUBIC METER) IN COLLECTIONS FROM LAKE MICHIGAN, MAY AND JULY, 1927

Organisms	Gary, Ind. May 14, 1927 (2 silk-net collections)	Dunes Park, Ind. May 14, 1927 (2 silk-net collections)	Dunes Park, Ind. May 15, 1927 (2 silk-net collections)	Dunes Park, Ind. May 14, 1927 (2 filter-paper collections)	Chicago, Ill. July 10, 1927 (2 silk-net collections)
Cyanophyceae					
Merismopedia glauca (Ehr.) Nag.*	....	....	200	....	....
Chroococcus dispersus (v. Keiss) Lenn.*	8,450	6,000	18,000	....	....
Chroococcus minutus (Kütz.) Nag.*	....	300	....	....	50,000
Coelosphaerium naegelianum Unger*	....	....	....	....	112,000
Gomphosphaeria aponina Kütz.*	....	....	....	....	4,000
Lyngbia sp.	67,600,000	120,000,000	48,000,000	825,000,000	....
Anabaena sp.	....	....	8,000,000	....	....
Anabaena circinalis (Kütz.) Rab.	....	....	....	....	300,000
Bacellariaceae					
Lysigonium varians Ag.	84 500	30,000	40,000	11,000,000	60,000
Lysigonium sp.	67,600	300,000	100,000	....	....
Cyclotella sp.	8,450	6,000	6,000	1,760,000	128,000
Stephanodiscus niagarae Ehr.	25,350	12,000	9,000	500,000	60,000
Striatella fenestrata (Kütz.) Kuntze	8,450,000	9,600,000	9,600,000	143,000,000	32,000,000
Striatella flocculosa (Roth.) Kuntze	....	300	....	44,000,000	9,000,000
Fragilaria virescens Ralfs.	1,267,500	720 000	40,000	8,250,000	7,680,000
Fragilaria crotonensis (Edw.) Kitton	67,600,000	18,000,000	48,000,000	200,000,000	384,000,000
Synedra tenuissima Kütz.	1,183,000	2,700,000	2,400,000	24,000,000	1,000,000
Synedra ulna (Nitz.) Ehr.	718,650	7,500,000	6,000,000	176,000,000	3,200,000

Asterionella gracillima (Hantzsch.) Heib.	30,420,000	34,000,000	13,600,000	100,000,000	56,960,000
Navicula sp.				2,250,000	8,000
Cocconeis placentula Ehr.			6,000	1,000,000	
Gyrosigma acuminata Ehr.		300	400		400
Amphiprora ornata Bailey				300,000	48,000
Gomphonema acuminatum Ehr.				1,200,000	
Cymbelia lanceolata (Ehr.) Kirchn.		3,000	800		
Encyomema prostatum (Berk.) Kütz.				1,400,000	
Cystopleura turgida (Ehr.) Kuntze		12,000	600	700,000	
Cystopleura sp.		5,000			
Homococladia sigmoidea (Nitz.) Elmore		600		11,000	
Sphinctocystis eliptica (Kütz.) Kuntze		6,000	2,000	11,000	2,000
Sphinctocystis librilis (Ehr.) Hass.		12,000	300		64,000
Surirella robusta Ehr.					85
Campylodiscus hibernicus Ehr.		300			
Chlorophyceae					
Closterium gracile Brèb.		600		16,500	
Closterium moniliferum (Bory.) Ehr.					80
Cosmarium sp.			500	27,000	
Spirogyra sp.*	845	600			
Rhizochrysis limneticus G. M. S.*					400
Dictyosphaerium pulchellum Wood.*	16,900	12,000	7,000	16,500	112,000
Oocystis sp.				30,000	
Sphaerocystis schroeteri Chodat	845				8,000
Ankistrodesmus falcatus (Corda.) Ralfs.		300	2,000	1,350,000	8,000
Coelastrum microporum Nag.*	8,450			11,000	4,000
Scenedesmus bijuga (Turpin) Lag.*	8,450			16,500	
Scenedesmus quadricauda (Turpin.) Brèb.*	4,225	600		33,000	
Crucigenia sp.	4,225				1,000
Pediastrum boryanum (Turpin.) Menegh.*		300			

* Per filaments or colonies.

TABLE III—Concluded

Organisms	Gary, Ind. May 14, 1927 (2 silk-net collections)	Dunes Park, Ind. May 14, 1927 (2 silk-net collections)	Dunes Park, Ind. May 15, 1927 (2 silk-net collections)	Dunes Park, Ind. May 14, 1927 (2 filter-paper collections)	Chicago, Ill. July 10, 1927 (2 silk-net collections)
Protozoa					
Centropyxis aculeata Stein	....	....	200	....	....
Difflugia globulosa Duj.	....	....	300	....	....
Difflugia corona Wallich	....	600	150	....	....
Difflugia pyriformis Perty	....	....	200	....	....
Actinophrys sol Ehr.	....	....	200	11,000	....
Trachelomonas hispida (Perty)	....	....	....	165,000	....
Euglena oxyuris Schmarda	....	600	....	275,000	....
Chlamydomonas sp.	....	....	....	330,000	....
Phacus triqueter (Ehr.)	....	....	....	16,500	....
Cryptomonas ovata Ehr.	....	....	....	110,000	....
Dinobryon sertularia Ehr.	....	30,000	....	7,000,000	320,000
Eudorina elegans Ehr.	....	1,200	500	....	....
Uroglena americana Calkins	4,225	....	....	....	....
Codonella cratera Leidy	....	1,200	....	....	32,000
Vorticella sp.	....	....	....	220,000	....
Nemathelminthes					
Nematoda	....	600	....	11,000	....
Rotatoria					
Synchaeta tremula Ehr.	6,336	24,000	3,500	16,500	....
Polyarthra trigla Ehr.	845	300	....	16,000	....
Keratella cochlearis (Gosse.)	100	600	550	17,000	15,000
Keratella quadrata (Müll.)	8,450	....	300	....	....
Notholca striata Müll.	1,690	1,200	2,500	....	75
Filinia longiseta (Ehr.)	....	....	....	800	....

Cladocera					
Bosmina longispina Leydig	12,675	....	1,200	....	120,000
Leptodora kindtii (Focke)	....	....	....	....	80
Copepoda					
Diaptomus ashlandi Marsh	....	....	200	....	2,000
Diaptomus minutus Lillj.	845	....	300	....	1,600
Cyclops bicuspidatus Claus	4,225	300	200	....	2,000
Cyclops prasinus Fischer	1,650	600	1,500	....	6,000
Young Copepoda	16,900	1,200	1,200	....	4,000
Canthocamptus sp.	4,225	....	....	....	....

NOTES ON CONSTITUENT ORGANISMS

CYANOPHYCEAE (BLUE-GREEN ALGAE)

The blue-green algae, never very abundant in plankton collections of Lake Michigan, were represented by a few species which were usually present in small numbers in most of our collections. Fourteen species were noted in all. Snow (1902) listed thirty-four species from Lake Erie. Ward (1896) noted several species from the Traverse Bay region. Whipple (Leighton, 1907) found three genera of blue-green algae in Lake Michigan at Chicago.

Merismopedia: *Merismopedia glauca* (Ehr.) Nag. appeared in small quantities in the collections of June, 1888. Fragments of the plate-like colonies occurred in the plankton Oct. 17-18, 1926 at Dunes Park, Michigan City, and Sawyer, and May 15, 1927 at Dunes Park. The colonies were never very abundant, averaging about 200 per c. m., although 3,750 per c. m. were counted in the 1926 collection from Dunes Park. Snow found this species in Lake Erie. Ward recorded *M. convoluta* Breb. at Traverse Bay.

Coelosphaerium: *Coelosphaerium kutzingianum* Nag. occurred in small numbers in the collections of Nov. 1887, Aug. and Sept. 1888, and Oct. 1926. The colonies reached a count of 90,000 per c. m. at Michigan City, Oct. 17, 1926. The absence of this species in all the spring collections suggests that it is not a spring form. Because of its small size and relative scarcity, it appeared to be of no great importance. Colonies of *C. naegelianum* Unger were common (112,000 per c. m.) in the plankton July 10, 1927 at Chicago. Snow recorded *C. Kutzingianum* Nag. and *C. roseum* Snow from Lake Erie.

Gomphosphaeria: Colonies of *Gomphosphaeria aponina* Kutz. occurred only sparingly (4,000 per c. m.) July 10, 1927 at Chicago. This species was reported from Lake Erie by Snow.

Aphanocapsa: Floating colonies of *Aphanocapsa elachista* W. & G. S. West appeared only in the collections made in the fall of 1926, when they were quite common. Colonies of much smaller cells, *A. delicatissima* W. & G. S. West, occurred at the same time but were never as abundant.

Aphanotheca: Colonies of an undetermined species belonging to this genus were quite common in the plankton collections in the fall of 1926.

Chroococcus: Three species of *Chroococcus* occurred in the recent collections. Probably because of the small size of the colonies, none of this genus were found in the earlier collections. Colonies of *C. dispersus* (V. Keiss.) Lemm. were found occasionally in the 1926-1927 collections. *C. minutus* (Kutz.) Nag. and *C. limneticus* Lemm. occurred sparingly in the 1926 collections. Snow reported the latter species and also *C. pallidus* Ehr. and *C. purpureus* Snow from Lake Erie.

Anabaena: Filaments of a very small undetermined species of *Anabaena* occurred sparingly in some of the collections of Dec. 1887, Sept. 1888, Oct. 1888, Oct. 1926, and May 1927. It was never abundant and was probably lost through the meshes of the net in many of the collections. *A. circinalis* (Kutz.) Rab. was common (300,000 per c. m.) in the silk-net collections July 10, 1927 at Chicago. Snow reported this species from Lake Erie. Ward recorded *A. flos-aquae* Kg. from the Traverse Bay region.

Lyngbia: An undetermined species of *Lyngbia* occurred abundantly in all the 1927 collections. This form was found sparingly in the collections of Oct. 1888. Snow found *L. wollei* Farlow in Lake Erie.

Oscillatoria: A few strands of *Oscillatoria princeps* Vaucher occurred in the collections of Oct. 1888. Snow recorded a number of species from Lake Erie but not this same species.

BACELLARIACEAE (DIATOMS)

Diatoms are the most abundant organisms in the plankton of Lake Michigan. Every collection contained them in large numbers. Twenty-six species, chiefly of four genera, were noted in all. Thomas and Chase (1886) collected 215 species of diatoms during a period of sixteen years from the water supply of Chicago, many of which undoubtedly were not plankton diatoms. Thompson (Ward, 1896) found diatoms very abundant at Traverse Bay and listed fourteen species. Whipple (Leighton, 1907) gave eight genera as being common in Lake Michigan at Chicago.

Lysigonium (Melosira): *Lysigonium varians* Ag. was common in all the collections examined. *L. granulata* (Ehr.) Ralfs. occurred occasionally, and a species of this genus resembling *L. arenaria* Moore was abundant in the October 1926 collections. Snow reported *Melosira arenaria* Moore, *M. granulata* (Ehr.) Ralfs., and *M. varians* Ag. from Lake Erie; but neither Whipple nor Ward reported any species of this genus.

Cyclotella: A species of *Cyclotella* resembling *C. meneghiniana* Rabh. was common (2,500-1,760,000 per c. m.) in the collections of 1926 and 1927. This small diatom occurred sparingly in the 1887-1888 collections. Snow reported four species of *Cyclotella* from Lake Erie. Ward listed *C. operculata* K. from the Traverse Bay region. Whipple found this genus abundant at Chicago.

Stephanodiscus: *Stephanodiscus niagarae* Ehr. occurred occasionally in most of the collections and was abundant in the 1927 collections, reaching a maximum of 500,000 per c. m. in a filter-paper collection May 14, 1927 at Dunes Park. Snow found *S. niagarae* in Lake Erie. Ward reported this species from Traverse Bay, but Whipple listed it as absent from Lake Michigan at Chicago.

Striatella (Tabellaria): *Striatella fenestrata* (Kutz.) Kuntze was one of the most abundant organisms in the plankton, reaching a maximum of 143,000,000 per c. m. May 14, 1927 at Dunes Park. Every collection throughout the year of 1887-1888 was filled with the zigzag chains of this diatom. *S. flocullosa* (Roth.) Kuntze was plentiful in most of the collections but never as abundant as *S. fenestrata.* Thompson found both species abundant in the Traverse Bay region, Snow reported them from Lake Erie, and Thomas and Chase found them in the Chicago water supply. Whipple listed this genus as abundant in Lake Michigan at Chicago.

Fragilaria: *Fragilaria virescens* Ralfs. and *F. crotonensis* (Edw.) Kitton were abundant at all times. The ribbon-like strands of these diatoms, together with *Striatella*, *Synedra*, and *Asterionella*, composed most of the plankton. The most abundant of all the organisms in the plankton was *F. crotonensis*, which reached a maximum of 384,000,000 per c. m. in a silk-net collection July 10, 1927 at Chicago. Thompson reported *F. capucina* Desm. as very common in Traverse Bay. Snow listed *F. crotonensis* and *F. virescens* from Lake Erie. Whipple found this genus only occasionally in Lake Michigan at Chicago. Chase and Thomas reported six species of this genus, including *F. virescens* but not *F. crotonensis*, from the Chicago water supply.

Synedra: *Synedra ulna* (Nitzsch.) Ehr. and *Synedra tenuissima* Ehr. were abundant in all collections. *S. ulna*, one of the most abundant, reached a maximum of 176,000,000 per c. m. May 14, 1927 at Dunes Park, while *S. tenuissima*, although never so abundant, reached a maximum of 24,000,000 on the same date. Both species appeared to flourish more abundantly in the spring and late fall than in other seasons. Thompson reported *S. ulna* and *S. affinis* Kutz. in Traverse Bay. Snow reported *S. ulna* and *S. oxyrhynchus* Kg. from Lake Erie. Thomas and Chase listed fourteen species of this genus including *S. ulna* but not *S. tenuissima* from the Chicago water supply.

Asterionella: *Asterionella gracillima* (Hantzsch.) Heib., one of the most common diatoms, occurred in all collections except those of June and July, 1888. Its occurrence throughout the rest of the year suggests that it has a longer season of growth in Lake Michigan than in other nearby waters, possibly because of the lower temperatures of Lake Michigan. Kofoid (1908) reported this species as a spring form in Illinois River with a maximum abundance of 891,000,000 per c. m. The greatest abundance observed in Lake Michigan was 100,000,000 May 14, 1927 in a filter-paper collection at Dunes Park. Thompson reported *A. formosa* Hass. from Traverse Bay. Snow also listed *A. formosa* from Lake Erie. Whipple found *Asterionella* to be the most abundant genus at Chicago. Chase and Thomas listed *A. formosa* from the Chicago water supply.

Navicula: Several undetermined species of *Navicula* occurred very sparingly in the collections of 1927. Diatoms of this genus never appeared in any quantity in any of the collections. Ward listed three species of *Navicula* from Traverse Bay, and Whipple found *Navicula* to be common at Chicago. Snow recorded three species from Lake Erie. Forty-nine species of this genus were listed by Thomas and Chase from the Chicago water supply, but many of them undoubtedly were not plankton species.

Cocconeis: *Cocconeis placentula* Ehr. was found rather sparingly May 1888 at Chicago and May 1927 at Dunes Park. This species reached a maximum abundance of 100,000 per c. m. in the filter-paper collections. Snow recorded this species from Lake Erie. Ward found *C. transversalis* Greg. in Traverse Bay. Thompson reported *C. placentula* as being dredged from the bottom of Traverse Bay. Thomas and Chase listed *C. lineata* K. and *C. pediculus* Ehr. from the Chicago water supply.

Gyrosigma (Pleurosigma): *Gyrosigma acuminata* (Kutz.) Cl. was found sparingly at Dunes Park, May 14, 1927, but was not observed in any other collections. *G. attenuatum* Sm. was reported by Snow from Lake Erie but was not among the six species of this genus listed by Thomas and Chase from the Chicago water supply.

Amphiprora: *Amphiprora ornata* Bailey occurred (300,000 per c. m.) in the filter-paper collections May 15, 1927 at Dunes Park and also (48,000) in the silk-net collections July 10, 1927 at Chicago. *A. alata* (Ehr.) Kutz. was found sparingly in the collections made Oct. 17-18, 1926. These species have not been reported by other workers in any of the Great Lakes except by Thomas and Chase who reported *A. calumetica* Thomas and *A. ornata* from the Chicago water supply.

Gomphonema: *Gomphonema acuminatum* Ehr., which occurred very sparingly in the silk-net collections at Dunes Park May 14, 1927, was quite common in the 1887-1888 collections except during the months of June, July, and December. It usually appeared in swarms attached to floating debris. Snow reported this species and three others from Lake Erie. Thomas and Chase listed eighteen species including *G. acuminatum* from the Chicago water supply.

Cymbella: *Cymbella lanceolata* (Ehr.) Kirchn. occurred sparingly in the silk-net collections May 14-15, 1927 at Dunes Park but did not appear in any of the other collections. Snow reported *C. maculata* Kg. and *C. rotundata* H. H. C. from Lake Erie. Thompson found *C. gastroides* to be common in the Traverse Bay region. Thomas and Chase reported twelve species including *C. lanceolata* from the Chicago water supply.

Encyonema: *Encyonema prostratum* (Berk.) Kutz. occurred in the filter-paper collections (1,400,000 per c. m. May 14, 1927) at Dunes Park. This species appeared in collections of Nov. 1887 and Oct. 1888, apparently having Thomas and Chase found it and three others of this genus in the Chicago a fall and spring distribution. Snow reported this species from Lake Erie. water supply.

Cystopleura: *Cystopleura turgida* (Ehr.) Kuntze occurred frequently in the collections May 14-15, 1927 from Dunes Park. An undetermined species of this genus also occurred rather sparingly in the same collections. No species of this genus were observed in any other collections. Snow reported *Cystopleura (Epithemia) turgida* and three other species of this genus from Lake Erie. Thomas and Chase listed six species of this genus including *C. turgida* from the Chicago water supply.

Homoeocladia: *Homoeocladia sigmoidea* (Nitz.) Elmore was found sparingly in some of the collections May 14, 1927 from Dunes Park, but did not appear in any of the other collections. Snow reported this species as *Nitzschia sigmoidea* (Nitzsch.) Sm. and another species, *N. linearis* Sm., from Lake Erie. Thompson recorded *N. sigmoidea* from Traverse Bay. Whipple listed diatoms belonging to *Nitzschia* as being very abundant at Chicago. Thomas and Chase found eleven species of this genus including *N. sigmoidea* in the Chicago water supply.

Sphinctccystis: *Sphinctocystis eliptica* (Kutz.) Kuntze occurred sparingly in the 1926-1927 collections. It was found only once (in June) in the collections of 1888. *S. librilis* (Ehr.) Hass. was present in small numbers in most of the 1887-1888 collections, not appearing from Dec. to April, and in most of the 1926-1927 collections. Snow reported *S. (Cymatopleura) eliptica* Sm. and *S. solea* Breb. from Lake Erie. Thomas and Chase listed five species of *Cymatopleura*, including *C. eliptica* but not *C. librilis*, from the Chicago water supply.

Surirella: *Surirella robusta* Ehr. occurred very sparingly (85 per c. m.) July 10, 1927 at Chicago. Snow recorded three species of this genus but not this species from Lake Erie. Thomas and Chase listed 10 species of this genus but not *robusta* from Lake Michigan at Chicago.

Campylodiscus: *Campylodiscus hibernicus* Ehr. was found in very small numbers in one silk-net collection from Dunes Park, May 14, 1927. Snow reported *C. cribrosus* Sm. from Lake Erie. Thomas and Chase listed *C. hibernicus* and *C. noricus* Ehr. from the Chicago water supply.

CHLOROPHYCEAE (GREEN ALGAE)

The green algae were never abundant in the plankton of Lake Michigan. Twenty species, some of which were very rare, occurred in the collections. Many of the smaller species which occurred rarely in the recent series did not appear in the earlier series; this may have been due to the use of a coarser net through which most of the smaller forms were lost. Snow (1902) recorded 126 species from Lake Erie. Thompson (Ward,

1896) reported that the green algae were almost entirely absent from the Traverse Bay region, as he found only a few species there. Whipple (Leighton, 1907) listed seven genera as common in Lake Michigan at Chicago.

Closterium: *Closterium gracile* Breb., which occurred sparingly in most of the recent collections, was not observed in any of the 1887-1888 collections. *C. moniliferum* (Bory) Ehr. occurred only in the July 1927 collections (80 per c. m.). Snow noted six species of this genus from Lake Erie but did not include *gracile* and *monoliferum*. Whipple reported *Closterium* as occurring occasionally in Lake Michigan at Chicago.

Spirogyra: Fragments of *Spirogyra* (several unidentified species) were found occasionally in the 1927 collections and in the collections of April and June 1888. This genus was not reported by Snow or Thompson, although it was noted by Whipple as "occasional" at Chicago especially around the water supply crib.

Cosmarium: An undetermined species of *Cosmarium* was found only in the filter-paper collections May 14, 1927 at Dunes Park (27,000 per c. m.). This species may have been lost through the meshes in the silk-net collections. Snow listed eleven species of *Cosmarium* from Lake Erie.

Chrysophaerella: Some colonies of green algae agreeing with *Chrysophaerella longispina* Lauterborn were quite common in the collections Oct. 17-18, 1926 at Michigan City and Sawyer and July 10, 1927 at Chicago. This species did not appear in any of the other collections and was not reported from the Great Lakes by any of the previous investigators.

Dictyosphaerium: Colonies of *Dictyosphaerium puchellum* Wood were quite common in all of the 1926-1927 collections. The greatest abundance recorded was 112,000 colonies per c. m. in a silk-net collection July 10, 1927 at Chicago. This species occurred in small numbers in the collections of August 1888. Snow reported *D. puchellum* and *D. ehrenbergianum* Nag. from Lake Erie.

Botryococcus: Colonies of *Botryococcus sudeticus* Lemm. occurred in small numbers in the collections of Oct. 17-18, 1926. Snow listed only *B. braunii* Kg. from Lake Erie.

Kirchneriella: A few species of *Kirchneriella obesa* Schmidle occurred sparingly (200 per c. m.) in the collections Oct. 15, 1926 from Michigan City. Snow reported this species and *K. lunaris* (Kirch.) Mob. from Lake Erie.

Oocystis: An undetermined species of *Oocystis* occurred rarely in the collections, 200 per c. m. Oct. 18, 1926 at Sawyer and 30,000 per c. m. May 14, 1927 at Dunes Park. Snow reported three species of this genus from Lake Erie.

Sphaerocystis: A few colonies (845 per c. m.) of *Sphaerocystis schroeteri* Chodat were found in a silk-net collection May 14, 1927 at Gary and also (7,000 per c. m.) July 10, 1927 at Chicago. This species has not been reported for the Great Lakes by any of the other investigators.

Ankistrodesmus: *Ankistrodesmus falcatus* (Corda.) Ralfs. was found only in the collections of May 14-15, 1927 from Dunes Park and July 10, 1927 from Chicago. Clusters of the crescent-shaped cells were quite abundant (1,350,000 per c. m.) in the filter-paper collections, showing that most of the cells passed through the silk net. This species was not mentioned by any of the previous investigators.

Coelastrum: Two species of *Coelastrum* were found in several of the collections. *C. reticulatum* (Dangeard.) Senn. was found occasionally in the collections of Oct. 17-18, 1926 and rarely in the collections of Sept. 1888. *C. microporum* Nag. was found in two silk-net collections, May 14, 1927 at Gary and July 10, 1927 at Chicago, and in a filter-paper collection, May 14, 1927 at Dunes Park. Snow reported four species of this genus, including these two, from Lake Erie.

Tetrastrum: An undetermined species of *Tetrastrum* occurred in small numbers (200 per c. m.) in silk-net collections Oct. 18, 1926 at Sawyer. Species of this genus were not observed in any of the other collections. This genus has not been reported from the Great Lakes by any of the previous investigators.

Scenedesmus: Two species of *Scenedesmus*, which is a very common genus in small lakes and ponds, were found in the 1926-1927 collections. Because of their minute size, these species were probably lost in the earlier collections, and only a few were retained in the recent collections. *S. bijuga* (Turpin) Lag. occurred (8450 per c. m.) May 14, 1927 at Gary and (16,500 per c. m.) in filter-paper collections of the same date at Dunes Park. *S. quadricauda* (Turpin) Breb. occurred in rather small numbers (600-33,000 per c. m.) May 14, 1927 at Gary and Dunes Park and Oct. 18, 1926 at Sawyer. Snow reported ten species of this genus, including these two species, from Lake Erie. Whipple found this genus rather abundant at Chicago.

Crucigenia: A very small undetermined species of this genus occurred (1,000-4,225 per c. m.) in the silk-net collections from Gary and Chicago. This form did not appear in any of the other collections, nor was it mentioned by any of the earlier investigators.

Pediastrum: Although *Pediastrum* is quite a common plankton genus, it was never abundant in our collections. *P. boryanum* (Turpin) Menegh. occurred rarely in the Dec. 1887 and Aug. 1888 collections and appeared in small numbers (100-7,000 per c. m.) Oct. 17-18, 1926 and May 14, 1927 at Dunes Park and July 10, 1927 at Chicago. *P. simplex* var. *duodenarium* (Bail.) Rab. occurred only in the silk-net collections Oct. 17, 1926 from Dunes Park and Michigan City. *P. duplex* Meyen. was present (40-2,500 per c. m.) in the collections of Oct. 17-18, 1926. Thompson reported only *P. boryanum* from Traverse Bay. Snow listed six species of this genus including these three in Lake Erie. Whipple found this genus to be common in the Chicago area.

PROTOZOA

Protozoa, because of their small size and relatively small abundance, were of little importance in the plankton, even in the warmer seasons when they were most numerous. The collections contained at least twenty-one species of protozoans, eleven of which seemed to be typical plankton forms. The others probably were washed up from the bottom or from the vegetation growing on piles and floating timbers. Smith (1894) found ten species in the surface plankton of Lake St. Clair and a number of others from the vegetation and bottom. Kofoid (Ward, 1896) reported eighteen species from the plankton of the Traverse Bay region, but no littoral species. Jennings (1900) listed twenty-two species as limnetic in Lake Erie. Whipple (Leighton, 1907) listed nine genera as present in the waters of Lake Michigan at Chicago.

Centropyxis: *Centropyxis aculeata* Stein occurred sparingly in the July 1888 collections and appeared in small numbers (200 per c. m.) Oct. 17, 1926 at Sawyer and May 15, 1927 at Dunes Park. This species was never abundant enough to form an important element of the plankton. Kofoid reported it from bottom tows in Traverse Bay.

Difflugia: Four species of *Difflugia* were found. *D. globosa* Duj., the most abundant of all the rhizopods, reached a maximum of 25,000 per c. m. in the autumn of 1926 but was rather rare (300 per c. m.) in the spring of 1927. This species was listed as abundant in Traverse Bay by Kofoid and in Lake St. Clair by Smith. *D. lebes* Penard appeared in small numbers in the Sept. and Oct. collections of 1888. *D. corona* Wallich occurred only sparingly (150-600 per c. m.) May 14-15 at Dunes Park. Smith found this species in the shallow waters of Lake St. Clair. *D. pyriformis* Perty was found in very small numbers (200 per c. m.) May 15, 1927 at Dunes Park. Kofoid reported this species as rare in the plankton of Traverse Bay.

Actinophrys: *Actinophrys sol* Ehr. appeared in small numbers (200 per c. m.) May 15, 1927 at Dunes Park. Kofoid reported this species as adventitious in the plankton of Illinois River. Smith found this species in small numbers in the surface tows from Lake St. Clair.

Trachelomonas: *Trachelomonas hispida* Perty was found abundantly (165,000 per c. m.) in the filter-paper collections May 14, 1927 from Dunes Park. This species and others of this genus may have been abundant in the plankton when the older series of collections were made, but because of their size they probably escaped or were impossible to identify in the preserved material. Landacre (1908) reported this species from Sandusky Bay.

Euglena: *Euglena oxyuris* Schmarda occurred frequently May 14, 1927 at Dunes Park, reaching a maximum of 275,000 per c. m. in the filter-paper collections. *E. viridis*, which was reported by both Jennings and Landacre from Lake Erie, was not identified in any of the collections examined.

Chlamydomonas: An undetermined species of *Chlamydomonas* was found abundantly (330,000 per c. m.) in the filter-paper collections May 14, 1927. This form did not appear in any of the other collections, probably escaping through the meshes of the silk net. Snow (1902) listed three species of this genus from Lake Erie.

Phacus: *Phacus triqueter* Ehr. occurred occasionally (16,500 per c. m.) in the filter-paper collections May 14, 1927. This species was not found in any of the silk-net collections. In Lake Erie Jennings reported it from East Harbor, and Landacre listed it from Sandusky Bay.

Cryptomonas: *Cryptomonas ovata* Ehr. was found in the filter-paper collections (110,000 per c. m.) May 14, 1927 at Dunes Park. This form was observed only in fresh living material, and probably because of its minute size it did not appear in the silk-net collections. Whipple reported this genus as present at Chicago.

Eudorina: *Eudorina elegans* Ehr. was found in small numbers (200-1200 per c. m.) in 1926 and 1927. This colonial flagellate has not been reported by previous investigators from the Great Lakes. Kofoid found the closely related form *Pandorin morum* Bory de. St. Vincent in Traverse Bay.

Uroglena: Colonies of *Uroglena americana* Calkins occurred occasionally in two recent collections. Kofoid reported *U. volvox* Ehr. as common in the form *Pandorin morum* Bory de St. Vincent in Traverse Bay.

Dinobryon: *Dinobryon sertularia* Ehr. was the most abundant protozoan in the plankton. This species seemed to have a swarming tendency, for it was found abundantly in some collections only to be almost absent from others of the same date and place. It was present also in small numbers in the Sept. 1888 collections. In those of Oct. 1926 it reached an abundance of 900,000 per c. m., and in the filter-paper collections of May 14, 1927 it reached an abundance of 7,000,000 per c. m. Kofoid found this species to be abundant in the Traverse Bay region. Smith reported it as abundant in Lake St. Clair, and Whipple listed it as plentiful in Lake Michigan at Chicago.

Ceratium: *Ceratium hirundinella* Müll. was common in the collections of Oct. 1926, and occurred in mall numbers in those of Aug. and Sept. 1888. Kofoid found this species abundant in the Traverse Bay region, and Smith also found it numerous in the surface tows of Lake St. Clair.

Peridinium: *Peridinium tabulatum* Ehr. occurred occasionally in the collections of Aug. 1888 but did not appear in any of the others. As this is a common species in other waters, its apparent scarcity in our collections may be due to its small size and consequent loss through the meshes of the silk net. Kofoid found *P. tabulatum* common in the summer at Traverse Bay, Smith listed it as scarce in Lake St. Clair, and Jennings recorded it from several parts of Lake Erie. Whipple listed this genus as fairly common in July at Chicago.

Codonella: *Codonella cratera* Leidy occurred in small numbers in the collections of July, Aug. and Sept. 1888 and in some of the 1926-1927 collections reaching a maximum abundance of 32,000 per c. m. in a silk-net collection July 10, 1927 from Chicago. This small-shelled ciliate was reported by Kofoid as abundant in the Traverse Bay region. Smith found it abundant in the plankton of Lake St. Clair and Jennings listed it from Lake Erie.

Vorticella: One or more undetermined species of *Vorticella* occurred occasionally in the collections of Sept. and Oct. 1888. They were found in considerable numbers (220,000 per c. m.) attached to floating debris and diatoms in the filter-paper collections May 14, 1927 at Dunes Park. Kofoid found *Vorticella* in the plankton of the Traverse Bay region. Smith recorded this genus as abundant on diatoms in Lake St. Clair. Jennings found *V. rhabdostyloides* Kellicott common in Lake Erie. Whipple listed this genus as common in Lake Michigan at Chicago.

Thuricola: A few specimens of an undetermined species of *Thuricola* were found attached to floating debris in a collection of Sept. 1888. This form was adventitious in the plankton, belonging more properly to the shore and bottom. Smith found closely related forms to be scarce among the algae in the shallow waters of Lake St. Clair.

Podophrya: An undetermined species of this genus occurred attached to floating debris in a Sept. 1888 collection. Smith reported *P. cyclopum* C. & L. on algae in Lake St. Clair. The same species was found rarely by Kofoid attached to *Epischura lacustris* Forbes in the Traverse Bay region.

Acineta: Several undetermined species of *Acineta* were found attached to algae in the collections of Sept. 1888. Jennings reported finding *A. mystacina* Ehr. attached to floating material in Lake Erie.

COELENTERATA

Several species of *Hydra* are the only coelenterates known to occur in the Great Lakes. *Hydra oligactus* Pallas was found sparingly (100 per c. m.) in a silk-net collection Oct. 17, 1926 from Michigan City. It occurred in small numbers in the December 1887 and the September 1888 collections. Welch and Loomis (1924) reported the occurrence of *Hydra* in great abundance in Lake Erie and in Lake Michigan near Michigan City, Indiana.

NEMATHELIMINTHES

Free-living nematodes are predominately bottom forms in Lake Michigan. A few undetermined nematodes were found in the collections May 14, 1927 from Dunes Park. These were probably bottom forms washed up from the shallow waters by wave action.

ROTATORIA

Sixteen species of rotifers were found in the plankton of Lake Michigan, although none of them were ever very abundant. These species were all typical plankton forms, several of them being distributed through most of the collections. The rotifers of the Great Lakes as a group have been thoroughly studied by several investigators. Kellicott (1896, 1897) published a long list of the rotifers of Lake Erie in the region of Sandusky Bay, including both bottom, shore, and limnetic forms. Jennings (1894) reported twenty-four limnetic species occurring in Lake St. Clair and referred to the distribution of many species in Lake Erie. In a later and more complete survey covering most of the rotifers of the United States, Jennings (1900, 1902) gave a list of twelve species as occurring in the plankton of Lake Erie and listed seven other species as occurring in the plankton of others of the Great Lakes. Jennings (Ward 1896) found the rotifers less abundant in the Traverse Bay region than in Lake St. Clair; he reported the limnetic forms in the Traverse Bay region to be well represented and listed fourteen limnetic and eight bottom species.

Synchaeta: Two species of *Synchaeta* occurred in our collections, *S. stylata* Wierzejski on Oct. 17-18, 1926 and *S. tremula* Müll. on May 14-15, 1927. No species of this genus were found in the earlier collections; they may have been present but overlooked, as this genus is sometimes very hard to identify in ordinarily preserved collections. *S. tremula* was doubtfully reported by Kellicott from a marsh near Lake Erie. Kellicott found *S. stylata* and *S. pectinata* Ehr. abundantly in Sandusky Bay. Jennings reported *S. stylata* as present in Traverse Bay, rare in Lake Erie, and one of the most abundant species in Lake St. Clair. Whipple listed this genus as present in Lake Michigan at Chicago.

Polyarthra: *Polyarthra trigla* Ehr. (*P. platyptera* Ehr.) was found in small numbers in the May, July, and Sept. collections of 1888. This species also occurred in the collections of Oct. 1926 and May and July 1927, ranging from 100 to 16,000 per c. m. Jennings found this species abundant in Lake Erie and reported it for the Traverse Bay region. Whipple listed it as present in Lake Michigan at Chicago.

Diurella: Small numbers (400 per c. m.) of an undetermined species of *Diurella* were found Oct. 17, 1926 at Michigan City. Jennings found many species of this genus in Lake Erie.

Trichocerca: A few specimens of *Trichocerca cylindrica* (Imhof) *(Rattulus cylindrica* Imhof) occurred in one of the September 1888 collections. Jennings found many species of this genus including *Rattulus cylindricus* Jennings present in Lake Erie.

Lepadella: *Lepadella oblonga* (Ehr.) *(Metopidia lepadella* Levander) was found rarely only in the July 1888 collections. This is not a typical limnetic species but probably a migrant from the bottom. Kellicott reported this species from Sandusky Bay. Jennings found it in Lake St. Clair and also in swamps about Lake Erie.

Trichotria: *Trichotria tetractis* (Ehr.) *(Dinocharis tetractis* Ehr.) was found sparingly in one of the July 1888 collections. This species is probably a migrant from the bottom, as Jennings listed it from the bottom vegetation of Lake Erie and Lake St. Clair.

Keratella: *Keratella (Anuraea) cochlearis* (Gosse) which was found occasionally in the May, July, Aug., Sept., and Oct. collections of 1888 was relatively abundant in all the 1926-1927 collections, reaching a maximum of 17,000 per c. m. in the filter-paper collections of May 14, 1927 from Dunes Park. *K. quadrata* (Müll.) *(A. aculeata* Ehr.) was found (300-8,450 per c. m.) in several of the 1927 collections and more rarely in the July 1888 collections. Jennings found *K. cochlearis* and *K. quadrata* abundant in Lake Erie, Lake Michigan, and Lake St. Clair. *K. cochlearis* was reported by Vorce (1881) from Lake Erie and by Kellicott from Sandusky Bay, as also was *A. stipitata* Ehr. Jennings reported *A. surrulata* Ehr. from Lake St. Clair. Whipple listed this genus as common at Chicago.

Notholca: *Notholca longispina* Kellicott was characteristic of most of the plankton collections, appearing in all except those of Dec. 1887, April 1888, and May and July 1927. Jennings found it in Lake St. Clair and in Lake Michigan. *N. striata* Müll. *(N. acuminata* H. & G.) occurred sparingly in our collections of July 1888 and May and July 1927. Forbes (1883) mentioned this species as occurring in the plankton of Lake Michigan at Chicago.

Brachionus: Only a single species of this common plankton genus was found in our collections, a single specimen of *Brachionus capsuliflorus* Pallas occurring in an Aug. 1888 collection. Kellicott reported two species of this genus, but not including this species, from Sandusky Bay. Jennings found this species and *Brachinous militaris* Ehr. abundant in the shallow parts of Lake Erie.

Schizocerca: A very few (50 per c. m.) specimens of *Schizocerca diversicornis* Daday were found Oct. 17, 1926 at Michigan City. This species, which is more typical of small shallow lakes, has not been reported from the Great Lakes by previous investigators.

Asplanchna: *Asplanchna priodonta* Gosse was found occasionally in the Aug. collections of 1888. Kellicott found this species abundant and *A. herrickii* de Guerne rare in Sandusky Bay. Jennings reported *A. priodonta* from the plankton of Lake Michigan and Lake Erie.

Filinia: *Filinia (Triarthra) longiseta* (Ehr.) occurred sparingly (800 per c. m.) at Chicago, July 10, 1927. Kellicott found this species abundant in Sandusky Bay.

Conochiloides: *Conochiloides dossuaris* (Hudson) was found in small numbers in the Aug. 1888 collections. This species was reported from Lake Erie by Kellicott, but not in any other of the Great Lakes by other workers. The closely related form *C. hippocrepis* (Schrank) *(C. volvox* Ehr.) has been reported from Lake St. Clair by Jennings and from Lake Erie by Kellicott. Another similar form *C. unicornis* Rousselet was common in tows from Lake Erie (Jennings) (Kellicott) and from Lake St. Clair (Jennings).

CLADOCERA

Eleven species of cladocerans occurred in our collections. Their relative abundance was greater in the older series than in the recent series, undoubtedly because of the type of net used for collecting. Two species, *Daphnia retrocurva* Forbes and *Bosmina longispina* Leydig, seemed to be generally typical of the plankton, as they occurred in most of the collections. Smith (1871) reported two species from Lake Superior. Birge (Reighard, 1894) found four species in the plankton of Lake St. Clair. Ward (1896) stated that the Cladocera formed an important element of the fauna of Lake Michigan in the Traverse Bay region; he found 25 or 30 species in this region but did not state how many of them belonged to the plankton. Whipple reported finding only one genus in the plankton of Lake Michigan at Chicago. Nine species of Cladocera were listed by Birge (1881) from the Chicago Water Supply, nine species by Sars (1916) from the Georgian Bay region, and twenty-seven species by Bigelow (1922) from Lake Ontario, Lake Erie, and Georgian Bay.

Sida: *Sida crystallina* (Müll.) occurred rarely in the Sept. 1888 collections and also (370 per c. m.) Oct. 17, 1926 at Dunes Park. Forbes found this species occasionally in Lal e Superior. Birge found it abundant in Lake St. Clair. Sars and Bigelow both reported it from Georgian Bay. Bigelow found it fairly common in the shallow parts of Lake Erie.

Diaphanosoma: *Diaphanosoma leuchtenbergianum* Fischer was occasional in the Sept. 1888 collections, but was common in the Oct. 1888 collections. Bigelow found *D. brachyurum* (Lièven) fairly common in Georgian Bay and Lake Erie. He reported that *D. leuchtenbergianum* was not as common in the waters of Georgian Bay.

Daphnia: *Daphnia retrocurva* Forbes occurred in nearly all the collections except those of 1927, running nearly throughout the year in the 1887-1888 collections. Because of its large size, it seemed to be quite common (100-300 per c. m.) *D. longispina* (Leydig) occurred in small numbers in the collections of Nov. 1887 and July and Sept. 1888. The species of *Daphnia* reported from the Great Lakes by the early investigators are rather confused, because of the use of synonyms and European specific names. Smith reported *D. galeata* Sars and *D. pellucida* Müll. from Lake Superior. Forbes (1881) reported *D. longispina* var. *hyalina* Leydig from Lake Michigan, and later (1887) he reported *D. retrocurva* from Lake Superior. Birge listed *D. kahlbergiensis* var. *intexta* Forbes and *D. retrocurva* from Lake St. Clair. Whipple reported this genus as occurring in Lake Michigan at Chicago. Sars found *D. retrocurva* in Georgian Bay. Bigelow reported *D. pulex* (de Geer), *D. retrocurva*, and *D. longispina* from Lake Erie and Lake Antario.

Ceriodaphnia: *Ceriodaphnia lacustris* Birge occurred in small numbers (100 per c. m.) in the Sawyer collections only. Sars found *C. scitula* Forbes in the plankton of Georgian Bay. Bigelow reported four species of this genus from Georgian Bay, including *C. lacustris* as "uncommon."

Bosmina: *Bosmina longispina* Leydig, the most abundant cladoceran of Lake Michigan, was one of the conspicuous organisms of the plankton. It was common in nearly all the collections, being entirely absent only from those of Dec. 1888, and reached a maximum of 120,000 per c. m. July 10, 1927 at Chicago. Birge reported this species as abundant in Lake St. Clair. *B. obtusirostris* Sars, which has not been reported previously from the Great Lakes, occurred (100 per c. m.) Oct. 17, 1926 at Dunes Park. *B. longirostris* (Müll.) occurred rarely from April until Nov. in the 1888 collections. This species was found occasionally by Forbes in the plankton of Lake Superior. Sars and Bigelow both reported this species from Georgian Bay, and Bigelow also found it in Lake Erie.

Alona: An undetermined species of *Alona* was found once in a collection of Aug. 1888. Forbes reported an undetermined species of this genus from Lake Superior. Birge found four species of *Alona* in Lake St. Clair. Bigelow found *A. affinis* (Leydig) abundantly in the plankton from shallow waters of Georgian Bay.

Chydorus: *Chydorus sphaericus* (Müll.) occurred occasionally July 1888 and rarely Sept. 1888 but was not found in any of the 1926-1927 collections. Forbes found *C. sphaericus* and *C. gibbus* Lillj to be common in Lake Superior. Birge reported *C. sphaericus* and *C. globosus* Baird in Lake St. Clair. Bigelow found three species of this genus, including *C. sphaericus*, in Georgian Bay.

Leptodora: *Leptodora kindtii* (Focke) occurred occasionally in the collections of Oct. 1888 and July 1927. This large form was reported by Forbes as occasional in Lake Superior and in Lake Michigan, by Birge as occasional in Lake Michigan and in Lake St. Clair, by Sars as common in Georgian Bay, and by Bigelow as common in Georgian Bay and in Lake Erie.

COPEPODA

Nine species of copepods, all typical limnetic forms, were found, three of them occurring in a majority of the collections. Like the cladocerans, they were more abundant in the earlier collections than in the recent. Smith (1871) mentioned the occurrence of several species of copepods in Lake Superior but did not designate the species or indicate their abundance. Forbes (1882) found four species abundant in Lake Michigan, and in Lake Superior (1887) he found nine species, most of which were common. (Marsh (1895) found nine species of copepods in the plankton of the Traverse Bay region which were the same as those of the other Great Lakes; he reported six species from Lake Erie, nine species from Lake Michigan, and sixteen species from the plankton of Lake St. Clair.

Epischura: *Epischura lacustris* Forbes occurred quite abundantly in all the early collections except those of Dec. 1887 and July 1888. For some unknown reason this species, which because of its abundance and large size was very prominent in the earlier series, did not appear at all in the recent series. Forbes found this species abundant in Lake Michigan at Chicago and Traverse Bay and also in Lake Superior. Marsh reported it as common in Lake St. Clair, Lake Erie, and Lake Michigan.

Diaptomus: Three species of *Diaptomus* were found in our collections. *D. minutus* Lillj. was common in the collections of Nov., July, Aug., Sept., and Oct. 1887-1888, and in those of 1926-1927. This species was quite conspicuous, ranging in abundance from 300 to 1600 per c. m. *D. ashlandi* Marsh was found (200-2,000 per c. m.) in 1926-1927. Marsh found both species in Lake Michigan and

Lake St. Clair and reported *C. minutus* as the most common copepod in the Great Lakes. *D. sicilis* Forbes occurred occasionally in the June, Aug., and Sept. collections of 1888. Forbes found this species abundant in Lake Michigan and in Lake Superior. Marsh found it common in both Lake Michigan and Lake St. Clair. Marsh also reported *D. oregonensis* Lillj. as occurring occasionally in Lake Michigan and in Lake Erie.

Limnocalanus: *Limnocalanus macrurus* Sars was found occasionally in the collections of Sept. 1888. Forbes found this species abundant in Lake Michigan at Chicago and also in Lake Superior. Marsh reported it from Lake Michigan and Lake St. Clair.

Cyclops: Three species of *Cyclops* occurred in our collections from Lake Michigan. *C. bicuspidatus* Claus was the most abundant, occurring in all the collections except those of Dec. 1887 and June 1888. This species was reported by Forbes as abundant in Lake Michigan and Lake Superior. Marsh mentioned it as the common *Cyclops* of the Great Lakes occurring in Lake Michigan, Lake St. Clair, and in Lake Erie. *C. prasinus* Fischer was abundant in the 1926-1927 collections and was fairly common in all the 1887-1888 collections except those of Dec., June, and July. Marsh (Ward and Whipple, 1918) stated that this species was common in the Great Lakes. *C. fimbriatus* Fischer was found occasionally in the July, Aug., Sept., and Oct. collections of 1888. This species was not mentioned, at least not under this name, by any of the previous investigators. A total of fourteen species have been reported from the Great Lakes by previous investigators, but many of these are synonyms.

Canthocamptus: An undetermined species of *Canthocamptus* occurred (4,225 per c. m.) in the collections of May 14, 1927 from Gary. Forbes found this genus to be rare in Lake Superior and Lake Michigan.

Summary

The uniformity of the plankton from year to year and from season to season strikingly demonstrates the stability of Lake Michigan as a fresh-water habitat. Comparisons of recent collections with those made forty years ago show that very little change has occurred in the general composition of the plankton and justify the inference that there have been no changes in temperature, currents, depth, and chemical composition of the water sufficient to influence the production of plankton. Of the species which were abundant in the 1887-1888 collections, only one, *Epischura lacustris* Forbes, was absent in the recent series. From the examination of the seasonal collections, there appeared to be a fairly constant and uniform phytoplankton throughout the year, although the zooplankton showed some response to seasonal conditions. Diatoms predominate at all times and constitute the majority of the organisms of the plankton, the same species being conspicuous in all the collections examined.

Acknowledgment

The writer wishes to thank Mr. R. E. Richardson and Mr. H. C. Oesterling, both of the Illinois State Natural History Survey, for much valuable criticism and assistance in preparing this paper.

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Some Properties of Oil Emulsions Influencing Insecticidal Efficiency

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L. L. ENGLISH

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FOREWORD

The first sprays used for combatting San Jose scale when it became established in the United States were made mainly from light oils, such as kerosene. Kerosene emulsion, one of the principal insecticides in use at that time, was first recommended for the control of San Jose scale by John B. Smith, of the New Jersey Agricultural Experiment Station, in 1897. During the next few years, when oil sprays were being tried for this purpose in many parts of the country, little attention was given to the standardization of the emulsion, and in some cases kerosene and water were applied in the form of a mechanical mixture made by forcing the two materials through a spray pump and mixing them in two jets discharged from the spray nozzle. Much injury resulted and many trees were killed, so that oil sprays as a class were more or less in disrepute for a number of years. Since 1917, however, there has been a marked increase in the use of oil sprays, due largely to the work of Federal and State entomologists with the so-called lubricating oil emulsions. These emulsions, made by several different formulae, have proved very effective and have largely taken the place of lime-sulfur in dormant spraying for the control of San Jose and other scale insects.

Entomologists and horticulturists generally have recognized that oil sprays as a class, while very effective, are dangerous to use unless properly prepared. In order to be sure that a spray is safe, we need to know its exact effect on insects and plants. This means that we must recognize differences in oils and differences in emulsifying agents, so as to learn what kind of emulsion to use for the result desired.

In the hope of throwing some light on these important questions concerning the use of oil sprays, the investigation herein reported by Mr. English was undertaken in February, 1925, on a Crop Protection Institute fellowship established by the Standard Oil Company of Indiana. The project was directed by a committee composed of W. P. Flint, J. S. Houser, J. J. Davis, and W. C. O'Kane, and the work was done at Urbana, Illinois, in cooperation with the Illinois State Natural History Survey.

December, 1927. W. P. Flint.

CONTENTS

SOME PROPERTIES OF OIL EMULSIONS INFLUENCING INSECTICIDAL EFFICIENCY*

L. L. English

An insect's initial experience with an oil emulsion is physical. After the contact or the physical reaction, there may be chemical action. Oil, the killing agent used in emulsions, is not highly active chemically, and the oil globules are given a "coat" of material which usually is even less active chemically. As Woodman ('24) points out: "The failure of a spray is not usually due to a lack of toxicity but rather to the absence of certain desirable physical properties." These properties have been considered in the investigations of Cooper and Nuttall ('15), Moore and Graham ('18), and others, but their importance has not been given sufficient attention in actual spray practice.

The term "oil emulsion" is often used with the incorrect inference that all oil emulsions are alike. Some emulsions are suitable for application to foliage, while others are not. Some are more effective than others on scale insects, and those that are effective on scale insects may not be effective on aphids. The more the subject is investigated, the greater becomes the variety of oils and the larger the number of emulsifying agents encountered. Each oil, each emulsifier, and each class of insect pest introduces factors that must be considered more or less separately.

It is very difficult to isolate any one property of an emulsion and determine separately its action on insects. The physical and chemical properties of the oil, the kind and amount of emulsifying agent, and the stability of the emulsion are all so closely interlocked that one property usually cannot be varied without changing the others. There is good reason for believing that no two emulsions—and, very likely, no two lots of an emulsion made by the same formula—are *exactly* alike. The "individuality" of any emulsion will depend upon the way in which it is put together, the manner and duration of manipulation, the type and amount of emulsifying agent, the kind of oil, the quality of water, and the temperature at the time of dispersion. Ordinarily, with the same amount of

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* This paper was submitted as a thesis for the degree of doctor of philosophy in entomology at Iowa State College of Agriculture, 1927.

emulsifying agent, and the same treatment, an oil of 80 to 100 viscosity* is easier to emulsify than one of 30 to 40 viscosity. Hence, the latter more nearly approaches the unstable, "quick-breaking" type of emulsion. Generally, the inert emulsifying agents, such as gums, calcium caseinate, glue, etc., at the usual concentrations, give less stable emulsions than fish-oil soaps or petroleum soaps. Everything else being equal, a reduction in the amount of emulsifier reduces stability.

The relative size of the globules of oil is an indication of the stability of an emulsion, and for lack of a better criterion this is used in correlating stability with efficiency. Very minute (1 micron or less), uniform globules, exhibiting pronounced Brownian movement, indicate a very stable emulsion. But a wide range in the size of the globules (from 1 micron to 30 or 40 microns) indicates a relatively unstable emulsion. The homemade, boiled emulsion of fish-oil-soap and lubricating oil is of this latter type. Such an emulsion may be less stable than one having relatively large (10 to 15 microns), uniform droplets. Two emulsions that look identical under the microscope may differ in stability; one may be more stable than the other because of an excess of emulsifier, a different emulsifier, or the kind of water used for dispersion.

The properties of oil emulsions which have been found to be important and which will be discussed are:

I. Physical properties—
 (1) Wetting ability of the emulsifying agent.
 (2) Volatility and viscosity of the oil.
 (3) Stability of the emulsion.

II. Chemical properties—
 (1) Saturated oils.*
 (2) Unsaturated oils.*

THEORY OF WETTING

Various efforts have been made to establish criteria of wetting.† Robinson ('25) was unable to find a definite relation between the surface tension of the liquid and its spreading ability. Neither did he find the interfacial tension of an oil-water system to be a suitable indication. The same idea was used by Smith ('16) and by Cooper and Nuttall ('20). As there is no satisfactory technique for measuring the interfacial tension of a liquid in contact with a solid, these workers substitute a heavy oil for the solid. Measurements of this kind certainly give some indication

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* See definitions, *Appendix A.*

† There are differences of opinion, especially among entomological workers, as to the distinction between wetting and spreading. Indeed, there is some doubt whether or not there is a real difference between the two phenomena. Consequently, there is no agreement as to what criterion should be used in determining the wetting ability of a spray. Woodman ('24) does not regard wetting and spreading as synonymous terms. He treats the contact-angle theory of wetting, but uses the amount of spray adhering to a glass slide as the measure of wetting. He states, however, that this is somewhat unsatisfactory. Moore ('21) and Nuttall ('20) also make a distinction between the two terms. But neither of the terms is well defined, and it is difficult to separate the two ideas, even if there is a real difference between them. For practical purposes, then, it may be just as well to continue to use both terms, although there seems to be no fundamental distinction. Freundlich ('22) uses the term "spreading" in speaking of liquid-liquid systems and the term "wetting" in speaking of liquid-solid systems, but exactly the same types of physical relations are involved in both.

of the relative wetting ability, but the index that is really wanted is the action of a particular spray on a particular solid. This index is expressed by the angle of contact.

The angle-of-contact theory is treated in various textbooks on physics and also by Freundlich and others of the authors previously mentioned. The discussion by Sulman ('20) is particularly good.

If a drop of liquid is in contact with a solid (Figure 1), three forces are involved: the surface tension of the liquid, T_1; the surface tension of the solid, T_2; and the interfacial tension of liquid-solid, T_{12}. The two latter, of course, are not measurable. The liquid meets the solid at a definite angle of contact at the point P. The forces T_1 and T_{12} tend to draw the drop into a sphere. The force T_2 is acting in the opposite direction and tends to cause the liquid to spread out over the solid. When the liquid does not spread or does not contract, the system is in equilibrium and the forces acting in opposite directions are balanced. This is expressed by the equation, $T_2 = T_{12} +$ the component of T_1 which is acting in the same direction as T_{12} and opposite to T_2. This component, by trigonometry, is $T_1 \cos \Theta$. The equation for equilibrium then becomes,

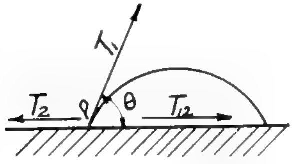

FIG. 1. DIAGRAM OF FORCES THAT DETERMINE THE ABILITY OF A LIQUID TO WET THE SURFACE OF A SOLID.

$$T_2 = T_{12} + T_1 \cos \Theta$$

If the equation is transposed,

$$\cos \Theta = \frac{T_2 - T_{12}}{T_1}.$$

Thus it will be seen that the angle Θ is a function of all three forces. For a condition of non-wetting, the angle of contact would be 180° and, theoretically, the drop of liquid would touch the solid at one point. For perfect wetting, the angle would be zero and the liquid would lie flat over the solid. Between zero and 180° there is partial wetting; and the smaller the angle of contact, the greater the wetting ability. For example, in Figure 2*A* where the system is in equilibrium at 60°, the wetting ability is about twice as great as in Figure 2*B*, where the angle is 120°.

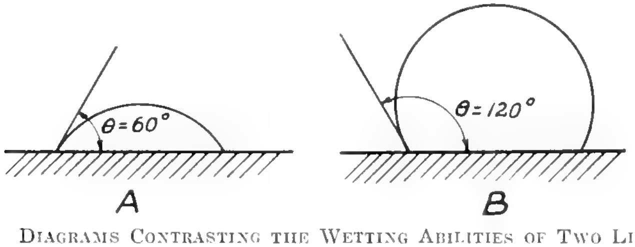

FIG. 2. DIAGRAMS CONTRASTING THE WETTING ABILITIES OF TWO LIQUIDS.

ANGLE-OF-CONTACT MEASUREMENTS

In practice it is difficult to measure the angle of contact of a drop of liquid. The force of gravity will flatten the drop somewhat; it is difficult to get drops of the same size; and the evaporation of small drops is rather rapid. Because of these difficulties it is not feasible to reflect the drop into a binocular microscope with a protractor in one barrel and measure the angle of contact. This method was tried and discarded for the simple method used by Stellwaag ('24).*

The apparatus is simple, and the method is quite rapid and entirely practical. The necessary pieces of equipment are: (1) a container for the liquid, (2) a device for holding the object to be tested, so that it can be turned, raised, and lowered into the liquid, and (3) a protractor etched on a mirror. For this particular work a museum jar (8x15x13 cm.) was used, and a device for holding the object was made from an old microscope stand. (See Figure 3.)

The jar should be perfectly level, and its rim should be coated with paraffin, so that the liquid will stand flush with the top or a little above it. Before testing, the surface of the liquid should be freshly cleaned with a glass rod. Leaves and other objects to be tested should not be handled, of course, and should be placed in the holder in a manner that will give as uniform a surface as possible. The liquid should be kept at a constant temperature.

As the object is slowly lowered, the liquid either will be depressed by it or will rise to it, forming a meniscus. The object is turned until the surface of the liquid is exactly horizontal at the point of contact. Then the angle of contact is read by means of the protractor, care being exercised to see that the bottom of the protractor coincides with the surface of the liquid and that the midpoint coincides with the point of intersection of the liquid by the object.

Suppose the liquid meets the leaf perpendicularily as in Figure 4*A*, the angle of contact is 90°. If, however, the liquid is depressed (Figure 4*B*), the angle is greater than 90°, and the leaf must be rotated to the left until the liquid meets it horizontally (Figure 4*C*).

The leaf should be inserted at an angle smaller than the proper angle of contact and slowly rotated until the liquid meets it on a horizontal

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* So far as known, Stellwaag is the first entomologist to use the angle of contact for measuring wetting ability, and much credit is due him for pointing out the action of liquids on plant leaves of different kinds and structures, and the importance of wetting in the control of aphids. This method was also used by Adam and Jessop ('25) in determining the polarity of various solids.

Trappman ('26) criticizes Stellwaag's method and prefers surface tension measurements. It is quite true that the determination of the angle of contact on leaves and twigs, no two of which are exactly alike, is subject to more variability than surface tension measurements in which nothing biological is involved. Another disadvantage of Stellwaag's method is that the surface of the liquid must be kept uncontaminated. Also, this method is not well adapted for use with coarse suspensions. But it is fundamentally correct, and, by careful and repeated observations, it affords a means of working out some of the underlying principles of spray practice.

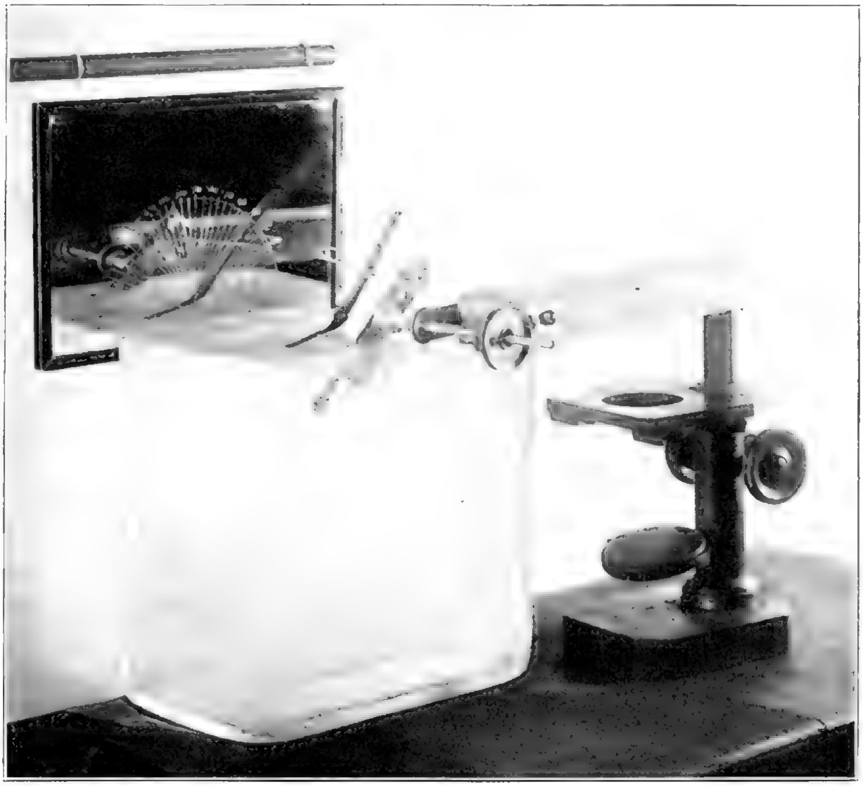


FIG. 3. APPARATUS USED IN MAKING ANGLE-OF-CONTACT MEASUREMENTS.
(Photo by K. F. Auden.)

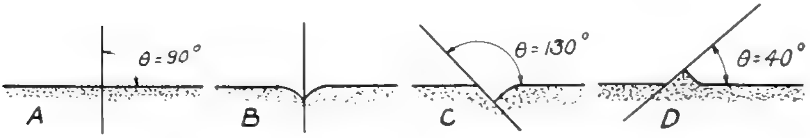


FIG. 4. DIAGRAMS SHOWING INSERTION OF A LEAF INTO LIQUIDS AT DIFFERENT ANGLES IN ORDER TO MEASURE WETTING ABILITY.

In *A*, where the liquid is neither elevated nor depressed at the point of contact, the angle is 90°. In *B*, where the liquid is depressed, the angle of contact is greater than 90°, and the leaf must be rotated to the position shown in *C*. *D* represents the position to which the leaf must be rotated when the liquid is elevated at the point of contact, the angle being less than 90°.

plane. This may necessitate several trials, especially if the angle is considerably smaller than 90°. Figure 4*D* shows the position at an angle of 40°.

It is difficult to make angle-of-contact measurements with oil emulsions because of the very thin film of oil which persistently appears on the surface; consequently, it was thought better to make a study of the emulsifying agents that were used in several emulsions. The objects to be tested were always selected fresh, and the measurements were carried out as soon after collection as possible. The liquids were kept at a temperature of 25° C. throughout the tests. From three to ten observations were made of each object in contact with the liquids at each dilution. The dilutions ranged from 1 per cent to 1/16 of one per cent. (For analysis of the water used for dilution, see *Appendix C*.)

It is not to be supposed that data thus obtained on the angles of contact represent fixed values, but they do represent relative conditions from which reliable deductions can be made.

No attempt was made to study the effect of time or repeated contact on the value of the angles. Indeed, it may be that the determinations which were made should be regarded as indications of the *initial* wetting ability. The hysteresis of liquid-solid systems is a study within itself.

Figure 5 shows the results obtained in tests with corn, oat, and cabbage leaves. These leaves were chosen because the hair-like structures on the corn and oat leaves and the waxy covering of the cabbage leaf make them difficult to wet; and the angle-of-contact measurements for each emulsifying agent against these three kinds of leaves were averaged in preparing the graphs of Figure 5. From these graphs it will be noted that the soaps give much lower angles than calcium caseinate or glue. This is to be expected, after reviewing the work of Harkins, Davies and Clark ('17); for glue, calcium caseinate, and such materials are not strongly polar, and are not as readily adsorbed as soaps, nor are they thrown into an interface as easily. So far as wetting ability is concerned, the soaps are in a class by themselves, both theoretically and practically, *unless* the spray mixture is of such composition as to destroy the soap.

RELATION BETWEEN WETTING ABILITY AND TOXICITY TO APHIDS

That aphids are not readily killed by a spray that does not wet them, is well known. One of the reasons for adding soap to nicotine sulfate is to give the spray wetting ability. Stellwaag states that the effectiveness of a spray on aphids is almost entirely dependent on its wetting ability.

The curve for soap No. 15 in Figure 5 shows almost the same angle of contact at all the dilutions used. With potash-fish-oil soap and soap No. 55, the angle begins to increase quite rapidly at dilutions of ½ and ¼ per cent, as these soaps begin to precipitate out with hard water;* and at

* See analysis of water, *Appendix C*.

weaker dilutions there is insufficient soap left to give good wetting. Dilution causes no appreciable change in the angle of contact with calcium caseinate and glue. The angles with these materials are not much below those obtained with water.

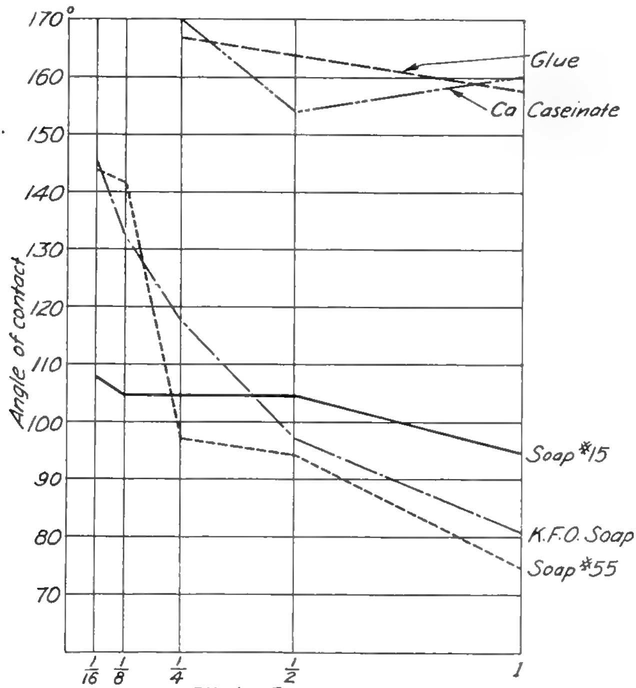


FIG. 5. CHART SHOWING CHANGES IN ANGLE OF CONTACT CAUSED BY INCREASED DILUTION.

Soap No. 15 is a petroleum product used in the preparation of soluble oils. Soap No. 55 is used for the same purpose but is made up largely of sodium oleate. KFO soap is potash-fish-oil soap.

The results of laboratory tests with three species of aphids are given in Table I. (For definitions of terms and methods of tests, see Appendix *A* and *B*.) The emulsions were diluted with tap water and were used at a strength of 2 per cent on *Hesteroneura setariae* Thos., 1 per cent on *Tritogenaphis ambrosiae* Thos., and 0.5 per cent on *Aphis pomi* De G. Here it will be noted that stock emulsion No. 5, made with an inert emulsifying agent, killed a relatively low per cent of the aphids. Homemade

TABLE I.

SUMMARY OF 17 TESTS ON APHIDS, SHOWING THE RELATIVE EFFECTIVENESS OF VARIOUS OIL EMULSIONS.

Item	Emulsion	Emulsifying agent	Aphids killed	Aphids used	Per cent killed
1	Stock No. 5	Inert [1]	3491	4449	78.46
2	Homemade	KFO soap [2]	3675	4738	77.56
3	Sol. oil No. 56	Soap No. 55	2712	4166	65.09
4	Soap No. 55		3654	4149	88.07
5	Soap No. 15		3749	4355	86.08
6	Sol. oil No. 90	Soap No. 15	4074	4606	88.44
7	Water check		540	4179	12.92
8	Untreated check		290	4326	6.70

[1] Materials such as glue, calcium caseinate, and gums are classed as inert.
[2] KFO soap is potash-fish-oil soap.

TABLE II.

SUMMARY OF 5 TESTS ON *Aphis spiraecola* PATCH.
Dilution of Sprays 0.5 per cent by weight.

Item	Spray	Tap water			Distilled water		
		Aphids killed	Aphids used	Per cent killed	Aphids killed	Aphids used	Per cent killed
1	Soap No. 15	770	999	77.0	871	1032	84.2
2	Soap No. 55	750	1068	70.3	951	1158	82.2
3	KFO Soap	358	1037	34.6	761	1024	74.3
4	Ca. Caseinate	184	955	19.3	157	968	16.2
5	Water Check	61	997	6.1	61	997	6.1

TABLE III.

SUMMARY OF 5 TESTS ON *Aphis spiraecola* PATCH.
Dilution of Sprays 1 per cent by Volume.

Item	Spray*	Tap water			Distilled water		
		Aphids killed	Aphids used	Per cent killed	Aphids killed	Aphids used	Per cent killed
1	Sol. Oil No. 90	1254	1346	93.3	854	1007	84.9
2	Sol Oil No. 17	1194	1239	96.4	924	1057	87.3
3	Sol. Oil No. 56	816	1046	78.3	657	962	68.3
4	Stock No. S15	748	980	76.3	645	989	65.3
5	Stock No. 5	581	991	58.6	367	803	45.7
6	Water Check	129	817	15.8	129	817	15.8

* Soluble oils Nos. 90 and 17 are emulsified with soap No. 15; soluble oil No. 56, with soap No. 55; stock emulsion No. S15, with potash-fish-oil soap; and stock emulsion No. 5, with a material similar to calcium caseinate.

emulsion and soluble oil No. 56, which are made with soaps that precipitate out with hard water, also show inefficiency.

It is quite striking that soluble oil No. 56 shows a kill of only 65 per cent, while its emulsifying agent (Soap No. 55), alone, shows a kill of 88 per cent. Soluble oil No. 56 consists of about 20 per cent of soap No. 55 and 80 per cent oil; hence, the spray contains only one-fifth as much soap as No. 55 at the same dilutions. From Figure 5 it will be seen that soap No. 55 at a dilution of 1 per cent still shows a low angle of contact. But soluble oil No. 56, being so much weaker, has soap precipitated from it quite rapidly and, hence, is low in wetting ability. Soap No. 15, by contrast, does not precipitate out so readily, and its soluble oils maintain their efficiency.

In view of the fact that fish-oil soap and soap No. 55 precipitate out in hard water, it would be logical to predict a higher per cent kill if these soaps were dispersed in distilled water instead of tap water. This prediction is borne out by Table II. While there are varying increases with all of the soaps, the increase from 34.6 per cent to 73.3 per cent with fish-oil soap is particularly noteworthy. Calcium caseinate shows very little difference, as would be expected.

Since the soaps are more effective with distilled water, it seems that the emulsions made from them should be more effective. This, however, is not true, as will be seen in Table III, where the per cent kill for distilled water is in no case higher than the per cent kill for tap water. Here the effect of the water on the type of emulsion is introduced. If tap water precipitates out some of the soap, an emulsion dispersed in it naturally is not as stable as one dispersed in distilled water. With the exception of emulsion No. S15 there is very little difference in stability of those diluted with tap water and those diluted with distilled water, as determined by centrifuging. There is no perceptible difference in the size of the globules of the tap water emulsions and the distilled water emulsions. If, however, the diluted emulsions are allowed to stand in cylinders for a few days, those made with tap water show a distinct separation of oil. Soluble oil No. 90 is very stable, and the difference in stability with tap and distilled water is insufficient to be preceptible in a photograph. If drops of the emulsions are compared under a binocular microscope, those diluted with tap water seem to have more oil at the surface of the drop than the corresponding emulsions diluted with distilled water. This adsorption of oil may be a factor in the wetting of aphids and the retention of spray by them. Drops of a poor wetting spray bounce off the aphids, and very little is retained. Much additional work is needed to clear up the relation of wetting ability and stability to the possible concentration of the oil on plants and insects.

RELATION OF CHEMICAL PROPERTY OF OIL AND STABILITY OF EMULSION TO EFFECTIVENESS AGAINST APHIDS

The kind of oil and the amount of emulsifying agent in an emulsion produce differences in efficiency, as shown in Table IV. (See Figure 6.) The emulsions under items 1 and 2 in this table are relatively ineffective. These emulsions are of the quick-breaking type, but they do not have the necessary wetting ability. The emulsions under items 3, 4, 5, and 6 have the necessary wetting ability, but vary in stability. Soluble oil No. 18, an extremely stable emulsion, the globules of which cannot be seen with the ordinary high power of the microscope, is the least effective of these four, its per cent kill being only 86.8. Soluble oil No. 90, the globules of which can barely be seen in the photograph, gives a kill of 88.4 per cent. When the amount of emulsifying agent is reduced as in No. 17, making a less stable emulsion, the kill is 94.6 per cent. Soluble oil No. 16 has the same amount of emulsifying agent as No. 90, but it is made from a saturated oil, which in this case gives an emulsion having about the same stability as No. 17, and the kill is in very good agreement. That emulsions having globules of different sizes would have different properties was indicated by Moore ('23), and the size of globules has been correlated with toxicity to aphids in recent work by Griffin, Richardson, and Burdette ('27).

As to instability, this theory is offered: The less stable the emulsion, the greater the amount of oil thrown to the surface of the spray drops, or adsorbed by them; and a very unstable emulsion thus approaches a water-in-oil type of spray, with a consequent increase in the amount of oil adhering to the plant or insect.

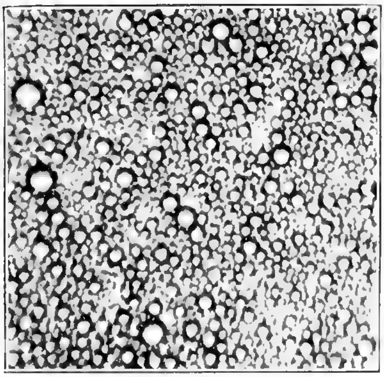
The chemical difference between the saturated and unsaturated oils in these emulsions appears to be of minor importance. The dominating factors are the wetting ability and the instability of the emulsion. The experimental data indicate that the most effective emulsion on aphids

TABLE IV.

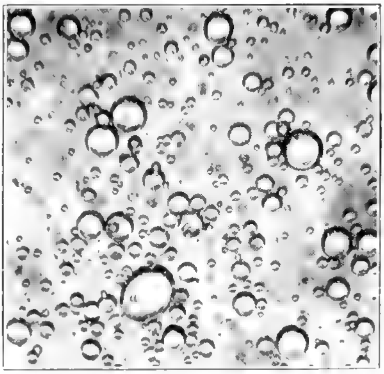
SUMMARY OF TESTS ON THREE SPECIES OF APHIDS (*T. ambrosiae*, *H. setariae*, AND *A. pomi*), SHOWING INFLUENCE OF CHEMICAL PROPERTY OF OIL AND STABILITY OF EMULSION.

Item	Emulsion	Oil	Emulsifying agent		Aphids killed	Aphids used	Per cent killed
			Kind	Amount			
1	Stock No. 5	Sat.[1]	Inert.	Reduced	3491	4449	78.46
2	Homemade	Unsat.[2]	K.F.O. Soap	Normal	3675	4738	77.56
3	Sol. Oil No. 18	Unsat.	Soap No. 15	Excess	4300	4952	86.83
4	Sol. Oil No. 90	Unsat.	Soap No. 15	Normal	4074	4606	88.44
5	Sol Oil No. 17	Unsat.	Soap No. 15	Reduced	4721	4986	94.68
6	Sol. Oil No. 16	Sat.	Soap No. 15	Normal	4837	5174	93.48
7	Water Check				540	4179	12.92
8	Untreated Check				290	4326	6.70

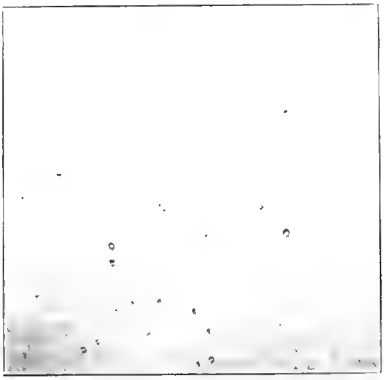
[1] Sat. = Saturated oil. } See definitions, *Appendix A*.
[2] Unsat. = Unsaturated oil. }



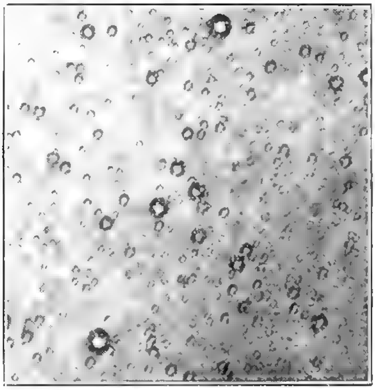
A. Stock emulsion No. 5.



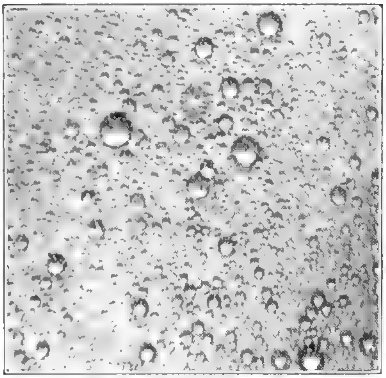
B. Homemade lubricating-oil emulsion.



C. Soluble oil No. 90.



D. Soluble oil No. 17.



E. Soluble oil No. 16.

Fig. 6. Microphotographs of Emulsions Used in Experiments. (× 290)

would be one that is relatively unstable and has high wetting ability. But antagonistic factors are encountered; for the emulsions that have high wetting ability are injurious to foliage, and chemically inert emulsions do not have high wetting ability.

RELATION BETWEEN WETTING ABILITY AND TOXICITY TO SAN JOSE AND OYSTER-SHELL SCALE (IN THE DORMANT STAGE)

Good wetting ability, which was shown to be an important requisite of emulsions for use on aphids (Table I), is not so important in the case of oyster-shell scale and San Jose scale. In this case, the emulsions that certainly have poor wetting ability are just as effective as those having good wetting ability. This can be seen from a series of laboratory experiments on oyster-shell scale* (Table V) and a typical field test on San Jose scale* (Table VI). It is not necessary to discuss this point at length or to present a great many data, for similar results have been obtained by

TABLE V.

SUMMARY OF TESTS ON OYSTER-SHELL SCALE, SHOWING INFLUENCE OF WETTING ABILITY.

Item	Emulsion	Emulsifying agent	*Per cent killed at dilution of			
			5%	10%	10%	10%
1	Stock Emul. No. S 15	K. F. O. Soap	36.3	99.4	99.8	97.3
2	Stock Emul. No. 5	Inert	96.2	90.9	99.8	99.5
3	Soluble Oil No. 17	Soap No. 15	47.3	93.3	99.4	99.8
4	Soluble Oil No. 90	Soap No. 15	41.7	92.8		96.4
5	Checks		0.0	0.0	0.0	0.0

* Check basis.

TABLE VI.

SUMMARY OF TESTS ON SAN JOSE SCALE, SHOWING INFLUENCE OF WETTING ABILITY.

Item	Emulsion	Emulsifying agent	Per cent live scale	
			2% solution	1% solution
1	Stock Emul. No. S 15	K. F. O. Soap	2.4	5.9
2	Stock Emul. No. 5	Inert	3.0	7.4
3	Soluble Oil No. 16	Soap No. 15	0.2	4.7
4	Soluble Oil No. 90	Soap No. 15	7.7	28.5
5	Checks		66.6	66.6

* For methods, see *Appendix B.*

TABLE VII.

ANGLES OF CONTACT (MEAN VALUES), SHOWING RELATIVE EASE OF WETTING VARIOUS LEAVES AND TWIGS.

Object	Liquid		
	K. F. O. soap	Glue	Tap water
Oat Leaf—Upper side	113	171	180
Corn leaf—Upper side	126	175	180
Cabbage leaf—Upper side	104	127	167
Apple skin—Ben Davis (Green)	89	107	130
Apple leaf—Upper side (Jonathan)	44	64	55
Peach leaf—Upper side (Elberta)	35	65	60
Apple twig—(Jonathan)*	27	41	40
Peach twig—(Elberta)*	45	50	50
Poplar twig*†			5
Lilac twig *†			0

* Dormant.
† Incrusted with Oyster-shell scale.

Chandler, Flint and Huber ('26) on San Jose scale;* by List ('24) on oyster-shell scale; and by Flint and Bigger ('26), Hawley ('26), Wakeland ('25), and Melander ('21) on the fruit tree leaf roller.

There are two reasons why these insects are controlled by oil emulsions that do not necessarily have high wetting ability:

(1) Apple, peach, poplar, and lilac twigs are not difficult to wet, as is shown in Table VII. Tap water wets them rather easily. This, by the way, may be responsible for a higher "runoff" with "good-wetting" sprays than with sprays of poor wetting ability, as is indicated in deOng's ('26) figures showing an increase in the amount of oil in the "runoff" with an increase in the amount of emulsifying agent. With other sprays Ruth and Kelley ('22) show, by weighing, that the amount of spray retained will vary with both the surface sprayed and the spray used.

(2) In comparing the effect on aphids with that on scales, it should be considered that scales are sessile, while aphids are not. Aphids become quite active when disturbed by spraying, and they have been observed to crawl out of a drop of liquid or to rid themselves of a globule by moving around. This, of course, applies only to sprays that do not wet them.

Therefore, wetting ability is not an important factor in the control of San Jose scale, oyster-shell scale, and apparently leaf-roller eggs, for the simple reason that the host plants, being easily wetted, retain sufficient spray to insure an oil film coverage as soon as the emulsion breaks. From the results of deOng ('27), Yothers ('24), and Woglum ('25), it seems that the same principle holds for citrus scales.

* In a private communication, B. A. Porter reports similar results.

RELATION OF VOLATILITY AND VISCOSITY OF OIL TO EFFECTIVENESS AGAINST SCALE INSECTS.

The theory formulated by deOng from his work on citrus scales may be applied also to oyster-shell and San Jose scales. The data in Table VIII demonstrate that a spray containing an oil of 60 viscosity and 5.3 per cent volatility is not as effective against oyster-shell scale as a corresponding spray containing an oil of slightly higher viscosity and lower volatility. Likewise, a refined kerosene of 32 viscosity and 35.1 per cent volatility, emulsified with potash-fish-oil soap, is very ineffective. If the toxicity were due to penetration alone, a light oil of this nature should be more effective than heavier oils. With this in mind, a series of laboratory tests were run with oyster-shell scale to determine the action of unemulsified, or "straight", oils on the scale (Table IX). Neither the refined nor the unrefined kerosene was effective. Oil No. 31, of 60 viscosity and 5.3 per cent volatility, which was run as a check, gave practically a perfect

TABLE VIII.

SHOWING RELATION OF VOLATILITY AND VISCOSITY OF OIL TO EFFECTIVENESS ON OYSTER-SHELL SCALE.—DORMANT.

Item	Emulsion	Emulsifying Agent	Properties of the oil			Per cent killed at dilution of	
			Kind	Viscosity *Sec.*	Volatility *Per cent*	5%	10%
1	Soluble Oil No. 34	Soap No. 37	Sat.	60	5.3	0.0	74.1
2	Soluble Oil No. 35	Soap No. 37	Unsat.	83	1.0	38.7	86.4
3	Soluble Oil No. 33	Soap No. 37	Sat.	83	1.0	69.6	94.1
4	Stock Emul. No. S 7	K. F. O. Soap	Sat.	32	35.1		13.5
5	Stock Emul. No. S 8	K. F. O. Soap	Sat.	60	5.3	6.0	90.8
6	Stock Emul. No. S 9	K. F. O. Soap	Sat.	83	1.0	9.6	99.9
7	Stock Emul. No. S10	K. F. O. Soap	Unsat.	104	0.2	36.3	99.4
8	Checks					0.0	0.0

TABLE IX.

SHOWING INEFFECTIVENESS OF UNDILUTED VOLATILE OILS ON OYSTER-SHELL SCALE.

Item	Oil	Properties of the oil			Per cent killed		
		Kind	Viscosity	Volatility	A	B	C
1	Refined No. 9	Sat.	32	35.10	9.0	4.0	52.7
2	Perfection Kerosene	Unsat.	32	54.28		41.7	67.7
3	Oil No. 31	Sat.	60	5.30			99.9
4	Checks				0.0	0.0	0.0

kill. An hour or two after twigs are treated with these light oils, there is no evidence of oil present; whereas a distinct residue of the heavier oil persists for a week or more. Analogous results were obtained on San Jose scale, as will be seen from Table X. The light oil of high volatility was not effective when emulsified with fish-oil soap or with an inert agent or when incorporated in a soluble oil.

There may be a wide range of viscosity (from 80 up to 250 or 300) without any appreciable change in volatility. When the viscosity drops as low as 60, there is a rise in volatility and a decrease in effectiveness. It is believed that a suitable oil for scale control should not fall below 80 viscosity and should not have a volatility of over 1 per cent.

TABLE X.*

SHOWING RELATION OF VOLATILITY AND VISCOSITY OF OIL TO EFFECTIVENESS ON SAN JOSE SCALE.

Item	Emulsion	Properties of the oil: Emulsifying agent	Kind	Viscosity *Sec.*	Volatility *Per cent*	Per cent live scale at dilution of: 3%	2%	1%
1	Stock Emulsion	K.F.O. Soap	Unsat.	104	0.19	0.9		
2	Stock Emulsion	K.F.O. Soap	Sat.	83	1.00	0.2		
3	Stock Emulsion	K.F.O. Soap	Sat.	32	35.10	36.2		
4	Stock Emulsion	Inert	Unsat.	104	0.19	2.0		
5	Stock Emulsion	Inert	Sat.	83	1.00	0.2		
6	Stock Emulsion	Inert	Sat.	32	35.10	11.6		
7	Soluble Oil No. 56	Soap No. 55	Unsat.	83	1.07		4.8	27.7
8	Soluble Oil No. 47	Soap No. 55	Sat.	32	35.10		24.3	35.6
9	Checks					43.0	66.6	66.6

* Data under items 1 to 6, inclusive, are by S. C. Chandler, of the Illinois State Natural History Survey.

RELATION OF CHEMICAL PROPERTY OF OIL AND STABILITY OF EMULSION TO EFFECTIVENESS AGAINST SCALE INSECTS

Data in some of the preceding tables suggest differences in the effectiveness of saturated and unsaturated oils on scale insects. With a slight repetition of some of the data an attempt will be made to demonstrate these differences.

Table XI shows data on oyster-shell scale obtained with the emulsions shown in the photographs of Figure 7. The first two emulsions listed here have the same oil content, and the emulsifying agent in both is a potash-petroleum soap, but No. 35 contains an unsaturated oil and No. 33 a saturated oil. The latter, being a quicker-breaking emulsion, gave a higher per cent kill than No. 35. Soluble oils Nos. 16 and 45 (items 3 and 4 in Table XI) are made from the same oil, but No. 45, having 40 per cent less emulsifying agent than No. 16, is a very unstable emulsion, and the difference in kill at a dilution of 5 per cent is very striking: 97.7 per cent kill for the unstable emulsion against 26.3 per cent for the stable one. Nos. S9 and S10, although made from different oils, are both quick-breaking emulsions. Here, apparently, the unsaturated oil seems to be slightly more effective than the saturated oil. If reference is made to Table IX, showing the toxicity of undiluted volatile oils to oyster-shell scale, it will be noted that the saturated oil gave kills of 4.0 per cent and 52.7 per cent in two separate experiments, whereas the unsaturated oil gave kills of 41.7 per cent and 67.7 per cent in the same experiments. The data under items 5 and 6 in Table XI also indicate that the unsaturated

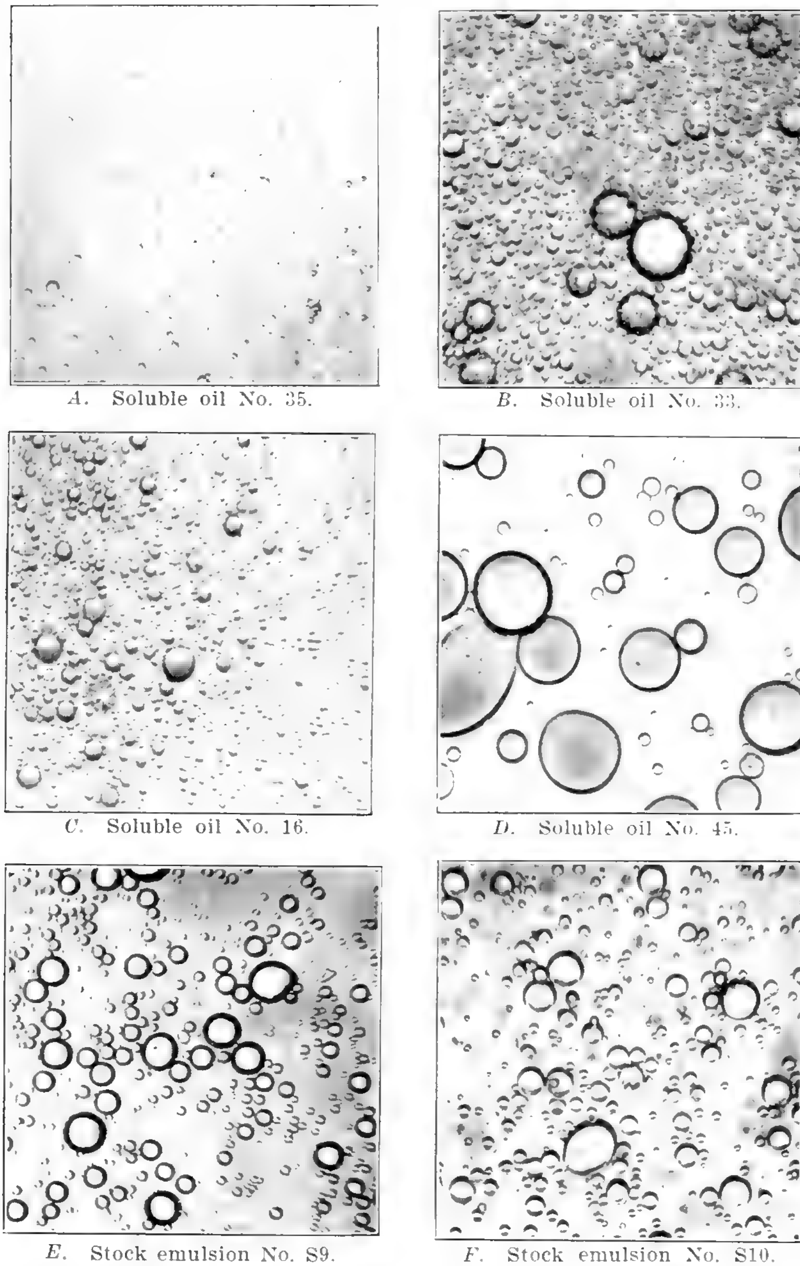
TABLE XI.

SHOWING RELATION OF CHEMICAL PROPERTY OF OIL AND STABILITY OF EMULSION TO EFFECTIVENESS ON OYSTER-SHELL SCALE.

Item	Emulsion	Emulsifying agent	Properties of the oil				Per cent killed at dilution of	
			Kind	Loss to H_2SO_4 *Per cent*	Viscosity *Sec.*	Volatility *Per cent*	5%	10%
1	Soluble Oil No. 35	Soap No. 37	Unsat.	9.0	83	1.0	38.7	86.4
2	Soluble Oil No. 33	Soap No. 37	Sat.	1.0	83		69.6	94.1
3	Soluble Oil No. 16	Soap No. 15	Sat.	0.0	83	0.2	26.3	98.9
4	Soluble Oil No. 45	Soap No. 15	Sat.	0.0	83	0.2	97.7	99.8
5	Stock Emulsion No. S 9	K.F.O. Soap	Sat.	1.0	83	1.0	9.6	99.9
6	Stock Emulsion No. S 10	K.F.O. Soap	Unsat.	7.0	104	0.2	36.3	99.4
7	Checks						0.0	0.0

oil is slightly more effective. Thus, the unsaturated oil may be more effective if the emulsion is quick-breaking; otherwise, the saturated oil may be more effective because of its influence on stability.

The influence that saturated and unsaturated oils may have on the stability of an emulsion, together with their relative effectiveness, is further indicated by the results on San Jose scale shown in Table XII. (See Figure 8.) Soluble oils Nos. 90 and 16 are made from equal amounts of the same emulsifying agent, but No. 90 is the more stable, probably on account of the fact that the oil from which it is made is not so highly refined as the oil in No. 16. It will be seen that No. 90 is relatively less efficient on San Jose scale on peach, as well as on apple. Soluble oil No. 17 made with the same oil as No. 90, but with a reduced amount of emulsifier, is relatively more effective. The influence that saturated and unsaturated oils may have on the stability of the emulsion and its effectiveness is indicated to a slight extent when the oils are emulsified with an inert material. It will be noted from the photographs in Figure 8 that stock emulsion No. 210 is slightly more stable than No. 200.



A. Soluble oil No. 35.

B. Soluble oil No. 33.

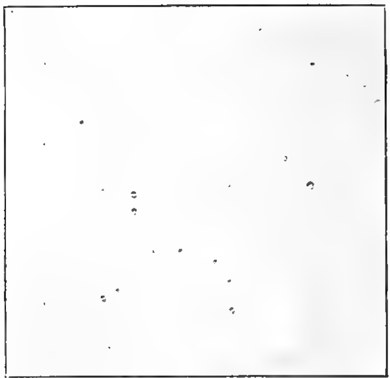
C. Soluble oil No. 16.

D. Soluble oil No. 45.

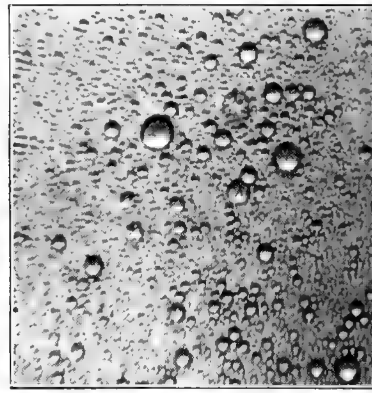
E. Stock emulsion No. S9.

F. Stock emulsion No. S10.

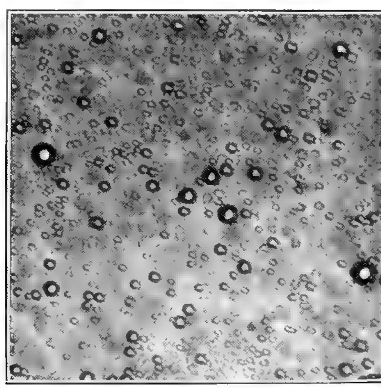
FIG. 7. MICROPHOTOGRAPHS OF EMULSIONS USED IN EXPERIMENTS. (× 290)



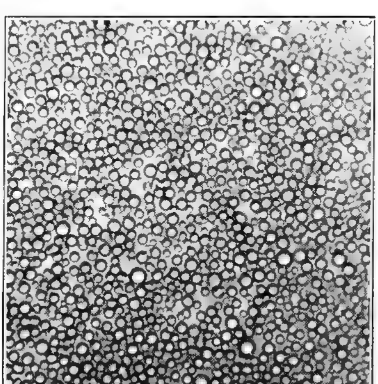
A. Soluble oil No. 90.



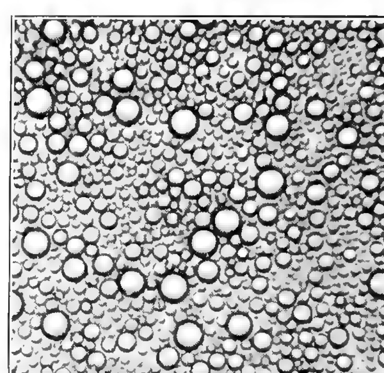
B. Soluble oil No. 16.



C. Soluble oil No. 17.



D. Stock emulsion No. 210.



E. Stock emulsion No. 200.

FIG. 8. MICROPHOTOGRAPHS OF EMULSIONS USED IN EXPERIMENTS. (× 290)

The results on scale insects corroborate deOng's work by indicating that the action of an oil emulsion in producing death is largely a physical one, causing suffocation. If the action is due to penetration alone, then the oils of low viscosity should be more effective, because of their greater mobility. But high volatility is usually associated with low viscosity, and if death is to be effected by penetration, the oil should persist. The ineffectiveness of light volatile oils has been demonstrated by Moore and Graham ('18), who state that such oils may evaporate too quickly to cause

TABLE XII.

SHOWING RELATION OF CHEMICAL PROPERTY OF OIL AND STABILITY OF EMULSION TO EFFECTIVENESS ON SAN JOSE SCALE.

Item	Emulsion	Emulsifying agent	Properties of the oil: Kind	Loss to H_2SO_4 *Per cent*	Viscosity *Sec.*	Volatility *Per cent*	Per cent live scale at dilution of	
			On Peach				2%	1%
1	Soluble oil No. 90	Soap No. 15	Unsat.	9.0	83	1.0	7.7	28.5
2	Soluble oil No. 16	Soap No. 15	Sat.	0.0	83	0.2	0.2	4.7
3	Check						66.6	66.6
			On Apple				3%	1.5%
4	Soluble oil No. 90	Soap No. 15	Unsat.	9.0	83	1.0	0.2	4.9
5	Soluble oil No. 17	Soap No. 15	Unsat.	9.0	83	1.0	0.6	1.5
6	Soluble oil No. 16	Soap No. 15	Sat.	0.0	83	0.2	0.4	0.0
7	Check						40.0	40.0
			On Peach				3%	2%
8	Stock Emul. No. 210	Inert	Unsat.	9.0	83	1.0	1.7	2.6
9	Stock Emul. No. 200	Inert	Sat.	0.0	83	0.2	0.6	1.3
10	Check						12.6	12.6

Note: Emulsifying agent in Sol. oil No. 17, reduced.

death. It has been observed by deOng ('27) that scale insects may actually expel the lighter oils from their tracheal systems. If the action were mainly chemical, the unsaturated oils, which are more active chemically, would be more effective. The important point in scale control is to apply an emulsion that will release quickly an oil of sufficiently high viscosity and low volatility to give a residue that will persist for sometime.

INJURY TO PLANTS

As a general rule, the higher the viscosity and the lower the volatility of an oil, the more likely it is to cause injury to plants, whether it is saturated or unsaturated. It is quite possible to apply a volatile, unsaturated kerosene without much danger of injury, but with oils that give a persistent residue it is necessary to increase the degree of refinement in order to insure safety to foliage. Wherever a persistent residue is required, therefore, the difference between saturated and unsaturated oils is the most important consideration with respect to plant injury.

In tests on apple foliage it has not been found necessary to use an oil of medicinal quality, i. e., an oil that shows *no* loss to 97 per cent sulfuric acid. An oil having a loss of 1 per cent to sulfuric acid and a viscosity of 83 has been found quite safe on apple foliage at dilutions as high as 4 per cent when emulsified with some inert material. But the incorporation of a saturated oil, even of medicinal quality, in a soluble oil did not prove safe, nor did it apparently decrease the injury below that of the corresponding unsaturated oil. Although the saturated oil itself and the petroleum soap were relatively innocuous when applied separately, a safe combination of the two could not be worked out. Replacing sodium with potassium in the soap did not reduce injury; neither did an entire change of emulsifying agent. The incorporation of a highly volatile saturated oil in a soluble oil did reduce injury considerably, but the combination was not entirely safe and was not of satisfactory insecticidal efficiency. (Tables VIII, IX, X.)

In the early stages of the work, various oils were applied undiluted, or "straight", to apple twigs in order to determine their liability to cause injury. The results of a typical test are seen in Table XIII.

TABLE XIII.

INJURY TO APPLE FOLIAGE BY UNDILUTED OILS.

Item	Viscosity	Volatility	Loss to H_2SO_4	Estimated per cent injury observed after					
	Per cent	*Sec.*	*Per cent*	20 hrs.	25 hrs.	2 da.	4 da.	6 da.	10 da.
1	32	35.1%	0.0	0	0	0	0	0	0
2	83		1.0	0	0	0	0	0	10*
3	83	0.2%	0.0	0	0	0	0	0	10*
4	32	54.3%	3.0	0	0	0	0	0	0
5	83	1.0%	9.0	0	40	80	90	100	100
6	104	0.2%	7.0	0	40	80	90	100	100

* Finally, yellowing and defoliation.

Tests of this kind illustrate strikingly the acute injury done by unsaturated oils. Twigs treated with unsaturated oils show almost complete blackening of the tissue within 48 hours, while it may be several days before the saturated oils cause injury, and even then the injury is not "burning" but "yellowing" and defoliation. The latter seems to be the result of suffocation of the cells in the tissue, while the action of the unsaturated oils appears to be chemical for the most part. The very volatile oils leave the plant without causing injury. The important point in selecting an oil emulsion for spraying foliage is to use one that is as nearly inert chemically as possible. Such an emulsion is obtained with a saturated oil and an inert emulsifier. This conclusion is in harmony with deOng's.

Conclusions

Emulsifying agents used in making oil emulsions for spray purposes vary in wetting ability, as measured by Stellwaag's angle-of-contact method, and consequently cause variations in the effectiveness of the emulsions. This is especially important in the control of aphids.

The stability of oil emulsions, which is indicated to some extent by the size of the globules, is one of the principal factors in insecticidal efficiency. The type of oil emulsified, the kind and amount of emulsifying agent, the quality of water used for dilution, and other factors commonly considered unimportant, are capable of causing changes in stability and consequent fluctuations in efficiency.

Increased effectiveness may or may not be accompanied by an increase in the size of globules. Increased size of globules is the result of desirable qualities in an emulsion rather than the cause of effectiveness.

For use against aphids, the most effective emulsion is one that has high wetting ability coupled with instability. Either of these factors may vary so as to be dominant. A relatively "poor-wetting", unstable emulsion may be more effective on aphids than a "good-wetting", stable emulsion. If the stability of two emulsions is about the same, then the one with the greater wetting ability is the more effective on aphids.

In the control of scale insects, the instability of the emulsion is the primary consideration. The less stable the emulsion, the greater its efficiency. High wetting ability is not necessary for the control of San Jose scale and oyster-shell scale, because of the comparative ease with which their host plants are wetted. The emulsions used for the control of these insects should release quickly an oil of sufficiently high viscosity and low volatility to give a persistent residue.

A saturated oil, because of its influence in some cases on the stability of the emulsion, may be more effective than an unsaturated oil.

The amount of oil adhering and taking proper effect on the insect is dependent upon both the wetting ability and the instability of the emulsion. Inadequate wetting is a common cause of inefficiency, but excessive wetting, which results in some of the emulsion running off from objects that are easily wetted, is also a possible cause of inefficiency. These conditions are dependent on the kind of emulsion and the insect involved.

In order to be innocuous to plant foliage, an emulsion should be as inert chemically as possible. Soaps and unsaturated oils tend to injure foliage.

Each oil emulsion should be considered as a particular *individual* insecticide, having properties peculiar to itself and giving results that other emulsions may not.

Acknowledgments

The writer hereby expresses his gratitude to Mr. W. P. Flint, of the Illinois State Natural History Survey, for arranging many of the experiments and for suggestions and assistance from time to time; to Dr. B. A. Porter, of the U. S. Bureau of Entomology, for assistance, particularly with the San Jose scale experiments; and to Dr. W. A. Ruth, of the Horticultural Department of the University of Illinois, for the use of equipment and orchards, and for most friendly cooperation in every way.

For a careful criticism of the manuscript, the writer is grateful to Dr. F. W. Sullivan and Dr. E. W. Adams of the Standard Oil Company (Indiana). Thanks are due, also, to these chemists and other members of the Technical Department of the Standard Oil Company for assistance and cooperation at all times. Most of the emulsions used in the various experiments were prepared by the laboratories of the Standard Oil Company.

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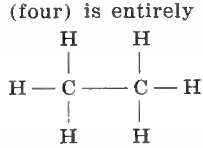
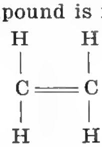
Appendix A

DEFINITIONS OF TERMS

A saturated hydrocarbon is a compound of hydrogen and carbon in which the normal valence of carbon (four) is entirely satisfied.

Example: ethane 

An **unsaturated hydrocarbon** is one in which the normal valence of carbon is not satisfied; hence, the compound is more active chemically than a saturated hydrocarbon.

Example: ethylene 

A **saturated oil,** or white oil, is one from which the unsaturated hydrocarbons have been removed by treatment with sulfuric acid. A saturated oil is practically inert chemically.

An **unsaturated oil** is not as highly refined as the white oils. While an oil of this kind may consist largely of saturated hydrocarbons, not all the unsaturated hydrocarbons have been removed in refining it.

Loss to Sulfuric Acid.* The loss in volume of an oil as a result of treatment with sulfuric acid is an index to the unsaturated hydrocarbon content. The greater the loss, the more unsaturated the oil. There is a standard method of procedure for this test.

Viscosity.* This is simply defined as resistance to flow, or negative fluidity. The standard of comparison used for oils is the Saybolt test. The units used are seconds, and they represent the time required for a given volume of oil to flow through a given orifice at a definite temperature.

Volatility.† This is an arbitrary test which expresses as per cent by weight, the evaporation of a given quantity of oil at 212°F for 8 hours.

"Soluble Oil" and **"Stock Emulsion".** For purposes of discussion, a distinction is usually made between "soluble oil" and "stock emulsion", although there is no basic difference between them, both being oil emulsions. "Soluble oils," which are more or less transparent because of the extremely fine degree of dispersion of the oil phase, are compounded petroleum products which form milky-white emulsions when diluted with water. Dendrol and Sunoco are examples. The term "stock emulsion" is used with reference to a concentrated emulsion, such as Volck, Sherwin-Williams Free-mulsion, homemade lubricating oil emulsion, etc.

---

* The determinations of loss to sulfuric acid and of viscosity were made by the Standard Oil Company (Indiana), according to United States Government Specifications for Lubricants and Liquid Fuels and Methods of Testing, U. S. Bureau of Mines, Technical Paper 323 A., March 18, 1924.

† Refer to British Engineering Standards Association, Tentative British Standard Specifications 148 (1923), pages 9-10, Section 14b.

Appendix B

EXPERIMENTAL METHODS

Tests on aphids. *Aphis pomi* De G. was obtained on the water sprouts of apple; *Aphis spiraecola* Patch on *Spiraea vanhouttei* Zabel; *Hesteroneura setariae* Thos. on a grass (*Echinichloa crus-galli* L.); and *Tritogenaphis ambrosiae* Thos. on wild lettuce (*Lactuca canadensis* L.). The infested shoots were cut from the plants a short time before spraying. Nearly all the leaves were removed so that the aphids would not be protected. The shoots were then placed vertically on a revolving stand and sprayed thoroughly with a hand sprayer having bottom feed. An excessive amount of spray on the aphids was insured, i. e., as much as would adhere. After treatment, the shoots were inserted in holes in the tops of pill boxes filled with water and isolated on squares of paper bordered with tree tanglefoot. After approximately 24 hours, the aphids were carefully removed with a camel's hair brush and counted.

Tests on oyster-shell scale. For the laboratory tests with oyster-shell scale, *Lepidosaphes ulmi* Linn., infested poplar (*Populus deltoides* Marsh) twigs were used. These were trimmed uniformly, and all scales were removed except 25 to 50, the number varying with separate experiments, but never within one experiment. Five of these twigs were treated with each material, and several untreated checks of five twigs each were carried through each experiment. After treatment, the twigs were placed in a moist sand bench to grow. A ring of tanglefoot around each prevented the escape of "crawlers" at the time of hatching. Throughout the hatching period, the twigs were examined daily with a binocular microscope, and the crawlers were removed as counted. The checks usually hatched very uniformly, and the hatch on the treated blocks was calculated to "check basis". About 3,000 to 3,500 eggs hatched from each check block of five twigs.

Tests on San Jose scale. All of the tests of sprays on San Jose scale (*Aspidiotus perniciosus* Comstock) were conducted in the field. In some cases, large infested branches were treated; in others, several entire trees were used in each block. The usual procedure of taking San Jose scale data was followed. A month or six weeks after treatment, twigs were collected from the various blocks, and a count of 1,000 scales was made to determine the percentage of survival. In making the counts, the scale was turned over in order that the insect itself might be seen. Robust, lemon-colored ones were recorded as "alive". Brown, black, shriveled, or "off color" ones were recorded as "dead."

Appendix C

ANALYSIS OF TAP WATER USED IN EXPERIMENTS

Illinois State Water Survey, Sample No. 51728, June 28, 1924

Determinations		Parts per million
Iron	Fe	1.2
Manganese	Mn	0.0
Silica	SiO_2	14.1
Nonvolatile		1.8
Alumina	Al_2O_3	0.0
Calcium	Ca	66.9
Magnesium	Mg	31.4
Ammonia	NH_4	5.3
Sodium	Na	34.8
Potassium	K	4.1
Sulfate	SO_4	1.2
Nitrate	NO_3	1.4
Chloride	Cl	4.0
Alkalinity as $CaCO_3$		
Phenolphthalein		0.0
Methyl Orange		376.0
Residue		380.0

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U. S. Bureau of Entomology, Vincennes, Indiana

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SOME CAUSES OF CAT-FACING IN PEACHES*

B. A. Porter, S. C. Chandler, and R. F. Sazama

INTRODUCTION

For a number of years the peach growers of southern Illinois and southern Indiana, as well as those of some other sections of the Middle West, have been suffering losses from a peculiar deformation of the peaches that generally has been supposed to be caused by the feeding of thrips. The injury has been named "cat-facing" by growers in several localities, and this term is now in common use in the Middle West. Similar injuries occur in peach orchards in the Northwest, in Georgia and the Carolinas, and probably in other localities, but the present paper reports investigations restricted to southern Illinois, southern Indiana, and western Kentucky.

NATURE OF THE INJURY

The injury known as cat-facing usually consists of scarred sunken areas around which the tissues are more or less distorted, but it sometimes takes the form of closed lesions, which vary from slight dimples or depressions to extensive puckered areas. No pubescence develops on an injured area, and in most cases the area is brown, corky, and harder than the normal flesh of the fruit. Such injury is obviously the result of the feeding of insects when the peaches are small. The more open scars suggest surface feeding by some kind of chewing insect, but the other scars look more like the work of sucking insects.

On a given tree, the injury sometimes tends to be localized; while some parts may be free of injury, almost all of the peaches on other parts may be disfigured. Apparently, the insects causing the injury often move from peach to peach, injuring almost every one they encounter.

Different varieties of peaches appear to be injured in varying degrees. The J. H. Hale often shows more cat-facing than the Elberta grown nearby. One instance has been observed in which at least 27 per cent of

* The investigations on which this paper is based were conducted simultaneously at two places—at the entomological field laboratory maintained by the Illinois State Natural History Survey at Carbondale, Illinois, under the direction of Mr. W. P. Flint, and at the field laboratory maintained at Vincennes, Indiana, by the U. S. Bureau of Entomology, under the general supervision of Dr. A. L. Quaintance, and in cooperation with the Purdue University Agricultural Experiment Station.

Acknowledgment is made to Mr. W. L. McAtee, of the Bureau of Biological Survey, for the determination of the species of *Lygus* and *Euschistus* referred to in this paper.

the peaches on Redbird trees were injured, while only 11 per cent of those on the J. H. Hale nearby were injured, and only 5 per cent of those on the Elberta next to them.

LOSSES

The commercial losses resulting from cat-facing are hard to estimate. The percentage of peaches damaged is very variable. Although in individual orchards the injury has run as high as 50 per cent or even 66 per cent, the general average in this region is less than 15 per cent.

TABLE I

COUNTS OF CAT-FACED PEACHES IN REPRESENTATIVE ORCHARDS IN JACKSON, JOHNSON, UNION AND PULASKI COUNTIES, OZARK PEACH SECTION OF SOUTHERN ILLINOIS

Year	Orchards examined	Per cent of peaches cat-faced		
		Maximum	Minimum	Average
1925	25	45	2	14.0
1926	41	17	0	2.6
1927	19	24	6	12.4

Cat-faced peaches usually are graded as No. 2 fruit, and those most severely injured are classed as culls. The actual money loss, of course, varies with market conditions. In years of large crops, the injured peaches are hard to sell, although the loss per bushel is not so great. In years of light crops, the loss per bushel is greater, but most of the lower-grade peaches find a ready market at fair prices.

When the insects causing cat-facing are very abundant, they often cause many of the small peaches to shrivel and drop, so that the crop loss is much greater than the percentage of disfigured fruit at harvest time would indicate. This loss is often very serious, although it may be unnoticed by the grower, or at least not attributed to its real cause. The actual commercial loss that results from the dropping of the fruit varies with the size of the crop and is very hard to measure. In years of heavy bloom, when many surplus peaches set, this loss may be comparatively slight, but in years when there is a light set of fruit, it may be more serious because of the greater proportion of peaches injured.

PROCEDURE

In order to determine which insects cause cat-facing, different suspects were caged with peaches on the tree. Various cages were used, but the one that proved the most satisfactory was a cylinder of 16-mesh wire screening, four inches in diameter by six to nine inches in length, fitted at one end with a cloth sleeve. (See Figure 1.) Such cages may be made readily to enclose a twig bearing two to four small peaches. In most cases the cages were put into place immediately following petal fall. Wherever it was necessary to cage larger peaches, they were carefully examined, and all those showing any sign of injury were removed. In no case did injury appear in check cages.

Several seasons of experience were required to enable the writers to manipulate the cages so as to produce the maximum number of typical injuries. Complete proof of the "guilt" of insects suspected as agents is not obtained as easily as may be supposed. The mere fact that an insect injures a peach when caged with it and deprived of other food, is not in itself complete proof that the insect is causing cat-facing in the orchard.

Fig. 1. Tree showing cages used in determining what insects cause cat-facing in peaches. Carbondale, Illinois. 1926.

Field observations are necessary in order to determine whether or not it normally feeds on peaches in the open. On newly formed peaches it is difficult to adjust the period of insect feeding so that the injury will not be overdone and cause the peaches to drop. When the peaches are further developed before being injured, they are less likely to drop; but the normal feeding period of certain of the insects, at least, is then nearly over, and the resulting lesions are not so closely similar to typical cat-facing. All of the insects that we consider responsible for cat-facing have been observed repeatedly in the orchard in the act of feeding on peaches, with their mouth parts actually inserted into the peach tissue. This is the final step in determining the causal agents.

SOME INSECTS THAT CAUSE CAT-FACING

THE TARNISHED PLANT BUG

The Tarnished Plant Bug (*Lygus pratensis* L.) has been recorded a number of times as feeding on peaches, particularly by Lowe[1] and Taylor.[2] This small, inconspicuous bug (see Figure 2) came under suspicion several years ago as a possible cause of cat-facing, and the type of injury done by it was described in a previous paper by Porter.[3] The fresh injuries consist of rather extensive irregular areas of broken-down tissue. In some cases the skin is left intact except for a central puncture, but in

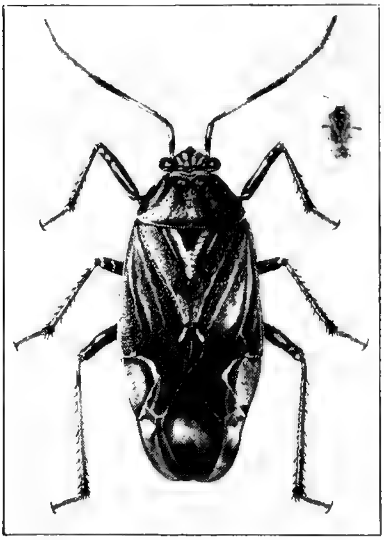

FIG. 2. Tarnished Plant Bug, *Lygus pratensis* L. (Insert is approximately natural size.)

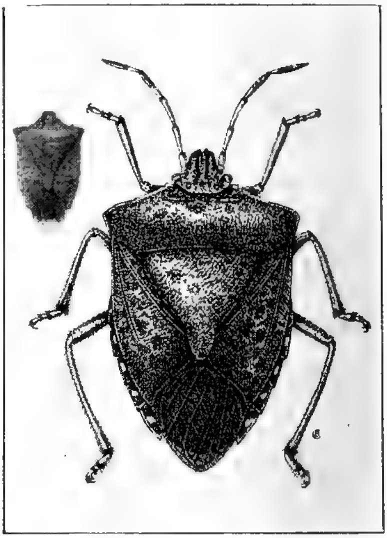

FIG. 3. Stink bug, *Euschistus servus* (Say). (Insert is approximately natural size.)

others the skin as well as the underlying tissue is broken down. The fuzz over the lesion is usually undisturbed, although the point where the beak of the bug was inserted may be marked at first by a yellowish or brownish stain, which later turns black. If the skin has not already broken down, it dries and sloughs off, and the inner surface of the cavity becomes corky and rough as it heals over. The surrounding tissues usually grow more rapidly than the injured spot, producing more or less distortion. The bugs in feeding apparently inject some poisonous material that causes

[1] Lowe, V. H., 1900. Miscellaneous Notes on Injurious Insects. New York Agr. Exp. Sta. (Geneva) Bull. 180, p. 135.

[2] Taylor, E. P., 1908. Dimples in Apples from Oviposition of *Lygus pratensis* L. J. Ec. Ent. 1, p. 370.

[3] Porter, B. A., 1926. The Tarnished Plant Bug as a Peach Fruit Pest. J. Ec. Ent. 19, pp. 43-48.

the tissues to disintegrate. Hypodermic injections of the juices of crushed bodies of the bugs produced lesions somewhat similar to cat-facing, but injections of distilled water, as well as injuries produced by probing with a sterile needle, failed to result in such lesions.

Peaches injured in cages by the Tarnished Plant Bug were carried through to the mature cat-face stage in 1926 and 1927, thus completing the proof that this insect plays a part in the production of cat-facing. Two of these peaches are shown in Figure 4.

The bugs that feed on peaches in spring are those that have become full-grown in the previous autumn and have passed the winter in the adult stage in or near the orchard. The Tarnished Plant Bug normally passes its life on various weeds and other succulent plants. It seems to be especially fond of the plants in the daisy family, such as wild asters and

FIG. 4. Peaches injured in cages by Tarnished Plant Bug. Carbondale, Illinois. 1926.

fleabanes, as well as the leguminous plants, such as red clover, alfalfa, and sweet clover. These last two also provide the bugs with very acceptable hibernating quarters, since, in addition to winter protection, they furnish satisfactory food very late in fall and very early in spring.

Many of the hibernating bugs are attracted to the peach blossoms, and for a period of two or three weeks they do the feeding that results in the injuries just described. The approximate period during which the bugs are present on the trees, as indicated by the number of bugs caught on the sheets when jarring for curculio, is shown in Figure 5. Very few eggs are laid on the peach trees, and after a short time most of the bugs desert the trees and return to various weeds or cultivated crops to lay their eggs. The Tarnished Plant Bug is said to pass through several generations during a season, and to hibernate almost entirely in the adult stage.

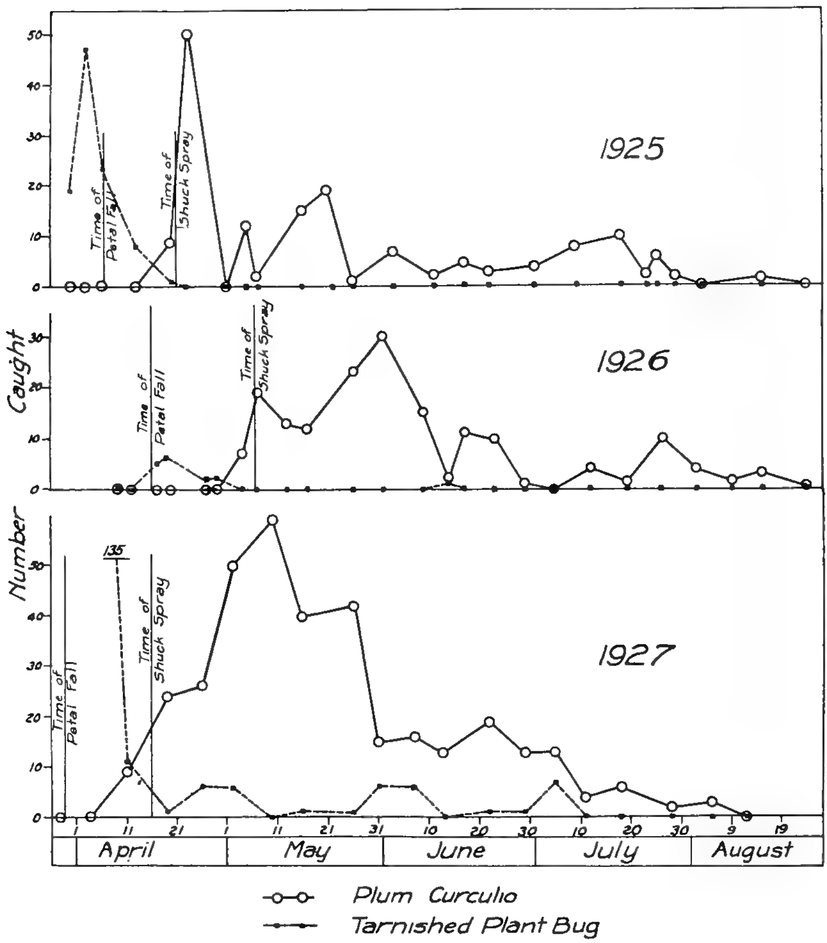

FIG. 5. Graphs showing numbers of Tarnished Plant Bug and Plum Curculio caught on sheets by early-morning jarring of 10 unsprayed peach trees, Carbondale, Illinois. The jarring was done between 6:00 and 7:00 a. m. The insects were turned loose after counting, in order to keep conditions as near natural as possible.

FIG. 6. Peaches injured in cages by three kinds of stink bugs: top row, *Euschistus variolarius;* middle row, *E. tristigmus;* bottom row, *E. servus.* Vincennes, Indiana. 1927. *Photos by R. L. Coffin, of Japanese Beetle Laboratory.*

STINK BUGS

Four species of stink bugs* produce cat-facing. (See Figures 3 and 6.) These large, angular bugs, gray to brown in color, are often very abundant in peach orchards in spring, and we have observed them repeatedly in the act of feeding on small peaches. When the peaches are very small, most of the injured ones shrivel and drop, but when the peaches are larger, most of those that have been fed upon remain on the tree and become distorted or cat-faced. The stink bugs continue to produce cat-facing for five or six weeks after petal fall, or until the peaches become an inch or more in diameter. Feeding continues after this stage of development, in diminishing amounts, and the lesions produced later are less extensive. Two of the species involved, *E. variolarius* and *E. tristigmus,* were very abundant during 1927 in southern Indiana, and the

FIG. 7. Colony of small stink bugs, clustered on leaf near egg mass from which they hatched. Vincennes, Indiana. 1927. (About six times natural size.)

other two species mentioned were probably responsible for very little of the cat-facing there in that season.

A few of the stink bugs lay eggs in small groups on the leaves of the peach trees. The egg masses observed have usually been in multiples of seven, fourteen being the most common number. On hatching, the young bugs remain clustered around the egg mass for a few days until they undergo the first molt (see Figure 7); they then disperse and feed for a short time on the leaves and on the young peaches, if they find any nearby.

* *Euschistus variolarius* (Palisot de Beauvois); *E. euschistoides* (Vollenhoven); *E. servus* (Say); and *E. tristigmus* (Say). These are the more common members of this genus in southern Illinois and southern Indiana.

Their feeding may cause slight dimples on the fruit, out of which ooze small quantities of gum; this kind of injury, however, is not very common, since the small bugs disappear from the peach trees soon after the first molt. They are found in abundance on weeds in the orchard in early summer, particularly on the young plants of one of the fleabanes, *Erigeron canadensis L.* Later on, bugs of all ages may be found in large numbers in fields of soy beans and cow peas. In 1927, one of the stink bugs (*E. variolarius*) was found in large numbers in red clover fields. They may be found, however, to a greater or lesser extent on almost any growing plant. Stink bugs are said to pass usually through two generations during a season, and they hibernate in the adult stage.

CURCULIO

The Plum Curculio, *Conotrachelus nenuphar* Herbst, so well known to all peach growers, produced cat-facing on peaches in our cages. The

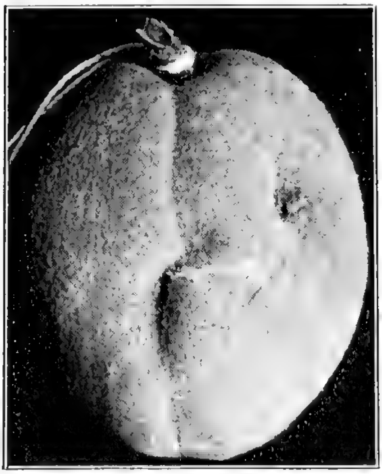

FIG. 8. Peach injured in cage by curculio. Carbondale, Illinois. 1926.

FIG. 9. Curculio ovipositing on a peach. (About four times natural size.)

work of this insect is best known to the growers by the dropping of peaches early in the season and the occurrence of wormy fruit at harvest. When the injured fruit remains on the tree, it is more or less distorted. (See Figures 8 and 9.)

OTHER POSSIBLE CAUSES

While we are confident that the list of insects already named includes the important causes of cat-facing in southern Illinois and southern Indiana, it is probable that further investigations will show that other insects are also capable of producing cat-facing.

The Green Soldier Bug, *Acrosternum hilare* (Say), one of the largest of the stink bugs, is occasionally seen in peach orchards, and its young stages sometimes cause considerable injury to the fruit[4] in the form of numerous small dimples (see Figure 10). None of the mature bugs have been available for caging tests in spring. A few peaches may be cat-faced by this species, but it is so scarce in the peach orchards of this section that it cannot be an important factor.

A species of thrips, *Frankliniella tritici* (Fitch), which is often present in large numbers in the peach blossoms and around the small fruit, was at first suspected as the cause of cat-facing, but we have been unable to connect this insect with the trouble. In one season in particular (1925) thrips were very abundant in our cages (they are so very small that they can pass through the ordinary screen cage), but no sign of injury appeared until other insects were introduced. Even when the normal population was augmented by the addition of fifteen to twenty thrips to each

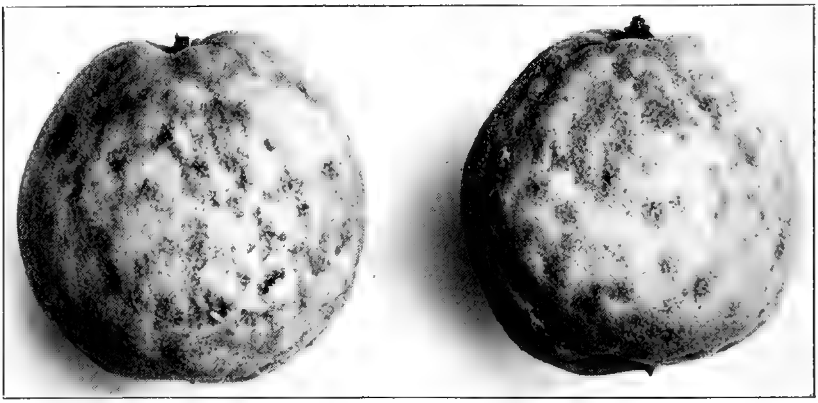

Fig. 10. Peaches injured by young of Green Soldier Bug, *Acrosternum hilare* (Say). Vincennes, Indiana, 1927. *Photo by R. L. Coffin, of Japanese Beetle Laboratory.*

peach, no injury appeared. Field observations and counts have failed to show any relation between thrips abundance and amount of cat-facing. The fruit in some orchards in which thrips have been almost entirely absent has suffered severe cat-facing. As a result of these studies, we believe that the work of thrips is a negligible factor.

Relative Importance of the Different Insects

We can make no definite statement at present that will hold true for every year, or in every peach section, or even in all parts of the same section, as to the relative importance of the different species implicated in

[4] Whitmarsh, R. D., 1917. The Green Soldier Bug. Ohio Agr. Exp. Sta. Bull. 310.

producing cat-facing. The curculio is probably of less importance in this respect than the sucking bugs—a belief which is supported by the fact that serious cat-facing injury occurs in some peach orchards in the Pacific Northwest where the curculio does not occur.

If it were possible to distinguish the injury caused by each of the different insects, it could be determined which insect is of the greatest importance in individual orchards. Although the different injuries when fresh may be identified with some degree of certainty, they cannot be distinguished one from another after they have healed over.

HOST PLANT RELATIONS

With the exception of the Plum Curculio, which is probably a lesser factor, the insects involved in this problem do not breed to any extent on peach. They are very general feeders, and may be found on any one of a long list of food plants. The Tarnished Plant Bug seems to favor plants in the family Compositae, especially the daisies, the fleabanes, and the wild asters. It also breeds freely on the legumes, but may be found on almost any other plant.[5]

The stink bugs are, likewise, very general feeders and may be found on a great many different kinds of plants. Among their preferred host plants may be mentioned red clover, cow peas, and soy beans. The presence of these bugs on peach fruit in the spring is merely incidental and in no way essential to their life cycle.

The plant relationships of the Plum Curculio are not as extensive as those of the other insects involved. Of the cultivated plants aside from peach, the curculio feeds regularly on apple, plum, cherry and other fruits, which are often planted close to peach orchards. Of the wild host plants, wild haw and wild plum are probably the most important.

HIBERNATION OF THE TARNISHED PLANT BUG

Studies were made of the hibernating habits of the Tarnished Plant Bug in an effort to discover some means of controlling this cause of cat-facing. The bugs were found in a variety of winter habitats; some in clumps of clover and alfalfa in fields where numbers of them had been observed to be feeding in late summer and autumn; some under fallen leaves of trees at the edges of these fields; a few in apple orchards under various kinds of cover, such as grass, leaves, and bits of bark; and a few in other places wherever there was sufficient cover. The woolly leaves of mullein seem to be the most favored winter quarters in this section of the country, for the bugs are usually to be found in mullein even when difficult to find elsewhere. As many as fifty of them have been found at one time in a single plant. The highest average found in any one peach district was eighteen bugs per plant.

Many Tarnished Plant Bugs do not go into true hibernation, but leave their winter quarters on warm days. Counts made on November

[5] For a detailed discussion of host plants of the Tarnished Plant Bug, see Cornell Bulletin No. 346, "The Tarnished Plant Bug", pages 467-472, by C. R. Crosby and M. D. Leonard, 1914.

27, 1926, near Carbondale, Illinois, showed an average of five bugs per square foot under hickory leaves at the edge of a sweet clover field. Counts made nine days later, in exactly the same places, after several mild* days had intervened, showed an average of only one bug in five square feet. On three occasions all the hibernating bugs were removed from certain mullein plants in an alfalfa field near Anna, Illinois; two or three days later, when these plants were examined, they were found to harbor as many bugs as had been present originally.

Control of the Tarnished Plant Bug and the Stink Bugs

Insecticidal Control. It is very difficult, if not impossible, to control the Tarnished Plant Bug and the stink bugs by sprays or dusts. Arsenate of lead, and other stomach poisons, have no effect on this group of insects, since their food is obtained by sucking the plant juices. They may be killed only by direct contact with the spray or dust. At the time when the fruit needs protection, the bugs are in the adult stage, very active and difficult to hit with a spray, and very resistant to ordinary contact materials. Even if it were possible to kill all the bugs on the trees at a given time, reinfestation would be likely to occur from weeds in the orchard or from nearby sources, if such sources of infestation exist. After their period of attack on the small peaches, the bugs return to their normal breeding plants in the orchard or in its vicinity. There is, therefore, no opportunity to attack the young stages of the bugs on the trees in the orchard. The treatment of the immature bugs on the weeds would be impracticable because of the extensive area that would ordinarily have to be covered both in and around the orchard. Another disadvantage of a general insecticide treatment of this nature lies in the fact that it would have to be applied during the summer or autumn in order to protect the following season's crop, and such efforts would be wasted in the event of subsequent loss of the peach crop by winter-killing or spring frosts.

Cage Tests. Because the Tarnished Plant Bugs are so active, our experimental work with contact insecticides has been largely with dusts, which we hoped might envelop them before they had time to escape. Before any orchard tests were made it seemed advisable to make tests to ascertain whether the bugs could be killed at all. Accordingly, numbers of Tarnished Plant Bugs and stink bugs were placed in screen wire cages (5 by 5 by 24 inches) and subjected to excessively heavy spraying and dusting, with results as shown in Table II.

In interpreting the results of these preliminary tests, it should be borne in mind that the materials were used in excessive amounts and at high strengths, and that the insects were closely confined and had no opportunity to escape.

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* Maximum temperatures ranged from 38° F. to 66° F. during this period, reaching 61°, 62°, and 66° on three of the nine days.

Control in the Orchard. In using these materials in the orchard, growers are certain to encounter serious difficulties. Contact dusts are essentially open-air fumigants, and their successful use requires a very still atmosphere. In addition, the nicotine dusts require temperatures of at least 70° F. for effectiveness. Weather conditions that permit effective use of contact dusts seldom occur during the brief period when these bugs are present in the peach orchards. In fact, low temperatures, high winds, and frequent rains made it impossible to do effective dusting during the critical period in the spring of 1927. All of these materials are very expensive, and even if control could be obtained with them, the cost would be high, if not prohibitive.

The time during which dusting can be done effectively is short, as will be seen by the graphs in Figure 5. Very little control of the Tarnished Plant Bug would be possible if the operation were delayed for a week.

Repellents. Since feeding by the bugs on peaches in spring is not at all necessary to them in their life economy, we have considered the possibility of applying some kind of material that would repel them from the

TABLE II

RESULTS OF PRELIMINARY EXPERIMENTS IN THE CONTROL OF TARNISHED PLANT BUG AND STINK BUGS. (INSECTS CONFINED IN CAGES AND SUBJECTED TO HEAVY DOSES.)

Materials and dosages	Tarnished Plant Bug Per cent killed	Stink Bugs Per cent killed
DUSTS		
Calcium cyanide[1] 17-25%	24	60
Calcium cyanide 40-50%	90	40
Sulfur-cyanide[2]	100	..
Sulfur-naphthalene 50-50	25	..
Nicotine[3] 2.5%	0	..
Nicotine 4.0%	85	90
Nicotine 5.0%	100	..
SPRAYS		
Nicotine sulfate[4] 1-1000	12	..
Nicotine sulfate 1-500	84	..
Nicotine sulfate 1-200	92	0
Sodium oleate-oleo-resin of pyrethrum[5] 1-15	28	0

[1] Commercial calcium cyanide mixtures containing the indicated amounts of calcium cyanide.

[2] Commercial dusting mixture, containing 50 per cent sulfur and 20 per cent calcium cyanide.

[3] Home-mixed dusts of hydrated lime and nicotine sulfate, giving the indicated amounts of actual nicotine.

[4] Used with fish-oil soap, 2 lbs. in 50 gallons.

[5] A commercial stock material, made after the formula developed by the Japanese Beetle Laboratory.

peach trees during the period when cat-facing is being caused. This should be easier than it would be to repel insects that must also use the peach trees or fruit for egg-laying and the nourishment of their young. In order to test possible repellents, a screen wire cage (5"x5"x24") was constructed into which Tarnished Plant Bugs were introduced at different times. The following materials were placed at different points in the cage: nicotine sulfate, creosote, naphthalene flakes, carbolic acid, wormseed oil, cresylic acid, lemon oil, oil of citronella, oil of pennyroyal, hydrated lime. No evidence was obtained that any of these materials were in the least degree repellent to the Tarnished Plant Bug. Stink bugs probably would be even more difficult to repel.

Cultural Control. Since the bugs that cause cat-facing breed almost entirely on plants other than peach, a certain degree of control probably may be accomplished by the right sort of cultural practices. The host plant relations and hibernating habits of these insects have already been discussed. Observations have been made as to the influence of different cover crops in the orchard, of farm crops or weedy or wooded areas nearby, and of the presence or absence of favorable hibernating quarters near the orchard. A greater accumulation of data is needed, however, before recommendations can be made.

Control of the Curculio

The amount of cat-facing caused by the Plum Curculio can be reduced by means of a more thorough and timely use of sprays. As most of the injury is caused while the peach is still small, and the curculios first begin to appear in large numbers in the orchard about two weeks after petal fall (see Figure 5), the "shuck spray" is the most important application for this purpose. The full schedule is important, however, since the number of curculios which are allowed to breed will have a bearing on the early infestation the following spring. Additional control measures include cultivation in early summer to destroy the delicate pupae in the ground, and the elimination of hibernating quarters, such as weed and brush growth in, and close to, the orchard.

Thinning

While thinning cannot be classed properly as a control measure, it does provide a means, especially during seasons of large crops, of reducing the losses caused by cat-facing. Since the usual thinning process on heavily loaded trees often involves the removal of nearly half of the total set of fruit, the removal of all the peaches that show cat-facing would not reduce the total number of bushels harvested, unless the trees were carrying a light crop.

Cat-face injury may be detected much more readily as the peaches become larger, as shown by recent experiments in Illinois.[6] Fortunately,

[6] Unpublished data by M. J. Dorsey and R. L. McMunn, University of Illinois.

other experiments by Dorsey and McMunn[7] have indicated that effective thinning may be done as late as four weeks before harvest, which is later than has heretofore been the practice. If extensive cat-face injury is apparent, the grower will therefore find it advantageous to defer thinning as late as possible, in order that a higher percentage of the injured peaches may be found and removed.

SUMMARY

Peach cat-facing is a scarred and distorted condition of the fruit, which causes serious losses in some seasons in the peach-growing sections of the Middle West and elsewhere.

The investigations reported in this paper have proved that at least six species of insects have a part in the production of cat-facing. These insects are the Tarnished Plant Bug, the Plum Curculio, and four species of stink bugs.

The curculio goes through its life cycle on peach and other fruits. The other insects, all of which are sucking bugs, breed on a wide variety of plants. They do not breed to any extent on peach, and they feed on the peach fruit for only a short time in spring.

No method of complete control of the Tarnished Plant Bug and the stink bugs is at present available. Insecticide treatments are unsatisfactory because these bugs are very active, and because they are very resistant to the most powerful contact materials known. Proper adjustment of cultural practices, to avoid the growth of weeds and certain crops in the orchard or in nearby fields, seems to offer promise of partial control.

Reduction in cat-facing caused by the Plum Curculio may be accomplished by following recommended control measures, mainly by spraying or dusting and cultivation.

[7] Dorsey, M. J., and R. L. McMunn. Development of the Peach Seed in Relation to Thinning. Amer. Soc. Hort. Sci.1926, p. 402.

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Vol. XVII. BULLETIN Article VII.

The Biological Survey of a River System---Its Objects, Methods, and Results

BY

STEPHEN A. FORBES

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THE BIOLOGICAL SURVEY OF A RIVER SYSTEM---ITS OBJECTS, METHODS, AND RESULTS*

Stephen A. Forbes

In taking up my complex and rather difficult subject, I greatly regret that I have not a larger field from which to draw my data. The attention of biologists especially interested in the aquatic biota was naturally drawn, first, to the wonderful assemblage of animals and plants and the system of life in the great seas and, next, to those of the fresh-water lakes, concerning both of which there are ample stores of knowledge from various sources to draw upon; but the rivers of the country have received so little comprehensive attention from our biologists that I do not know of a single attempt anywhere in America to develop and disclose the complete biology of a river system except that which has been made by us in Illinois, and it is for this reason that I am forced to make our own operations rather unpleasantly conspicuous.

It was in 1874, when serving as curator of a small public museum which ten years later became the Illinois State Laboratory of Natural History, that I first began, with only casual assistance and with trifling funds, to investigate, as one of the items of a too complex program, the zoology of the Illinois River system, and in 1876 and 1877 that I began to publish the result of such investigations in the first of a series of bulletins now in the seventeenth volume.

By 1894 this incipient survey, although limited and fragmentary and frequently interrupted by other operations, had developed to a degree that made desirable and possible a permanent field station to be established by the State on the Illinois River, at which investigations could be carried on continuously throughout the year, and such a station, provided with an excellent portable equipment, was opened April first of that year, with a program directed especially to two main objectives—one the effect on the plant and animal life of a region produced by the periodical overflow and gradual recession of the waters of great rivers, of which the Illinois affords a notably marked example; and the other the collection of materials for a comparison of chemical and biological conditions of the water of the Illinois River at the time then present and after the opening of the sewage canal of the Sanitary District of Chicago which occurred five years later.

* Read at a public meeting of the Committee on Aquiculture of the National Research Council at Nashville, Tennessee, December 29, 1927.

The bearing of this program of over 33 years ago upon the fundamental objects of our present committee on aquiculture may be inferred from the following letter sent me in October, 1894, by Col. Marshall McDonald, then the U. S. Commissioner of Fish and Fisheries.

"I have carefully gone over the plans of the biological station proposed by you, and am particularly struck with the comprehensiveness of the plan of work to be undertaken. The knowledge to be obtained by such investigation as you contemplate is absolutely necessary as a foundation upon which to build an intelligent, rational administration of our fishery interests. A knowledge of life in its relation to environment is an important subject which biological investigators have not heretofore sufficiently dealt with, but which, it seems to me, is necessary in order to give practical value to special studies of the different species. After all, it is the relations and interdependence of life in the aggregate, and of the conditions influencing it adversely or otherwise, that mainly concern those who are seeking to apply scientific methods of investigation to economic problems.

"I need not tell you that you may count on the Commission for any cooperation and aid that we may be able to give you in this direction, which, looked at from a purely economic standpoint, I consider of the utmost importance."

This station at Havana was maintained for the first year under the immediate charge of Mr. Frank Smith, then instructor and later professor of zoology at the University of Illinois; for the years 1895-1900 under that of Dr. Charles A. Kofoid, now and for many years professor of zoology at the University of California; and from the latter date to 1923 under that of Mr. R. E. Richardson, still in active service as aquatic biologist of the State Natural History Survey. During these fifty-odd years we have published twenty bulletins on strictly Illinois river biology, containing a total of 1,856 pages and illustrated by 142 plates, and we are now preparing for the press manuscripts which will add about 150 pages to this total. We have had from the beginning the unstinted cooperation of the State Water Survey, which has answered all our calls for chemical and bacteriological data; and in 1923 these cooperative conditions were reversed, the Water Survey continuing its Illinois River studies with Peoria as its central station and the Natural History Survey cooperating as it may be called upon.

The more comprehensive program on which we are now working was determined in 1923 by an expansion of our aquatic operations, proposals for which were presented to our board of control in the following terms:

"For our further work in aquatic biology, I would like to take up a comprehensive, systematic survey of the waters of the state, one river system after another, to be studied as features of our natural resources, especially for recreation, scientific study, and the production of food, in all of which our streams might be made very much more profitable to us if they were well understood.

"Illinois is essentially a river state. About three-fourths surrounded by the Mississippi, Ohio, and Wabash, and traversed diagonally by the Rock, Illinois, and Kaskaskia systems with their many branches, it contains in all 480 permanent streams, with a combined length of 11,912 miles, 8,213 miles of which is that of streams at least 20 miles long.* This is exclusive of the large surrounding rivers, although Illinois extends on the west to the middle of the Mississippi and has concurrent jurisdiction with Indiana over the Wabash, where this river forms the common boundary.

"Moreover, most of our streams are by nature remarkably productive because of the richness of the land from which they derive their organic content and because of their sluggish flow over a level surface by which ample time is given for the organization of their food materials into forms fit for the maintenance of animal life and, finally, by means of this, for the life of man. I especially ask your attention to the fact that this wealth of waters has one decided advantage over the land area through which it flows, as a source of animal food for man, in the fact that this is produced in our streams from materials which have no other use to us, while our butcher's meats cost us several times their nutritive value in the vegetable products which our pigs and cattle devour; and yet our native waters still lie a primitive wilderness, not only wholly unimproved, but seriously injured in many places by various kinds of appropriation and pollution. I believe that our river systems are well worthy of the same kind of serious study which the Agricultural Experiment Station has given for many years to the land areas of the state, and such a study I would like to see initiated without delay. For these, among other reasons, one of which is the certainty of many important additions to biological science which an intelligent survey of this field would produce, I would like the approval of this Board to the general plan, details of which I should be ready to present at your next meeting."

This proposal being unanimously approved by our board of control, it thus became the permanent charter of our aquatic operations in Illinois, and in accordance with it we transferred our principal activities as a new project to the Rock River system, to which area I have now to ask your attention.

Rock River, which enters Illinois from Wisconsin somewhat east of the middle point of the common boundary and swings thence in a fairly even curve to the south and west to empty into the Mississippi at Rock Island, is one of the most beautiful, interesting, and popular streams in Illinois, quite unlike any other important river in the state, excepting perhaps the Fox, which flows through a similar territory. It is approximately 286 miles long, the lower 169 miles in Illinois and the remainder in Wisconsin, where it is fed by numerous glacial lakes, the total area of which is about 80 square miles. Its width in Illinois varies from 500 to 800 feet, its mid-channel depth is about 4 feet at average stages, and

* Data from a "Gazetteer of Illinois Streams", in "Water Resources of Illinois", published by the State Rivers and Lakes Commission in 1914.

its ordinary rate of flow averages 2 to 3 miles per hour, rising to 5 miles when the stream is in flood. Its banks are steep, often abrupt, and its shores are bold, frequently rocky, and sometime precipitous. Its bottom in Illinois is mostly of rock and gravel, except in its lower section, through which the Mississippi River formerly flowed, in which there is a good deal of sand. Its basin has a rolling surface with hills sometimes rising to a hundred feet or more above the valley floor, and it is generally covered by glacial drift, especially deep in the northern division except along its principal branch, the Pecatonica, which flows in Wisconsin through a district that was never glaciated and in Illinois over a glacial deposit older than, and very different from, that of the adjoining basin of the main stream. The total area of the entire Rock River basin is 10,820 square miles, about equally divided between Wisconsin and Illinois. The Pecatonica, whose basin is about two-thirds that of the Rock above the mouth of this tributary, is in strong contrast to the main stream in its broad bottom lands and its tortuous course, which is about three times its air-line length. Oxbow loops some miles long are often separated by only a few feet at their beginning and end. It differs from the Rock also in its generally muddy bed, in its much slower current, and in its extreme and rapid changes of level, amounting in one observed instance to 14 feet in 6 hours and in another, as reported, to 22 feet, although 8 feet is about the maximum variation of the Rock River gauge. Great pains have been taken by us to make comparable collections from these two neighboring but widely different streams. Details of the comparison have not yet been worked out, but it is obvious that the Pecatonica is, for various reasons, relatively poor in plankton and in bottom fauna, and hence in fishes.

The current of Rock River is much beset by several hydro-electric power dams which disturb the natural tenor of its life, especially that of its fishes. When the river is low and the power plants are idle, the water accumulates quickly in reservoirs above the dams, leaving a shrunken stream below, thus stranding and killing large numbers of fishes, especially the younger ones. As the entire flow of the river goes through these power plants during most of the year, the fishes which try to pass them are almost always killed, or injured so that they die from wounds or later fungous infection.

The stream is frequently tormented also in late winter and early spring, by great ice gorges, 10 to 40 feet in depth, which break loose before the dammed-up waters and plow their way downward, trapping and killing many fishes between the ice and the shores and bottom. One such gorge of unexampled depth and size crushed and ruined our cabin boat last spring. Great quantities of fishes are sometimes lost by the spread of the waters over the bottoms above the ice dams and their sudden recession, leaving the fishes in them stranded, when the barriers give way.

The principal items of our equipment for the Rock River work, mainly transferred from the Illinois as we were leaving it, were a cabin boat, 15 by 30 feet, a 24-foot gasoline launch, two flat-bottom skiffs, 16 and 18 feet in length, with a 4-horsepower outboard motor, four seines of various mesh and of lengths from 10 to 300 feet, a trammel net, common hoop nets, dip nets of several sizes, fish spears and assorted tackle for hook-and-line fishing, a beam trawl, a quantitative bottom sampler, a naturalist's dredge, a mussel dredge, two crow-foot mussel bars, a plankton net, and a Juday-Foerst centrifuge. We have also used an automobile and its trailer for cross-country travel between small streams and for the transportation of a skiff and the necessary light apparatus.

With this equipment and a party of three or four men in the field with Dr. David H. Thompson in charge, working steadily each year through the spring, summer, and early fall, with occasional visits in the winter also, collections have been made (and data secured from them) amounting in round numbers to 90,000 fishes belonging to 90 species of the 151 species occurring in the state; 2,400 stomachs of fishes, the contents of 1,100 of which have been analyzed and studied; 15,000 river mussels belonging to 40 species; 820 quantitative collections of the small invertebrates of the bottom fauna, among which 300 species have been identified; and 500 collections of plankton and algae, about half the former taken with filter paper and the remainder with a plankton net of silk bolting cloth, except for a few concentrated by the centrifuge. Special attention has also been paid, by a botanist detached for the purpose from our plant disease survey, to the rooting plants of the river and its tributary waters. Records have been entered as frequently as necessary of water temperatures, rates of flow, turbidity, percentages of dissolved oxygen, of acidity or hydrogen ion concentration, and of biological oxygen demand; and a multitude of data of observation and experiment of kinds too miscellaneous for convenient classification have been entered in the field notes. The permanent collections have all been shipped to the laboratories in Urbana, where their contents have been assorted, determined, and studied by another group of two to four men of whom Mr. Richardson was chief. Our expenses since the work was fully organized have averaged about $10,000 a year, of which $7,280 was for salaries and wages and $1,450 for purposes classed as travel.

Significant data concerning the basic elements of productivity in the river as shown by its plankton and small bottom invertebrates have been assembled and generalized, and I give a few examples. Taking the weight of the total nitrogen contained in the bodies of the plankton obtained by use of the centrifuge, as a measure of the richness of the water of Rock River in elementary fish food, surprisingly high results were obtained in August, 1925, normally a time of low production in rivers. The figures ran to more than twenty times the largest quantities obtained by Juday in August and September in Lake Mendota in Wisconsin, and more than three times the largest obtained in the same lake in *any* month, including the months of the spring maxima. General indications are that the Rock River produces very much more plankton in a single year than could be utilized by a fish population many times as great as the river has ever contained. Valuations of the small bottom fauna in pounds per acre for the year 1925 gave us the richest yield where small rocks were the principal constituent of the bottom. The figures there ran to over 700 pounds per acre made up largely of May-fly larvae which hide under stones, a situation difficult of access to hungry fish, which fact doubtless accounts in part for the extraordinary abundance. In the mud-bottom sections of the river, on the other hand, the poundage per acre in 1925 ran only slightly over 300 pounds, to be compared with 2,693 pounds per acre given by an exceptionally rich mud-bottom section of the Illinois River in 1915. The largest items in the mud-bottom sections of the Rock River were large burrowing May-fly larvae and small oligochaete worms.

We notice a striking decline in the abundance of the plankton both in the Rock and Illinois rivers as we go down stream. For example, in August, 1927, the numbers per cubic meter of water for the upper part of the Rock in Illinois (Beloit to Dixon) were to those in the lower part (Sterling to Colona), as follows:

Diatoms	1.17 to 1
Other algae	8.7 to 1
Protozoa	7.6 to 1
Rotifers	2.1 to 1
Entomostraca	4 to 1

Similarly, in the Illinois we found in May, 1899, that the entire plankton measured, in volumes, 1.77 parts per million of water for the section from Peoria south to Liverpool (35 miles) and 0.12 p. p. m. for the section from LaGrange to the mouth of the river (56 miles), being thus nearly 15 times as abundant in the middle region of the stream as in its lowest part. To this fact I can only call attention here without attempting an explanation of it, as the subject is so complicated that a full discussion of it would take too much of the time allotted to this paper.

The more fundamental elements of the nutrition of fishes are the algae, protozoa, and animal plankton, the algae and the protozoa serving mainly as a food to small invertebrates, including those of the plankton, which in turn is an indispensable food for the young of fishes of every description. An accessible abundance of these elements is thus a preliminary requisite in aquiculture, and this fact at once raises the question as to what constitutes an accessible abundance of them in the various seasons and in any given situation.

Those algae and protozoa which are not themselves parts of the plankton are easily enough dealt with, for they are stationary in their habit, and if they are continuously and uniformly numerous in collections at times and places when and where they are needed, this is sufficient evidence that the supply is adequate, except as they may be so situated as to be inaccessible to the organisms requiring them. The case is somewhat different, however, with the plankton of a flowing stream, for as this is always being carried downward by the current, the supply at any one place is dependent on its receipts from above, and a local surplus may be followed by a scarcity farther down unless the rate of multiplication of its constituent organisms is sufficient to replace the losses from normal death and from depredation incurred on the way. On this account the plankton of a river system must be studied as a whole, including sources and tributaries of every description, and the complex data of abundance thus obtained must be everywhere correlated with all the local demands. The plankton of that expansion of the Illinois River which is called Peoria Lake, is, for example, enormously superabundant, as has been already noted, and its constituent organisms seem to multiply there at a prodigious rate, but we must go beyond it down to the mouth of the stream and outward into the associated waters before we can pass judgment on the competency of the supply for the river system as a whole, and if it is anywhere found inadequate, we must study ways and means for its enlargement.

One of the novelties in the ecology of fishes discovered by us in Rock River was an epidemic infestation, in winter only, of a single species of buffalo fish by a single species of leech, an occurrence of the winter of 1925 and 1926 wholly unexampled within the knowledge of the oldest fishermen and never seen by us in any other stream. Nearly every redmouth buffalo caught was infested by leeches varying in number from two to fifty and averaging about twenty to each fish, with a notable lowering of the market value of the fish. The details are given in an article by Dr. Thompson, published as a recent Survey bulletin.

This is the place to mention also a *new disease* of the European carp, quite general and very injurious in the middle section of the Illinois River, but diminishing and finally disappearing down stream. It is wholly unknown in Rock River, a difference between the streams which confirms our inference that it is due to the pollution of the Illinois by sewage. It affects the fish from the fingerling stage upwards, reduces its rate of growth by about one-half, causes deformities, especially of the head, from which it gets the common name of "knot-head", embarrasses respiration, and apparently impairs metabolism in nearly every part of the body. We know, however, of nothing to indicate that the food value of carp so affected is in any way impaired. Our only present evidence that this disease is produced by sewage pollution is a complete coincidence in the distribution of the two, and parallel variations in their intensity. An exhaustive study of this disorder is now being made by us, and a bulletin on the subject amply illustrated will soon be ready for distribution.

There are several other parts of our program on which I have not the time to report, but I hope that this sketchy outline of our objects and operations and these few samples of our product may serve to give some general idea of the kind and value of the materials which the survey biologist offers to the aquiculturist. They seem to me to be not very unlike the materials which the soil surveyor and the crop specialist give to the agronomist and through him to the actual farmer; but their assortment, selection, and practical application is altogether a different matter from their accumulation, and calls for a liaison agency now non-existent in Illinois—one competent to sift out from our bulletins and reports the facts, generalizations, inferences, and speculations even, which may be brought to bear on aquiculture as an art, and so to rearrange, assimilate, and present them as to bring them within the reach and comprehension of the fisherman, the fish culturist, the conservation office or department, and the legislative committee on fish and fisheries.

Agriculture *has* that kind of middle man in the county farm adviser, who must be an agricultural college graduate competent to prepare and pass on to the farmer the experiment station product in predigested form; and these farm advisers are useful also to the college and the station in bringing to their better knowledge practical problems still to be solved, and the need of a closer adaptation of the college teaching to the essential operations of the farm; but I know of nothing in the field of aquiculture, in this country at least, at all corresponding to this machinery of practical education. Without it the harvest of our biological researches, however well chosen our objects and sound our methods may have been, fails to reach the ultimate consumer, and with this failure at a critical point everything else fails which has preceded it. So my conclusion to this brief paper may be taken as an introduction to another topic which I can not now discuss but which I wish might be found to lie within the province of this committee, or if not, of some other agency toward whose creation our organization might profitably lend its advice and cooperation.

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DIVISION OF THE

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The "Knothead" Carp of the Illinois River

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THE "KNOTHEAD" CARP OF THE ILLINOIS RIVER

David H. Thompson

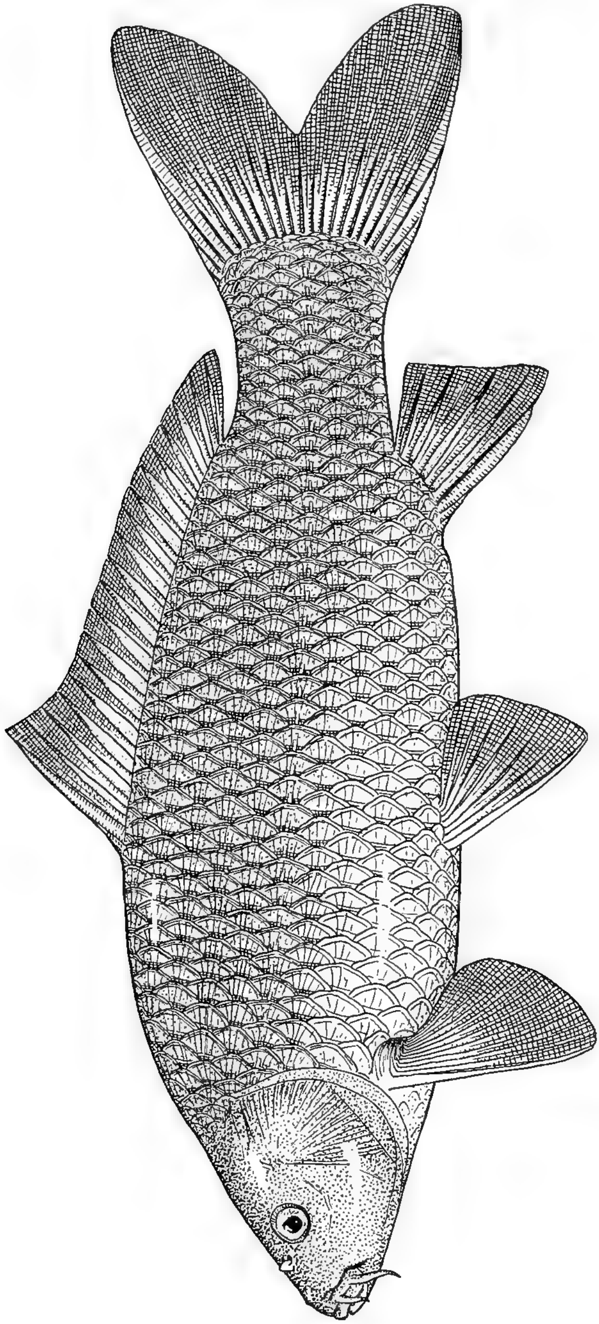
FOREWORD

The investigation reported here was begun in collaboration with Doctor Ludwig Scheuring, of the Bayerische Biologische Versuchsanstalt für Fischerei and the University of Munich, during his visit to this country in the winter of 1926-1927. While the "knothead" carp of the Illinois River had been known to the writer for some time, no start had been made on the problem because of the lack of such a fund of information on the biology and pathology of fishes as Doctor Scheuring was equipped to furnish. During the two months when he took an active part in the work in field and laboratory, most of the important facts were brought out, and since his return to Germany he has given advice and suggestions for the continuance of the investigation and has aided in the preparation of the manuscript.

INTRODUCTION

Any serious hazard to the carp of the Illinois River is of considerable economic consequence, inasmuch as the carp is by far the most important commercial fish of this stream. Introduced in 1885, out of a stock brought to the United States a few years earlier from Europe,[1] the carp first became an important item in the Illinois River fishery soon after 1890. In 1898, the Illinois Fishermen's Association reported that the carp catch exceeded the value of all other commercial fishes. Statistics gathered by the United States Bureau of Fisheries[2] show that in 1908 the total yield of commercial fishes of the Illinois River was 23,896,000 pounds, of which carp constituted 64 per cent, or 15,400,000 pounds. More recently, because of the decreased acreage of water due to drainage of bottomlands for agricultural uses, and because of the southward encroachment of pollution, the annual yield of the entire river has been reduced about one-half, and even more in the middle section of the stream.

[1] Forbes, S. A., and R. E. Richardson. The Fishes of Illinois. Illinois State Natural History Survey Final Report. Vol. III. Second Edition. 1920.
[2] Fisheries of the United States. Bureau of the Census. Special Reports. 1908.



J.F.Müller

FIG. 1. Normal carp of the Illinois River.

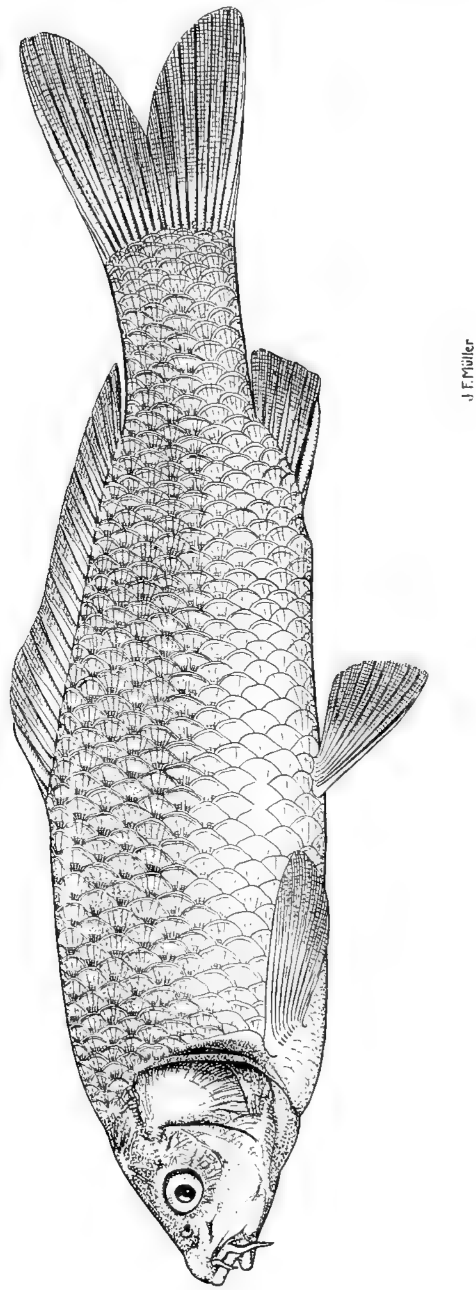


FIG. 2. Knothead carp of the middle Illinois River.

The carp has a greater viability under these unfavorable conditions than other fishes and now contributes between 80 and 90 per cent of the total annual catch of commercial fishes.

The plant and animal life of the middle Illinois River changed fundamentally during and immediately following large increases in the load of pollution in the years 1916-1918. One of the changes was a marked alteration in the growth form of the carp. While this alteration varied widely in degree, it was generally obvious in most of the carp and was readily recognized by the fishermen. This change has been found to resolve itself into two general outstanding differences: retardation of the rate of growth throughout the life of the carp; and marked anatomical abnormalities, especially of the bones. A number of methods have been employed to find out what factors are responsible for these structural and functional changes. Several months of painstaking search gave no evidence of an infection of a kind to have any bearing on this case. However, a variety of information has been accumulated which indicates the presence of developmental and metabolic disturbances similar in many respects to those found in rickets among the higher vertebrates, and this has been supplemented with evidence of factors, in both the early and adult food supplies of the carp, apparently capable of inducing diet-deficiency disease.

DESCRIPTION OF KNOTHEAD CARP

The carp (*Cyprinus carpio* L.) of the Illinois River are not at all broad or high-backed like the cultivated European races. The malformed carp considered in this paper are, as a rule, still more slender (see Figures 1 and 2) and have a body shape similar to the German wild carp (Bauernkarpfen). The carp of the Mississippi River, on the other hand, tend to have a more fleshy body and a "roach" back and can usually be distinguished readily from Illinois River specimens. This seems not to be an inherent difference but rather a result of more favorable conditions for growth in the Mississippi. Some of the smaller bottomland lakes of the Illinois valley occasionally have their outlets closed during seasons of low water, so that the imprisoned fishes may exhaust the available fish food. Under such conditions of starvation, carp are often found which appear stunted and have the slender form that accompanies the present abnormality, but they lack many other readily recognized and more significant characteristics of the abnormal carp described in this paper.

"Knothead" is the name that the Illinois River fishermen use most often to designate these abnormal carp, but the terms "lunkhead", "pop-gill", "clam-jaw", "lump-jaw", etc., are also heard. These names all refer to the striking malformation of the head and opercles. The sweeping streamlines of the normal carp are broken up by several irregularities in the conformation of the knotheads. The opercles, instead of being slightly convex as in normal carp, are more or less bulged or curled up, with an average curvature about like that of the bowl of a spoon. The skull is narrowed and the cheek region is conspicuously sunken between the eye and the opercle. Many of the knotheads have a marked lateral constriction or narrowness at the pectoral girdle just back of the opercles, and a more or less well-defined wrinkle over the snout. The head appears generally emaciated, and the sclerotic ring and the sculpturings on the cranial bones can be plainly seen (see Figure 3). On the under side there is usually a depression beneath the chin and a bulge in the region of the heart. All these external peculiarities which are commonly found in the more seriously affected individuals, together with a "drooping" of the fins and general sluggishness of habit, present a very different picture from the trim, sleek, and alert normal carp.

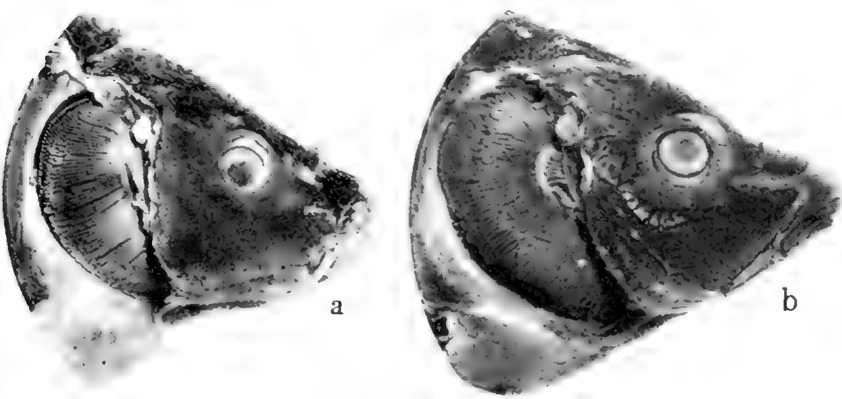


Fig. 3. Carp with their opercles removed: a, normal; b, knothead.

The knothead malformation is variable, and all degrees of it have been found up to monstrous, emaciated individuals three times as old as normals of the same weight. (See Figure 4.) There seems to be a close correlation in the degrees of malformation of the previously mentioned parts; that is, individuals with slightly bulging opercles have all these parts affected slightly; those of moderate degree have them all moderately affected, and so on. The bulging of the opercle is the most practical criterion of the knothead malformation, at least for use in the field, but it is so variable that among any dozen carp from the middle Illinois River one or more are usually difficult to classify as normal or abnormal (see Figure 10a). All references to the frequency of knotheads in this paper are based on specimens exhibiting obvious malformation; and specimens that were doubtful or only slightly malformed were commonly included with the normals.

When a number of living carp from the middle Illinois River are observed in a crib or pond or aquarium, the knotheads are seen to be some-

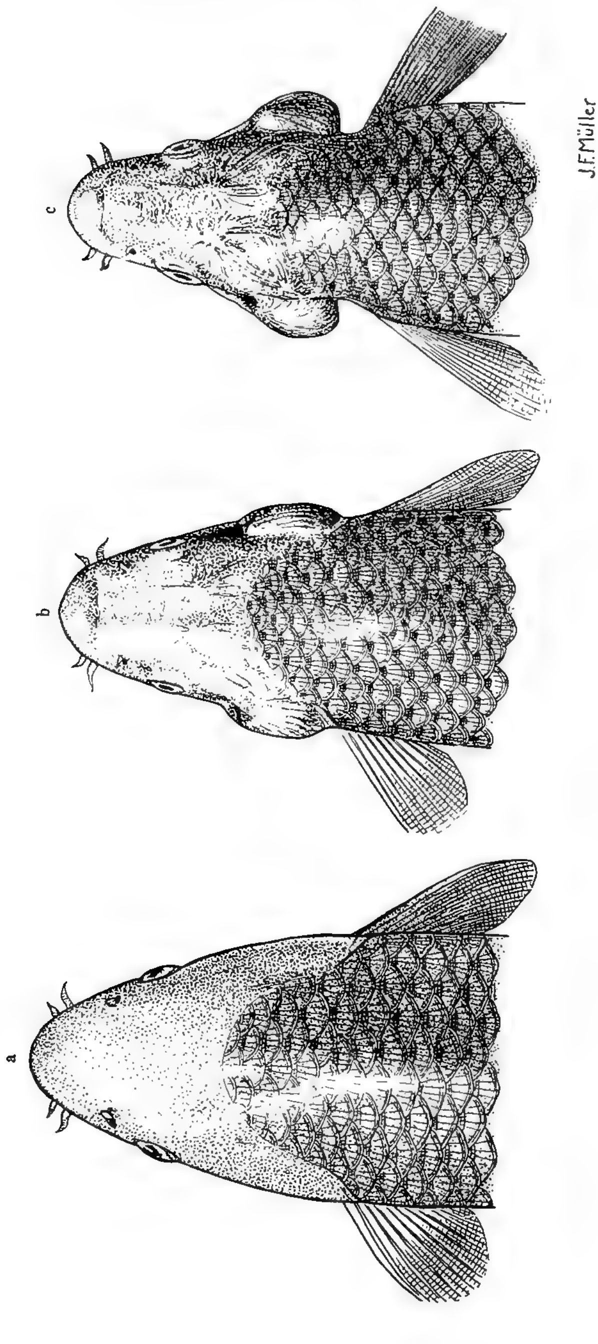


FIG 4. Heads of carp; a, normal; b, moderate knothead; c, extreme knothead.

what darker and less uniform in color than the normals, the darkest of them usually being the most malformed.

The large serrated spines of the dorsal and anal fins are strikingly altered in most knothead carp, being more or less reduced in length, sometimes to vestiges scarcely one-fourth the normal length, and having fewer and shorter serrations, or none at all. The dorsal spine of a normal carp is a little longer than the anal spine, but the reverse is usually true in knothead carp. The spines of knothead carp are often thicker laterally than those from normal carp of the same size, especially in the more distal portions. The right and left halves of these malformed spines are not so closely fused as in the normal spines, and in some instances they can be readily pulled apart. The dorsal spines of the knothead carp are not held erect as in normal carp, but are inclined backward, sometimes lying flat. (See Figures 1, 2, and 5.)

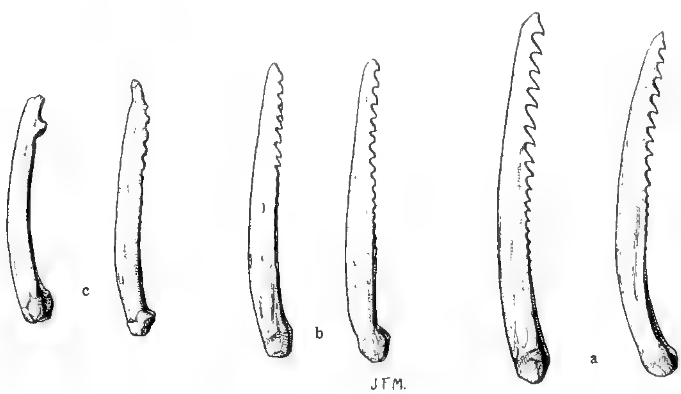


Fig. 5. Dorsal and anal spines of carp of the same length: a, normal; b, moderate knothead; c, extreme knothead. In each pair the dorsal spine is at the left and the anal spine at the right.

Many of these abnormal carp have the opercle so highly arched that it fails to reach the posterior margin of the gill chamber; in consequence, the opercular membrane does not lap flat on the body wall as in normal fishes, but extends inward or is curled under the edge of the opercle, seriously hampering the mechanics of respirations. In extreme cases considerable portions of the gills are always exposed, and the ragged and irregular arrangement of the lamellae in some knotheads may be the result of constant irritation by the edges of opercles that fall short of the posterior margin of the gill chamber. In such cases some of the lamellae have club-like thickenings at their tips (see Figure 3); less often they are partly grown together and show evidence of branching.

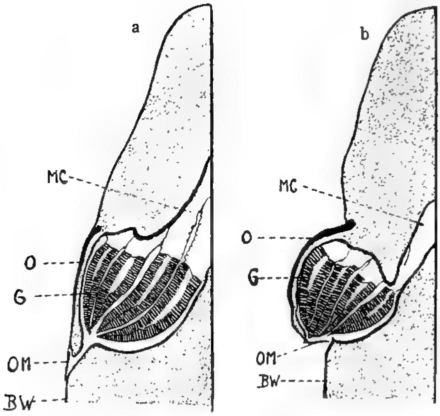


FIG. 6. Frontal sections through carp heads of the same length: a, normal; b, knothead. MC—mouth cavity; O—opercle; G—gills; OM—opercular membrane; BW—body wall.

To ascertain whether the bulging of the opercles might be due to an enlargement of the gills as an adaptation to diminished concentration of dissolved oxygen, counts and measurements of the lamellae on each gill were made on one normal and another malformed head, with the result that the lamellae were found to be both smaller and less numerous on the malformed head—averaging 15.5 mm. long on the normal head and 11.0 mm. on the malformed, with numbers of the lamellae to each gill as shown in Table I. Moreover, the gill chamber in the knothead was smaller than in the normal, as can be seen in Figure 6.

TABLE I.

NUMBERS OF LAMELLAE ON THE GILL ARCHES OF NORMAL AND KNOTHEAD CARP

	First gill arch	Second gill arch	Third gill arch	Fourth gill arch
Normal	138	133	117	118
Knothead	132	122	105	100

A close study of the opercles and the bones of an abnormal head showed no traces of an infection of the bones, either at present or in the past, which could be responsible for this malformation. Some of the bones of the abnormal head were thicker and heavier than those of the normal head, but this may have been due partly to the greater age of the knothead, which was 6 summers old as against 3 summers for the normal carp.

Age determination in knothead carp is more difficult than in normal ones, not only because the rings are more crowded as a result of the greater age, but also because there are numerous secondary rings in the scales. This is also true for the growth rings of the cranial bones and the vertebrae. It is possible, however, according to the criteria given by Hoffbauer,[3] to distinguish the winter rings from secondary rings, since at the division line of the scale the annuli of the winter ring

[3] Hoffbauer, C. Die Altersbestimmung des Karpfen an seiner Schuppe. Allgemeine Fischerei Zeitung. Vol. 23, p. 341. 1898. Vol. 25, pp. 135, 150, 297. 1900.

diverge, but those of the secondary ring do not. Most knothead carp have scales that are granular and opaque, and it is often necessary to examine large numbers to get a few showing the rings clearly—a condition found also among cultivated carp that have been starved.

Dissection and examination of normal and abnormal specimens showed that the skin, gill surfaces, and internal organs were free from infection or parasites; and the color of the gills in the living carp was bright red in both. There is less fat on the mesenteries and pericardium in the abnormal than in the normal ones, but fat is never altogether lacking. The flesh of the knotheads is softer than that of normal carp, although it is not as flabby and watery as in starved carp. Fishermen

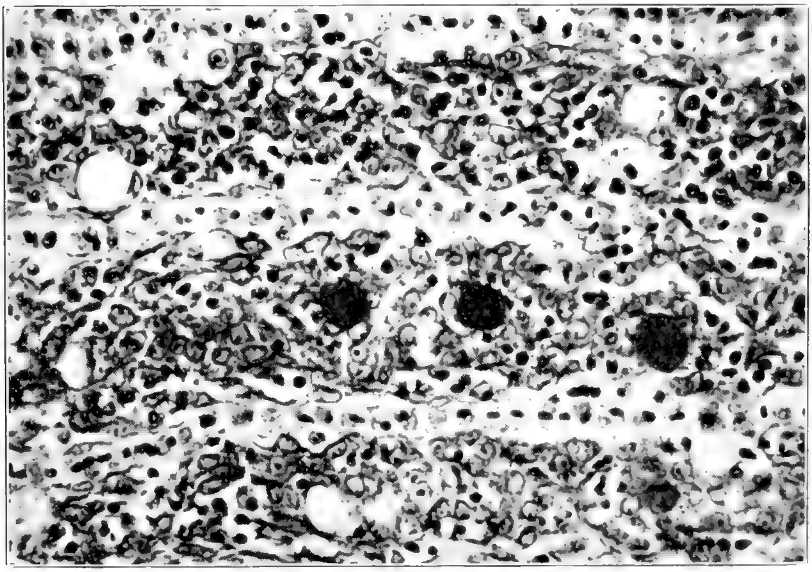


Fig. 7. Microphotograph of gill tissue of knothead carp.

of the middle Illinois River say that it is difficult to dress these carp for the market without seriously tearing the flesh and removing portions of it with the scales and skin when they are "fleeced". This softness of the flesh is well known to fish culturists and has been produced artificially in the experiments of Podhradsky and Kostomarov.[4]

Examination of the gill tissues of knothead carp gave no evidence of an infection, but sections of the gills showed varying numbers of bodies larger than ordinary tissue cells (10 to 20 microns in diameter) and staining differently. (See Figure 7.) These bodies were observed throughout the epithelium of the lamellae and gill arch and occasionally

[4] Podhradsky, J., and B. Kostomarov. Das Wachstum der Fische beim absoluten Hungern. Archiv für Entwicklungsmechanik und Organismen. Vol. 105, p. 587. 1925

in the connective tissue, but most often in the deeper proximal parts of the lamellae. They were found in each of the several normals and knotheads examined, but were more abundant in the latter. For a time they were thought to be parasites, with perhaps some connection with the knothead disease, but after considerable study it was seen that they had no characteristic resemblance to microscopic parasites of any known kind. They are quite different from mucous cells. They evidently belong to the tissues of the carp itself, but their place in its histology has not been determined.

A knothead carp of moderate degree and a normal one of the same age were selected for comparison from a collection made at Peoria in November, 1927, which was kept alive and under observation several days in large aquaria, in order to make sure that the selected individuals were representative of the two kinds and not obviously injured or affected differently by other factors. By taking these precautions, differences due to age, environment, parental stock, etc., were largely eliminated, so that any observed differences were probably effects of the disease. Data on these two carp are given in Table II.

TABLE II

MEASUREMENTS OF CARP USED FOR COMPARISON

	Normal	Knothead
Age	4 summers	4 summers
Length	14.2 inches	12 4 inches
Depth (at front of dorsal fin)	5.0 inches	3.9 inches
Width (at front of dorsal fin)	2.9 inches	2.5 inches
Weight	57 ounces	30 ounces

These two carp were anaesthetized, and dorsal and lateral X-ray photographs were made of them by Dr. C. S. Bucher at the Bucher Clinic, Champaign, both being rayed at the same time and on the same sensitized surface in order to maintain conditions as uniform as possible. These X-ray photographs, reproduced in Figures 8 and 9, show many of the malformations already described—the bulged opercles, sunken cheeks, narrow pectoral girdle, etc. Examination of the original negatives by strong light also shows a difference in the thickness of flesh on top of the head. In the normal specimen the median ethmoid, frontals, parietals, and pterotics, are overlaid by flesh 1 to 2 millimeters in thickness, while in the knothead practically none is visible over the frontals, parietals, and pterotics and a layer only ½ to 1 millimeter thick over the median ethmoid.

These X-ray pictures, besides confirming observations already made and revealing further malformations, give a clue to the more intimate nature of these malformations; for, other factors being substantially equal, the depth of the "shadow" cast by a bone depends mainly on the thickness of that bone and its degree of mineralization.

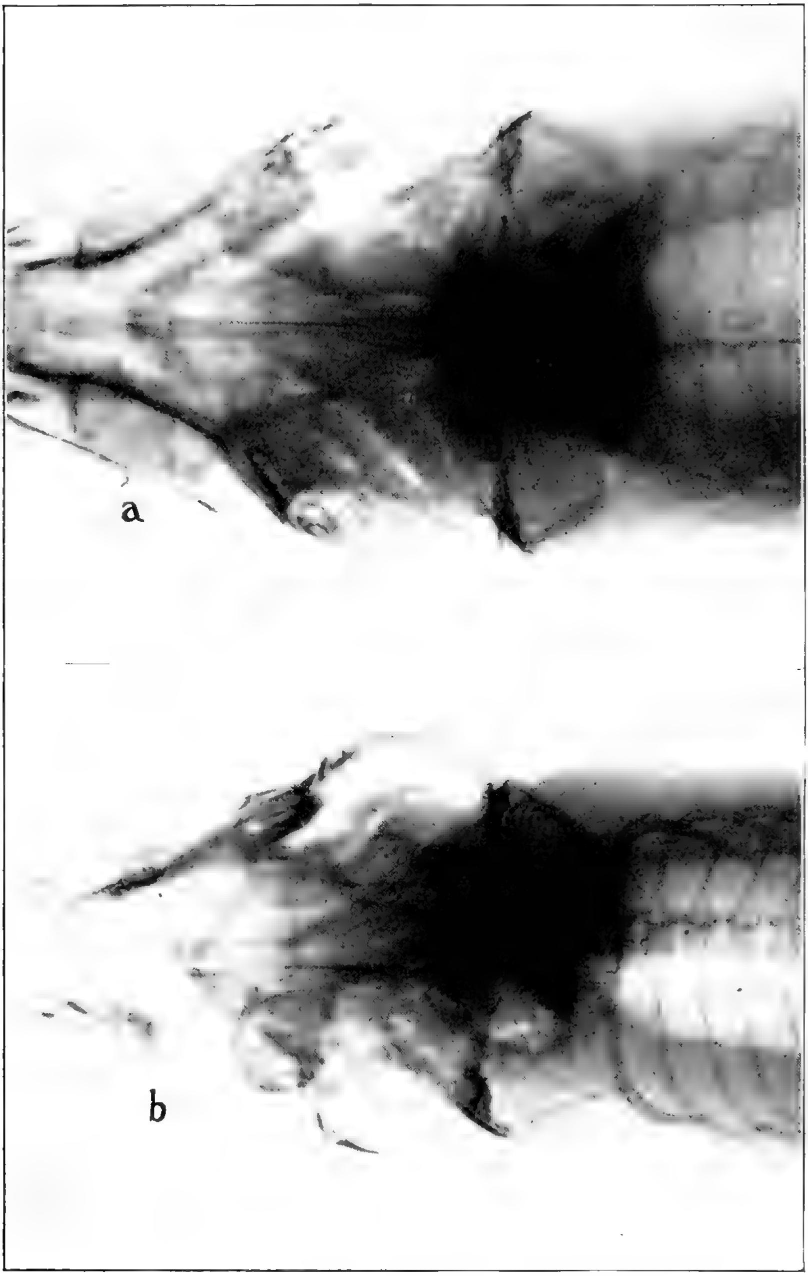


FIG. 8. Dorsal X-ray photographs of 4-year-old carp: a, normal; b, knothead.

The heads of the two 4-year-old carp used in the above comparison were heated almost to boiling, and the flesh was cleaned off the skulls and the bones of the pectoral girdle. The right opercle, the right cleithrum, and the right pharyngeal bearing the teeth were selected from each for chemical analysis. These bones were weighed and their percentages of ash and calcium determined by Mr. O. W. Rees, chemist of the Illinois State Water Survey, and the weights and percentages are given in Table III as an indication of the degree of mineralization.

TABLE III

	Weight of bone in grams Dried at 105°C.	Ash Per cent of bone weight	Calcium Per cent of bone weight
Right opercle			
Normal	1.2705	56.0	21.2
Knothead	1.0243	54.7	21.3
Right cleithrum			
Normal	0.9700	50.0	19.6
Knothead	0.6262	53.3	21.3
Right pharyngeal bearing teeth			
Normal	0.7562	51.3	15.8
Knothead	0.3489	54.1	17.7

The analyses show that the percentage of ash is about the same in both the normal and the knothead and that the percentage of calcium is slightly greater in the bones of the knothead. The calcium determination is of greater significance for comparison of X-ray "shadows", since calcium is the only element of importance in bone which produces the shadow. The percentages of calcium, however, are so similar that any considerable differences in the X-ray shadows of corresponding bones of the two heads are probably due to differences in the thickness of bone penetrated.

The shadows cast by the various bones of each head in the present comparison differ greatly in density. The roentgenograms show that the frontals, parietals, pterotics, opercles, and a few other bones of dermal origin on the top and sides of the knothead skull are more opaque to X-rays than the corresponding bones in the normal. The denseness of these malformed bones is not evenly distributed, but is most pronounced near the ossification centers, while other parts of the same bones often cast lighter shadows than the corresponding parts of normal bones.

The deeper-lying bones of the knothead skull, both of dermal and chondral origin, throw lighter shadows than corresponding normal bones because they are generally thinner. Many of the longer bones of the skull are not only thinner in the knothead but are often much narrower than the ratio of the lengths of the two would indicate. The greatest difference in the shadows cast by the bones of the two skulls is to be found in those about the base of the skull, which are perhaps the deepest-lying bones of the head.

FIG. 9. Lateral X-ray photographs of 4-year-old carp: a, normal; b, knothead.

The relation of the weight of the bones of the head to their depth beneath the surface is well shown in Table III. The opercles are covered by only a thin skin and are taken as representative of the peripheral bones. The ratio of the weight of the normal to the knothead opercle is 1 : 0.81. The cleithra form part of the pectoral girdle and are of intermediate depth. The ratio of their weights is 1 : 0.64. The pharyngeals that bear the teeth are fairly large and more easily removed entire than the other deeper-lying bones. Their ratio is 1 : 0.46.

This pronounced thinness of the bones of the occipital region of the knothead skull is quite obvious in the cleaned skulls. While the knothead skull is actually smaller than the normal, its foramina for the passage of nerves and blood vessels are almost always actually larger. The two heads had been heated in the same vessel of water and cleaned and treated throughout in the same manner, and the skulls had been air dried in the same box; but the thinner bones forming the brain case of the knothead skull opened at the sutures, leaving gaps occasionally more than a millimeter in width. These gaps are not due to a general disarticulation of the skull, because it is still held firmly together by the heavy bones on top of the head and the parasphenoid. No such gaps appeared in the normal skull as it dried. Those of the knothead skull are apparently produced by differential shrinkage of the heavy, dense bones forming the roof of the cranium and the thin, lightly mineralized bones lying deeper in the head.

X-ray photographs of knotheads of different degrees of malformation, from slight to extreme, made for comparison with the one of moderate degree we have been considering, are shown in Figure 10. The extreme knothead (Figure 10d) shows heavier and denser bone at the ossification centers of the peripheral bones of the skull than those in Figure 8b, and these centers of heavy ossification are lacking in the head with only a slight degree of malformation (Figure 10a).

Photographs of the skulls from these two heads are reproduced in Figure 11. The difference in conformation is greater than would have been suspected from the appearance of the living fishes or from their X-ray photographs. The areas of heavy mineralization found in the peripheral bones of the knothead are visible in its skull as unusually heavy sculpturing and ridging at the ossification centers. The anterior margins of the malformed opercles have a slightly inflated appearance, and, when freshly cleaned, they had the red color of cancellated bone tissue. There are further alterations in shape and details of structure in every bone of the knothead skull, but a detailed description of them is hardly justified in this account.

In proportion to the length of the spinal column, the head in these malformed carp is 2 to 5 per cent shorter than normal. This is understandable in view of the fact that there is no malformation visible in the vertebrae of the knotheads, either by direct examination of the bones or from their X-ray shadows.

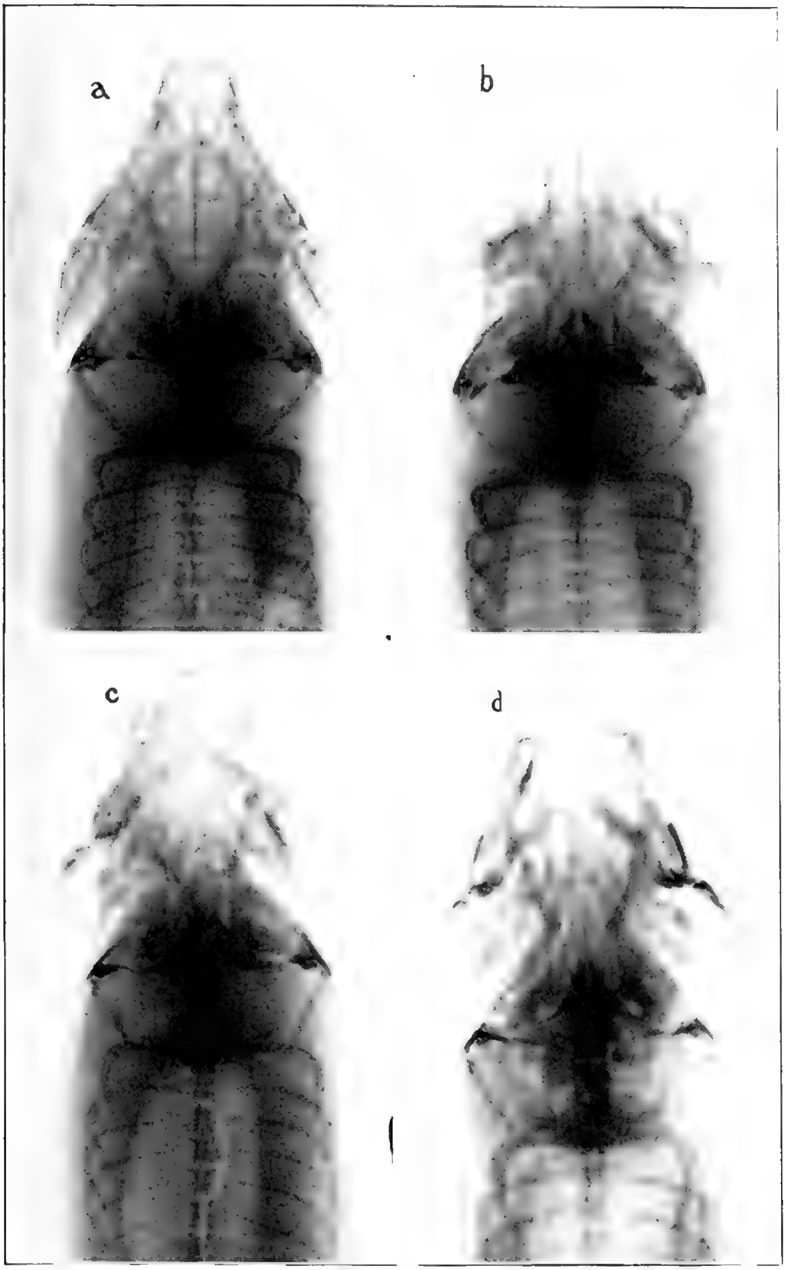


FIG. 10. Dorsal X-ray photographs of knotheads showing different degrees of malformation: a, slight; b, moderate; c, moderate; d, extreme.

Differences in the intimate structure of the skull bones of normal and diseased carp were studied by means of X-ray photographs made by Dr. G. L. Clark of the University of Illinois by the monochromatic pin-hole method,[5] showing the degree of diffraction of a beam of X-rays passed through the bone. The crystals of both were found to have a random orientation and to be within the range of size of colloidal particles, those of the knothead being slightly larger than those of the normal—a fact which substantiates previous observations of the greater brittleness of knotheads' bones.

DISTRIBUTION OF KNOTHEAD CARP

Carp fingerlings with bulging opercles were first noticed in the fall of 1918 in the Illinois River at Peoria. Fishermen report that knothead

[5] Clark, G. L. Applied X-rays. McGraw-Hill Book Co. 1927.

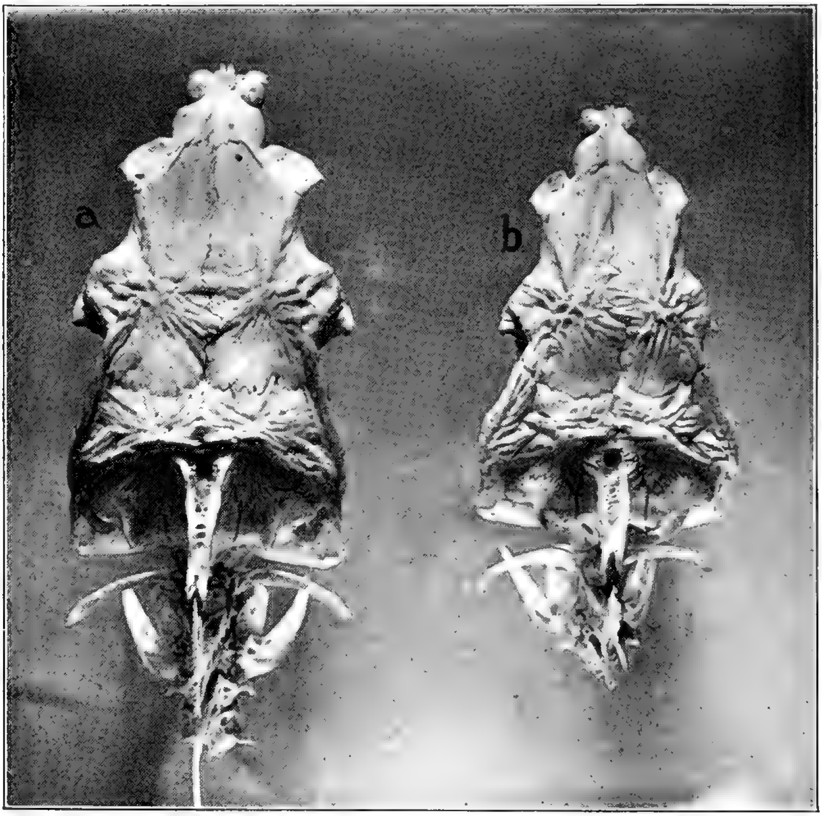


FIG. 11. Skulls of 4-year-old carp: a, normal; b, knothead.

carp began to appear in the catch of market-size fishes in 1920, and that the percentage of knotheads increased rapidly, reaching about 50 per cent in 1922 at several points on the river. In order to find out more definitely the distribution of the malady and the percentage of market-size carp affected, many points on the river were visited during 1926 and 1927, and catches of carp were examined and information was obtained from fishermen. A summary of the data is given in Table IV, and the location of sampling stations is shown in Figure 12. These data were all obtained during the winter of 1926-1927 except the Peoria and Meredosia numbers, which are for the summer and fall of 1927. The rather high percentage of knotheads at Peoria is largely due to the recognition of slight degrees of malformation in individuals such as had formerly been included with the normals. The observed percentages are based on hoop-net catches and give a more accurate measure of the proportion of knothead carp than hauls made with seines which have larger meshes and allow many of the stunted and slender knotheads to go through.

In the course of several years work on the fishes of Rock River, less than a dozen knotheads have been noticed among the many thousands of carp taken. Careful examination of catches of carp from various parts of the Mississippi Valley in the Chicago markets has occasionally revealed a few individuals with distinctly knothead characteristics. Indirect reports have been received of large numbers of knothead carp being taken in Lake Pepin on the Upper Mississippi, but no direct information has been available as yet on this point.

RELATION TO POLLUTION

The beginning of this malformation among the carp was coincident with a period of very rapid increase in pollution, due partly to an increase in the population of Chicago and other cities which pour their wastes into the river, but still more to the war-time boom in many industries, particularly those engaged in the packing and manufacture of food products. The subsequent fundamental alteration of the character of the bottom fauna of the Illinois River has been described by Richardson in the various publications of the Illinois Natural History Survey.

As indicated in Table IV, knothead carp range from Utica (Starved Rock) down to the Copperas Creek Dam with only occasional individuals below that point. There are no fishes of any kind above Utica, since, because of pollution, the amount of dissolved oxygen in that part of the river is so low throughout most of the year that fishes can not live. As long ago as 1912 Utica was the upper limit of most of the species of fishes in the Illinois.[6] The few species that were occasionally found above that point disappeared completely, according to the reports of fishermen, in the years between 1912 and 1917.

[6] Forbes, S. A., and R. E. Richardson. Studies on the Biology of the Upper Illinois River. Ill. Nat. Hist. Surv. Bull. Vol. IX, Art. X. 1913.

In the years since 1917, pollutional conditions have prevailed over a hundred-mile stretch of the middle Illinois River, and the fishery yield of this section has shown marked reduction as compared with the yield before 1917. The fishes themselves are largely restricted to the cleaner bottomland lakes and backwaters of this section. The carp, being of more tolerant habit than other fishes, have continued to range over a large part of this pollutional area except during periods of severe oxygen depletion

TABLE IV

DISTRIBUTION AND PERCENTAGE OF KNOTHEAD CARP IN THE ILLINOIS RIVER DURING 1926 AND 1927

Stations going downstream	Number of carp examined	Observed percentage of knotheads	Information and estimates of local fishermen
Utica	none	......	About 50 per cent of the carp are knotheads. This is the upper limit of fish life in the Illinois River.
LaSalle-Peru	none	......	About 50 per cent of the carp are knotheads.
Depue	23	91	Not as many knotheads as this sample indicates. 60 to 75 per cent is more nearly correct.
Henry	316	75	60 per cent is more nearly correct as a year-round average.
Chillicothe	117	64	About the correct proportion.
Spring Bay	302	46	Hardly as many knotheads as usual from this place.
Averyville	149	57	About the correct percentage.
Peoria	256	78	The carp in Lower Peoria Lake average 50 to 60 per cent knotheads.
Pekin	about 500	about 30	About average percentage of knotheads. Knotheads are found downstream as far as the Copperas Creek Dam. The knotheads here are not slender and many even tend to be pot-bellied.
Havana	539	none	An occasional knothead carp is taken which is believed to have straggled down the river from where they are plentiful. The percentage is extremely low, as only a few individuals are taken among many tons of carp.
Beardstown	3	none	No knothead carp have been seen here.
Meredosia	42	2	Fishermen have not noticed knothead carp here. The one taken was of moderate degree and pot-bellied.

in summer and under heavy ice in winter. The distribution of knothead carp coincides, both in main features and in detail, with the areas of greatest change in sanitary condition.

Below the Copperas Creek Dam the carp are all normal except for occasional knotheads that have straggled down the river. Natural purification of the sewage load of the upper and middle river is approaching completion in midsummer by the time this lower section is reached;

FIG. 12. Sketch map of the Illinois River.

and there has been no general or serious alteration in the character of the food supply of the carp.

The observed percentages of knotheads at various points on the Illinois River indicate that the proportion of affected carp decreases downstream, as is to be expected if the malformation is correlated with pollution.

The knothead malformation appears among those races of carp with reduced scalation (mirror and leather carp) to the same extent as among the scaled variety. The proportion of these mutant races of carp in the original stock of the Illinois River was quite large, but their numbers soon decreased to the present proportion of one or two per cent of mirror carp and still fewer leather carp. The carp populations of other waters of the Mississippi Valley show these varieties in about the same proportions.

The occasional occurrence of a few knotheads in the Rock River and other waters seems to have no relation to pollution.

No malformations similar to those of the knothead carp have been found in other species of fishes of the middle Illinois River. During the course of this and other investigations considerable numbers of about twenty species of larger fishes from this section of the river were handled without any appearance of alteration in their growth form, but an examination of other cyprinoid fishes (minnows) of this area might discover an abnormality like that of the knothead carp.[7]

CHANGES IN THE FOOD SUPPLY OF THE CARP

The following statement by Mr. R. E. Richardson concerning recent changes in the natural food supply of the carp in the middle river is based on various field observations and unpublished plankton data in the possession of the Natural History Survey, accumulated between 1910 and 1925.

The most significant changes in the plant and animal food supply of the carp in the middle Illinois River in recent years had to do either directly or indirectly with the plankton and the coarse aquatic vegetation. That the latter usually serves to some extent as green forage for carp above the late fingerling stage can hardly be doubted, though the exact extent to which either the roots or the stems or other parts of coarse aquatic plants enter into the normal food supply of these fishes has not been quantitatively determined. The almost complete extermination of the Potamogetons and other large plants in Peoria Lake and also in the river and in its connecting lakes and sloughs far below that point, between 1915 and 1920, left large numbers of carp practically without any green forage at all for several seasons. Since 1922 or thereabout, restoration of the Potamogetons particularly has proceeded rather

[7] Some young goldfish, spawned in the summer of 1927 in the University of Illinois lily pond, were brought indoors in October and kept in a large aquarium, which was supplied with running tap-water and aerated with compressed air. They were fed commercial goldfish food occasionally, and there was no other food available except mud on the bottom. There were no algae or other green plants present. The fishes were an inch to an inch and a half long when they were brought indoors, and they did not grow perceptibly afterwards. In December some of them showed signs of emaciation and an occasional one died. About half of the 50 fishes in the aquarium on December 15 had distinctly arched opercles, most frequent on the emaciated fishes but present also on some of the fleshier ones. Those with arched opercles also showed the sculpturing of the skull bones, the drooping fins, the narrow pectoral girdle, and the general sluggishness characteristic of knothead carp.

More recently a few golden shiners with strongly bulged opercles have been found in the Salt Fork River in Champaign County.

rapidly in many sections of Peoria Lake as measured by the areas affected, though the growths are yet generally very sparse as compared with those of the pre-1920 years, and the areas covered are still decidedly smaller.

The distinct change in the general composition of the normal summer plankton in the section of river extending from Spring Valley to a point in Peoria Lake only a few miles above Peoria Narrows, between 1913-1915 and 1920, was probably no less important in its final effects than the reduction in the coarse aquatic vegetation as an item in the general reduction of the green forage supply that took place during the period as a result of pollution; and this has continued substantially without visible relief up to the date of our latest observations. This change involved the substitution on a large scale of non-chlorophyll-bearing *Protozoa* for chlorophyll-bearing kinds, and the replacement of vast numbers of DIATOMACEAE and CHLOROPHYCEAE by filamentous or non-filamentous blue-green algae. The change was so marked in the summer of 1920 between Chillicothe and the foot of Upper Peoria Lake that the water, which in former years had shown a normal pale-green tint when relatively free of silt during the hot season, took on a distinctly blackish tinge, apparent to the unaided eye in bright sunlight. The recovery of the diatoms and CHLOROPHYCEAE as well as of other green microscopic forms, was quite rapid both that summer and in the summer of 1922 below the upper third or half of Middle Peoria Lake—a fact enabling us to make fairly satisfactory, though rough, colorimetric determination on given days of the location of the boundary line between preponderance of blue-green and green plankton by observing the change in color of the plankton samples in the bottle in the field a few minutes after pouring on the alcohol-formalin mixture used for preservation. A similar boundary line between the greens and the blue-greens of the plankton could be made out in the same way in the summers of 1911 and 1912 at points usually lying only a short distance below Spring Valley.

These changes in the plankton could obviously affect directly the fry of carp and other fishes depending upon it for their first food. A far more important effect upon the carp between the fingerling and adult stage could apparently be exerted through the medium of the bottom, shore, and limnetic organisms of microscopic size, which had fed upon the plankton and had later entered into the carp's rations in the same or adjacent areas. During the same period (1913-1915 to 1920-1922) the changes in the principal constituent organisms of the small bottom fauna,[8] though also great in degree, appear to have been in themselves of no particular importance to the health of the carp and other bottom-ranging fishes. The increased restriction of the diet of the small bottom animals above Peoria to microscopic organisms lacking in chlorophyll or food elements, such as vitamins, directly or indirectly derived from it can easily be believed, however, to have been capable of caus-

[8] Richardson, R. E. The bottom fauna of the middle Illinois River, 1913-1925; its distribution, abundance, valuation, and index value in the study of stream pollution. Ill. State Nat. Hist. Surv. Bull. Vol. XVII, Art. XII. (In press.)

ing disturbances both in the growth and metabolism of fishes confined to these small bottom animals for food, if the requirements in that respect of man and many lower animals above the grade of fishes are to be accepted as in any sense a usable criterion.

RATE OF GROWTH OF KNOTHEADS

During the winter of 1926-1927, representative samples of carp, obtained from fishermen at various points on the Illinois River, were weighed to the nearest ounce and measured for length and for depth at the front of the dorsal fin, and about twenty scales were taken from the left side of each fish between the dorsal fin and the lateral line. The carp were classified into normals and knotheads, but many with doubtful or slight degrees of malformation were included with the normals. The scales were cleaned and age determinations were made by counting the winter rings of at least ten scales from each fish. Scales which have been regenerated, and consequently have smaller numbers of winter rings, can usually be recognized by their irregular shape, and avoided. The data on the age and weight of normal and knothead carp at various points on the Illinois River are given in Table V.

Differences in age of normals and knotheads of the same size are shown in Table VI, the data of which have been arranged in twelve 5-ounce weight classes and the ages of the two kinds compared in each class. The knotheads average older than the normals in each of the twelve classes. Arithmetical averages (not weighted) of the ages of the two kinds in the first six and the last six classes show that the difference in age between normals and knotheads of the same size is much greater in the heavier classes.

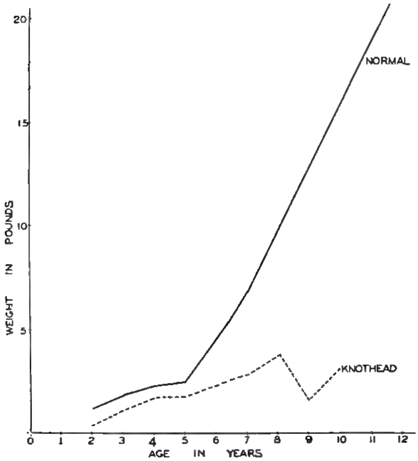


FIG. 13. Growth curves of normal and knothead carp of the Illinois River.

Growth curves plotted from the data in Table VI are shown in Figure 13. These curves indicate that the stunting effect of the disease is cumulative and stops growth altogether in the knotheads at the time when normals are growing most rapidly. Since it has been obvious throughout the investigation that growth is retarded in proportion to the degree of malformation, it seems probable that carp with slight degrees of malformation have a growth rate intermediate between normals and knotheads, and the inclusion of knotheads of slight degree with the normals has probably resulted in an appreciable lowering of both the curves between the third and sixth years.

Calculated from the data in Table VI, the average individual growth rate of normal carp is about 11 ounces a year[9] and that of knothead carp is only about 6 ounces a year. There is no considerable variation in the growth rate of the former from one end of the river to the other, but the growth rate of the latter tends to increase downstream. Thus the lowest rate for knotheads, 3.8 ounces a year is at Depue, while the highest rate, 9.1 ounces a year is at Pekin.

The greater growth rate down the river is strikingly reflected in the body contours of the knotheads. A large number of them were seen at Pekin and practically all, instead of being more slender than the normal, were pot-bellied—a condition strikingly illustrated in a single knothead taken at Meredosia in July, 1927, a drawing of which is shown in Figure 14. An examination of the gonads of this fish showed that it was a spent female. Its scales showed that it was four years old, and the relatively greater width of the last two growth rings indicated that in those years growth had gone on at a relatively rapid rate.

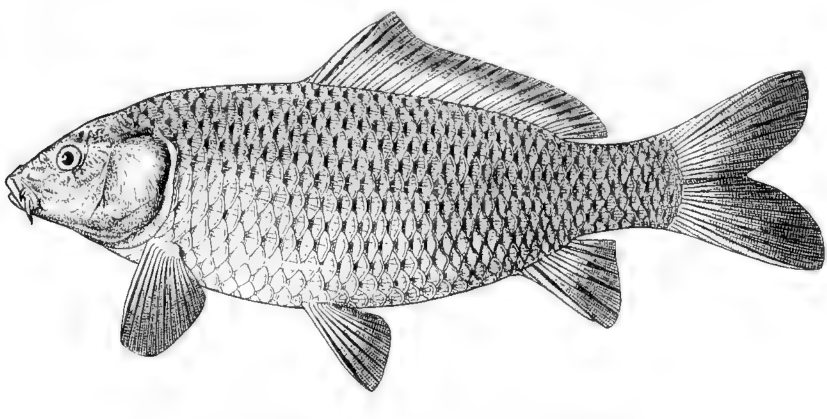


FIG. 14. Pot-bellied knothead carp from the lower Illinois River.

The 30 per cent or so of pot-bellied knotheads seen in catches from the stretch between Pekin and the Copperas Creek Dam may indicate either that the conditions associated with pollution and inducing malformation were of short duration or else that these fishes migrated downstream, perhaps from the Peoria Lake region, after their growth form had been altered by exposure to the knothead-inducing conditions during their early life. The development of the pot-belly seems to indicate that, under non-pollutional and hence more favorable conditions, the viscera tend to grow at a normal rate while the growth of the skeleton and muscles of the carp is permanently retarded.

[9] Doctor Scheuring says that the growth of normal carp in the Illinois River is about as rapid as under fairly good cultivation in Germany.

TABLE V

WEIGHT (IN OUNCES) OF NORMAL AND KNOTHEAD CARP OF DIFFERENT AGES

Based on random samples obtained from fishermen during the winter of 1926-1927. The data on knothead individuals are in bold-face type.

Locality	Miles below Lake Michigan	Age in years: 2	3	4	5	6	7	8	9	10	11	12
		Year spawned: 1925	1924	1923	1922	1921	1920	1919	1918	1917	1916	1915
DEPUE Depue Lake	114.3	3 **3** **8**	**12** **13** **14** **16**	**10** **13** **30**	**11** **11** **14** **15** **20** **21** **23** 23 **26** **32**	**15** **24** **28**		**18**				
HENRY Sawmill Lake	129.5	26 28	**25** **28** 31	**23** **33**	**15** **28** **28** **28** **33** **37** **46**	**65**	**31**					

CHILLICOTHE Rice Pond	145.3			25 37 46 50	18 22 24 25 31 31 33 33 36	26 26 43 62 68	33 108	73				
SPRING BAY Spring Bay	153.2		34	19 32 34 44	16 17 36 38	27 33	37	48 65 80		48 53		
AVERYVILLE Peoria Narrows	161.0		42	47 106	39 42	33 47	80	75				352
PEORIA Peoria Slough	163.7				29	17 24 37	43		26			
PEKIN Down the river	180.5					55 59						

TABLE V—*Concluded*

Locality	Miles below Lake Michigan	Age in years										
		2	3	4	5	6	7	8	9	10	11	12
		Year spawned										
		1925	1924	1923	1922	1921	1920	1919	1918	1917	1916	1915
HAVANA												
Clear Lake	195.3			35	65 68							
Quiver Lake	202.4		22	19 19 27 29 29 32 32 33 39 47 50 56	27 33 37 37	30 64 133						
Cook's Ditch	206.0		22 24	22 26 30 31 32 34 35 35 67	22 35 41 43 54							
BEARDSTOWN												
Ditch below town	241.6			50 74	62							

TABLE VI

AGE IN YEARS OF NORMAL AND KNOTHEAD CARP OF THE ILLINOIS RIVER ARRANGED IN 5 OUNCE WEIGHT CLASSES

Classes below 18 ounces and above 77 ounces are omitted because they do not include both normals and knotheads.

Station	18-22		23-27		28-32		33-37		38-42		43-47		48-52		53-57		58-62		63-67		68-72		73-77	
	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k
Depue		5, 5, 8	5	5, 5, 6		4, 5, 6																		
Henry			2	3, 4	2, 3	3, 5, 5, 5, 7		4, 5, 5				5								6				
Chillicothe		5, 5	4	5, 5, 6, 6		5, 5		4, 5, 5, 5, 7			4	6	4					6				6		8
Spring Bay		4		6		4	3	4, 5, 6, 7	5			4		8, 10		10				8				
Averyville								6	3	5, 5	4	6												8

TABLE VI—*Concluded*

Station	18-22		23-27		28-32		33-37		38-42		43-47		48-52		53-57		58-62		63-67		68-72		73-77	
	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k	n	k
Peoria				6 9		5		6				7												
Pekin																6	6							
Havana	3 3 4 4 4 5		3 4 4 5		4 4 4 4 4 4 4 6		4 4 4 4 4 5 5 5 5		4 5		4 5		4		4 5				4 5 6		5			
Beardstown													4				5						4	
Average age in years																								
NORMAL	3.8		3.9		3.9		4.3		4.2		4.2		4.0		4.5		5.5		5.0		5.0		4.0	
KNOTHEAD	5.3		5.5		4.9		5.3		5.0		5.6		9.0		8.0		6.0		7.0		6.0		8.0	
Weight classes	*18-47 oz.*												*48-77 oz.*											
Average age in years																								
NORMAL	4.05												4.67											
KNOTHEAD	5.27												7.60											

BEHAVIOR OF KNOTHEAD CARP

The reactions of knothead carp to their environment differ from those of normal carp in many details. Our present information, although rather fragmentary, shows that some of the differences in behavior are of considerable importance, and that they are attributable to various manifestations of three defects found in the knotheads—an inefficient respiratory apparatus, a general flaccidity of the body that implies a lack of muscular tone, and a comparatively low sensitivity to stimuli.

Many fishermen of the middle Illinois River have given us information concerning knothead carp and their habits, one of the most important items of which is a difference in the habitat of normal and knothead carp. Carp are distributed throughout many kinds of situations in the Illinois River proper, in the connecting bottomland waters, and in Peoria Lake, which is a widening of the river. Those taken from situations where there is a considerable flow, and where it is probably necessary for them to swim more or less constantly to hold their position, are almost invariably normals. The catch from the deeper quiet waters includes both normal and slightly deformed carp. Most of those taken from the shallower backwaters of the section between LaSalle and Peoria, extensive areas of water choked with brush and vegetation, have moderate degrees of malformation. The writer has examined single catches with as many as 200 carp from these shallow backwaters without finding a single entirely normal individual, although during periods of high water, normal carp are taken there in fair numbers along with knotheads.

In summer extremely malformed and emaciated knotheads can often be picked up by hand where they are lying quiescent in shore vegetation. These are known to fishermen as "grass" carp. Their behavior suggests that extreme malformation has so embarrassed respiration that they can live only in relatively high concentrations of dissolved oxygen, and that they are so occupied with getting sufficient oxygen that they do not feed or react to ordinary stimuli. Such individuals are often found dead in nets and along the shores.

A large part of the commercial catch of carp is taken by means of hoop-nets set along the shores and in other shallow waters from 2 to 8 feet deep. The openings of these nets are directed downstream and are flanked by wings to guide the fishes into the openings. Such nets capture, of course, only those fishes that swim into them, and their usefulness depends on the fact that the fishes react to small changes in environmental factors, such as stage of water, temperature, turbidity, rate of flow, waves, light, ice movement, dissolved oxygen, and food supply. Since minor changes in these factors occur from day to day, some fishes are always moving from place to place, and a more or less constant number of them are taken daily in these hoop-nets. The catch of knotheads, however, is more irregular than that of normal carp and other fishes. This indicates that the knotheads do not so readily react to these minor changes in condition, but are quiescent for long periods of time. When major variations of environmental factors cause them to move, they are taken in large numbers, because they are less alert and more blundering than normal carp. For example, an upstream wind apparently drives these knotheads before it along the shores, where they are taken in large numbers by hoop-nets.

The first fingerling knothead carp seen by the writer had been washed ashore in late August, 1923, while the laboratory boat was tied up at Peoria Narrows. An upstream wind which blew continuously for several days, producing waves a foot or more in height, caused thousands of small carp and a sprinkling of other small fishes to be thrown up on the beach, along with uprooted vegetation and miscellaneous debris. These little carp were apparently uninjured, and a quantity of them were gathered up and kept alive for several weeks in the large aquarium on the laboratory boat. They were from 1 to 3 inches long and were obviously of the brood spawned during May and June of that year. At that time the local fishermen pointed out that many of these young carp had the bulged opercles characteristic of the knothead fish that had been numerous in their catches. They further remarked that it was very unusual for carp to be driven ashore, inasmuch as the carp, of all fishes in the river, are the most alert and best able to take care of themselves.

Occasionally the Illinois River is frozen over for a few weeks in winter and a condition of stagnation develops which is accompanied by a decrease in the amount of dissolved oxygen in the water.[10] When the amount of dissolved oxygen in the heavily polluted channel waters drops to 3 parts per million or less, the fishes begin to retreat into the backwater lakes, spring holes, mouths of tributaries, and other places where there is more oxygen. At such times large hauls of fishes are taken by fishermen in certain spring holes, the best known of which is at Spring Bay in Upper Peoria Lake, where 200,000 pounds of carp were taken in December and January, 1917-1918. Large numbers were taken there also in the winter of 1924-1925, and a fair number in the winter of 1926-1927. The early hauls from this spring hole are almost all knothead carp, but later hauls, made after stagnation in the river is more advanced, are mostly normal carp. This is further evidence that the knotheads are more quickly affected by low oxygen concentrations than are normal carp.

Illinois River fishes often have a very disagreeable "gassy" taste or odor, which seriously lessens their palatability, and these gassy fishes are definitely associated with periods of prolonged ice on the river, mortality in nets and traps, and other indications of a scanty oxygen supply. Fishermen find that this gassy taste occurs more often and is more pronounced in knothead than in normal carp, and for this reason

[10] Thompson, David H. Some observations on the oxygen requirements of fishes in the Illinois River. Ill. Nat. Hist. Surv. Bull. Vol. XV, Art. VII. 1925.

the knotheads are culled out when carp are shipped to New York from the Illinois River, because it is very costly to ship such long distances by express and any defect in the quality of the fish is likely to cause them to be docked in price to a point where the money received will not pay the transportation charges. To remove this gassy taste, fishermen place their fishes for a week or two in cribs or ponds fed by spring or other well-aerated water.

A spring-fed pond of about half an acre has been constructed by a fishing firm on the east shore of Lower Peoria Lake as storage space for live carp. In warm weather the carp are hardened in this cold spring water before they are shipped alive in tank cars to New York, and in winter they are left in this clean, well-aerated water for a few weeks to improve the flavor. The first live carp were put in this pond for storage during the latter part of the summer of 1927, and by the middle of September about 120,000 pounds had been accumulated.

During a fortnight of very warm weather in September some of these fishes died of suffocation, and it was noticed that the first to die were almost all knotheads, and that those dying a few days later were both normals and knotheads. A few dissolved-oxygen determinations made at this time indicated that the knotheads began to die in numbers as soon as the dissolved oxygen fell to about 2.8 parts per million, and that the normals began to die when it had fallen to about 2.45 parts per million.

The weather turned cool, the aeration of the spring water was improved, and the carp stopped dying. Some determinations made a little later showed about 5 parts per million of dissolved oxygen in various parts of the pond. At this time many of the knotheads were lying in the shallow water at the margin, while the normals were moving about in the deeper parts of the pond or making repeated attempts to ascend the stream of spring water as it poured in. These normals kept their fins fully extended and were seldom quiet for more than 2 to 5 seconds, but the knotheads would lie on the bottom for many minutes at a time, seldom moving unless they were nudged by other fishes. Their fins were rarely fully extended, and the dorsal was usually inclined backward or lying flat.

Three normals and six knotheads, each weighing between 1½ and 3½ pounds, were hauled from this pond to the laboratory at Urbana in 10-gallon cans and kept in a large aquarium in well-oxygenated water at about 62°F. The average numbers of respiratory movements per minute of five of the knotheads were 61, 63, 67, 69, and 87. Although accurate counts could not be made on any of the normals because they were constantly moving about, their respiratory movements were obviously slower than those of any knotheads and were estimated to be about 50 per minute. The relative viability of the two kinds is indicated by the fact that 4 of the 6 knotheads died during the first three days while none of the normals died. The death of the former could not have been due to over-crowding or lack of oxygen, because the aquarium was large and was supplied with a good flow of well-aerated water which was further oxygenated by bubbling compressed air through the tank. This greater loss of the knotheads is experienced by fishermen who ship carp to New York in tank cars that are constantly aerated by air compressors.

The supernumerary rings on the scales seem to indicate that the knotheads stop feeding for considerable periods of time during the growing season, perhaps because of embarrassment in respiration during periods of dissolved-oxygen deficiency in summer.

ETIOLOGY OF KNOTHEAD DISEASE

The possible causes of malformation in fishes are usually considered as falling into three classes: (1) hereditary defects, (2) infections, and (3) environmental changes that disturb the normal metabolic and developmental processes. There is no reason to suppose that the knothead malformation of carp is hereditary; neither has any evidence been obtained, during several months of work on the histology and morphology of knotheads, of an infection of any kind that could produce it. The first two possible causes of malformation being thus eliminated, it seems probable that we have to deal with some external influence which has interfered with the developmental processes or the metabolism of these carp and has altered their growth form.

No significant similarity has been discovered between the knothead malformation and any of the many abnormalities that have been produced in fishes by various workers by changing the physical and chemical conditions of the medium during the egg and early embryonic stages. Double-headed monsters, multiplication of parts, coalescence of parts, supernumerary organs, etc., such as have been described by O. Hertwig, G. and P. Hertwig, Mielewski, Stockard, Tornier, Werber, and others, obviously have nothing in common with the malformation we are considering. The explanation of knotheads, therefore, is to be sought in terms of metabolic disturbance.

The marked difference in the growth rates of normal and knothead carp is direct evidence of some metabolic change, the production of large numbers of knotheads in a certain part of the river indicates some general environmental cause, and the fact that growth is retarded throughout the life of these fishes indicates, further, that the causative conditions are persistent in this area. The few pot-bellied knotheads, which we have found farther downstream, are individuals that partly recovered after they had escaped from the waters in which the causative conditions obtained.

It has been shown that the distribution of this abnormality coincides with a certain pollutional area of the river, and this limits the causative agent to conditions which accompany pollution. The fact that carp alone show abnormality delimits the cause to some condition which affects carp and not other fishes of the area—on the supposition that the innate liability of all fishes of the area to abnormality is the same. In the middle Illinois River under pollutional conditions, carp constitute a much higher percentage of the total catch of fishes than in the cleaner waters of the lower river. This is mostly because the carp are more tolerant of pollution and feed over much larger areas than the other less tolerant fishes, which are mostly restricted to the cleaner backwaters of the region. The character of the food supply available to the carp in this region has been strikingly altered by the pollutional conditions which have prevailed during the past decade. Since the other fishes have been restricted to the cleaner backwaters, probably no marked change in their diet has been produced. Since no other condition affecting only the carp is known which could conceivably induce metabolic disturbances, food is taken to be the causative agent of the abnormality. In recent years, many metabolic disturbances traceable to food have been found to be due to the lack of certain food elements, or vitamins. To date, very little is known about diet-deficiency diseases except in man and a few other warm-blooded animals, but in the latter the changes resulting from the lack of the different vitamins have been fairly well worked out.

The knothead malformation shows definite changes in calcium metabolism, since the bones are altered in shape and thickness; the bones of the skull are malformed while the vertebrae are unaffected; there is also a marked lack of muscular tone, as indicated by the flaccid body and general sluggishness of the affected fishes. In warm-blooded animals such symptoms have been found to be associated with the lack of vitamin D. Growth curves for experimental rachitic and normal rats[11] are practically identical with the growth curves for knothead and normal carp. In the higher vertebrates, where the etiology of rickets has been worked out most completely, the most characteristic symptoms are found in the long bones of the appendages and in the ribs. Critical comparison with rickets as known in these higher animals is made difficult, however, by reason of the fact that the carp has no long appendicular bones and its ribs are haemal bones, not homologous with the pleural ribs of the TETRAPODA. In the long bones of the latter a very characteristic indication of rickets is to be found in the tissues about the line of calcification in the epiphyses,[12] but there are no epiphyses in the skeleton of the carp.

Sunlight or ultra-violet rays seem to be essential to the production of the antirachitic factor, vitamin D. A number of workers[13] have pointed out that our richest sources of vitamin D are animals, such as the cod, which feed directly or indirectly on chlorophyll-bearing, and hence sunlight-loving, plankton and other green organisms. Rickets is

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[11] Cahan, M. H. Studies of cholesterol in prevention of rickets. Thesis. University of Illinois Graduate School. 1927.

[12] McCollum, E. V., and N. Simond. The new knowledge of nutrition. Macmillan Co. Third Edition. 1925.

[13] Coward, K. H., and J. C. Drummond. On the significance of vitamin A in the nutrition of fish. Biochemical Journal, Vol. 16. 1922.

commonly cured either by the direct effect of sunlight or ultra-violet light, or else by a diet containing vitamin D. The fact that the peripheral bones of the knothead skull are thickened suggests the direct effect of sunlight on the local deposition of bone. The origin of the knothead abnormality among the carp of the middle Illinois River seems, then, to be due to the replacement of chlorophyll-bearing plankton by non-chlorophyll-bearing kinds and to the loss of the coarser aquatic vegetation from the dietary of the carp and of the organisms upon which they feed; but extensive feeding experiments under carefully controlled conditions would be required to determine positively whether or not the knothead malformation is due to a lack of vitamin D.

Experimental work on fishes has not produced anything similar to knotheads. Among the entire group of cold-blooded vertebrates, the only known abnormality comparable to the knothead malformation was seen by Klatt[14] in *Triton* and *Rana* which he had fed exclusively with mussel flesh. The heads of these amphibians were short, broad, and oedematic, and their bones were not normally calcified.

Coward and Drummond *(op. cit.)* found that brown trout fry fed on a diet deficient in vitamins A and D did not grow much or show the vigor of those which received a diet rich in A and D.

In Germany, a carp disease characterized by a softness of the bones (Knochenweiche) is occasionally seen in artificial ponds in which the carp have been heavily fed with cereals (corn and lupines). The calcium content of the bones of such fishes does not differ from the normal.[15]

Schäperclaus[16] describes two carp which had several of the anatomical characteristics of knothead carp. They were found among a population of older carp and other fishes which had been fed on barley in a pond free from plant life. The rings of the scales of these two carp showed normal growth during their first year, before they were placed in this pond, and very little growth during their second year, when they were in the pond.

Davis and James,[17] of the U. S. Bureau of Fisheries, have made experiments showing the effects of deficient diets on carp, and report as follows:

"Since the discovery of vitamins by Funk a little over a decade ago, marvelous strides have been made in our knowledge of these elusive food factors, but until very recently we had no information as to their importance in the metabolism of lower vertebrates. It was recently found by

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[14] Klatt, B. Fütterungsversuche an Tritonen. Verhandl. d. Deutsch. Zool. Ges. 30 Vers. Jena, Leipzig. 1925.

——— Fütterungsversuchen an Tritonen. I. (1926) II. (1927). Arch. f. Entwicklungsmechanik. Vols. 107 and 109.

[15] Personal communication from Doctor Scheuring.

[16] Schäperclaus, W. Kiemendeckelaufwölbung bei zweisommerigen Karpfen. Fischerei Zeitung. Nr. 24, Bd. 29. 1926.

[17] Davis, H. S., M. C. and James. Some experiments on the addition of vitamins to trout foods. Trans. Am. Fisheries Soc. Vol. 54. 1924.

Drummond that trout eggs are very rich in vitamin A while several investigators have shown that cod-liver oil is far richer in this vitamin than any other known substance. The fact that fish tissues contain such large quantities of vitamin A[18] is in itself an indication that it must be just as essential to them as to higher animals. However, we had no knowledge of the effect of vitamin deficiency on fishes and in order to supply this want feeding experiments were carried on at the Fairport, Iowa, station for about two months during the summer of 1923. In these experiments young carp from the Mississippi River were confined in troughs supplied with running water and fed diets deficient in one or more vitamins. The results clearly indicate the importance of these accessory food factors in the diet of fishes. In every case there was a high mortality, ranging from 40 to 67 per cent among the fish fed vitamin-deficient diets while there were no deaths among the controls which were fed a diet rich in these substances. The most striking results were obtained with the fish fed a ration containing no water-soluble B. After 3 or 4 weeks these fish became very nervous and a number developed convulsions which were especially noticeable whenever the covers were removed from the troughs. During these convulsions the fish would dart rapidly from side to side, twisting and whirling about and striking their heads violently against the sides of the trough. At intervals they would leap some distance from the water until finally, with a last convulsive shudder, the fish would sink quietly to the bottom where they would gradually recover and after a few minutes would swim about in a perfectly normal manner. These convulsions became more and more frequent and more intense from day to day until the fish succumbed to the inevitable. Conclusive proof that they were due to absence of B is shown by the fact that in several instances fish which had developed convulsions and would certainly have died if continued on a vitamin-deficient diet were fed considerable quantities of yeast and fully recovered within a few hours.

"Fish given diets deficient in fat-soluble A showed no distinctive lesions although the mortality was very heavy. As is well known the absence of A causes a disease of the eyes in rats and other mammals known as xerophthalmia, and its failure to affect the eyes in this case may cause surprise. However, it is generally believed that the xerophthalmia is really due to the fact that the tear glands do not function properly in the absence of A so that the results in this case are, after all, only what we should expect. A deficiency of water-soluble C resulted in high mortality with white spots on the gills caused by the development of necrotic areas."

It seems probable that the reason Davis and James did not find malformation caused by the diet deficient in vitamin A (and D) was either that the carp were too old and their growth form was fixed or else that the experiments were not continued long enough for malformation to become apparent.

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[18] Since the publication of this paper, vitamin D has been distinguished from vitamin A, both of which are found in codliver oil D. H. T.

CONCLUSION

The knothead malformation of carp described here is believed to be the first known instance of rickets among fishes. Its resemblance to rickets in man and other higher vertebrates is as close as can be expected in view of the anatomical difference between a fish and a mammal. Carp may be affected by it from the fingerling stage through life. Their sluggishness of habit and their retarded growth are further indications of a rachitic condition. These rachitic carp are recognized by the bulging of the opercles, which is often so extreme that respiration is seriously embarrassed.

Rickets in the higher vertebrates is due to a lack of vitamin D in the food, and there is evidence that this is also true in the present case, inasmuch as the green aquatic vegetation which supplies vitamin D has been depleted in the same area and during the same period of time that the carp have been thus malformed. The depletion of the green aquatic vegetation took place following upon large increases in the sewage load of the Illinois River in the years 1916 to 1918. In the latter year knothead carp appeared, and they have continued up to the present time. They are numerous in the Illinois River from the upper limit of fish life near Utica (Starved Rock) down as far as the Copperas Creek Dam, a distance of about ninety miles. The average frequency of knotheads in this stretch is over 50 per cent, and in certain waters near the upper end it is well over 90 per cent. Other fishes of the area are unaffected, probably because they are less tolerant of pollution than the carp and feed in the cleaner backwaters.

The retardation of growth of the knothead carp contributes to the general reduction in yield of the river by pollution, which, in recent years, has probably run into millions of pounds per year, but the present studies give no reason for believing that the value of these carp as food for man is in any way impaired.

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METHODS AND PRINCIPLES FOR INTERPRETING THE PHENOLOGY OF CROP PESTS*

L. R. Tehon

INTRODUCTION

The dominating influence exerted by weather and climate in determining the occurrence and distribution of phytopathogenes and phytophages, as well as the extent and the intensity of their attacks, is so conspicuously self-manifesting that it receives universal recognition; and much effort has been expended in trying to determine experimentally, with the aid of accurately regulated laboratory devices, the manner in which temperature and moisture, the two chief elements, operate. While such work has an inestimable erudite value, much so learned is, at present at least and from the practical standpoint, to a very large extent incapable of being applied to the immediate and pressing problems of the farm and orchard.

For this, there appears to be a fair justification; for the investigator, trained to methods inseparable from the microscope, the test tube, and the precision of apparatus and reagent, as well as being greatly restrained by the demands of the varied tasks of teaching and agricultural extension, can attack this problem only with the resources at his command, and the essential background furnished by an intimate knowledge of the conditions under which organisms exist naturally remains, as a result, unilluminated. Another consequence is that there are few methods known by means of which geographical and seasonal variations, whether in numbers or other characters, exhibited by pests coincidentally with climatic variations or the weather of an environment can be expressed and explained.

There is need, therefore, of more extensive and complete knowledge of distribution, of the extent and intensity of plant disease and insect invasions, and especially of suitable means to express these things exactly in their relation to climate and to weather. Recently, through the Plant Disease and Insect Surveys of the U. S. Department of Agriculture and similar separate or cooperating agencies in several States, a start has been

* The material given under this title constitutes an enlargement and revision of a paper previously prepared but never published, except in an abstracted form (see: Tehon, L. R. The field survey as a basis for the phenological interpretation of the plant disease epidemic. Phytopathology 16: 63. 1926).

The term phenology is used so rarely by plant pathologists that I venture to define it, briefly, as the study which recognizes the effects of weather and climate in determining the time of appearance of phenomena, or events, in nature and seeks to define their influence exactly.

made with the first task; and the ultimate value of their accomplishments will depend not merely upon the success with which they record distribution, but (as it seems to the writer) more particularly upon the progress they make with the second task, by measuring and reporting, in understandable and comparable terms, periodic and seasonal fluctuations in abundance and intensities of attack. The third task, that of relating these phenomena to their particular meteorological accompaniments, naturally will fall to the investigator, who, by being employed expressly for the purpose or urged thereto by his personal inclinations, finds the time and means at hand to solve these intricate problems.

In the present state of affairs, this paper proposes primarily to call attention to a method of defining the relations of plant diseases to climate and weather; but it intends, also, to make additional suggestions which may be useful to entomologists (the latter having used the method to a limited extent) and to point out some of the fundamental principles concerned. If certain sections of the paper should appear to readers to be lacking in conclusiveness, the writer would respond that his aim has been not so much to draw final conclusions as to illustrate the potentialities of a method.

GRAPHIC DEPICTION OF CLIMATE AND WEATHER

The device* here used to depict climate and weather is not new, for it appears to have been originated by Ball (2) about 1910 and to have received its first application to practical problems in the hands of Taylor (17) in 1916; but certain of its meanings are newly shown in the latter part of this paper. Being concerned with temperature and rainfall, it has been termed a hythergraph. A variation of it, which makes use of temperature and relative humidity, is known as a climograph, for the reason that relative humidity, resulting from the influence of light, wind, and other lesser factors, as well as heat and rain, is considered to be a more exact expression of climate; but, as records of relative humidity often are not readily available, it can not be used with the same facility as the hythergraph.

By referring to Figures 4 and 5 (pp. 327 and 328), both of which are simple and typical examples, the hythergraph will be seen to be nothing more than a graphic diagram, its vertical scale customarily representing temperature and its horizontal scale rainfall; and any given combination of measurements relating to these elements will be shown thereon by a point located at the intersection of the proper ordinate and abscissa.

As a result of the ways in which it can be constructed, this graph will assume one or the other of two general forms, both of which are used in this paper. The simpler form consists of a series of points which mark combinations of temperature and rainfall for successive days or for longer

* An interesting discussion, with suggestive notes, is contained in an article by V. E. Shelford, with the title "Physiological life histories of terrestrial animals and modern methods of representing climate", which occurs in the Transactions of the Illinois State Academy of Science, vol. 13, pp. 257-271, 1920.

periods; and the general trend from one to another of these points often is shown by connecting lines, according to Ball's suggestion, as has been done in Figure 5.

In constructing the more complicated form, a considerable number of mean temperature—total rainfall combinations for stated periods, such as months or years, or for localities or regions, are plotted in the manner illustrated by Figure 15 (p. 337): and the particular range of the conditions associated with a given phenomenon, or with certain degrees of its manifestation, as indicated by correlative data, then may be determined by joining the plotted points with straight lines. The result is usually one or a number of irregular polygons, which may be made more inclusive, and probably more indicative, by "smoothing" them by the use of mathematical formulae or, as frequently may be done with entire satisfaction when data are abundant, simply by applying the draftsman's "French curve" and making the lines indicated by it.

The two types of graphs often may be combined advantageously, as in Figure 14 (p. 336), to show not only the ranges but also the trends of months, seasons, or other desirable periods associated with a given phenomenon; indeed, the variations of which the hythergraph is capable are so diverse that they provide almost unlimited opportunities for comparing correlative facts and so of drawing therefrom inferences relating to a wide scope of inquiries.

For the sake of simplifying the language in the subsequent pages of this paper, I am suggesting two new terms, namely, **thermohyet** and **thermohyetic,** the former to designate a combination datum consisting of a record of temperature and of rainfall (and, by analogy, any point placed on the hythergraph to represent such a datum), the latter to serve as an adjective replacing generally such unwieldy terms as "temperature—rainfall", "mean temperature—total rainfall", and the like. It is obvious that the noun can be used only within strict limits; but the adjective often can be used somewhat loosely, at the same time expressing the thought with sufficient clearness, or if it is desirable another word, thermohyetics, may be used also with a looser meaning.

WEATHER IN RELATION TO THE LATE BLIGHT OF POTATOES

As a first illustration of the use of the graphs described in the foregoing section, the relation of the late blight disease of potatoes to weather furnishes a simple and striking example, not only because the influence of weather upon the occurrence of severe epidemics is so universally recognized but also because numerous attempts, ranging from the statement of opinions based upon experience (which are by no means in agreement, superficially) to a graphical presentation of facts, have been made to explain specifically the connection between the two.

Without attempting to furnish either an extensive citation list or an adequate review of the literature pertaining to this subject, most of which would be entirely outside our problem anyway, we proceed immediately to the work of Martin (13) in New Jersey, who gathered data showing the variation in severity of the annual late blight epidemics in that State for many years and indicated their relations to the rainfall and average temperatures of the Julys of their respective years by showing graphically how far, in each case, the thermohyetic conditions departed from the normal July weather. The conclusion of Martin's work, though in several respects illuminating, was in the main lacking in definiteness, in part because the data, in the manner in which they were presented, applied only to New Jersey, and in part because the graphical method he employed was essentially a correlation graph, from which, because the location of the axes of correlation had been predetermined erroneously as lying along normals of temperature and rainfall for New Jersey, the scientific deductions usually expected in such a case could not be obtained.

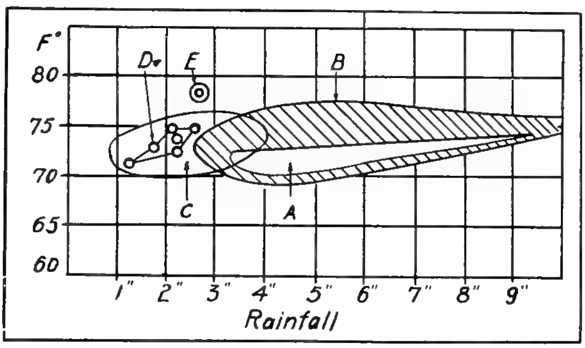

FIG. 1. Hythergraph for potato late-blight. The areas labeled A, B, and C mark the thermohyetic conditions conducive to severe attacks, mild attacks, and an absence of blight, respectively, as shown by Martin's New Jersey data. The points indicated by D are for northern Illinois, where blight occurs but rarely; and E is the thermohyet for East St. Louis, where blight never occurs.

After restating Martin's data, so that they appeared as measurements of actual temperature and rainfall instead of departures from normals, it was possible to construct from them the hythergraph shown in Figure 1, in which, as directed in the foregoing section, the polygons resulting from Martin's data have been smoothed to include all the probable combinations of temperature and rainfall likely to result in heavy attacks of blight *(A)*, in light attacks of blight *(B)*, and in an absence of blight *(C)*.

It is not to be supposed that these three areas on the graph show incontrovertibly the precise limits of the thermohyetic combinations required for these respective grades of blighting; indeed, the overlapping of the region labeled *C* upon both the regions *A* and *B* indicates a fault in the data which would be even more apparent if the points plotted from the data to delineate the regions *A* and *B* had been retained; yet for this apparently serious discrepancy the only explanation that needs to be made is that the type of disease data, and the sources drawn upon for them, rendered it exceedingly difficult for Martin to make unfailingly correct classifications of his yearly records.

Still, some sort of test of the general applicability of this diagram can be made by introducing and comparing observations on blight occurrence in another region; and because of my familiarity with Illinois, I have made this test by using facts relating to late blight in this State, where there are two main regions in which potatoes are grown and in which the late blight disease would be the source of serious economic loss. The first lies in the southwest, in a rather extensive territory about the city of East St. Louis, and the second, ranging throughout the northern fourth of the State, occupies especially the north tier of counties. In the East St. Louis region, late blight never has been known to occur; but in the north, particularly in the northeast, in McHenry County, it sometimes occurs in mild epidemics, though here too, as a rule, it is absent.

It is of interest, therefore, to see what relation the thermohyetic conditions that exist in these contrasting localities in Illinois just previous to potato harvest bear to the areas marked on our diagram. The large dot, marked *E* in Figure 1, represents the average weather for this period at East St. Louis, and, from the position of this point on the diagram it is readily inferred—indeed, it seems quite self-evident—that the usual temperature-rainfall complement for this region differs so much from that required by the late blight disease for its development that only in the most unusual years could this disease be expected to occur there; and, though it should, by chance, occur, its becoming either an extensive or a destructive epidemic is too remote a possibility to admit of consideration.

The northeastern region of Illinois presents, however, a different situation, and one which agrees with the facts observed. The series of points marked *D* on the diagram represent the normal thermohyetic conditions during the period when late blight develops for six stations in this region. In accordance with Martin's data, and with the observed fact that late blight usually does not develop here, the points all fall within the area marked *C*, the characteristic of which is that the combinations of temperature and rainfall contained by it are not productive of late blight epidemics.

By inspecting the diagram, one readily sees, however, that the normal conditions, in the case of four of the northern Illinois stations, lie quite close to the boundary of the area *B*, defined by Martin's data, and that only slight variations in temperature and rainfall during the critical period could move these points, for a season, into the area *B*; and when this occurs (as has been observed to be the fact) the development of a late blight epidemic is not only possible, but is, indeed, to be expected.

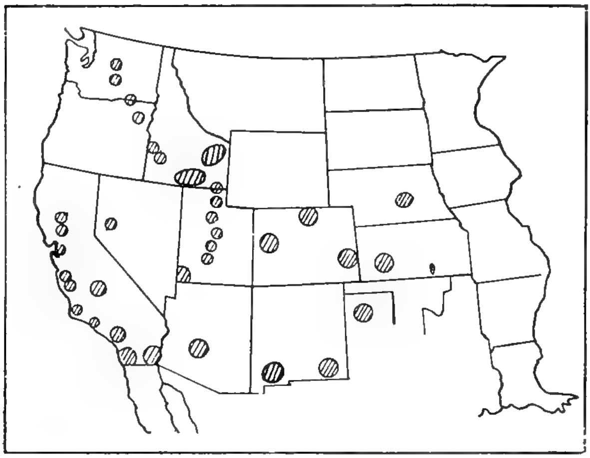

FIG. 2. Regions in which sugarbeets are infected with "curlytop". (Compiled from data by Ball and by Haskell and Wood.)

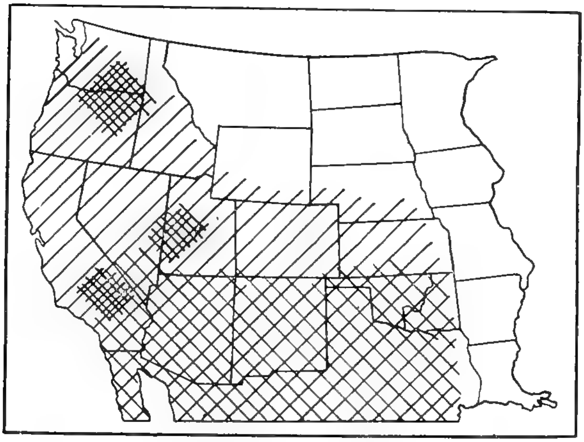

FIG. 3. Range of the beet leafhopper. Widely spaced cross hatching shows the probable natural breeding range, and the closely spaced cross hatching marks additional breeding spots from which considerable migration occurs. (Redrawn from Ball.)

THERMOHYETICS OF THE BEET LEAFHOPPER AND SUGARBEET "CURLYTOP"

"Curlytop" of sugarbeets, a virus disease carried and disseminated by the beet leafhopper, *Eutettix tenella* Bak., is known to occur in epidemic proportions only in the western and drier regions of the United States, where, according to Ball (1) and Haskel and Wood (8), it has been recorded definitely in the regions shown in Figure 2; but the leafhopper, being by no means locally restricted to these regions, ranges over the very extensive territory indicated by the diagonal lines in Figure 3,

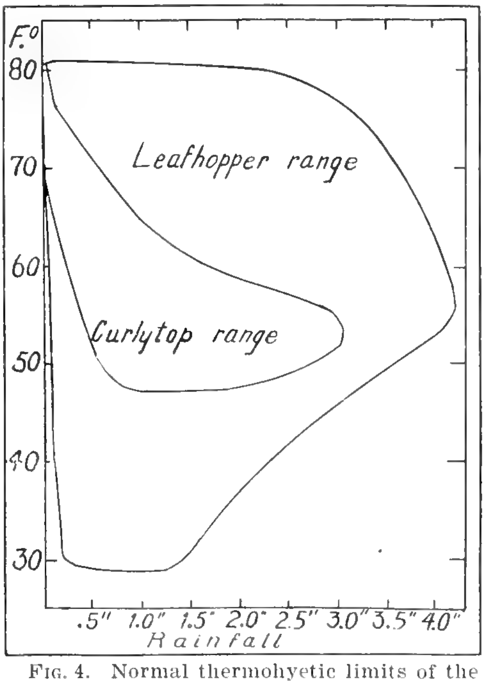

FIG. 4. Normal thermohyetic limits of the geographic ranges of the beet leafhopper and the "curlytop" disease.

supposedly breeding successfully throughout as much of the southern part of its range as is shown (after Ball) by the more widely spaced cross-hatching, but breeding and migrating in large numbers from the regions designated in the figure by the more closely spaced cross hatching.

From the records of Weather Bureau Stations situated in representative regions, one may draw a composite picture, in terms of monthly average total rainfall and normal temperature, of the year-long thermohyetic conditions which the leafhopper and the curlytop disease find suitable. The outer line in Figure 4, represents the outer limits of the annual variations in the thermohyetic conditions associated with the geographic region throughout which the leafhopper ranges; but records from weather stations located in the neighborhood of curlytop-infested regions all fall within the inner line and give a diagram strikingly different in shape and much less extensive. Thus is it shown that the thermohyetic conditions permitting the occurrence of the disease are very definitely circumscribed as compared to those controlling the leafhopper's migratory range.

This very evident difference between the conditions that favor the insect and those that favor the disease may be illustrated in a more particular manner by comparing in Figure 5 the trend of the normal monthly thermohyets of a locality in which only the insect abounds with those of a locality where both insect and disease occur, the localities represented being El Paso, Texas, and Merced, California, respectively. Since the disease appears only in the summer months, the upper part of diagram *B* defines particularly the thermohyetic conditions necessary for its occur-

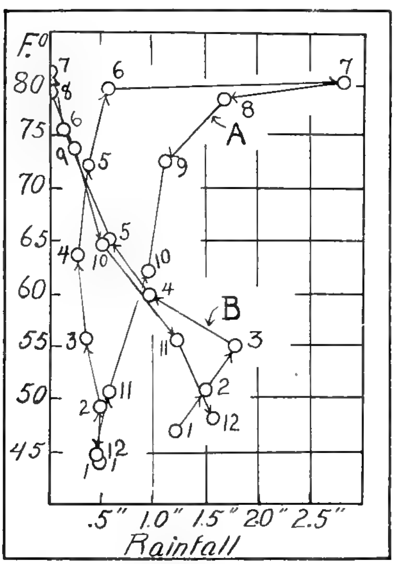

FIG. 5. Comparison of the monthly thermohyets and annual trend for El Paso, Texas, A, which lies in the range of the leafhopper only, and Merced, Cal., B, where both the leafhopper and "curlytop" occur. The summer season is very dry where "curlytop" abounds, but the leafhopper can thrive in a region where an appreciable amount of summer rainfall occurs.

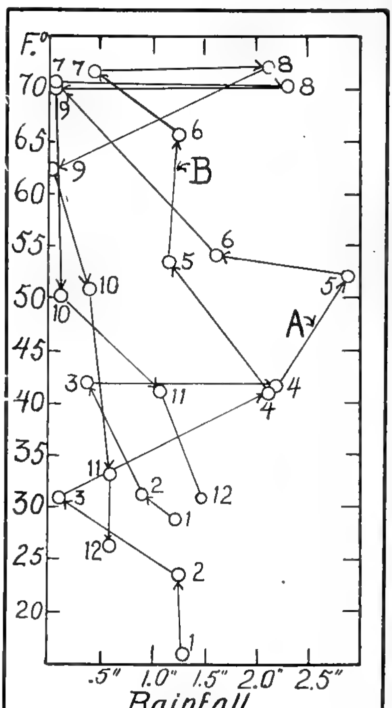

FIG. 6. Monthly thermohyets for 1921 (A) and 1922 (B) at Burley, Idaho. This locality, which lies within the range of the beet leafhopper was infested by "curlytop" in 1921, but not in 1922.

rence; and there is a decided contrast with those under which the leafhopper alone thrives, the difference apparently being a matter of summer rainfall, as a practical absence of precipitation at this time seems necessary for the disease.

Outbreaks of curlytop occur, rarely and at long intervals, in unusual situations, last a single season, and then disappear. Such an instance occurred at Burley, Idaho, in 1921. A hythergraph for that locality, giving the monthly thermohyets for that year in comparison with those for 1922 (normals are not available), is shown in Figure 6; and the difference between the two diagrams emphasizes again the connection between dryness and disease incidence, the absence of rainfall during July being a distinctive characteristic of the year of disease. The fact that the July rainfall in 1922 exceeded that of the previous year only by slightly less than half an inch gives additional weight to a common observation, namely, that in nature what appear to be exceedingly slight differences in habitat serve effectively to predetermine the successful existence of an organism.

In many regions, both the leafhopper and the disease occur every year, the disease varying in severity and the leafhopper in numbers from year to year. So far as recorded information goes, it seems to be rather generally true that a year of severe disease is also a year of abundant leafhoppers. From the weather records for the years of severe disease in such a region, one would expect consequently to obtain a hythergraphic representation of the thermohyetic limits favorable to both the disease and the leafhopper.

Such a diagram, smoothed, for Fresno, California, is given in Figure 7. One would expect the normal thermohyets of other regions to fall within this diagram, and the probable truth of this expectation is shown also in Figure 7, in which the monthly normal thermohyets for Sacramento and for southern California as a whole are inserted and actually fall within the smoothed or generalized diagram. On the other hand, the hythergraph of a locality unsuited to both the insect and the disease ought not to conform in any important respect to the smooth diagram which represents the thermohyetic characters of the normal habitat: and this is demonstrated by the hythergraph for the year 1922 at Burley, Idaho, superposed in Figure 7, which shows not only a striking inconformity of trend but also a series of monthly thermohyets falling, with 3 exceptions, entirely outside the natural range of the insect and the disease.

Although abundance of leafhoppers and severity of disease usually are coincident, they need not be always so; and one is led to surmise from this that there are certain thermohyetic conditions that have a special influence upon disease incidence while certain others determine insect abundance. The growing season of the crop, the characteristics of which have been noticed already, is undoubtedly the period of the year most influential with respect to the disease, whereas other periods of the year may be of greater significance with respect to the leafhopper; and it seems likely that the abundance of the leafhopper, while dependent in some measure upon the weather of spring and summer, probably is influenced to the

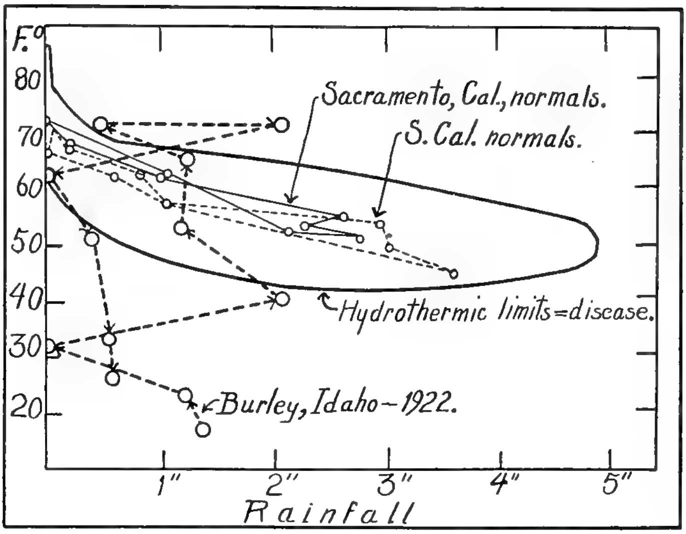

FIG. 7. The annual thermohyetic limits of regions in which "curlytop" is severe include the normal thermohyetic conditions of a locality (Sacramento, Cal.) and of a region (southern California) where the disease is normally abundant but do not include or conform to a locality (Burley, Idaho) where the disease rarely occurs.

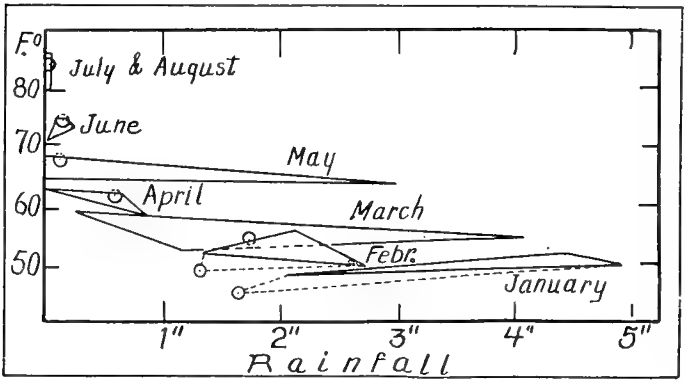

FIG. 8. In the Lake Tulare region of California, the thermohyets for January and February preceding seasons of leafhopper abundance fall in the warmer and wetter ranges of these months, as indicated by the location of the triangles with respect to the normal thermohyets shown by the circled dots.

greatest extent by that of the hibernating or resting period. The range of weather for this period in years of insect abundance is shown by months in Figure 8 for the Lake Tulare region in California, a typical hibernating locality which supplies an abundance of the leafhoppers to surrounding territories during favorable years. When the corresponding normal thermohyets for the same region are indicated on the hythergraph, it becomes apparent that the thermohyetic conditions of January and February in years of leafhopper abundance lie definitely within the wetter and warmer ranges of those months.

THERMOHYETICS OF THE CUCUMBER BEETLES AND THE BACTERIAL WILT OF MELONS

The peculiar interdependence of the cucumber beetle, *Diabrotica vittata* Fab., and *Bacillus tracheiphilus* (EFS) Stev. in the production of the bacterial wilt of cucurbits affords an unusually good opportunity to show how the thermohyetic characters of the natural habitat may be determined and how its variations influence in greater or less degree the activities of the organisms concerned in so complex a relation.

Muskmelons and the other members of the plant family Cucurbitaceae, excepting only the watermelon, are subject to a wilt disease which results from the pathogenic activity of *Bacillus tracheiphilus* (EFS) Stev. In pure culture, and under the exacting conditions imposed by the bacteriologist in his laboratory, this microbe shows a marked sensitivity to temperature, its minimum requirement for growth being 46° F., its optimum lying between 77° and 86°, its maximum temperature for growth being 95°, and its thermal death-point lying at 110°. Within its host, it lives only in the xylem ducts of the water-conducting tissue and, unless it can gain access to them immediately after being introduced into the plant, it is not able to cause wilting. It is this peculiarity that brings cucumber beetles into the problem; for they serve as carriers of the bacterium, and the punctures they make while feeding afford a means of entrance for the bacterium, directly from their mouth parts or indirectly from their droppings, into the xylem ducts. The only known place in which the bacterium overwinters is the digestive tracts of the beetles.

Experimental evidence shows that both the striped cucumber beetle (*Diabrotica vittata* Fab.) and the 12-spotted beetle (*D. duodecempunctata* Say) act as carriers of the bacterium; but field observations indicate that the striped beetle, which is the more abundant of the two in ordinary seasons, is the chief carrier.

The principal sufferers from the wilt disease are the muskmelon and its cultural modifications, the cantaloupe and the Honey Dew melon. The distribution of these crops is indicated in Figure 9, which shows the approximate location of farms reporting 1 acre or more in the 1910 Census. Unfortunately, later data are not available; but the reports of the U. S. Department of Agriculture, through its Bureau of Agricultural Economics,

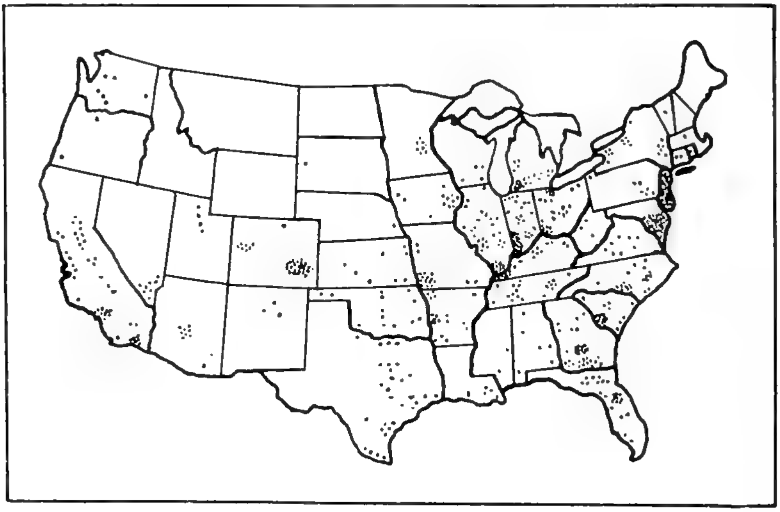

FIG. 9. Distribution of melon crops subject to bacterial wilt. Each dot represents 50 acres grown in 1909. (Redrawn from Finch and Baker's Geography of the World's Agriculture.)

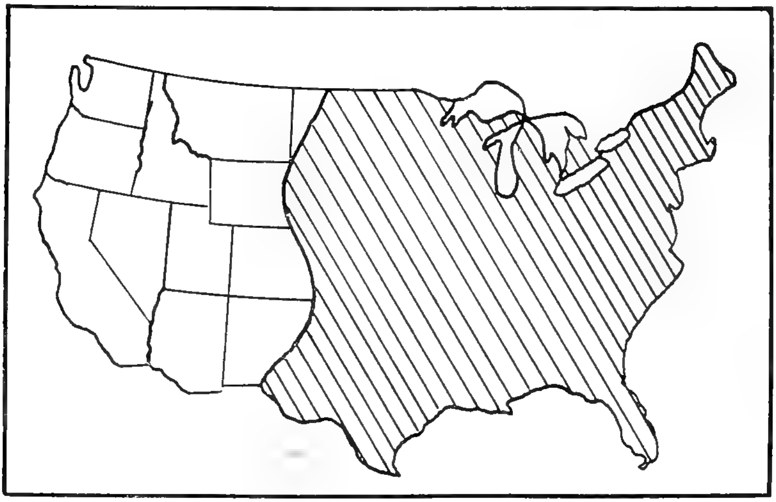

FIG. 10. Range of the striped cucumber beetle. (Redrawn from Chittenden.)

indicate that the distribution of the crop has not changed greatly since that time, although the acreages have changed considerably in several states, and the map will serve to indicate where the disease and the beetles may be of economic importance.

Data showing exactly the limits of distribution for either of the cucumber beetles are not available. Chittenden (3) gives the distribution of the striped beetle as the entire eastern two-thirds of the United States, illustrating his statement with the map reproduced in Figure 10; and the belief prevails among entomologists that there is virtually a coincidence of distribution for the two species. A search of literature and an extensive correspondence have failed to indicate that either beetle occurs outside the North American continent, though both apparently range northward into Canada and southward into Mexico. Throughout this territory the average rainfall is 20 inches or more per year.

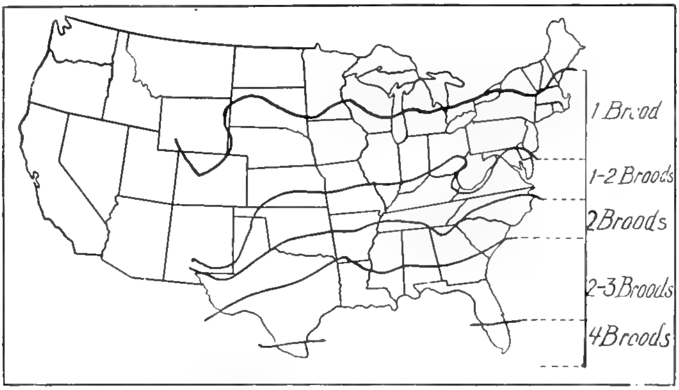

FIG. 11. Broad ranges of the striped cucumber beetle. This map is drawn from data in publications and from information secured by correspondence.

The general effect of temperature upon the striped beetle is most readily seen in connection with the number of broods which it produces per year. Throughout the northern part of its range, there is but one brood, while southward the broods increase to two and exceptionally three, and at times there may be as many as four in extreme southern Texas. The approximate geographic limits of these brood numbers are indicated in Figure 11 by the wavy horizontal lines, and it is, perhaps, not altogether an unexpected coincidence that these brood lines pretty definitely follow certain isotherms indicating mean annual temperatures. Where the mean temperature is annually less than 55° F., the brood number is constantly one; between 55° and 60° there is one brood and usually a partial second; between 60° and 65° there are generally two broods; between 65° and 70° there are two broods and sometimes a third; and where the annual mean temperature exceeds 70° there may be four broods in a year.

The available data on the occurrence of the bacterial wilt of cucurbits show it to be prevalent through a large part of the United States and to have occurred, at least in isolated instances, in Canada, Germany, Russia, the Transvaal, and Japan. The Canadian records can not be verified; the report from Russia is based upon a single wilted plant found in a greenhouse; those from Germany, the Transvaal, and Japan appear to be authentic, but are not accompanied by any statement as to the presence or absence of the cucumber beetles as carriers; hence it is apparent that these records of occurrence outside of the United States can not be made the basis of a world-wide study. But records within the United States since 1918 are sufficiently complete to be fairly satisfactory. All of the states from which the disease has been reported since that year are shown by

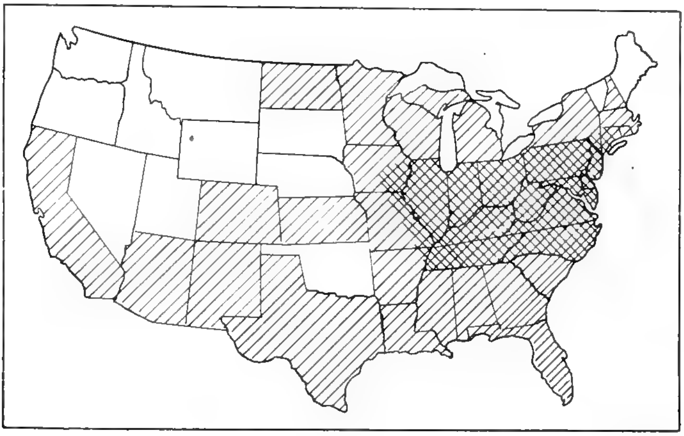

FIG. 12. Distribution of cucurbit wilt in the United States, compiled from Plant Disease Survey Reports. Diagonal lines mark the States from which this disease has been reported authentically, and cross hatching marks the region from which reports of severe wilt usually come.

the hatching in Figure 12, while those states in which the disease is commonly reported as serious are indicated especially by the cross hatching. Probably the disease, though present, is not a serious menace to the commercial crop throughout all of this territory, nor even throughout the territory in which it is commonly reported as being severe; rather, the regions of severity are probably rather localized and could be ascertained with fair accuracy by comparing Figure 9 and Figure 12.

Although the bacterial wilt has a distribution in the United States practically coextensive with that of the striped beetle, the territory throughout which it is most severe lies in a latitude ranging generally north of the southern boundary of Tennessee, while the territory in which the beetle appears to be most successful, as indicated by the number of generations per season, lies to the south of this line. The extent of the wilt's range is not limited northward in the United States, but the disease rarely is found in epidemic proportions much farther north than the southern third of Wisconsin. To the southward, it is limited, unless in exceptional cases, by the increase in temperature during the summer months.

Certain thermohyetic characteristics of the coincident ranges of the beetles and the wilt are expressed hythergraphically in Figure 13. For convenience, in this case, the two halves of the year have been separated,

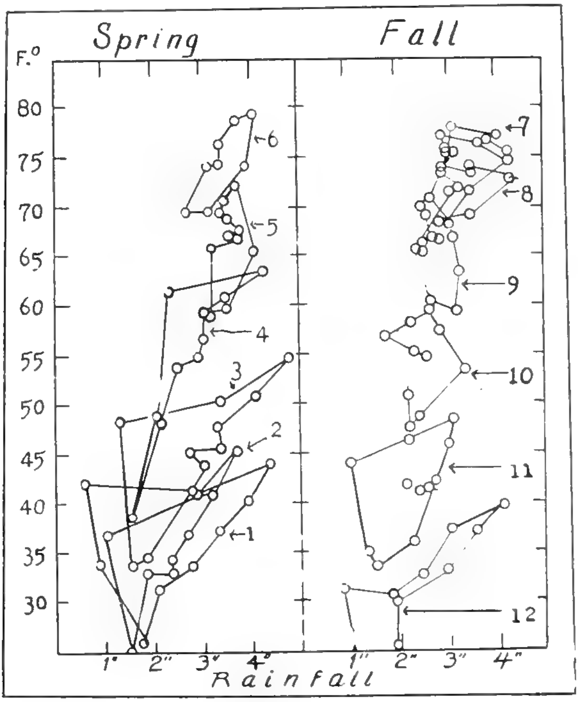

FIG. 13. Thermohyetic range, month by month, of a normal year for the coincident range of the striped cucumber beetle and cucurbit wilt. Circled dots show normal monthly thermohyets for selected States, and the months are indicated by numbers.

and the thermohyets for certain States for each month of the year have been plotted, the outer points being connected by inclusive lines. As this represents graphically the actual thermohyetic conditions reported by the Weather Bureau, it, of course, is not to be understood as showing the only conditions under which either the beetles or the wilt can exist, but is to be considered as an inclusive statement of the average weather conditions prevailing in the territory in which these organisms occur. It is probable that a closer approximation of the limits of habitable climate for these organisms can be obtained by regarding the individual points for each month, as lying in undetermined ellipsoids and then connecting them by curved lines, thus substituting the rotund diagrams for the irregular polygons of Figure 13. Such an arrangement, shown in Figure 14, ought to be considered a reasonably comprehensive statement of the ranges, month by month, of the thermohyetic conditions under which the cucumber beetles and cucurbit wilt can exist successfully.

As was pointed out, the geographical limits of severe wilt are by no means as extensive as the territory throughout which it and the beetles range. It is usually severe in the region in which the beetles generally have one to two broods per year, tending to be less so both to the north and the south. By arranging reports on wilt, secured from the mimeographs of the federal Plant Disease Survey and by special correspondence, into the five general classes, light, mild, destructive, moderately destructive, and severely destructive, I have found it possible to construct a hythergraph, using annual means of temperature and annual totals of rainfall for the regions and the years in which these degrees of disease were

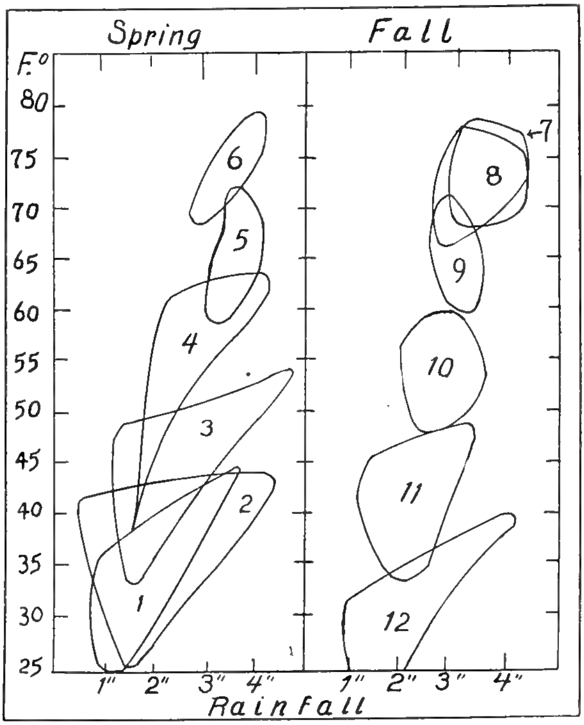

FIG. 14. Smoothed hythergraph drawn from Figure 13. The numbers indicate the months.

reported to have occurred. In the resulting graph, given in Figure 15, the outer range of thermohyetic combinations, marked *A*, includes those conditions under which the wilt occurs in light form; the thermohyetic limits bounded by the line marked *B* include regions and years characterized by mild wilt and usually 1, 3, or 4 broods of beetles per year; within the limits marked *C*, the wilt is generally destructive, and the number of broods of beetles is either 1, or 1 to 2 per year; and the line marked *D* incloses indubitable records of moderate and severe destruction. The differences in temperature and rainfall which distinguish these limits on the dry side of the graph are wide at first, but decrease as the intensity of disease attack increases; and the very slight difference between the limits *B* and *C* may be taken to indicate that at this point even very small changes in thermohyetic combinations affect very greatly the intensity of the wilt attack.

As it is possible to be more specific regarding the wilt in Illinois, I give the following generalized comparison of the destructiveness of this dis-

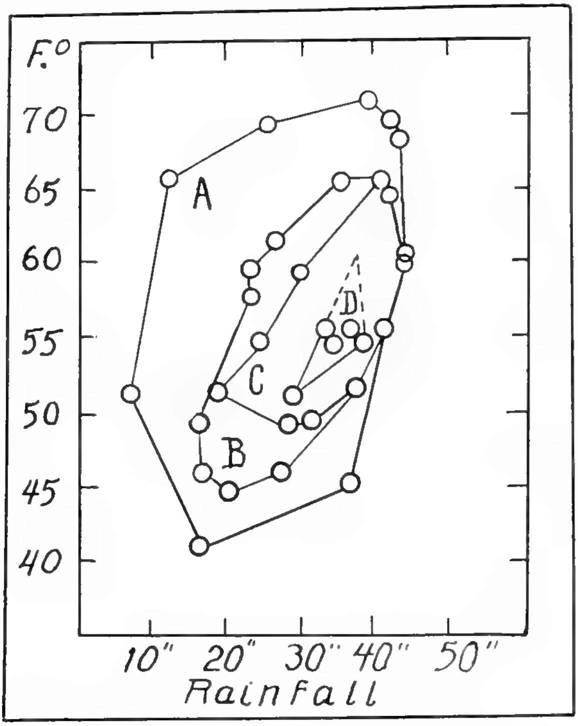

FIG. 15. Mean annual thermohyetic ranges under which various intensities of cucurbit wilt develop. In the region marked A, the wilt occurs in light form; in B, it is mild but heavier than in A; in C, usually destructive; and in D, moderately to severely destructive.

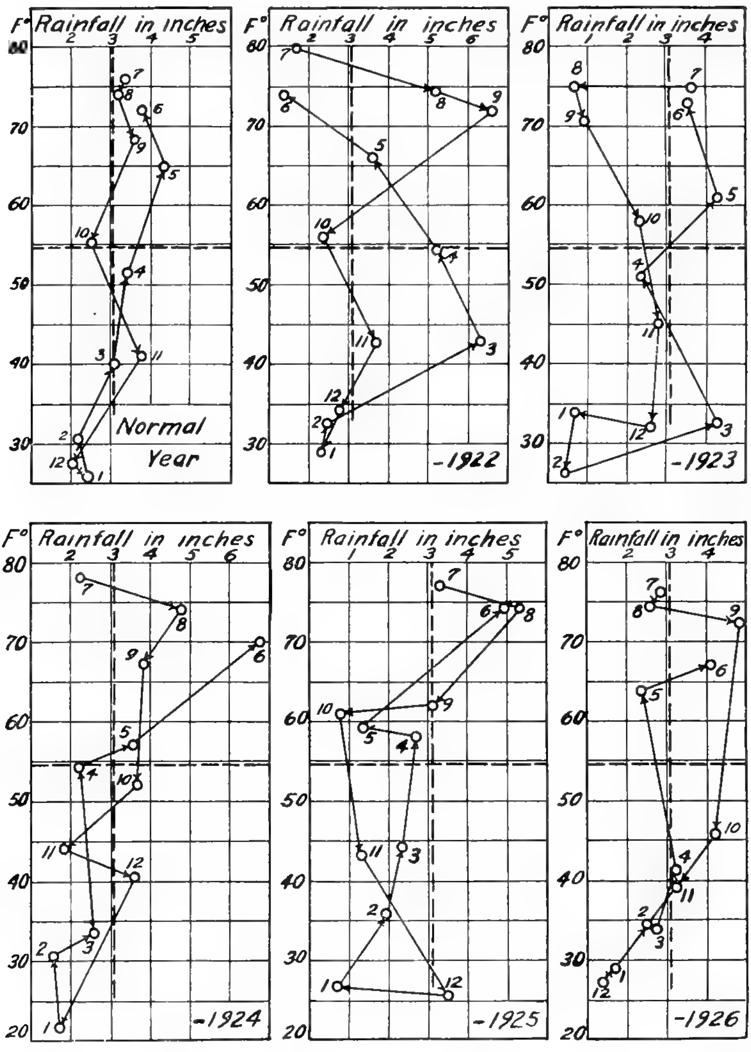

FIG. 16. Hythergraphs for Illinois, showing the monthly thermohyets for a normal year and for the years 1922-1926. The normal year falls near the 3-inch rainfall coordinate; but the year 1922, when bacterial wilt was most severe, falls near the 4-inch coordinate. The succeeding years, in which wilt was progressively less severe, fall more and more toward the dry side of the graph.

ease, as determined for the State by our field examinations, using the same terms of distinction as above.

Year	Destructiveness of Cucurbit Wilt
1922	Moderately destructive
1923	Destructive,or moderately so
1924	Mildly destructive
1925	Light to mild
1926	Light

A fairly steady decrease in abundance has occurred since 1922, the minimum being reached in 1926. This is due, in part, to a more general use of an efficient beetle control during the last three years; but as the beetles were still abundant in many untreated fields, the difference is not attributable wholly to this cause. A comparison of the normal hythergraph of Illinois and hythergraphs for the years 1922 to 1926, inclusive, these being shown in Figure 16, reveals marked differences in the thermohyetic trends of the years and in the monthly thermohyets—differences which are progressive and which correspond to the decrease in amount of disease by moving uniformly toward the dry side of the graph. The normal year, in Illinois, lies close to the ordinate marking 3 inches of rainfall. The 1921-1922 season, with destructive disease, falls roughly about the 4-inch co-ordinate, although it shows a great fluctuation from this average during most of its months. The year 1922-1923 rather closely approximates the normal, falling quite near the 3-inch line; 1923-1924 lies still farther to the dry side of the diagram, especially in the spring months; and the year 1924-1925, with the exception of the summer, lies very close to the dry side, falling practically on the 2-inch rainfall line; while the year 1925-1926, which is not greatly different from a normal year, bears out the rule.

SIGNIFICANCE OF HYTHERGRAPHS

Hythergraphs such as I have used as illustrations in the preceding pages have been employed in a number of instances* to indicate habitats and probable habitat ranges for various organisms. Originally devised by Ball in 1910, and first used by Taylor in 1916, they have been used since by Pierce in connection with insect life histories, by at least two persons to suggest the geographic ranges of insects, and by Huntington as the basis of an analysis of the relation of climate and weather to human health and progress. But none of these workers analysed the meaning of their graphs further than to draw such conclusions as were apparent upon inspection of the completed charts. It should be expected that diagrams such as these, which appear to offer exceptionally plain evidence of the dependence of organisms upon climate, and of the marked limitations placed upon organisms by variations in thermohyetic conditions, would be founded upon certain natural laws, or have such a close relation to them that sufficient study would reveal some basic facts regarding all habitats.

* See the appended bibliography.

As it is used now, the hythergraph takes two forms. As they seem to be distinct, both in their construction and in their use, so each has its own significance in interpreting biotic phenomena.

The first type, exemplified in Figure 16, shows diagrammatically the progress, from one month to another, of individual or grouped thermohyets attending any given phenomenon. Beyond the fact that it pictures conditions more simply and clearly than words, and so makes comparison easy, it has no significance.

The second type is represented especially in Figure 15. In its construction, a considerable number of thermohyets are plotted in such a way as to indicate, when they are sufficiently numerous and accompanied by good correlative data, what specific conditions govern, or are related to, the occurrence of definite phenomena. When such a diagram has been completed, it is usually true that the thermohyetic conditions productive of successive degrees of phenomenon development, such as amounts of disease, healthiness, and the like, can be defined quite exactly by connecting in series the plotted thermohyets in accordance with the correlative data. The resulting lines, called "isopracts" by Huntington, are roughly circular, elliptical, or ovoid, and usually are eccentrically arranged.

These relations may be illustrated concretely with data and a modification of a diagram which I have used in another connection (20). As the result of careful surveys of wheatfields in Illinois, numerical indexes showing the destructiveness of leaf rust (*Puccinia triticina* Erikss.) were obtained for each of five years, with the intention of determining from them what relation the yearly mean temperature and the total rainfall bore to the intensity of the rust attack. The data at hand were those given in the following table:

Year	Destructiveness index	Mean temperature of the rust years	Total rainfall of the rust years
1922	50.3	54.8	41.73
1923	31.3	53.1	32.69
1924	19.1	51.9	38.74
1925	17.1	53.0	31.15
1926	11.2	51.3	35.15

Neither by inspecting the table nor by employing the usual graphic methods can one demonstrate the relation that actually exists between the rust indexes and their accompanying thermohyets; but it can be demonstrated by the hythergraphic method with the diagram given in Figure 17. In constructing this diagram, a preliminary graph was made, upon which were plotted the thermohyets for each index of the rust; and, as these seemed to fall into two well-defined series, the trend of each series was marked by a dotted line. The relative values of the temperature and rainfall scales were then adjusted by the simple expedient of redrawing the dotted lines at 45° angles to the axes and then locating on them the points on the old lines by swinging intersecting arcs with a compass. The result was such as to indicate that a difference of 1° of mean annual temperature would equal, in its effect, an approximate difference of 5 inches in total annual rainfall.*

Having thus located the trend lines, and having replotted the thermohyets accurately, as they are shown in Figure 17, I could readily see that the trend lines lay one on each side of the line of perfect correlation. But neither in the data nor in the graph is there any indication of the probable location of this line or of the line of absolute non-correlation. It seemed to me reasonable to suppose, however, that, as Illinois appeared to be fairly representative of the rust's habitat, these lines ought to have some rather close relation to the normal thermohyet for that State; and this thermohyet, therefore, I plotted at the intersection of the normal mean annual temperature line of 52° and the normal total annual rainfall line of 36.42 inches. Through the point thus located, I drew tentative lines of correlation and non-correlation; and, by good fortune, I found the

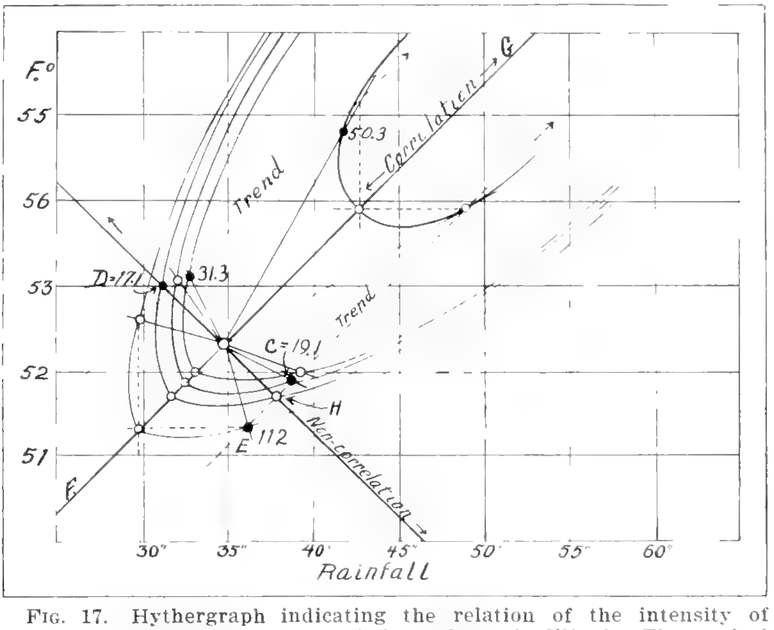

FIG. 17. Hythergraph indicating the relation of the intensity of wheat leaf rust attacks to annual thermohyets in Illinois. The method used in constructing this graph is described in the text.

* It appears from a hythergraph given by Griffith Taylor on page 271 of his "Environment and Race" (Oxford University Press. 1927), that *survival* of infants in Australia—the converse of increase in prevalence and fatality of infant diseases—increases as both temperature and rainfall decrease but Taylor has not determined the relative effects of the two elements.

latter passing so near the point *D,* which had a predetermined rust index of 17.1, and cutting the lower trend line at *H*—which appeared upon inspection to lie very close to the point where, between *E* and *C* (which had determined indexes of 11.2 and 19.1, respectively) one would expect to find an index of 17.1—that I took this to indicate with fair certainty: first, that my hypothetical line of non-correlation lay so close to the real line as to serve the same purpose; and, secondly, that the line of true correlation must consequently be situated parallel to the two trend lines and very nearly midway between them. I, therefore, replaced the tentative correlation line, which at first I had drawn through the normal Illinois thermohyet, with another (*F-G* in the figure) and proceeded to locate all given rust indexes not only on the trend lines but also on the correlation line in accordance with the following reasoning.

It seemed clear to me, in view of certain other data I had at hand, that the rust fungus might very well be regarded as having physiological properties similar to those long since proved for other organisms and that if I followed, deductively, for my organism the same steps as had been traversed experimentally for others, I ought to arrive at a tenable, though necessarily quite general, hypothesis of thermohyetic relations. I considered, therefore, that if a complete correlation between increasing temperature and increasing rainfall, singly or in combination, and disease increase were assumed to exist throughout all ranges of temperature and rainfall, the graphic expression of such a condition would be a straight diagonal line of the general formula $y=kx$, when y represented increase in disease and x increase in either temperature or rainfall or both. With this assumed, it is apparent that all the various combinations of temperature and rainfall capable, when acting together, or producing a given amount of disease would be shown by a rectangular hyperbola of the general formula $xy=k^2$.

Of course, it has been determined experimentally many times and for a great diversity of organisms that, though appearing to be true within a limited range of conditions, no such fine regularity as the above exists. Instead, we have come to expect in place of the straight diagonal, a curve which rises slowly at first, then rapidly and quite regularly through most of its length, until it reaches an optimun and thereafter falls precipitately to a maximum. Such a curve often has no definite formula, though its type is usually indicated as $y=f(x)$. The rapidly rising portion of this curve, though approximating the straight-line diagonal, never conforms to it completely; for there is continual readjustment throughout its length to the increasing, decreasing, and inhibiting effects of the changing environmental factor. Consequently, the curve for a constant amount of disease, when plotted with temperature and rainfall as the axes, can not be a rectangular hyperbola; for, when the amount either of temperature or of rainfall becomes inhibitive, that effect must be counterbalanced by the addition, upon the curve, of an increasing effect from the other; and the curve, though approaching the hyperbola in its mid-region, is made, toward its extremities, to swing away from the axis. The result is an ellipse of the type to which the general formula $ax^2 + by^2 + cxy + dx + ey + f = o$ usually applies.

Returning then, to my rust problem, I was confident that all the points denoting any given amount of rust attack ought to lie in an isopract of an elliptical or ovoid shape, the long axis of which would be the line of perfect correlation; and, having demonstrated the position of this line as midway between the trend lines, I saw that for every themohyet of known rust value I could determine geometrically two other thermohyets having, hypothetically, the same rust value, one upon the opposing trend line and one upon the correlation line, for I could measure by running a line from a thermohyet of known value to the junction of the correlation axis, an angle which would determine the position of another line drawn from this junction to cross the other trend line at a point geometrically equivalent to the first and, with two such points located, I could determine their equivalent upon the correlation line by marking the point where it and their respective temperature and rainfall values coincided. By this means, I was able to increase my original five points of data to fifteen, having three points to denote the location of the isopract for each of five known rust indexes, and, after drawing a large series of partial ellipses through each of these five sets, I selected from each series the one which in conjunction with all the others, seemed most apt to fulfill the conditions imposed.

It is not to be supposed that I considered these isopracts, so hypothetically constructed, as by any means proved; yet the verisimilitude between the chart thus developed and the hythergraphs so readily obtained with more abundant but less accurate data, together with the fact that all the requirements of natural processes appeared to have been satisfied, led me to believe that I had obtained a clear, though general, picture of the relation of rust to annual thermohyetic conditions and that I had, at the same time, shown why hythergraphs similar to Figure 15 do indicate so clearly the limitations imposed by climatic conditions upon the occurrence and distribution of organisms and the influences of fluctuations in weather upon the success of an organism in a given region.

The ellipses, or isopracts, of an hythergraph, since they usually mark measured degrees in the manifestation of some natural phenomenon, are comparable to the contour lines used by physiographers to show differences in altitude on plane-surface maps. Indeed, to carry the physiographic comparison still farther, the hythergraph may be regarded as a representation, in a single plane, of three of the factors which enter into the composition of a natural phenomenon; for the flat surface has width and length, and the isopracts show height. Though two distinct elements, temperature and rainfall, are shown by the flat surface, their reative values, with respect to the third dimension and to each other, can be determined readily by means of correlation charts and graphs, and the two scales can be arranged in units of equal value; that is, with a series of increases in one element there must be corresponding increases in the other, and a plotting of points resulting from these increases should determine a line lying at an angle of exactly 45° from either the abscissa or the ordinate.*

Because they are considered to have a definite relation to the adjusted factors denoting width and length, the isopracts should be smooth in outline and regular in shape; but in practice they often are not so—a fact for which the explanation may be advanced that, as there are other elements, such as sunlight, wind, and the like, acting also, their influence will be shown in the isopracts in much the same manner as the action of wind and water as erosive agents appears in contour lines.

This conception of the inter-relation of the weather elements and natural phenomena as a 3-dimensional subject seems to me to be so important, not only as a basis for understanding and interpreting the effects of weather and climate upon the distribution and abundance of organisms but also as a fundamental law bearing directly upon the results of precise laboratory experimentation, that I have ventured to embody it concretely in the perspective drawing shown as Figure 18. The data from which this figure is formed are the same as those used for Figure 15, except that, in place of the rather generalized terms previously used, I have substituted concrete limits to the amount of disease, designating somewhat arbitrarily the circle A of Figure 15 as having 5 per cent diseased plants; circle B, 20 per cent; circle C, 35 per cent; and circle D, 50 per cent—thereby providing for every point shown on Figure 15 a datum of 3 items, one of temperature, one of rainfall, and one of disease abundance, by means of which four planes of the cone in Figure 18 were very easily located. The outlines of the cone and the smoothed circumferences of the four planes are, of course, drawn entirely by inference; but it seems to me from this figure that the relating of a natural phenomenon, in all its degrees of manifestation, to any two outstanding factors of environment involves measurements expressible, as a whole, in a three-dimension diagram, the resulting object being conic in form.

One characteristic of this cone appears to have a rather important significance when results obtained by experimentation, under controlled conditions, upon the reaction of an organism to an environmental factor are made the basis for predicting any event in nature. The cone is not symmetrical. In profile, it has upon one side an extensive base, which rises slowly, at first almost imperceptibly, from the plain; as the altitude increases, the gradient of the slope also increases, until the peak rounds it off; and, on the other side, the downward slope falls away very steeply and merges abruptly into the plain. The shape of this profile is similar in all respects to the characteristic curve of response that is secured experimentally when one factor is held constant and the other is varied: indeed, from its shape and composition, it seems apparent that the cone, if cut into an infinite number of longisections, would furnish exactly the same set of curves as would be secured from an equal series of experiments.

* The proof of this statement would require a recapitulation of a considerable part of the mathematical theory relating to the standardization of measurements, which, though simple, lies outside the scope of this paper and therefore is not given in detail.

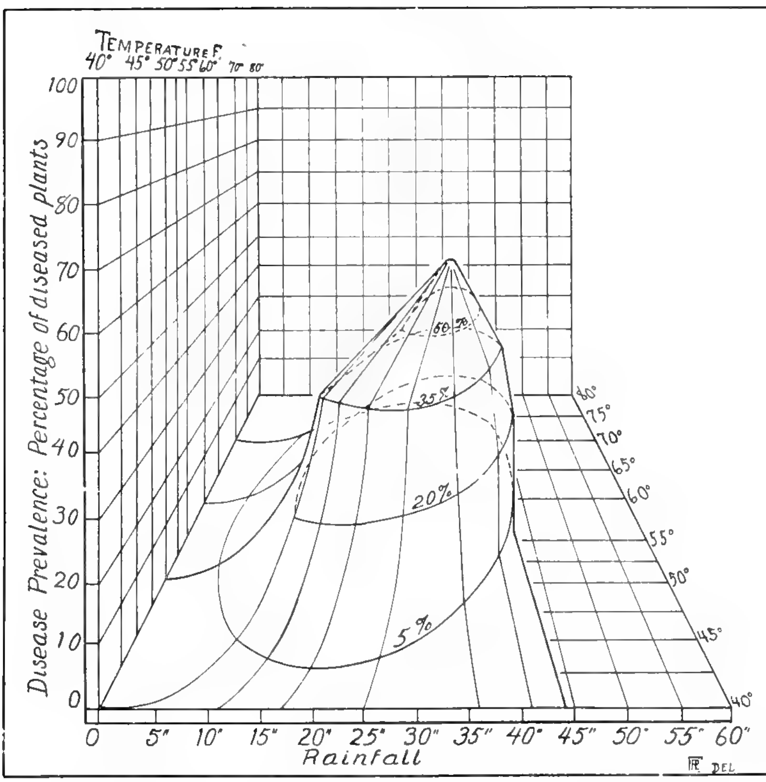

FIG. 18. Three-dimensional graph indicating the interrelation of annual mean temperatures, totals of annual rainfall, and the severity of disease attack. This is a reconstruction of Figure 15.

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* Citations given here but not mentioned in the text are included in order to furnish suggestive source references to readers interested in weather diagrams.

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AN ACCOUNT OF CHANGES IN THE EARTHWORM FAUNA OF ILLINOIS AND A DESCRIPTION OF ONE NEW SPECIES*

Frank Smith

The contents of this paper include additions to the list of species previously recorded from Illinois and also furnish evidence of obvious changes in the earthworm fauna of one locality which are probably similar to changes taking place in other parts of the state. The tendency is towards an increasing domination of European species and a corresponding decrease in the abundance of some indigenous forms. There are various records of similar modifications of the earthworm fauna in other parts of the world in which Europeans have settled and in which the European species of LUMBRICIDAE have to a greater or less extent replaced the indigenous species.

Recent additions to the former lists of European species found in the state include *Helodrilus venetus hortensis* (Michaelsen), *H. chloroticus* (Savigny), *H. octaedrus* (Savigny), and *Lumbricus rubellus* Hoffmeister. Additions to the list of indigenous species include *Helodrilus beddardi* (Michaelsen) and *H. heimburgeri* n. sp.

During a period of over 30 years (1893-1927) the writer has been interested in Illinois earthworms and their distribution, partly because of their utilization in some of his instructional work and partly because of using them as objects of research leading to the publication of several papers on the subject. In connection with these activities numerous collecting and observation trips have been made in the vicinity of the University of Illinois in order to obtain specimens of the various kinds represented and, incidentally, to learn something of their relative numbers and the kinds of situations in which representatives of the various species are most abundant. A comparison of the results of such trips made in earlier years of that period and those near its close shows that some marked changes have occurred. Some kinds found infrequently or not at all in the earlier years have become abundant in some areas in which there has been a corresponding decrease in other species. Increasing irregularities of distribution have been apparent which are presumably due to increased numbers of introduced forms which have not as yet had time to become abundant except in restricted areas.

* Contributions from the Zoological Laboratory of the University of Illinois, No. 322.

UPLAND-SOIL SPECIES

The collecting and observation trips which involved ordinary upland-soil species have mostly been made immediately after rainfalls when large numbers of individuals of some species were crawling about on the surface or were sheltered under debris of various kinds and especially likely to be found on the sidewalks and along the curbing of paved streets. Actual digging for such forms has been restricted to small areas. The lack in the earlier years of a knowledge of the changes in the fauna which were to take place resulted in a failure to make records of dates and of many numerical data which, if available, would have been very useful in the preparation of the present paper.

The three species of LUMBRICIDAE listed under other names by Garman (1888) as frequent or abundant in Champaign, Illinois, were *Helodrilus foetidus* (Savigny), *H. roseus* (Savigny) and *H. caliginosus trapezoides* (Dugès). They were found in similar abundance throughout the whole period of 1893-1927. *Octolasium lacteum* (Örley) was also of frequent occurrence throughout the same period, though not listed by Garman. *H. longicinctus* Smith and Gittins (1915) was found in limited numbers in a woodland of the vicinity of Urbana in 1901 and in considerable numbers in parkings and lawns of the city itself in 1910-1915, but has not been noticed since the latter date. The most interesting feature in the relations of the earthworms of the upland-soil localities that received attention, centered in the relations between *Diplocardia communis* Garman (1888) and *Lumbricus terrestris* Linnaeus, Müller. Garman's description of the former species was based on material from the Champaign-Urbana region, and he states: "Hundreds were seen this spring in this locality, migrating during showers of rain." The same statement has been equally applicable to this species during the period 1893-1927, with the exceptions noted in certain following statements.

The actual time of the first arrival of *Lumbricus terrestris* in Illinois is very uncertain. Garman (1888) and Michaelsen (1900) in their lists of North American OLIGOCHAETA refer to Eisen's (1874) record of its occurrence in "New England" but have no record farther west. The Mount Lebanon, New England, of Eisen's record was actually in the eastern part of New York. The first definite record for Illinois is that of the writer published in 1900 and based on specimens found still earlier. The exact date is not known, but it was certainly before 1898 and probably about 1896 that a few specimens were seen by the writer in a restricted locality in Champaign, crawling about during a rain storm. About the same date a workman engaged in digging a trench in an artificially forested area on the University campus (locally known as the Arboretum) found and gave to the writer a few specimens. These were the basis for the record mentioned above. During this period and for several years subsequently, it was necessary to send to dealers elsewhere for specimens needed for class work. Then came a time, not far from 1905, when specimens were sufficiently abundant in the Arboretum to meet some of the needs for material, but they had not spread in any appreciable numbers to other areas. Subsequently, the area within a few blocks of the campus became abundantly stocked with them, while specimens of *Diplocardia communis* became correspondingly infrequent.

In the forenoon of March 19, 1927, following a rainy night, the writer traveled along the streets bordering an area of about one-half mile square adjacent to the east side of the campus in Urbana and found *Lumbricus terrestris* abundant in the streets bordering all of the 24 city blocks involved, while the total number of specimens of *Diplocardia communis* seen was but 19, or an average of less than one per block—a marked contrast to conditions existing in the same region in earlier times when *D. communis* was abundant throughout and *L. terrestris* was rarely seen. A trip on the following day through the area lying still farther east resulted in finding that *D. communis* was still abundant in a good deal of the territory covered and that *L. terrestris* was abundant in only a few detached areas. No noticeable difference was found in the relative numbers of smaller introduced European forms, such as *Octolasium lacteum*, *Helodrilus roseus* and *H. caliginosus trapezoides*, which were still abundant in both of the localities examined. The area in Champaign into which *L. terrestris* has extended its distribution has also greatly increased in recent years.

WOODLAND SPECIES

No observations have been made which would provide information concerning changes in relative abundance of the species that are more commonly represented in decaying tree trunks, under logs, and in masses of decaying leaves. *Helodrilus gieseleri hempeli* Smith (1915), *H. zeteki* Smith and Gittins (1915), and *H. tenuis* (Eisen) (1874) are such forms, and the writer is unaware of any notable changes having taken place during the past 30 years in their relative numbers, or of the appearance in such locations in recent years of introduced forms not previously found there.

STREAM-BANK SPECIES

The stream which has been most easily accessible and from which most of the collections of stream-bank species have been obtained, is locally known as the Boneyard Branch of Salt Fork. It is a small stream, but a few yards wide, which originates a short distance north of Champaign and flows south through the northern part of that city and then east through the eastern part and through the city of Urbana, which lies adjacent, and then joins the Salt Fork in the outskirts of the latter city. Its course extends across the University campus in the western part of Urbana. During the period 1893-1927 there have been extensive changes in the character of the water content and hence in the fauna contained. Increasing sewage contamination, due to increasing population and inadequate sewage disposal equipment in the two cities, of which it furnished the principal drainage outlet, gradually led to the elimination of all of its fauna except that which could exist under conditions similar to those of an open sewer. The earthworm fauna of the banks has necessarily been influenced by these changes. Such conditions reached a maximum at about the time (1922-1923) that J. L. Hyatt, a graduate assistant, made an extensive series of collections of the earthworms inhabiting the soil in the banks of the stream in various parts of its course. Since that time the installation of a more adequate sewerage system and of a modern and efficient sewage-disposal plant has greatly altered the conditions, and resulting changes in the fauna are already in progress. During the time of Mr. Hyatt's collecting activities there was great diversity in the degree of sewage contamination in different parts of the course of the stream. In the part lying north of Champaign and in the northern outskirts there was but little. In progressing down stream an observer would find contamination from the few factories, the streets, and other sources becoming more and more evident, and the waters were already laden with foul material before the eastern limits of Champaign were reached. Still further additions were made in its course through the University campus and Urbana.

A study of the earthworms collected from the banks of the stream in various locations showed correlated changes in the relative abundance of the representatives of the different species of earthworms. Certain indigenous species and most of the species common in the upland-soil regions were found in much greater numbers in the places of least contamination, and certain other introduced species reached their maximum abundance where contamination was very pronounced. Most of the common upland species were represented in at least small numbers, and in addition about a half-dozen other species were represented which have not been found in the upland-soil locations. A very decided lack of uniformity was found in collections made from different localities even when the conditions and degrees of contamination seemed similar. Some species had a rather limited area of distribution, indicating a relatively recent introduction into the region.

The specimens collected were obtained by digging them from the soil of the banks of the stream, and they were then taken to the laboratory and fixed in a well-extended condition. The specimens were all preserved for the sake of greater certainty in identification and also with a view to their use in other ways, including a search for abnormal specimens, of which a considerable number were found. Collections were made from 11 different locations, distributed along some four miles of the course of the stream, from the northern outskirts of Champaign to its junction with Salt Fork east of Urbana. Five of these locations were in Champaign and six in Urbana. For convenience they will be designated by the letters *A* to *K*, which will be applied to the locations in the order of their occurrence along the stream, beginning with the one nearest the source in the northern Champaign region. The number of collections in each location varied from one at *A* to twelve at *F*, but in most of them three or more collections were made from each, and the times of making the collections were distributed over parts of two years, 1922 and 1923. Unfortunately, no similar extensive series of collections had been made in earlier years; hence, definite comparisons of the fauna with that of earlier years could not be made, with the exception of locations *F* and *G*, where collections had been made at various times in preceding years.

One surprising result of a study of the collections by Mr. Hyatt was the discovery of the presence of a considerable number of specimens of *Helodrilus venetus hortensis*, a European species which had been previously recorded from North America only from California (Michaelsen, 1900). Thirty-one specimens were collected at one spot in location *F* on April 15, 1922, and a few had been found in neighboring locations in the preceding month. Still larger numbers were collected at location *G* in 1923. Since Mr. Hyatt had made collections at these two localities in 1921, and the writer also at various times in preceding years had made collections in the same places without finding any representatives of this species, it seems reasonable to assume that a recent introduction into this region has occurred.

Another unexpected result was the finding of large numbers of the species *H. chloroticus*. A single specimen had been found by Mr. Hyatt in October, 1921, which was the first record from the Boneyard Branch. It probably was taken at location *F* or *G*, where only eight specimens were found in the 16 collections made in 1922 and 1923. I know of no record of careful collections prior to 1921 from the banks of the stream at location *H* and below, where Mr. Hyatt found several hundred specimens of *H. chloroticus;* hence, the supposition of a relatively recent introduction of this species has less supporting evidence. The only record of the species being found in Illinois prior to 1921, which is known to the writer, is that of a dead specimen found September 12, 1918, by F. C. Baker while hunting mollusks in a shallow place in the Salt Folk about nine miles east of Urbana. The waters of the stream where the specimen was found were carrying much sewage contamination received from the Boneyard Branch at Urbana. An examination by the writer of the shores at a few points up stream from the place where the specimen was found, failed to disclose the presence of other specimens.

Another species of which specimens were found to be most abundant in badly contaminated localities is *H. subrubicundus* (Eisen). It has been abundantly represented since 1911 but was not found during the first few years of the period beginning with 1893.

The accompanying table shows the numbers and distribution of the specimens of the Hyatt collections and requires but little explanation. Locations *A*, *B*, and *C* were those which were most free from sewage contamination. The first vertical column of figures gives the total number of collections made at each of the locations, the next one shows the total number of specimens from each location, and the following columns show the total numbers of specimens of each of the species as found at each of the stations. The lower part of the table contains footings showing the total numbers of specimens of each of the species represented.

In addition to these collections which were all from the banks of one stream, other collections were made in rivulets or ditches tributary to the stream, or in adjacent fields. The more pertinent features of a few of these will be mentioned. In a field near location *A* a collection of 80 specimens included 77 *Helodrilus roseus,* one *Octolasium lacteum* and two *Diplocardia communis.* A collection of 367 specimens from near the margins of a ditch near location *C* contained 350 *D. singularis* (Ude), the others being common upland species. A collection of 209 specimens from a small tributary stream near location *D* had 18 *Helodrilus tetraedrus* (Savigny), two of the variety *H. t. hercynius* (Michaelsen), three of *H. tenuis,* and the others were common upland species. A collection of 21 specimens from the margin of Salt Fork above the entrance of Boneyard Branch, and where there was no sewage contamination, had 11 *Sparganophilus eiseni* Smith (1895), 8 *Helodrilus tetraedrus,* and two *H. caliginosus trapezoides.* *Sparganophilus eiseni* is widely distributed in the North Central States east of the Mississippi River and is abundant in the mud of the bottom and margins of many of their rivers and lakes, but does not appear to thrive in waters badly contaminated by sewage.

TABLE I

DISTRIBUTION OF BONEYARD BRANCH SPECIES OF EARTHWORMS

Locations	Collections	Total numbers, each location	*H. tetraedrus typ.*	*H. t. hercynius*	*H. venetus hortensis*	*H. foetidus*	*H. roseus*	*H. cal. trapezoides*	*H. chloroticus*	*H. subrubicundus*	*O. lacteum*	*L. terrestris*	*D. communis*	*D. singularis*
A	(1)	58	1				43	14						
B	(6)	830	666	22			45	63		6	28			
C	(3)	216	52					56		14	1	2		91
D	(3)	246	8	2	11	77		104	3	36		5		
E	(2)	161			31	9		84		29		8		
F	(12)	782	106	54	79	11	7	448	5	48	1	23		
G	(4)	917	4	4	204	36	4	402	3	248	2	10		
H	(2)	61	5		1	6		10	32	7				
I	(7)	1276	17	6	6	17	1	235	475	500	2	15		2
J	(3)	388	41	13		26	4	106	80	112		3	2	1
K	(3)	219	65	13		30	18	50	20	23				
Totals		5154	965	114	332	212	122	1572	618	1023	34	66	2	94

ADDITIONS TO THE LIST OF ILLINOIS EARTHWORMS

Helodrilus beddardi was not reported in the writer's list of Illinois species in 1915, but in a later paper (1917) dealing with the distribution of North American LUMBRICIDAE, Illinois was included among the "new localities" in the account of that species. The specimens on which the record was based had been collected in October, 1910, by Dr. P. S. Welch, then a graduate student, who found them in a field north of Urbana. They were not carefully studied until 1916. Several specimens have more recently been collected near Muncie, 20 miles east of Urbana. In both of these localities the specimens were found in damp places near standing water in pastures. The finding of *H. venetus hortensis* and *H. chloroticus* in Illinois was mentioned in a paper by the writer (1924) dealing with the calciferous glands of LUMBRICIDAE. Dr. Libbie Hyman of the University of Chicago collected specimens of *H. chloroticus* at Fox River Grove, Illinois, May 8, 1926.

Helodrilus octaedrus has recently been found in two different Illinois localities. In November, 1925, S. L. Neave, a chemist of the State Water Survey, found several specimens in a very restricted area near the new sewage-disposal plant in the outskirts of Urbana; and in November, 1926, J. F. Müller, a research assistant, found specimens at Starved Rock, Illinois, in moss in crevices of the rock and crawling about on stems of vegetation. *Lumbricus rubellus* was represented in a collection at LaSalle, Illinois, in the autumn of 1925, made by Dr. R. E. Greenfield of the Department of Chemistry at that time, who found them under debris on the banks of the Illinois River.

One specimen of a new form, together with specimens of other species, was collected by H. V. Heimburger, April 16, 1914, from the banks of a small stream flowing into the Sangamon River a few miles below White Heath, Illinois. The writer had sagittal sections made from one half of the anterior 17 somites, which showed that the specimen in some important characters resembles *H. palustris* Moore (1895). The specimen and sections were turned over to Mr. Heimburger, then a graduates student at the University of Illinois, and were part of the material used by him in the preparation of a thesis as a part of the requirements for a degree (A. M.). After an interval of several years the sections have been returned to the writer for examination and use in the description of the species, but the unsectioned part has not been available for study.

Helodrilus heimburgeri n. sp.

Length, 7.7 cm. Diameter, 0.25-0.3 cm. Color, very little pigmentation. Somites, 112. Setae, closely paired. Prostomium, epilobic. Clitellum, 25-32 and encroaching slightly on 33. First dorsal pore on 5/6. Male pores, paired on posterior part of 15, between seta lines *b* and *c*; surrounded by prominent glandular elevations. Oviducal pores, on 14 slightly dorsad of *b*. Septa 11/12, 12/13, and 13/14 somewhat and progressively thickened, the latter about two or three times as thick as septa anterior to 11. The calciferous gland has inconspicuous lateral pouches in 10; has no conspicuous enlargements in 11 and 12; longitudinal chambers not much over 40 in number. Hearts, paired in 7-11. Spermaries, paired in 10 and 11. A pair of large chambers or atria in posterior part of 15, with large gland masses extending into 15 and 16, the latter one being smaller; sperm ducts extend dorsad on the anterior walls of atrial chambers and open into them at their summits. Sperm sacs, two pairs, in 11 and 12. Ovaries, paired in 13. Spermathecae lacking. Ovisacs, paired in 14 and open into the cavity of somite 13.

One specimen, collected near White Heath, Illinois, by H. V. Heimburger.

Holotype.—Sections of a part of the specimen in the collection of the writer.

But little attention was given by the writer to the external characters of the specimen when it was available, but a memorandum was made of the location of the clitellum. For certain other features the data of Mr. Heimburger have been utilized. The seemingly close relationship to the species described in 1895 by Dr. H. F. Moore under the genus name *Bimastos*, which species until the present time has been unique among the LUMBRICIDAE in the characters of the distal parts of the sperm ducts, has added to the interest felt in making a study of the new form. A comparative study has been facilitated by the use of three series of sections of *H. palustris* made from specimens kindly sent to the writer by Dr. Moore several years ago.

EXTERNAL CHARACTERS

Rather small in size and also similar to *H. palustris* in having a moderate number of somites, closely paired setae, and conspicuous glandular enlargements on 15, surrounding the external orifices of the spermiducal apparatus. The specimen was seemingly not in a state of sexual activity at the time of fixation, but apparently had passed through such a state previously and the gonads were of diminished size. The location of the clitellum on 25-32 very definitely distinguishes the new species from *H. palustris* in which the clitellum is on 23-28. The clitellum was stated by Mr. Heimburger to be nearly complete and to include the ventral setae. He also stated that no trace of tubercula pubertatis was found.

The two species show marked similarity in the locations of the first dorsal pores; the external openings of the spermiducal organs on the posterior part of 15 and a little dorsad of seta line *b;* the oviducal pores on 14 slightly dorsad and posteriad of *b;* and of the nephridiopores, in the anterior part of the somites with some of them opening a little dorsad of seta line *b,* and others approximately midway between seta line *d* and the mid-dorsal line. Moore in his description of the nephridia of *H palustris* states: "The external opening is near the ventral couple of setae." An examination of the sections from three of his specimens reveals a variability in the positions of the openings similar to that of the new species. Like variability has been noted by certain other writers and myself in the location of these pores in other species of LUMBRICIDAE. (Langdon, 1895, p. 215) (Smith, 1915 and 1925)

INTERNAL CHARACTERS

The septa connecting the alimentary tract with the body wall are mostly without much thickening. Septa 11/12, 12/13, and 13/14 are somewhat thickened with the thickness gradually increasing from anterior to posterior; 13/14 being most thickened, but not very strongly. *H. palustris* differs in having none of the septa with increased thickness. The deeply staining glandular bodies attached to the wall of the pharynx and anterior esophagus in somites 4-6 in *H. palustris* are represented in only 4 and 5 in the new species; the space in 6 being largely filled by a mass of cells of different type and but lightly stained. The calciferous gland is similar to that of *H. palustris* (Smith, 1924) with approximately uniform diameter in 10-12, with paired esophageal pouches in 10, and but few more than 40 longitudinal chambers posterior to 10. Communications of the chambers of the gland with the pouches in 10 were found in both species and none were found elsewhere. No especial differences have been noticed between the two species in the location and relations of the crop and gizzard, respectively, the former in 15 and 16 and the latter in 17 and 18.

Circulatory system.—This has not been studied in detail otherwise than to determine the relations of the hearts and lateral-longitudinal vessels to the other vessels of the vascular system and to the calciferous gland. Five pairs of hearts are present in 7-11 and have the usual relations to the dorsal and ventral vessels. The hearts of 11 are similar in size to the others. An examination of the three series of sections of *H. palustris* resulted in finding similar conditions in them except that in two of them the hearts of 11 were much smaller than the others. In no instance was there any indication of any of the hearts passing into the wall of the alimentary tract in a part of their course, as described by Moore (1895, p. 489) in some of the specimens examined by him. The lateral-longitudinal vessel of one side of the specimen of the new species, which was included in the sections studied, extends through the space between the anterior pairs of hearts and the esophageal wall to the posterior part of 9, and then dorsad and mesad along the anterior surface of septum 9/10 until near the dorsal side of the esophagus where with a turn posteriad it extends through the septum and presumably joins the dorsal vessel about midway of the length of somite 10. Since the sections do not include much of the dorsal vessel and the last ones are imperfect, a more positive statement cannot be made. In his description of *H. palustris*, Moore states: "A pair of esophageal vessels arise from the sub-intestinal trunk in somite X and pass laterally forward to supply the tissues surrounding the anterior portion of the alimentary canal." Elsewhere on the same page he says, "The vascular system has not been investigated, except in a very general way." The writer has not found among the LUMBRICIDAE studied by him any species in which the lateral-longitudinal vessels arise from the ventral vessel, and but few in which they do not have their posterior union with the dorsal vessel in 12. The three series of sections of *H. palustris* available for comparison include a transverse, a sagittal, and a frontal series. All of them have been utilized but have not always been equally helpful for each particular problem. In all three specimens the course of the lateral-longitudinal vessels has been similar to that found in the new species. They extend to the posterior part of 9, then dorsad and mesad anterior to septum 9/10, then through the septum into 10, where they join the dorsal vessel. The junction with the dorsal vessel is clearly shown in two of the series and nearly as certainly in the third one.

Reproductive organs.—There is marked similarity between the two species in respect to the reproductive organs. There is agreement in the number and location of the gonads in 10, 11, and 13, and of the sperm sacs in 11 and 12. Spermathecae are lacking in both. No essential differences have been noted in the characteristics of the oviducal organs. The characteristics of the spermiducal organs are of especial importance in determining the relationship of this species to others, and it would be highly desirable to have specimens more nearly at the height of sexual activity than is the only one of the new species now available. In this specimen the maximum height of the atrial chamber including the thick glandular wall, as seen in sagittal sections, is but little more than half of the dorso-ventral diameter of the worm. The apex of the atrial cavity, which is the place where the slender cylindrical lumen of the sperm duct opens into that cavity, is about one-third of the diameter of the worm from the ventral margin, as seen in section. In the specimens of *H. palustris* the chamber and cavity are more nearly cylindrical and extend nearly to the dorsal wall of the body cavity. In the new species, as in the other, the course of the sperm duct after reaching somite 15 is dorsad along the anterior wall of the chamber, going deeper and deeper into the glandular wall tissue, until finally reaching the uppermost part of the chamber, or atrial cavity, where the lumen of the duct is continuous with the cavity. No modified setae with related glands in 13 and 16 comparable with those of *H. palustris* have been found in the new form, but perhaps such setae may be present at the time of sexual activity. Large masses of gland cells associated with the wall of the atrial chamber and extending into the body cavities of 15 and 16 are present in the new species and resemble those of *H. palustris* in general appearance, but no careful study of their histological characters has been made. Nothing is known concerning the presence or absence of spermatophores in the new species at the time of sexual activity.

Moore created the genus *Bimastos* for the species *palustris,* in part because of the striking difference from other LUMBRICIDAE in the character of the terminal organs of the spermiducal apparatus, to which he applied the terms prostates and atrial chambers. Later writers have used the name with corrected spelling (Bimastus) as a name for a sub-genus to include Moore's species and others that resemble it in having no spermathecae and regardless of the presence or absence of atrial chambers. To the writer, the existence of this latter character in two species that are also closely related in other ways seems to be a sufficient basis for the restriction of the use of the name Bimastus to these two species and others that may later be discovered having similar characteristics including the paired atrial chambers. There may perhaps be as much justification for recognizing a genus Bimastus as there is for the genus Octolasium. If more were known about the details of the relations of the lateral-longitudinal blood vessels in the various species of LUMBRICIDAE, it might aid in the determination of a more correct classification. The similarity between *H. palustris* and the new species in the course of the lateral-longitudinal vessels seems to be a matter of considerable significance. The only other species in which the writer has found a similar course in these vessels is *H. octaedrus* (Savigny), but in this species there are several important characters in which it differs materially from the Bimastus group.

The lateral-longitudinal vessels of the three last-named species seem noticeably smaller and less conspicuous than those of other species in which these vessels join the dorsal vessel in 12.

DISTINGUISHING CHARACTERS OF ILLINOIS SPECIES

A list of species, together with statements of the important characters which serve as the basis for determining their systematic relationships, can be presented in a convenient and compact manner in tabular form (Table II), as was done in an earlier paper on the species of the State (Smith, 1915). Before presenting this list, reasons will be given for changes in the statements of some of the characters of certain species from those given in the former list or from those commonly found in the literature dealing with such species.

In the former paper the sperm sacs of *H. tetraedrus* and of its variety *hercynius* were listed as being contained in somites 9-12, in conformity with statements commonly made by writers on the group. Since the majority of the specimens examined by the writer lack sperm sacs in 10, though small ones are present in that somite in occasional specimens, they are listed as in 9, 11, 12. A change has also been made in the location given for the spermathecal pores of the same forms. Instead of 8/9 and 9/10 as stated by earlier writers and in the former paper, the location of these pores in most specimens has been found by the writer to be in 9/10 and 10/11, and this location has also been found by Cognetti (1905) to be the normal one in European specimens (Smith, 1917, p. 162).

Specimens apparently related to *H. tetraedrus*, but having spermiducal pores on other somites than 13 or 15, have been found by investigators in Europe, and certain species, varieties, or forma have been named on the basis of such specimens. *Tetragonurus pupa* Eisen with spermiducal pores on 12 was described from specimens collected in North America near Niagara Falls, and one specimen considered by Eisen as the type and presented to the United States National Museum was later studied by the writer and found to be in all probability an abnormal representative of *H. t. hercynius* (Smith 1917, p. 163). Many abnormal specimens belonging to several different species were found by Mr. Hyatt in his collections from the banks of the Boneyard Branch, and among

TABLE II
KEY TO THE ILLINOIS EARTHWORMS

Clitellum	Tubercula pubertatis	Prost. pores	Sp'd. pores	Spermathecal pores	Setae	Sperm sacs	Last hearts	Somites	Length cm.	Species
13-18 sad.		18, 20	19	7/8, 8/9	wide	9, 12	13	136-157	20-25	*Diplocardia riparia* Smith
13-18 sad.		18, 20	19	6/7-8/9	wide	9, 12	12	123-165	20-30	*D. communis* Garman
13-18 cing.		18, 20	19	6/7-8/9	wide	9, 12	12	95-115	5-10	*D. singularis* (Ude)
13-18 cing.		18, 20	19	6/7-8/9	wide	9, 12	12	100-120	6-10	*D. s. fluviatilis* Smith
13-18 sad.		19, 21	20	8, 9	wide	9, 12	12	100-125	7-15	*D. verrucosa* Ude
15-25		23-26	19	6/7-8/9	close	11, 12	11	165-220	15-20	*Sparganophilus eiseni* Smith
22, 23-26, 27	23-25, 26		13	9/10, 10/11 dors.	close	9, 11, 12	11	70- 90	3- 6	*Helodrilus tetraedrus* (Savigny)
22, 23-27	23-25, 26		15	9/10, 10/11 dors.	close	9, 11, 12	11	70- 90	3- 6	*H. t. hercynius* (Michaelsen)
24, 25, 26-32	28-30, 31		15	9/10, 10/11 dors.	close	9-12	11	80-110	6-13	*H. foetidus* (Savigny)
25, 26-32	29-31		15	9/10, 10/11 dors.	close	9-12	11	120-150	3- 8	*H. roseus* (Savigny)
26, 27-32, 33	30-31		15	9/10, 10/11 dors.	wide	9, 11, 12	11	80-120	4-10	*H. venetus hortensis* (Michaelsen)
27-34	31-33		15	9/10, 10/11 *cd*	close	9-12	11	105-240	6-17	*H. caliginosus trapezoides* (Dugès)
29-37	31, 33, 35		15	8/9-10/11 *cd*	close	9-12	11	80-125	5- 7	*H. chloroticus* (Savigny)
28, 29-33	31-33		15	9/10-11/12 *d*	sep.	9, 11, 12	9 or 10	80- 95	2.5-4	*H. octaedrus* (Savigny)
26-31	28-30		15	9/10, 10/11 *c*	wide	9, 11, 12	11	60-110	4-7.5	*H. subrubicundus* (Eisen)
26-31	29-30*		15	usually none	wide	11, 12	11	90-105	4-8	*H. tenuis* (Eisen)
24-31, 32	24, 25-30*		15	none	close	11, 12	11	66-100	2-6.5	*H. beddardi* (Michaelsen)
23, 24-32, 33	none		15	none	close	11, 12	11	98-122	6-9	*H. longicinctus* Smith & Gittins
27-37	none		15	none	close	11, 12	11	100-142	10-14	*H. zeteki* Smith & Gittins
22-29	none		15	none	close	11, 12	11	105-115	5-8	*H. gieseleri hempeli* Smith
25-32	?	Atrial po. 15		none	close	11, 12	11	112	7.7	*H. heimburgeri* n. sp.
30-35	31-34		15	9/10, 10/11 *c* or *d*	wide	9-12	11	100-165	5-16	*Octolasium lacteum* (Örley)
26, 27-32	28-31		15	9/10, 10/11 *cd*	close	9, 11, 12	11	95-150	7-15	*Lumbricus rubellus* Hoffmeister
32-37	33-36		15	9/10, 10/11 *cd*	close	9, 11, 12	11	110-180	10-30	*L. terrestris* Linnaeus, Müller

* Indistinct.

EXPLANATION OF SYMBOLS AND TERMS USED IN TABLE II

As the above table may sometimes be utilized by persons not familiar with the various symbols and terms in common use in systematic papers dealing with earthworms, it seems desirable that some of these be explained.

Arabic numerals are conveniently used to designate the number of a somite, counting from the anterior end. In the first two columns of the table, a comma separating two numbers is equivalent to the word *or*. Elsewhere in the table, a comma is equivalent to the word *and*. Externally, the limits of somites are ordinarily indicated by transverse (intersegmental) grooves; while, internally, the septa serve this purpose. Not infrequently, especially in the anterior part of the worm, there is a considerable lack of correspondence in the external and internal boundaries of somites thus indicated. Septa and intersegmental grooves for any two adjacent somites are represented by the same formula (for example, 5/6), the context showing which is meant.

In all Illinois earthworm species except a few chiefly limited to greenhouses and which are not included in the list, there are but eight setae per somite and these are more commonly arranged in pairs. It is customary to indicate the setae of either side by the use of the letters *a*, *b*, *c*, and *d*; the ventralmost one being designated by *a*, the next by *b*, the next by *c*, and the dorsalmost one by *d*. If the distances *ab* and *cd* are less than one third of the distance between *b* and *c*, the setae are said to be closely paired; and if otherwise, they are widely paired; or they may be unpaired, or separate (sep.).

The clitellum may be incomplete ventrally (saddle) or, in some species of Diplocardia, it may be nearly as thick on the ventral surface as elsewhere (cingulum). Tubercula pubertatis are glandular ridges closely associated with the ventral edges of the clitellum on some of its somites.

The spermathecae are pouches which open to the exterior and receive sperm cells from another individual. They are the same as the seminal receptacles mentioned in many text-books. The sperm sacs open into the cavity of 10 or 11 and store temporarily the sperm cells produced in those somites. Each sperm sac lies in a somite adjacent to the one into which it opens. These organs are often called seminal vesicles in the text-books. The prostate glands are not found in the LUMBRICIDAE and, hence, are not ordinarily mentioned in the text-books. They are large glands more or less closely associated with the external openings of the sperm ducts (sp'd. pores), and in indigenous Illinois species open separately from them on neighboring somites (prostate pores).

Spermathecal pores (sp'th. pores), when present, are located in the intersegmental grooves or very near them. *Diplocardia verrucosa* is the only exception among the species listed in the table. In some species they lie between seta line *d* and the mid-dorsal line (dors.), and in others they are in line with the dorsal pairs of setae (*cd*), or with the single lines of setae as *c* or *d*. In *Octolasium lacteum* some of the spermathecal pores are in seta line *c* and others in seta line *d*.

Diplocardia riparia Smith, *D. singularis fluviatilis* Smith, and *D. verrucosa* Ude have been found in the Illinois River region but have not yet been reported in the vicinity of Urbana and Champaign.

The table includes all but two of the described species of earthworms of which specimens are known to have been collected in Illinois. *Pheretima heterochaeta* (Michaelsen) and *P. hawayana* (Rosa) have been found in greenhouses, but their identification is complicated because of the very large number of species in the genus Pheretima. *Helodrilus longus* (Ude) has been found in Indiana by Heimburger (1915), and *H. parvus* in Michigan by the writer; hence, their occurrence in Illinois seems probable. It is also probable that still other species of Diplocardia will be found in the State as a result of further study and collection.

them were 16 specimens belonging to *H. tetraedrus* and two to the variety *hercynius*. In eight of these specimens asymmetry is found, and in ten specimens the spermiducal pores are paired on somites other than 13 or 15. Sections were made of parts of these ten specimens and studied with the following results. In one specimen with spermiducal pores on 14, the clitellum, tubercula pubertatis, oviducal pores, spermathecal pores, gonads, sperm sacs, hearts, and calciferous gland were all found one somite anterior to the location normal in the variety *hercynius*. In each of three specimens with spermiducal pores on 12, the various parts named above are located one somite anterior to the positions normal in *H. tetraedrus typicus*. In four specimens with the spermiducal pores on 11, the other organs named are two somites anterior to the positions normal for specimens of that species. In one specimen with spermiducal pores on 10, the various other organs named, in so far as they are present, are three somites anterior to the normal positions. Only the three posterior pairs of hearts were recognized. In this specimen there are four spermathecae in 4-7 on one side and three in 5-7 on the other side. The general appearance of a few anterior somites suggests strongly their having been regenerated. One specimen that at first glance with a lens showed spermiducal pores on 9 was found on more careful study to have lost some anterior somites (probably four) and had just begun regeneration for their replacement. Thus far the writer has not made a sufficiently careful study of the specimens with spermiducal pores on 11 or on 12 to provide a basis for a satisfactory conclusion concerning the probable cause of such departures from the normal numerical relations—whether it may be due to injury and subsequent incomplete regeneration or to some other cause.

H. venetus hortensis is given in the table as having a length of 4-10 cm. instead of the 3.5-5 cm. found in an earlier paper (Smith, 1917) and based on the statements of European writers. Specimens in the collections studied by the writer included several that were 7-10 cm. in length. They had been anesthetized before fixation and were in a well-extended condition.

Specimens of *H. octaedrus* from Norway, Colorado, and Illinois have been sectioned, and in them the writer has found hearts in 7-9 only. In specimens from Virginia no hearts have been found posterior to 10. In the other species of LUMBRICIDAE listed the posterior pair of hearts is in 11.

Specimens of *H. tenuis* are usually without spermathecae, but the writer (1917, p. 177) has reported specimens from Michigan and Indiana with spermathecae imperfectly developed or in reduced numbers (less than four), and more recently has found three specimens from Homer Park, Illinois, which also have spermathecae in reduced numbers or imperfectly developed.

GENERIC NAMES OF LUMBRICIDAE

There has been much confusion in the present century in the use of generic names for LUMBRICIDAE. In 1845, Hoffmeister created a genus *Helodrilus* for a species *oculatus* which he erroneously believed to differ from related forms in the absence of a clitellum in all stages of the life history. The related species were left in the genus Lumbricus. In 1874, Eisen separated the species of Lumbricus into four groups, leaving but few species in Lumbricus and creating three new genera: Allurus, Dendrobaena, and Allolobophora. Michaelsen, in a monographic paper (1900a) on OLIGOCHAETA, replaced the name Allurus Eisen, which was preoccupied, by the new name Eiseniella Michaelsen. He also substituted the genus name Helodrilus Hoffmeister for Allolobophora Eisen, using the latter name for a subgenus of Helodrilus. He felt that a strict adherence to certain rules of nomenclature, which he was obligated to follow, required such substitution. In this procedure he was followed by the majority of writers of systematic papers dealing with LUMBRICIDAE. During the past few years there has been a rather general tendency among various writers, including Michaelsen, to restore the genus Allolobophora and discard Helodrilus. Five groups—Eiseniella, Eisenia, Dedrobaena, Bimastus, and Eophila—are variously treated as distinct genera, or as subgenera of Helodrilus or of Allolobophora, depending on which of the latter happens to be recognized as a valid genus. Such diversities of terminology cause little inconvenience to the specialist familiar with the situation, but are naturally confusing to others. In the present paper the writer has preferred to follow the precedent set in his earlier paper (1917) based on Michaelsen's paper of 1910. The real need for a satisfactory system of nomenclature carefully followed is obvious.

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The following list includes the papers to which direct references are made in the text. More extensive lists of the literature on OLIGOCHAETA will be found in the bibliographic lists in some of the papers here listed, especially in those of Beddard (1895), Michaelsen (1900a and 1910), and of Smith (1917 and 1924).

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The Hessian Fly and the Illinois Wheat Crop

BY

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PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
August, 1928

Map of Illinois showing average date of seeding wheat for highest yield and to avoid damage by Hessian-fly.

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THE HESSIAN FLY AND THE ILLINOIS WHEAT CROP

W. P. Flint[1] and W. H. Larrimer[2]

INTRODUCTION

The Hessian Fly, an insect that infests practically all of the large wheat-growing areas of the world, was first found in North America on Long Island in 1779 and was probably brought into this country in the straw used by the Hessian Troops sent here during the Revolutionary War. It was first recorded in Illinois in 1811, according to Webster[3], and it has been a factor in wheat production in this State ever since that time.

Of all the agricultural crops grown in Illinois, wheat is second in importance, being outranked only by corn. The annual value of the wheat crop to Illinois farmers is in the neighborhood of fifty million dollars. Of the 41,034,000 bushels produced in 1926, almost 95 per cent, or 38,934,000 bushels, was winter wheat[4]. Success in growing winter wheat in this State depends on many factors, including the weather, type and fertility of soil, variety of wheat grown, presence of plant diseases, and infestation by insects, particularly the Hessian Fly.

In years when this insect is very abundant, it may be the most important factor in the production of winter wheat, for it sometimes destroys a fourth or even a half of the entire crop of the State. On individual farms it may, and often does, destroy from fifty to one hundred per cent of all the wheat plants in a field.

The Hessian Fly feeds on rye and barley, besides wheat, and it has been found on some wild grasses, though not in sufficient numbers to affect the surrounding wheat. It does *not* feed on oats.

For many years, experiments have been carried on by entomologists and others in an effort to devise practicable methods of protecting the wheat crop against the ravages of this pest. In order to fight the fly successfully, we had to learn just how it lives through the year, and just where it is to be found during each season. A vast amount of detailed information on these questions has been accumulated as a basis for practical recommendations, but a brief outline of the main facts in the life history of the insect will serve our present purpose and show why certain methods are here recommended.

[1] Chief Entomologist, Illinois State Natural History Survey.
[2] Senior Entomologist in charge of cereal and forage insect investigations, United States Department of Agriculture, Bureau of Entomology.
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LIFE HISTORY

The Hessian Fly passes the winter in the puparium, or "flaxseed" stage, resting as a larva, or maggot, within a brown flaxseed-like case, which is usually to be found behind the lower leaf sheath of early-sown or volunteer wheat, and sometimes in the old stubble. In the latitude of central Illinois the spring brood emerges about the middle of April; that is, the maggots within the flaxseed cases change to the pupal stage and shortly thereafter burst open these cases and emerge as small sooty-black flies, a little smaller than the common house mosquito. The adult flies do not feed, so far as is known. The females, whose abdomens are packed full of orange-red eggs, mate with the males shortly after emerging and then proceed to deposit their eggs on the leaves of the wheat.

The eggs, which are so small that they can hardly be seen without the aid of a magnifying glass, are almost always deposited in the little grooves on the upper side of the wheat leaf. Hatching takes place from three to twelve days later, depending on the temperature and moisture.

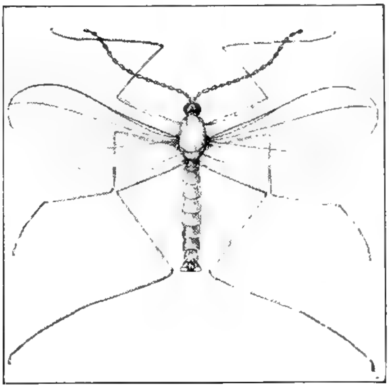

Fig. 1. Adult Hessian Fly, male.
(U. S. D. A. Bureau of Entomology.)

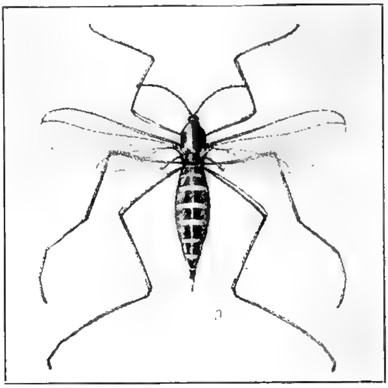

Fig. 2. Adult Hessian Fly, female.
(U. S. D. A. Bureau of Entomology.)

The little orange-red maggots which hatch from the eggs work their way downward until they reach a point where the leaf-sheath is joined to the main stem of the wheat plant. Their descent may be assisted by a drop of dew or rain. Having reached this point, they become permanently established and feed by sucking out the sap. A shoot that is attacked by several of them is weakened and finally killed. Under favorable weather conditions, the maggots grow very rapidly and become full-grown in about two weeks; and by this time they have attained a length of about an eighth of an inch and have become nearly white.

Shortly after the maggot is full-grown, its outer skin loosens, becomes detached from the inner skin, and then turns brown, forming a protective case, which is known as the puparium or "flaxseed," and from which the adult fly will emerge in due time.

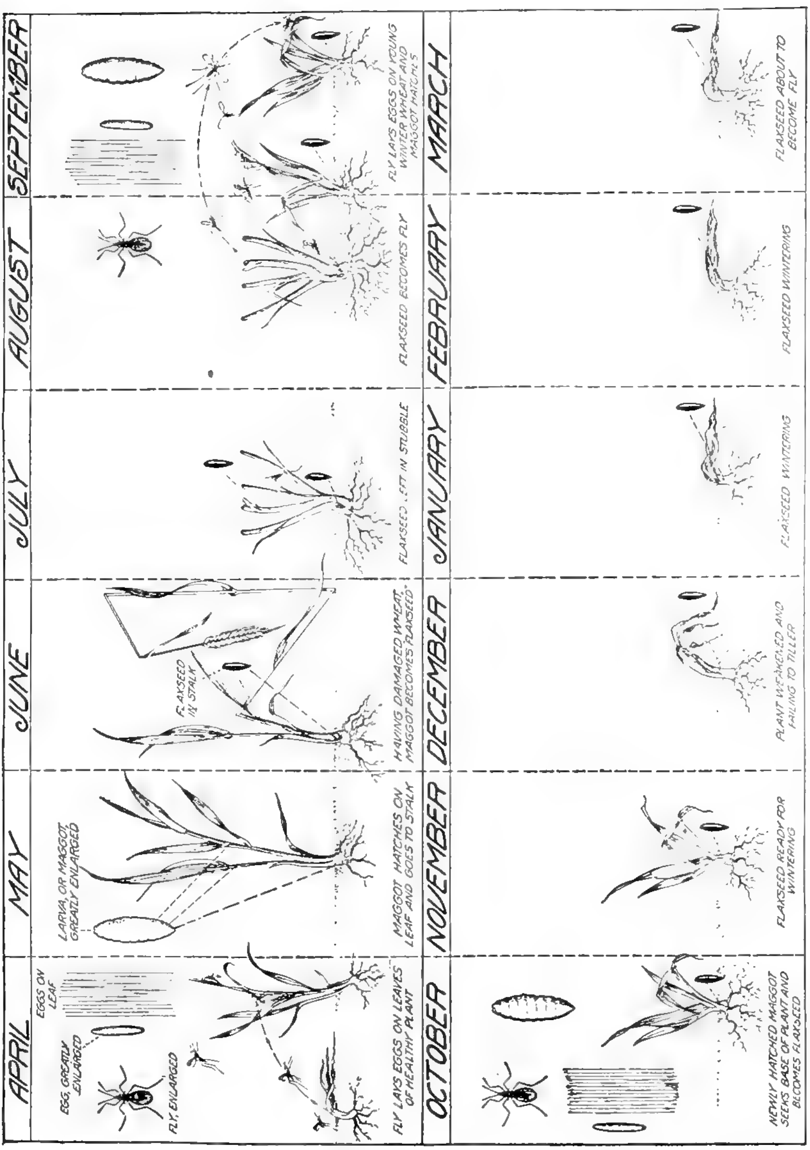

Fig. 3. Hessian Fly life history chart. (*U. S. D. A. Bureau of Entomology.*)

In central Illinois the spring brood of maggots, which usually hatch in April, may reach the flaxseed stage by the first week in May; and sometimes, if conditions are favorable, adults may come out from some of these flaxseeds during the early part of May and lay eggs which produce a second spring brood of maggots. These maggots usually become established rather high up on the wheat plants and cause serious breaking over of the wheat when the heads begin to fill.

The Hessian Fly has been associated with wheat so long that it passes from stage to stage in its life history according to the development of the wheat plant. As the wheat ripens and the straw hardens and dries, the maggots change into the flaxseed stage, in which they remain, inactive, in the stubble or in the cut straw in the stack. If there is little rainfall during the summer, so that conditions are unfavorable for the growth of volunteer wheat, the flies remain in the flaxseed stage until the time of heavier rainfall in early autumn; but if the summer's rainfall is sufficient to bring about a growth of volunteer wheat, the flies emerge and lay their eggs on the wheat at about the time the volunteer plants become two-bladed; and the maggots hatching from these eggs become full-grown and ready to produce another brood of flies by early fall.

In most years, fortunately, the flies remain in the wheat stubble until the early fall rains have produced good conditions for the growth of volunteer wheat, or have brought up early-sown wheat in the fields. They usually begin coming out about the middle or latter part of August in central Illinois (somewhat earlier in northern Illinois and later in southern Illinois) and continue to emerge for about six weeks. These adult flies cannot survive the winter, and in central Illinois practically all of them die by the first week in October. If they find no growing wheat or other host plants on which to lay their eggs, they leave no progeny; but if they do find growing wheat, a fall brood of maggots will be produced, which will become full-grown and reach the flaxseed stage before cold weather sets in, and will thus be able to withstand the lowest winter temperatures that are likely to occur in any part of Illinois.

From these statements, it will be seen that normally there is at least one spring brood and one fall brood of the Hessian Fly. Under more favorable conditions there may be two spring broods and two fall broods, and under the most favorable conditions, two spring broods, one summer brood, and two fall broods, or five broods in the course of a single year. Some live puparia of the first spring brood always carry over to the fall, and usually even through the winter to the second season, thus providing for perpetuation of the species under adverse conditions.

The development of this insect is very largely dependent on temperature and moisture, or rather a combination of the two, as high temperatures will not bring through a brood of flies unless combined with an abundance of moisture. Some idea of the great differences in the length of time required for the completion of the life cycle under different sets of weather conditions may be gained from the fact that McColloch[5] in Kansas carried a brood through one complete generation in a period of

[5] McColloch, James W. Variations in the Length of the Flaxseed Stage of the Hessian Fly. *J. Ec. Ent.* 12: 252-255. (1919.)

twenty days, while under other conditions it required four years for an individual to complete the same cycle.

Under normal weather conditions in Illinois, the relatively fly-free date is September 18 for the northernmost tier of counties and progressively later as one goes southward, as shown on the map in Figure 4.

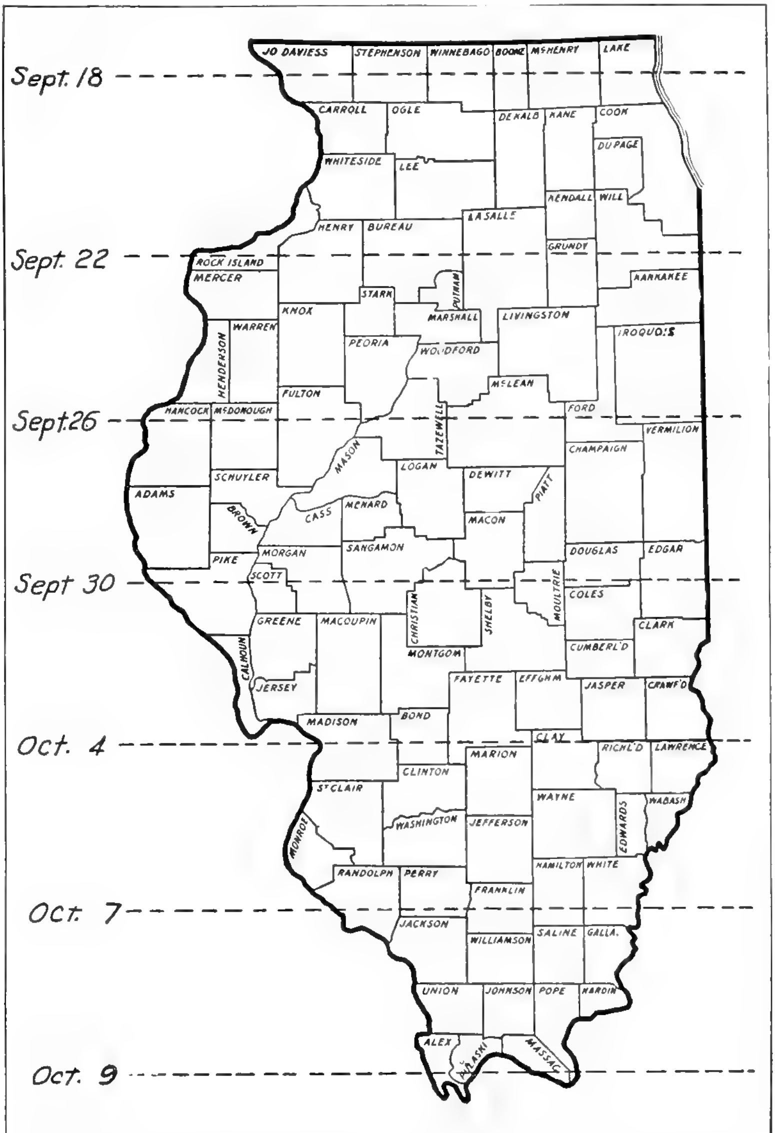

Fig. 4. Map of Illinois showing normal relatively fly-free dates for wheat seeding.

CONTROL MEASURES

It is advisable for wheat growers to protect their crop against the Hessian Fly in every way possible. The methods that have proved to be the best may be summarized as follows:

First: *Sow wheat late enough,* so that it will come up and make a growth at a time when there are no adults of the Hessian Fly to deposit their eggs upon it, *but early enough to withstand the winter.*

Second: Keep down all volunteer wheat, in so far as possible.

Third: Have the seed bed in good condition and the land in a high state of fertility, so that the wheat plants will start a vigorous growth. This is especially important in years of moderate to light infestation, when the first shoots to come up may become infested and die, but the later ones may still make a good crop.

Fourth: Plow under during the summer the stubble from the last crop, if such plowing does not interfere with good agronomic practice. This is an important, though often neglected, means of fighting the fly.

Fifth: Grow strong-stemmed varieties of wheat which do not easily break over.

Of these methods, the proper date of seeding is the most important. It has long been recognized, throughout the wheat-growing areas of North America, that wheat sown early in years when the Hessian Fly is abundant will be killed, and that wheat sown moderately late will often entirely escape infestation. On the other hand, there is a danger that very late seeding will cause a reduction in yield through winter killing.

DATE-OF-SEEDING EXPERIMENTS

In order to determine as exactly as possible what effect the date of seeding has on the degree of infestation by the Hessian Fly and on the yield of wheat, the entomologists of the Natural History Survey have been conducting a series of experiments since 1917 in fields in six different parts of the State, namely, in Winnebago (Boone, two years), LaSalle (Bureau, three years), Hancock, Macoupin, Jackson, and Champaign counties. During this time the federal Bureau of Entomology, cooperating with the Natural History Survey and the Illinois Agricultural Experiment Station, has also made similar experiments in Marion, Pulaski, and Randolph counties.

The general plan of these experiments was to sow a series of plots of wheat, each at least a half-acre in extent, making the first seeding at least two weeks before the date which was considered the average relatively fly-free date for that particular locality, and making the next seeding approximately five days later, and so on, until six or more seedings had been made. This plan gave a range of seedings extending over a period of one month or more, including approximately two weeks before and after the normal fly-free date.

In all fields north of Macoupin County, the variety of wheat grown was Turkey Red, most frequently the strain Turkey 10-110 developed by the University of Illinois. Fultz and Fulcaster were the varieties generally grown in the southern fields.

With the exceptions of the plots on the University Farm at Urbana and the field in charge of the Bureau of Entomology at Centralia, the seedings were made by farmers in parts of their wheat fields. Some of the experiments have been transferred from one farm to another in the same locality.

During the first half of November in each year, the percentage of fly infestation in each plot was taken by the entomologists, using the sampling method described in a previous paper[6]. The yield of wheat from each plot was measured at the regular time of harvest.

RESULTS

The following tables give the yield in bushels per acre and the percentage of fly infestation for each field and each date of seeding in each year throughout the period of the experiments, and the accompanying graphs are made from the averages for the entire period.

Several facts show up very clearly in these results. In the first place, it is evident that there is a very definite relationship between yield and infestation. By consulting the tables it will be seen that, without any exception, wheat heavily infested by the Hessian Fly has made lower yields than wheat grown during the same year and in the same field but seeded later so as to avoid the fly. Furthermore, as shown in the graphs, the average yield has always increased as the infestation decreased. Good yields were obtained from some early seedings during certain years, but never when the fly was abundant. In general, the degree of infestation has been of great importance in early seedings but of no consequence in late seedings. From the results of this work, and also from many other observations made in fields throughout the State, it is evident that the yield is not noticeably affected when less than ten per cent of the plants in a field are infested.

WINNEBAGO AND BOONE COUNTIES

In the extreme northern part of the State, the experimental plots have been located on farms in the vicinity of Rockford, for four years in Winnebago County and for two years just across the boundary line in Boone County. The work was begun in 1917 and continued to 1926 except for interruptions in 1918, 1921, and 1923. The dates of seeding ranged from September 2 to October 6. The painstaking work of Mr. E. R. Derivent, who has been our cooperator for several years, has contributed to the success of the experiment.

[6] Flint, W. P., Turner, C. F., and Davis, J. J. Methods in Entomological Field Experimentation. *J. Ec. Ent.* 12:178-183. (1919.)

Table I shows the yields from all the plots, arranged according to the date of seeding, for each of the six years; it also shows what per cent of the wheat plants in each plot were infested by the Hessian Fly. The normal relatively fly-free date for this locality is September 18. The average yield from all plots seeded before this date has been 24.8 bushels per acre. From all plots seeded after this date, the average yield has been 28.1 bushels per acre.

Judging from these results, anyone growing wheat in the northern tier of counties in the State will obtain the best yields if he sows during the period of September 17—30. It seems, also, that the degree of fly infestation drops very sharply in seedings made after September 16 and, in fact, can be considered of no consequence in its effect on yields from such seedings. The direct relationship of fly infestation and wheat yield appears very clearly in the graphs of Figure 5, which are made from averages for the six years.

TABLE I

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

WINNEBAGO AND BOONE COUNTIES
1917—1926

Date of seeding☞	Sept. 2—6	Sept. 7—11	Sept. 12—16	Sept. 17—21	Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6
Infestation November, 1917	8	7	4	2	0	0	....
1918 Yield	33.8	27.2	34.3	37.2	36.3	33.8	....
Infestation November, 1919	41	48	23	11	7	....	....
1920 Yield	17.3	18.5	19.3	20.1	19.3	....	....
Infestation November, 1920	21	1	1	2	....	0	0
1921 Yield	14.5	20.4	23.4	21.7	....	25.0	23.8
Infestation November, 1922	....	....	60	....	15	0	0
1923 Yield	....	....	15.3	....	13.7	16.1	16.1
Infestation November, 1924	12	0	2	....	0	0	0
1925 Yield	27.2	23.6	40.1	....	34.3	39.6	33.2
Infestation November, 1925	5	....	....	2	0	0	....
Yield 1926	32.8	....	....	35.9	38.9	32.4	....
Average Infestation	17	14	18	4	6	0	0
Average Yield	25.0	22.4	26.5	28.7	28.5	29.4	24.4

Normal fly-free date is September 18.

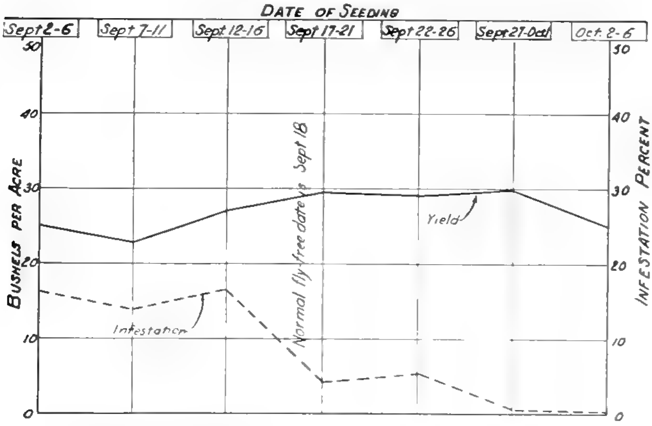

Fig. 5. Graphs showing average yield and average infestation for experimental plots in Winnebago and Boone counties.

LaSalle and Bureau Counties

The experiment which was started in Bureau County in 1917 has been continued in LaSalle County since 1920. The work has been done on three different farms. Mr. L. C. Rinker, of Grand Ridge, who has co-operated with the Natural History Survey for several years in this work, has been very careful in his handling of the fields. Most of the seedings were made between September 7 and October 6.

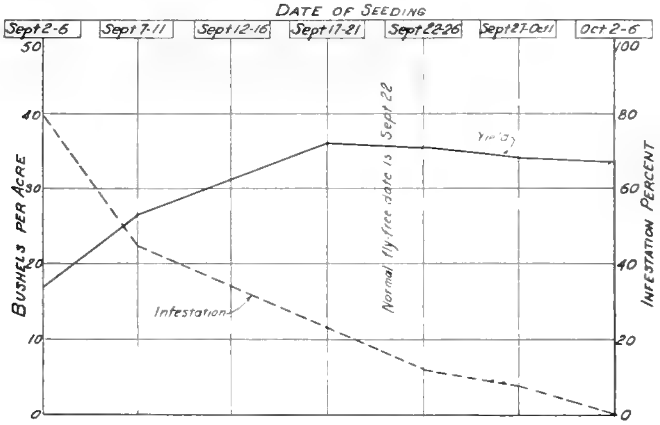

Fig. 6. Graphs showing average yield and average infestation for experimental plots in LaSalle and Bureau counties.

As shown in Table II, wheat sown in the period of September 17—26 gave the highest average yield. Infestation by the Hessian Fly was fairly heavy in most years up to September 22, which is the normal relatively fly-free date for this locality. This date, in general, coincides with the date of highest yields. In years when the Hessian Fly has been very abundant, the early seedings have made poor yields. Figure 6 shows graphically how the average yield rises as the average infestation falls in plots sown during the first three weeks in September; it also shows a slight reduction in yield from plots sown in October, due to winter killing.

TABLE II

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

LASALLE AND BUREAU COUNTIES
1917—1926

Date of seeding☞	Sept. 2—6	Sept. 7—11	Sept. 12—16	Sept. 17—21		Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6
Infestation November, 1917	....	47	27	0		....	0	0
1918 Yield	....	27.8	31.9	35.6		....	32.2	27.8
Infestation November, 1918	....	15	12	4		0	0	0
1919 Yield	....	34.8	36.3	43.3		47.7	41.9	41.8
Infestation November, 1919	79	58	51	45	Normal fly-free date is September 22.	14	18	....
1920 Yield	20.9	20.9	29.0	24.2		33.1	27.4	....
Infestation November, 1920	....	50	28	44		43	43	11
1921 Yield	....	27.8	29.8	32.3		33.1	26.6	27.4
Infestation November, 1921	74	50	37	....		0	3	....
1922 Yield	12.1	16.1	20.1	....		20.1	20.1	....
Infestation November, 1922	....	83	90	79		25	7	0
1923 Yield	....	16.9	25.0	29.8		25.8	35.4	29.0
Infestation November, 1923	....	53	29	0		0	0	0
1924 Yield	....	19.8	27.0	40.3		39.5	36.7	29.4
Infestation November, 1924	....	33	33	23		16	6	2
1925 Yield	....	41.5	42.8	47.1		47.1	43.5	45.0
Infestation November, 1925	....	19	20	0		0	0	0
1926 Yield	....	32.8	33.9	34.4		37.3	42.0	35.0
Average Infestation	17	45	36	24		12	8	2
Average Yield	16.5	26.5	30.6	36.0		35.4	34.0	33.6

HANCOCK COUNTY

The experiment in Hancock County was carried on for the entire period from 1917 to 1926 on the farm of Mr. Kent Campbell near La-Harpe. Mr. Campbell has taken a great deal of personal interest in this work, and it is due to his care that we have such a complete set of records as are shown in Table III. His farm is kept in a very good state of fertility, and the average yield from his plots for the entire period is higher than that from any others in the State. The yields in the plots, moreover, correspond very well with the yields generally obtained in his fields.

TABLE III

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

HANCOCK COUNTY
1917—1926

Date of seeding☛	Sept. 7—11	Sept. 12—16	Sept. 17—21	Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6	Oct. 7—11	Oct. 12—16
Infestation November, 1917.....	42	....	3	0	0	....	0	....
1919 Yield..........	33.8	....	42.8	50.0	49.7	....	40.3	....
Infestation November, 1918.....	45	13	2	0	0	0	....	....
1919 Yield..........	34.2	37.3	35.3	35.5	36.3	40.3	....	....
Infestation November, 1919.....	84	91	....	33	0	0	....	....
1920 Yield..........	20.8	23.4	....	31.0	35.4	34.6	....	....
Infestation November, 1920.....	90	81	58	49	36	2		...
1921 Yield..........	21.8	29.0	26.6	25.0	27.4	29.9	...	....
Infestation November, 1921.....	....	....	9	2	0	0	....	...
1922 Yield..........	....	....	18.1	20.9	23.4	24.2	...	..
Infestation November, 1922.....	....	22	21	7	....	4	2	2
1923 Yield..........	....	39.5	44.3	48.4	....	44.3	45.1	50.8
Infestation November, 1923.....	....	26	10	6	2	0	....	0
1924 Yield..........	....	39.9	33.4	33.8	44.4	35.8	....	27.0
Infestation November, 1924.....	64	55	....	48	19	4	0	....
1925 Yield..........	17.7	21.0	....	20.1	23.0	26.6	28.2	....
Infestation November, 1925.....	....	....	20	1	0	....	0	....
1926 Yield..........	....	....	35.2	45.8	38.9	....	26.6	....
Average Infestation	65	48	18	16	7	1	0	1
Average Yield......	25.7	31.7	33.7	34.5	34.8	33.7	35.0	38.9

Normal fly-free date is September 26.

Here, as at other points, the early seedings have been severely damaged by the Hessian Fly during several seasons, so that the yields were greatly reduced. Though differences in yields are only partly due to the influence of the fly and partly to other seasonal factors, a comparison of the records for several years will show how large a part is played by the fly in early seedings. Plots seeded during the period of September 12—16, for example, produced more than 39 bushels per acre in 1923 and 1924, when the infestation was very light; but those seeded during the same period in 1919 and 1924, when the infestation was very heavy, produced only 23.4 and 21.0 bushels per acre, respectively.

For this locality, the highest average yield has been obtained from plots seeded between September 22 and October 7, although a few plots seeded later than October 12 have given very good yields. Here again, as shown by the averages, the normal relatively fly-free date, September 26, corresponds very closely with the date of highest yield. See Figure 7.

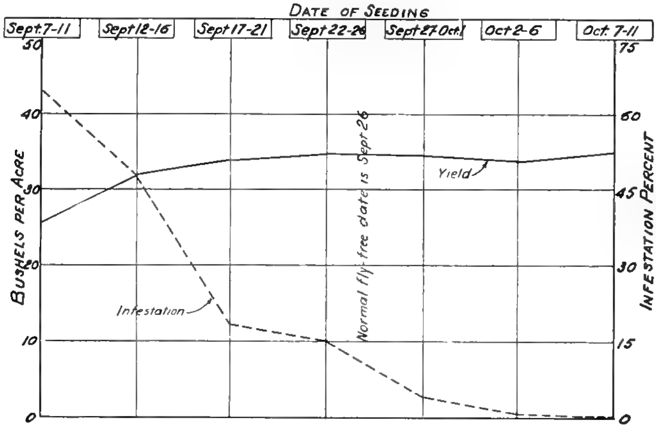

Fig. 7. Graphs showing average yield and average infestation for experimental plots in Hancock County.

Champaign County

The date-of-seeding experiments on the University Farm in Champaign County were not started until the fall of 1919, but a very extended series has been carried out. Some very early and very late seedings, beginning with August 28 and ending with October 31, have been made since 1923. The results are shown in Table IV and Figure 8.

While all the early seedings have made a good growth and the plants have borne large tops in the fall, the yields from them have not been as high as those from the later seedings. The highest average yields were obtained from plots seeded between September 27 and October 12, that is, within two weeks after the normal relatively fly-free date for this locality.

In some seasons, however, October 12 is too late to prevent severe winter killing, and for this reason the best yield generally may be expected from seedings made between September 27 and October 6.

The figures for the first two years are especially significant. In 1920, the lowest yields were obtained from the early-sown plots, which all became heavily infested by the fly, and progressively higher yields were obtained from the late-sown plots as the infestation decreased. In 1921, on the contrary, the relatively high infestation in wheat sown between September 22 and October 1 was not of serious consequence because the infestation occurred late, and the feeding of the maggots that were in the wheat in the fall was curtailed by cold weather, and they all died during the winter.

TABLE IV

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

CHAMPAIGN COUNTY
1919—1927

Date of seeding☛	Aug. 28—Sept. 1	Sept. 12—16	Sept. 17—21	Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6	Oct. 7—11	Oct. 12—16	Oct. 17—21	Oct. 27—31	After Oct. 31
Infestation November, 1919	....	100	100	75	0	0	....	....	....	....	....
1920 Yield......	....	23.3	28.5	40.3	43.1	37.9	....	....	....	....	....
Infestation November, 1920	....	100	100	100	95	38	0	0	....	....	....
1921 Yield......	....	33.9	32.3	33.1	37.1	40.3	39.1	34.7	....	....	....
Infestation November, 1921	....	16	5	0	0	0	0	....	0	....	....
1922 Yield......	....	25.0	30.6	28.2	33.8	32.2	36.3	....	40.3	....	....
Infestation November, 1922	....	1	0	0	....	0	....	0	0	0	....
1923 Yield......	....	36.3	45.9	45.9	....	39.5	....	37.9	39.5	31.4	....
Infestation November, 1923	13	2	5	0	....	0	....	0	0	....	0
1924 Yield......	32.1	34.3	33.2	36.0	....	40.8	....	38.9	31.4	....	32.7
Infestation November, 1924	74	42	17	6	4	6	0	....	0	0	....
1925 Yield......	15.9	20.2	21.2	17.4	34.1	41.1	38.6	....	31.4	21.6	....
Infestation November, 1925	93	....	43	0	0	0	0	....	0	....	0
1926 Yield......	12.1	....	20.4	35.3	34.0	32.7	33.1	....	27.3	....	24.6
Infestation November, 1926	29	17	6	....	....	....	9	....	6	8	0
1927 Yield......	35.8	39.4	38.5	....	....	....	35.6	....	32.4	33.0	28.5
Average Infestation	52	40	35	26	20	6	2	0	1	2	0
Average Yield..	24.0	30.3	31.3	33.7	36.4	37.8	36.6	37.2	33.7	28.7	28.6

Normal fly-free date is September 28.

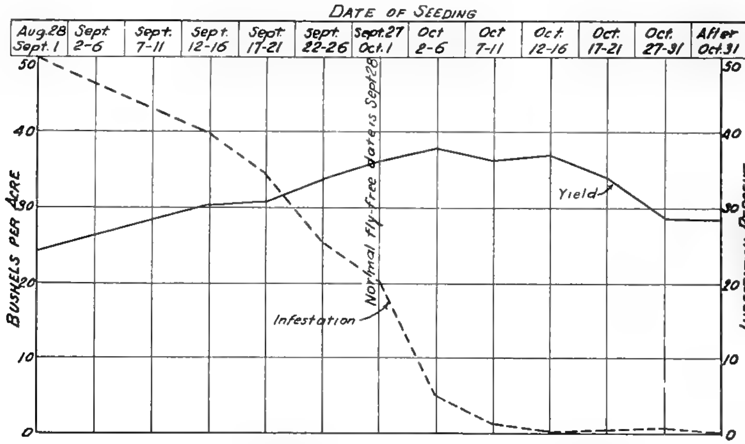

Fig. 8. Graphs showing average yield and average infesta-tionfor experimental plots in Champaign County.

MACOUPIN COUNTY

The experiment in Macoupin County has been conducted for the entire period on the farm of Mr. Vernon Vaniman two miles south of Virden. Mr. Vaniman and his tenant, Mr. Theo. Anspaugh, have helped in every way in carrying on this experiment. Seedings were made as early as the middle of September and as late as the fourth week in October. The records for the eight years, as shown in Table V, are very good and may be relied upon as typical of conditions in that locality.

The figures on average infestation over the whole period indicate that the Hessian Fly normally is most abundant there in wheat sown from

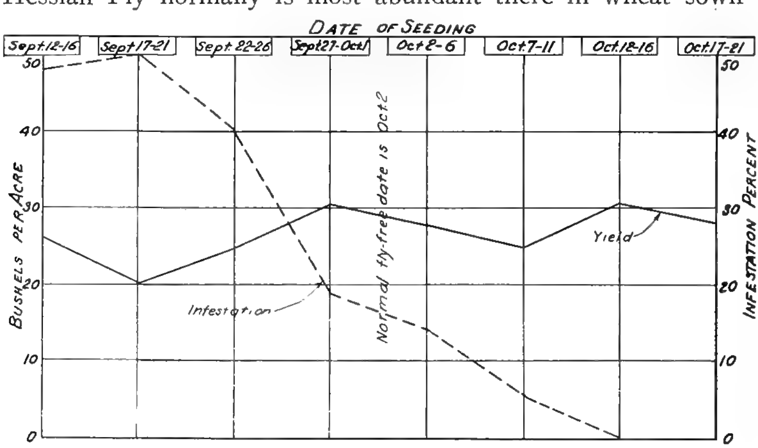

Fig. 9. Graphs showing average yield and average infestation for experimental plots in Macoupin County.

September 17 to 21, and progressively less abundant in wheat sown later. In certain years, however, notably in 1919, 1920, 1921, and 1925, plots seeded during September 22—26 became heavily infested and, on the whole, made very low yields. In every year except the first, when the flies were scarce throughout the season, the highest yields were obtained from plots seeded within a few days of the relatively fly-free date, October 2.

Figure 9 shows graphically this close relationship between fly infestation and yield. The graph for infestation reaches its highest point at the same time as the graph for yield reaches its lowest point. Then, as the former falls, the latter rises, and after October 1, when infestation becomes negligible, the yield is comparatively high. It is evident, therefore, that the best yields in this section can be expected, on the average, from wheat sown between October 1 and October 16.

TABLE V

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

MACOUPIN COUNTY
1917—1926

Date of seeding☛	Sept. 12—16	Sept. 17—21	Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6	Oct. 7—11	Oct. 12—16	Oct. 17—21
Infestation November, 1917.....	10	....	3	0	....	0	0	....
1918 Yield..........	46.8	....	43.6	41.9	....	37.1	37.1	....
Infestation November, 1918.....	....	28	16	0	0	0	....	0
1919 Yield..........	....	14.9	17.3	17.4	20.9	19.4	....	17.2
Infestation November, 1919.....	100	100	81	13	....	0	0	....
1920 Yield..........	10.5	12.1	23.4	30.6	....	29.8	33.1	....
Infestation November, 1920.....	....	94	88	85	73	44	0	....
1921 Yield..........	....	13.7	11.3	13.7	17.8	17.8	16.1	....
Infestation November, 1921.....	....	70	50	....	9	5	....	0
1922 Yield..........	....	11.3	12.9	....	22.7	17.7	....	19.3
Infestation November, 1922.....	....	2	1	....	1	1	....	0
1923 Yield..........	....	23.3	25.8	....	35.4	29.0	....	29.8
Infestation November, 1924.....	33	17	20	19	0	0	....	....
1925 Yield..........	21.7	21.6	23.0	24.4	29.4	26.0	....	....
Infestation November, 1925.....	....	68	55	0	0	....	0	0
1926 Yield..........	....	43.6	37.4	52.6	43.7	....	34.8	47.7
Average Infestation.	48	54	39	19	14	7	0	0
Average Yield......	26.3	20.1	24.3	30.1	28.3	25.3	30.3	29.0

Normal fly-free date is October 2.

MARION COUNTY

The plots for date-of-seeding experiments in Marion County were located during the entire period on the farm of Mr. Ben Michael, west of Centralia. Mr. Michael's friendly cooperation has been enjoyed and is highly appreciated. During most of the period covered by these experiments, the Bureau of Entomology has had a man stationed there to devote his entire time to the Hessian Fly work, making observations not only on the degree of infestation in relation to yield, but also on the weather conditions which brought out the fly, the rate of parasitism, and the possible resistance of different varieties of wheat to the attack of the fly. In addition to the usual series, a number of very early seedings were made, beginning on August 28.

TABLE VI

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

MARION COUNTY
1919—1927

Date of seeding☛	Aug. 28—Sept. 1	Sept. 12—16	Sept. 17—21	Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6	Oct. 7—11	Oct. 12—16	Oct. 17—21
Infestation November, 1919........	....	96	....	96	89	56	13	0	0
1920 Yield..............	....	9.9	....	14.9	11.2	14.9	10.6	9.8	10.9
Infestation November, 1920........	....	....	77	85	85	54	6	0	0
1921 Yield..............	....	....	18.0	15.7	12.0	14.8	17.7	21.8	28.3
Infestation November, 1921........	78	56	....	75	....	17	7	0	0
1922 Yield..............	33.0	37.5	....	36.4	....	35.0	30.1	29.0	29.8
Infestation November, 1922........	64	63	....	42	85	74	77	72	15
1923 Yield..............	10.0	14.5	....	14.5	16.5	14.0	16.0	21.0	22.8
Infestation November, 1923........	67	96	95	66	....	1	0	0	....
1924 Yield..............	1.5	2.0	2.5	6.5	....	26.8	21.0	25.5	....
Infestation November, 1924........	....	15	....	22	24	15	0	0	0
1925 Yield..............	....	22.5	....	29.5	29.0	35.0	34.0	32.0	34.0
Infestation November, 1925........	56	59	94	49	....	0	0	0	0
1926 Yield..............	8.0	10.0	8.5	20.5	....	28.0	26.0	23.5	26.0
Infestation November, 1926........	....	....	....	....	....	....	0	0	....
1927 Yield..............	....	....	....	....	....	....	23.0	14.0	....
Average Infestation....	66	64	89	62	71	31	13	9	3
Average Yield.........	13.1	16.1	9.7	19.7	17.2	24.1	22.3	22.1	25.3

Normal fly-free date is October 5.

The results as shown in Table VI and Figure 10 again indicate how directly the Hessian Fly affects the yield of wheat. It certainly is not merely an accident that the yield graph reaches high points whenever the infestation graph reaches low points, and *vice-versa,* throughout the experiment. The connection is unmistakable.

The normal relatively fly-free date for this locality is October 5. Judging from the data on the experimental plots, one can generally expect the best yields of wheat in this section from seedings made between October 4 and October 20.

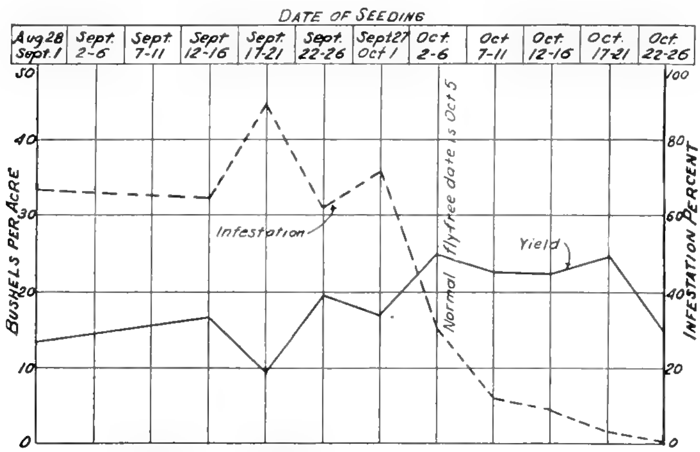

Fig. 10. Graphs showing average yield and average infestation for experimental plots in Marion County.

RANDOLPH COUNTY

The experimental work in Randolph County was done in the vicinity of Sparta. It was started on the farm of Mr. H. B. McIntire and has been continued, since 1920, on the farm of Mr. W. M. Beattie, whose reliability and interest have aided greatly in carrying on the work. The dates of seeding range from September 22 to October 21.

As will be seen by an analysis of Table VII, or by a glance at Figure 11, the yields have been about the same, on the average, for all dates of seeding. Leaving out of account the exceptionally high yield in 1921 from the earliest seeding, the data show that plots sown about October 7, which is the normal relatively fly-free date for this locality, have given the best average yield. The infestation percentages indicate that the fly usually is not abundant enough there to cause any considerable damage to wheat sown after October 4. In unusual years, however, such as 1919, seedings made during the first week in October may become heavily infested and may give low yields.

TABLE VII

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

RANDOLPH COUNTY 1919—1927

Date of seeding☞	Sept. 22-26	Sept. 27—Oct. 1	Oct. 2—6	Oct. 7—11	Oct. 12—16	Oct. 17—21
Infestation November, 1919	100	100	99	....	13	2
1920 Yield	7.3	5.5	12.1	....	22.0	16.5
Infestation November, 1920	26	8	13	0	....	0
1921 Yield	42.5	33.8	30.5	31.5	....	35.0
Infestation November, 1921	35	39	18	4	....	0
1922 Yield	32.5	30.5	33.0	24.0	....	23.0
Infestation November, 1922	9	16	23	19	....	4
1923 Yield	12.5	16.0	16.5	20.5	....	17.5
Infestation November, 1923	....	8	0	0	0	0
1924 Yield	....	16.5	16.5	14.0	20.5	16.0
Infestation November, 1924	....	29	1	0	0	0
1925 Yield	....	32.0	33.5	31.5	27.5	28.5
Infestation November, 1925	....	20	0	....	0	0
1926 Yield	....	17.5	20.0	....	19.5	22.0
Infestation November, 1926	....	7	0	0	0	0
1927 Yield	....	21.0	21.5	21.0	19.5	14.0
Average Infestation	43	28	19	4	3	1
Average Yield	23.7	21.6	23.0	23.8	21.8	21.6

Normal fly-free date is October 7.

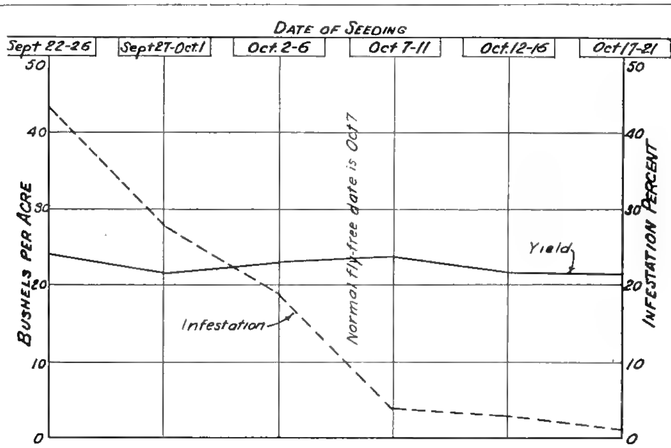

Fig. 11. Graphs showing average yield and average infestation for experimental plots in Randolph County.

JACKSON COUNTY

The work in Jackson County has been done on several different farms in different years, under conditions that are hardly comparable. It has been interfered with by flooding of the plots, by winds, and by several other factors which have tended to confuse the results. In 1918, for example, when the plots were on rich bottomland that had been heavily treated with fertilizer, flooding interfered with cutting, so that the data had to be discarded. The results shown in Table VIII and Figure 12, therefore, cannot be considered as truly representative of this section of the State. The difference in the yields obtained from plots sown before the relatively fly-free date (October 7) and from those sown after this date, has been less than in any other county where the experiments were made. On the average, nevertheless, the best yields have been obtained from seedings made between October 2 and

TABLE VIII

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

JACKSON COUNTY
1918—1926

Date of seeding☞	Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6	Oct. 7—11	Oct. 12—16	Oct. 17—21	Oct. 22—26
Infestation November, 1918..	2	1	0	0	0	0	....
1919 Yield.......	19.2	22.2	20.2	20.2	21.2	9.1	....
Infestation November, 1920..	20	29	16	0	0	0	....
1921 Yield........	6.5	12.1	10.5	9.7	8.1	6.5	....
Infestation November, 1921..	....	65	33	0	....	0	0
1922 Yield........	....	12.1	16.4	14.9	....	18.5	18.5
Infestation November, 1922..	....	52	72	....	26	3	0
1923 Yield........	....	3.6	4.6	....	6.4	4.8	11.2
Infestation November, 1923..	....	0	0	0	0	....	0
1924 Yield........	....	13.0	16.5	16.5	20.6	....	24.6
Infestation November, 1924..	10	7	0	0	0	0	....
1925 Yield........	24.1	29.7	30.7	35.0	27.7	24.5	....
Infestation November, 1925..	....	....	0	0	....	0	....
1926 Yield........	....	....	32.4	29.6	....	26.9	....
Average Infestation	11	26	17	0	5	0	0
Average Yield....	16.6	15.5	18.8	21.0	16.8	15.1	18.1

Normal fly-free date is October 7.

October 12, though the yields from other seedings have not been much lower. More information on plots under more uniform conditions is needed in this locality before any definite conclusions can be drawn.

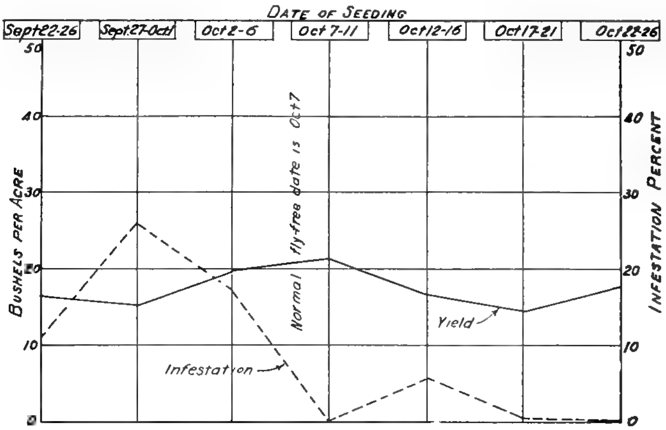

Fig. 12. Graphs showing average yield and average infestation for experimental plots in Jackson County.

Pulaski County

The date-of-seeding experiment in Pulaski County was made in cooperation with several different farmers in the vicinity of Grand Chain. Since 1922, the experiment has been located on the farm of Mr. A. J. Schoenborn, whose interest in the work has been a great help.

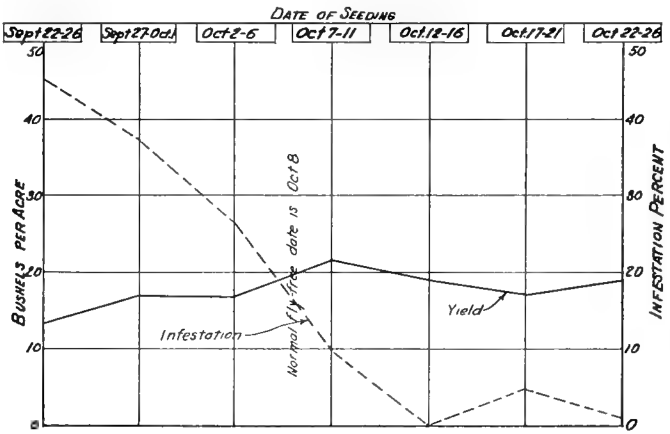

Fig. 13. Graphs showing average yield and average infestation for experimental plots in Pulaski County.

The experimental plots have had very good attention, and the results shown in Table IX can be considered as representing average conditions in this locality. Most of the seedings were made between September 27 and October 26.

In general, the best yields have been obtained from plots sown between October 5 and October 26. It will be noticed in Figure 13 that the yield graph reaches its highest point in the period of October 7—11, when the infestation graph falls to the 10 per cent mark. From this we may conclude that wheat sown within a few days after the normal fly-free date, October 8, will usually escape serious infestation. In the fall of 1922, however, when the fly was unusually late in making its appearance in this locality, wheat sown during the second week of October became heavily infested and made a low yield.

TABLE IX

PER CENT INFESTATION BY THE HESSIAN FLY AND WHEAT YIELDS (BUSHELS PER ACRE)

PULASKI COUNTY
1919—1927

Date of seeding ☞	Sept. 22—26	Sept. 27—Oct. 1	Oct. 2—6	Oct. 7—11	Oct. 12—16	Oct. 17—21	Oct. 22—26
Infestation November, 1919..	100	92	92	....	....	....	0
1920 Yield........	6.5	16.0	10.0	....	....	....	15.5
Infestation November, 1920..	10	0	0	0	0	0	0
1921 Yield........	14.0	7.5	9.0	15.5	12.0	13.5	14.0
Infestation November, 1921..	....	19	12	0	0	0	0
1922 Yield........	....	20.0	18.5	28.5	25.5	26.0	24.5
Infestation November, 1922..	25	38	39	68	....	28	7
1923 Yield........	18.5	23.5	17.5	16.5	....	19.5	16.5
Infestation November, 1923..	....	....	36	0	0	....	0
1924 Yield........	....	....	17.5	25.0	32.5	....	26.0
Infestation November, 1924..	....	....	15	0	0	0	....
1925 Yield........	....	....	11.0	13.0	11.5	7.5	....
Infestation November, 1925..	....	....	0	0	....	0	....
1926 Yield........	....	....	36.0	35.5	....	28.8	....
Infestation November, 1926..	....	....	11	4	0	0	....
1927 Yield........	....	....	17.5	15.0	11.0	9.0	....
Average Infestation	45	37	26	10	0	5	1
Average Yield....	13.0	16.8	17.1	21.3	18.5	17.4	19.3

Normal fly-free date is October 8.

SUMMARY

Table X shows the average yields of wheat obtained from all seedings made before, and from all those made after, the normal relatively fly-free date for each of the localities named. In every locality, with the exception of Randolph and Jackson counties (see pp. 379-382), there has been an appreciable increase in the yield from the later seedings as compared with the earlier seedings. In most cases the increase in yield is sufficient to pay an added return equal to, or greater than, the taxes on the land. This increase does not involve any additional labor or any expenditure for fertilizer or any other outlay.

From Table X, which also gives the average per cent infestation by the Hessian Fly in these two groups of seedings, it will be seen that the wheat sown after the relatively fly-free date has not been sufficiently infested at any point in the State to cause a marked decline in yield. In all the fields except the one in Marion County (Table VI), seedings made on the normal fly-free date have been relatively free from infestation throughout the entire period of the experiments. In a few sections of the State it seems safe to make seedings a little earlier than this date in years when the Hessian Fly is known to be comparatively scarce in those particular localities.

Early seeding does not produce high yields of wheat on the average. The same is true of very late seeding.

In years when the Hessian Fly is abundant, it is almost sure to cause a very marked decrease in yield from wheat sown early. The

TABLE X

AVERAGE YIELDS OF WHEAT (BUSHELS PER ACRE) AND PERCENTAGES OF PLANTS INFESTED BY HESSIAN FLY IN PLOTS SOWN BEFORE AND AFTER THE NORMAL RELATIVELY FLY-FREE DATE

INCLUDING ALL YEARS COVERED BY EXPERIMENTS

Location of plots	Number of years	AVERAGE YIELD from wheat sown BEFORE	AFTER	AVERAGE INFESTATION in wheat sown BEFORE	AFTER
Winnebago County[1]	6	24.8	28 1	17	2
LaSalle County[2]	9	29 8	34.4	39	8
Hancock County	9	32.0	35.0	33	3
Champaign County	8	30.6	34.8	44	5
Macoupin County	8	24.8	27.7	40	6
Marion County	8	17.8	23.0	60	8
Randolph County	8	22.5	22.3	28	2
Jackson County	7	17.0	17.2	19	1
Pulaski County	8	16.2	19.2	33	4
AVERAGES (weighted by years)		25.1	27.4	36	4

[1] Boone County, two years.
[2] Bureau County, three years.

results obtained from the experimental plots in such years are summarized in Table XI, showing that the difference between the yields from wheat sown before the fly-free date and after this date has averaged more than five bushels per acre.

TABLE XI

AVERAGE YIELDS OF WHEAT (BUSHELS PER ACRE) AND PERCENTAGES OF PLANTS INFESTED BY HESSIAN FLY IN PLOTS SOWN BEFORE AND AFTER THE NORMAL RELATIVELY FLY-FREE DATE

EXCLUDING YEARS OF SLIGHT INFESTATION

Location of plots	Number of years	AVERAGE YIELD from wheat sown BEFORE	AFTER	AVERAGE INFESTATION in wheat sown BEFORE	AFTER
Winnebago County[1]	2	17.6	16.9	43	6
LaSalle County[2]	7	28.1	32.2	46	10
Hancock County	3	24.0	29.3	65	11
Champaign County	4	25.7	34.4	65	11
Macoupin County	4	22.8	27.3	67	12
Marion County	6	16.2	21.8	66	11
Randolph County	3	18.3	20.6	49	7
Jackson County	2	9.2	12.4	55	5
Pulaski County	2	15.3	17.0	64	26
AVERAGES (weighted by years)		21.2	25.6	58	11

[1] Boone County, one year.
[2] Bureau County, two years.

In view of the very definite relationship between infestation and yield, the Hessian Fly cannot be disregarded as a factor in wheat production in Illinois, but must be considered every year. The entomologists of the State Natural History Survey and the Federal Bureau of Entomology cooperatively make a special Hessian Fly survey of Illinois each season during August, and the results of this survey, giving the relative abundance of the fly in all of the principal wheat-growing sections of the State, can be obtained by writing to the chief entomologist of the Natural History Survey at Urbana or through the Farm Bureau in each county. With this information at hand, growers should use their own judgment in regard to the time of seeding.

ACKNOWLEDGMENT

This work was made possible through the assistance of a number of entomologists connected with the field station of the Bureau of Entomology at Lafayette, Indiana, and the entomologists of the Natural History Survey. Thanks are also due to the department of agronomy of the Illinois Agricultural Experiment Station for threshing all wheat samples from the experimental plots.

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DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, *Chief*

Vol. XVII. BULLETIN Article XII.

The Bottom Fauna of the Middle Illinois River, 1913-1925

Its Distribution, Abundance, Valuation, and Index Value in the Study of Stream Pollution

R. E. RICHARDSON

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FOREWORD

The present article is the twenty-third of a series of bulletins strictly devoted to Illinois River biology, containing 2108 pages and 155 plates, published during the past 52 years by the Illinois State Laboratory of Natural History and its successor, the State Natural History Survey, as a product of operations carried on from 1874 to 1927.

It was the guiding purpose of these studies to make a comprehensive survey of the plants and animals of the stream and its tributary waters, and to analyze their interactions with each other and with their physical environment during all seasons of the year and under the various conditions of successive years, especial attention being paid to food relations and to effects produced upon the biological system of the stream by the periodical overflow and gradual recession of its waters—a phenomenon of which the Illinois offered a notable example owing to its generally sluggish current and the unusual extent of its bottomlands. During the early years of this period especial attention was given to the fishes of the stream and its connected waters, but not to the exclusion of the other inhabitants.

In 1894 these preliminary studies, which were a part only of a general program covering the entire state, were concentrated and adequately provided for by the establishment of a biological station, with a completely portable equipment, at Havana on the Illinois River, at which place continuous investigation was carried on from 1895 to 1900, supplemented by a summer's operation with Meredosia, 47 miles below, as its center, and by a year's work on the upper river for which the station equipment was moved to Ottawa in 1901. The Illinois River operations were thereafter limited for a time to occasional visits while the other streams of the state were being explored and a report on the fishes of Illinois was being prepared and published, but continuous operations on Illinois River biology were resumed in 1909 and were carried on with only occasional interruptions until 1925.

The time necessary to accomplish the purposes in view was greatly prolonged by the repeated occurrence of revolutionary changes in condition, affecting the biological system of the river so profoundly as presently to render obsolete much that had been done and to call for a repetition of a considerable part of the work. The most important of these changes were, first, the introduction in 1885 of the European carp and its rapid multiplication, until by 1908 its yield to the commercial fishermen was greater than that of all the other fishes of the river taken together; second, the completion and opening in January, 1900, of the drainage canal of the Sanitary District of Chicago, greatly increasing the amount of raw sewage from the city of Chicago introduced into the Illinois at its source; and, third, a general movement for the reclamation of the bottomlands of the river for agricultural uses, by the construction of levees to prevent an overflow of the streams and by the drainage of bottomland lakes.

Our biological studies of the Illinois River have, of course, been carried on by the aquatic biologists of our own staff, but for a knowledge of the ecological conditions of an aquatic situation, an acquaintance with the chemistry of the water was essential, and this has been made possible to us by the generous cooperation, at first of the Department of Chemistry of the University of Illinois, which began analyses for us in May, 1894, and since then by the Water Survey of the State which was organized the following year. These chemical studies became increasingly important as problems of stream pollution grew in prominence and led to the addition of a chemist to the river field party during the summer season of three years (1911, 1920, 1922), to the analysis of weekly samples sent to the chemical laboratory in 1914, and to occasional trips to the river in other years by chemists of the Water Survey, as called for by the biologists; and finally, upon the transfer of the main operations of the Natural History Survey to Rock River in 1925, the State Water Survey took over the Illinois River program as a problem in river pollution, with its center of operations at Peoria, to which the Havana equipment had been transferred in 1920.

The Natural History Survey still retains a permanent interest in the Illinois River, especially as a field for the solution of individual problems; and it dealt with one such problem in 1926 and 1927, when it made an exhaustive study of a new and remarkable disease of the European carp, traceable to the effects of pollution on the food supply of the carp. The Survey sustains also relations of cooperation with the Water Survey, to which it furnishes a biologist whenever his services are likely to be needed in elucidation of chemical conditions disclosed.

The place of the present bulletin in the series of which it is, in a sense, the final number, dealing as it does with the last twelve years of our active period on the Illinois, and discussing topics related to the whole range of our studies, may be made more evident by reference to the list of publications on the subject printed as an appendix to this paper.

STEPHEN A. FORBES.

CONTENTS

THE BOTTOM FAUNA OF THE MIDDLE ILLINOIS RIVER, 1913-1925

Its Distribution, Abundance, Valuation, and Index Value in the Study of Stream Pollution

R. E. Richardson

The present paper adds the findings of two more years (1924 and 1925) to our previous accumulation* on the small bottom fauna of the middle Illinois River, and brings into comparison with the data obtained under the comparatively clean-water conditions of 1913-1915 the results of five summers' collecting in the more or less seriously polluted bottom muds in the same territory between the years 1920 and 1925. The dissolved-oxygen readings for the same or neighboring years have been furnished by the Illinois State Water Survey. The collection of the biological material in 1923 was the work of Dr. D. H. Thompson of the Natural History Survey. The same part of the work in 1924 and 1925 was in the hands of Dr. H. J. Eigenbrodt. Especial thanks are also due to Dr. Thompson for considerable clerical work in the organization of recent data, and for valuable suggestions in the course of preparation of the manuscript.

Collections, Dates, Apparatus, River Levels

The statements contained in the present paper concerning the changes in the Illinois River bottom fauna during the twelve-year period, 1913-1925, are mainly based on a total of 749 dredge and Petersen sampler collections taken between Chillicothe (146.5 miles below Chicago) and the Lagrange Dam (249.5 miles below Chicago). Of these, 237 hauls, with various dredges or with the mud dipper, were taken during the three years 1913-1915. The remainder, 512 collections with the Petersen sampler, were taken during the summers of 1920 and 1922-1925, covering five

* Richardson, R. E., The Small Bottom and Shore Fauna of the Middle and Lower Illinois River and its Connecting Lakes, Chillicothe to Grafton; its Valuation; its Sources of Food Supply; and its Relation to the Fishery. Bull. Ill. Nat. Hist. Survey, Vol. XIII, Art. XV, pp. 363-524, and maps; June, 1921.

———, Changes in the Bottom and Shore Fauna of the Middle Illinois River and its Connecting Lakes since 1913-1915 as a Result of the Increase Southward of Sewage Pollution. Bull. Ill. Nat. Hist. Survey, Vol. XIV, Art. IV, pp. 33-75; December, 1921.

———, Changes in the Small Bottom Fauna of Peoria Lake, 1920 to 1922. Bull. Ill. Nat. Hist. Survey, Vol. XV, Art. V, pp. 327-388; August, 1925.

———, Illinois River Bottom Fauna in 1923. Bull. Ill. Nat. Hist. Survey, Vol. XV, Art. VI, pp. 391-422; October, 1925.

seasons. The 749 collections mentioned were all taken either in the river proper or in the extra-channel portions of the expanded river above Peoria known as Peoria Lake, but include none from the smaller, more nearly inclosed, but connecting, bottomland lakes below or above Peoria. The distribution of these 749 collections in time and their apportionment to river reaches was as follows:

		Number of collections
1913	Chillicothe to Lagrange Dam	44
1914	Vicinity of Havana	13
1915	Chillicothe to Lagrange Dam	180
1920	Chillicothe to foot of Hickory Island	71
1922	Chillicothe to foot of Peoria Lake	71
1923	LaSalle to Beardstown	158
1924	LaSalle to Beardstown	137
1925	LaSalle to Beardstown	75
	Total	749

In addition to the above collections from the river and Peoria Lake there were taken in the river below Lagrange Dam in 1913 and 1915 a total of 153 hauls with dredges; and in the connecting bottomland lakes between Clear Lake (about 10 miles above Havana) and Meredosia Bay between 1913 and 1920 a total of 406. The apportionment of these collections follows:

		Number of collections
1913	Illinois River, Lagrange Dam to Grafton (mouth of river)	78
1915	Illinois River, Lagrange Dam to Grafton	75
1913	Connecting bottomland lakes, Clear Lake to Meredosia Bay	113
1914	Connecting bottomland lakes, Clear Lake to Sangamon Bay	102
1915	Connecting bottomland lakes, Clear Lake to Sangamon Bay	171
1920	Connecting bottomland lakes, Liverpool Lake to Stewart Lake	20
	Total	559

Adding this group of bottom collections to the first list given, we have a grand total of 1,308 dredge and Petersen sampler hauls taken between 1913 and 1925 in the Illinois River and immediately connecting waters; 406 of these coming from the smaller connecting bottomland lakes below Peoria; and 902 from the river proper and Peoria Lake.

The usual collecting period, in all years, has been June to September, with the larger part of the work falling in July and August. In the 1913-1915 period a small number of spring collections were taken, and in the autumn of 1914 work was extended to the end of October.

The collections of the small bottom fauna in 1920 and 1922 were made without exception in the deeper open water, both of Peoria Lake and of the river, being thus confined to those areas where the effects of pollution were felt most fully, and where there was no unusual aeration or other protection afforded by coarse aquatic vegetation. In 1923, 1924, and 1925, a few collections were made near the margins, in the rather sparse new growths of vegetation since 1920, but the data from those lots are excluded from the figures used in valuation, and the species there taken are segregated for special treatment in the arrangement of the lists of species taken in order of index value, and their discussion. Weed and edge species have been excluded also from all 1913-1915 data used for comparison.

River levels during all but two of the eight seasons of collecting from 1913 to 1925 were either unusually low or about average for the warm season of recent years. The summer of 1915 was unusually wet, but apparently not sufficiently so to affect seriously the distribution or the abundance of the bottom invertebrates. The summer of 1924 had several successive floods that seem to be reflected in the bottom fauna figures for that year. For a brief further statement on river levels, and some account of the effects of the floods of 1924 on the small bottom animals, see page 448.

River Reaches Covered, Main Hydrographical Features, and Principal Collecting Stations

The portion of the Illinois River north of the Lagrange Dam covered either by the collections of 1913-1915 or by those of 1920-1925, or in both periods, has a length of 148 miles, lying between mile numbers 101.5 and 249.5 below Lake Michigan, or between LaSalle and the Lagrange Dam, respectively. This region of river breaks naturally into three main sections: the first, the 45 miles between LaSalle and the approximate head of Peoria Lake at Chillicothe; the second, the 19.9 miles of greatly expanded river between Chillicothe and the Peoria and Pekin Union Railway Bridge at South Peoria, which we have assigned to Peoria Lake; and third, the 83.1 miles between the Peoria and Pekin Union Railway Bridge, or foot of Peoria Lake, and the Lagrange Dam.

The 45-mile reach, LaSalle to Chillicothe, is mainly a sluggish, black-mud-bottomed section, with no important tributaries or other varying hydrographical features, except for the low dam at Henry, about three-fourths of the distance downstream from LaSalle. The effect of this dam is not important at either present or recent low-water stages; the swifter current immediately below continuing an almost negligible distance into the region of exceedingly low slope between there and Chillicothe.

The 19.9-mile section called Peoria Lake is made up, first, of two unusually wide and sluggish, mud-bottomed lakes or "wide-waters" (Upper and Middle Peoria Lake), about 7.7 and 6.8 miles in length, respectively; differing scarcely perceptibly in hydrographical character; and separated by a wide "narrows", of visibly faster-moving water which covers a distance of around three-quarters of a mile and has mud bottom. The lower 5.4 miles of this 19.9-mile section (Lower Peoria Lake) is both shorter and narrower than either the Upper or Middle Lake; has a distinctly swifter average current, relatively much wider channel and correspondingly narrower "lake" or "wide-water" portion; and is separated from the Middle Lake, at Peoria Narrows, by a narrow neck about one-half mile in length, with unusually fast current and generally well washed, lightly silted, and *Bryozoa*-covered bottom.

The 83.1 miles between the foot of Peoria Lake and the Lagrange Dam presents a great variety hydrographically, having alternating swift and sluggish reaches, a dam (Copperas Creek) about one-fourth of the way down, two tributaries of considerable size (Mackinaw and Spoon Rivers, the first important ones below LaSalle) between Peoria-Pekin and its midway point, and another still larger tributary (Sangamon River) about 10 miles above its lower end. For purposes of convenience, mainly, we have broken it up, in various comparisons, into five sections; the first four being short ones, covering only the first 40.6 miles below the foot of the Lake and ending just below Spoon River at Havana; and the fifth covering the entire remaining 42.5 miles between Havana and the dam at Lagrange.

The four upper short reaches recognized between the foot of Peoria Lake and Havana, in their turn, break into two groups at the Copperas Creek Dam, 23.8 miles below the foot of Peoria Lake. The upper 23.8 miles, again, has a natural break at Pekin, due to the access there of large additional factory wastes and to the marked slowing up of current that begins very shortly below that point as a consequence of the backing effect at low water of the Copperas Creek Dam. Also, the 16.8 miles between Copperas Creek Dam and Havana has a more or less natural dividing line about one mile above Liverpool, marking roughly the complete subsidence of the faster flow following the fall over the crest of the dam, and the entrance into the very sluggish deep-soft-black-mud-bottomed pool lying between that point and the Spoon River bar about 9 miles south.

The stretch of 42.5 miles between Havana and the Lagrange Dam covered in the seasons 1913-1915 is much more uniform over most of its length than the Peoria-Havana section. Sand, sand and shell, hard clay, or very lightly silted soft bottom is the rule throughout this stretch with the single important exception of a few miles of more heavily silted bottom lying immediately above the Sangamon River bar, about 5 miles above Beardstown and about 15 miles above Lagrange.

The scheme of main reaches and subdivisions and a list of the principal sampling stations, or location of cross-sections, with distances below Lake Michigan, will be found in Tables I and II, respectively.

TABLE I

MAIN REACHES AND SUBDIVISIONS OF THE ILLINOIS RIVER COVERED BY COMPARABLE BOTTOM FAUNA SERIES, BOTH 1913–1915 AND 1920–1925

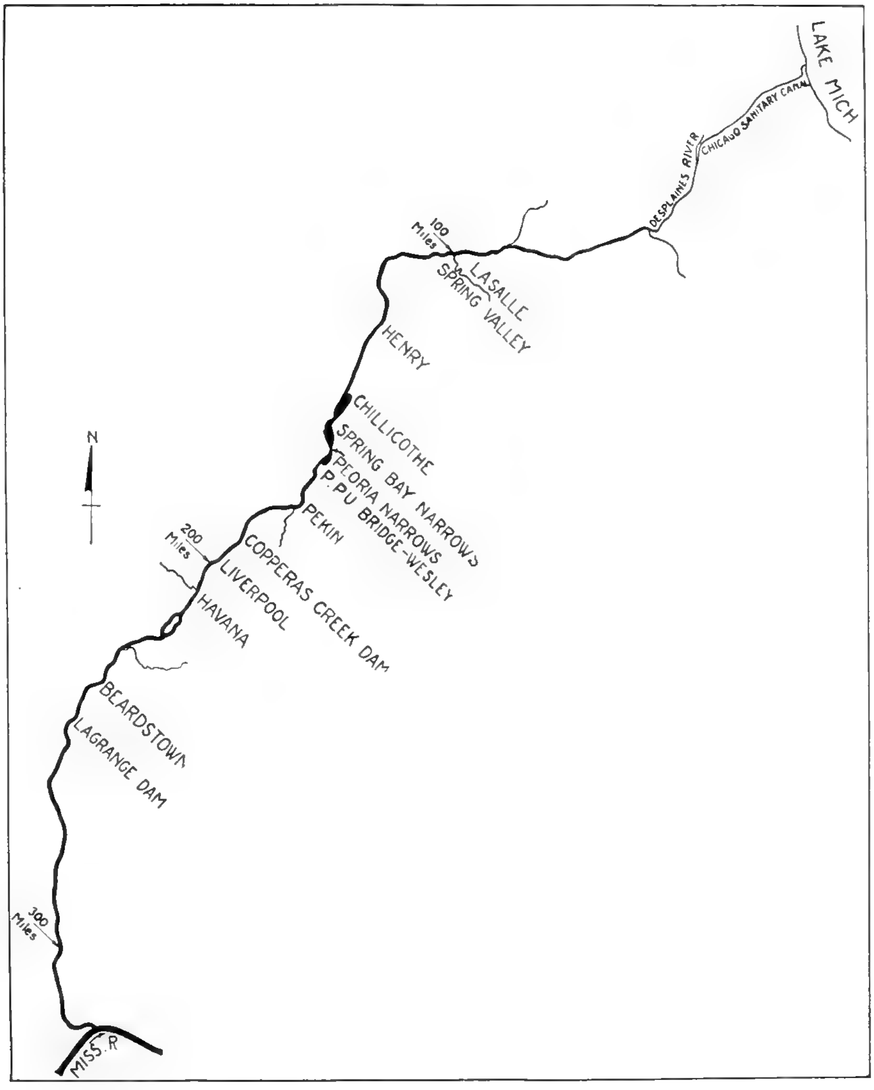
Reaches and subdivisions	Distance in miles	Upper and lower mile numbers (below Lake Michigan)
Chillicothe to Foot of Peoria Lake	19.9	146.5—166.4
Upper Peoria Lake	7.7	146.5—154.2
Middle Peoria Lake	6.8	154.2—161.0
Lower Peoria Lake	5.4	161.0—166.4
Foot of Peoria Lake to Lagrange Dam	83.1	166.4—249.5
or Foot of Peoria Lake to Beardstown	71.6	166.4—238.0
Foot of Peoria Lake to Copperas Creek Dam	23.8	166.4—190.2
Foot of Peoria Lake to Pekin	7.6	166.4—174.0
Pekin to Copperas Creek Dam	16.2	174.0—190.2
Copperas Creek Dam to Havana	16.8	190.2—207.0
Copperas Creek Dam to 1 Mile above Liverpool	7.8	190.2—198.0
1 Mile above Liverpool to Havana	9.0	198.0—207.0
Havana to Lagrange Dam	42.5	207.0—249.5
or Havana to Beardstown	31.0	207.0—238.0

TABLE II

LOCATION OF PRINCIPAL SAMPLING STATIONS
(BOTTOM FAUNA AND DISSOLVED OXYGEN)
ILLINOIS RIVER, 1913–1915 TO 1925

Sampling stations	Distance below Lake Michigan in miles	
*LaSalle	101.5	
Spring Valley	108.6	
Hennepin	119.5	
Henry	131.0	
*Lacon	137.8	
Chillicothe	146.5	
Rome	149.3	Upper Peoria Lake
Foot of Partridge Island	151.0	Upper Peoria Lake
Spring Bay	153.2	Upper Peoria Lake
Spring Bay Narrows	154.0	Upper Peoria Lake
Mossville	154.9	Middle Peoria Lake
Maple Point	156.6	Middle Peoria Lake
Long Shore Beach	158.2	Middle Peoria Lake
Opposite center of Towhead Island	158.8	Middle Peoria Lake
Al Fresco Park	159.3	Middle Peoria Lake
Peoria Narrows	161.0	Lower Peoria Lake
U. S. Slips (approximate equivalent of Averyville of early collections)	162.8	Lower Peoria Lake
Main Street, Peoria	164.2	Lower Peoria Lake
Peoria and Pekin Union Railway Bridge	166.4	
Wesley	167.8	
Head of Seven Mile Island	170.0	
Pekin	174.0	
Kingston	181.5	
Copperas Creek Dam	190.2	
Liverpool	199.0	
Havana	207.0	
Foot of Matanzas Lake	212.5	
Foot of Grand Island	220.2	
Head of Hickory Island	226.3	
Foot of Hickory Island	228.2	
Beardstown	238.0	
Lagrange Dam (77.5 miles above mouth of River at Grafton)	249.5	

* Quantitative bottom fauna collections between LaSalle and Lacon only in 1923 and after.



Sketch Map of the Illinois River, Showing Location of Principal Sampling Stations

Load of Sewage and Industrial Waste and Zones of Pollution

In the summer of 1914, when the small bottom fauna and the fish fauna of the central portion of the Illinois River, between the head of Upper Peoria Lake and the Lagrange Dam, were both in all their larger features for practical purposes normal, the population of the City of Chicago, more than 140 miles above the head of Peoria Lake, was estimated as 2,437,526, and the population equivalent of the wastes from animals slaughtered at the Chicago Stock Yards was approximately 869,000 persons additional. At that time Peoria and Pekin and suburbs had a combined population of about 86,000 and industrial wastes of unknown population equivalent, though thought to amount to several hundred thousand persons; but all these wastes were absorbed without noticeable effect upon the small bottom animals and without depressing the dissolved oxygen unduly. By 1920, the Chicago population is estimated to have increased around 10 per cent, to about 2,701,000; and the stock yards wastes, in population equivalent equal to 1,040,000, were about 19 per cent greater than in 1914, after having fallen off 353,000 since the peak of the war-time activity of 1918. Between 1914 and 1920, all of the wastes from the sources above described were received by the Sanitary Canal and Illinois River wholly untreated and subject after delivery only to the effects and processes of dilution and biological purification, varying with river levels, temperature, and other physical conditions, as chance might offer.

Between 1914 and 1920, the increase in the combined population of Peoria and Pekin and suburbs, estimated to have been over 11 per cent, but amounting to only about 10,000 in actual human units, was too small to account for any measurable part of the unfavorable changes below those two cities. During the same period, however, there is known to have been large increase in the grind of corn at the Corn Products Refining Company's plant at Pekin, so that the wastes from this plant were increased by an amount possibly almost equivalent to the combined wastes from the human population of the two towns.

Other untreated wastes from the City of Chicago and environs, of which we have incomplete record, included between 1914 and 1920 that from some 300,000 so-called floating population, temporarily in hotels, etc.; as also the wastes from the Corn Products Refining Company's plant at Argo, a suburb of Chicago, and from other industries outside of Packingtown, amounting in all probably to several hundred thousand additional population equivalent. The changes in all these items between 1914 and 1920 were with little doubt upward, in unknown amount, with those at the Argo plant of the Corn Products Refining Company probably holding a leading place in importance. During this six-year period the growth of the other small up-river cities between Peoria-Pekin and Chicago, while relatively considerable, is not thought to have been important in comparison with the other sources of up-river wastes named. All of the Peoria and Pekin wastes, those from Chicago additional to the Packingtown wastes and the sewage of the residential population, as well as the wastes from the mostly small up-river centers of population between Chicago and Peoria were, as was true of the Chicago Stock Yards and residential sewage and that from Pekin and Peoria, received in the raw state, up to and somewhat after 1920. A saving feature of the situation, however, both before and since 1920, has been the fact that, with the exception of the Peoria and Pekin wastes above described, there has been at no time any important contribution of pollution from down-state sources along the Illinois River. Below Peoria and Pekin, in fact, with 150 miles of the trip to the mouth still unrun, such amounts of house sewage and industrial waste as have been received have always been negligible.

The changes in the amounts of waste received from the various sources above mentioned between 1920 and 1925, so far as we have any account of them, were by no means uniformly in one direction, but, so far as they affected materials received from Chicago and vicinity, seem to have about balanced each other *in toto*. These shifts evidently included an unusually heavy rate of increase in the city's human population, which is, in fact, currently estimated as having increased by 400,000—1,000,000 between 1920 and 1927. But to offset this increase, considerable construction of the new sewage treatment plants has already been completed; and there has been reported an 80 to 90 per cent reduction in the amount of waste received from the Corn Products Refining Company's Argo plant, amounting by itself possibly to a few hundred thousand persons, in population equivalent. Further than the fact that the annual pack has recently continued large, we have no information on changes in the volume of Packingtown wastes in the last few years.

Changes between 1920 and 1925 at Peoria-Pekin, though largely conjectural, seem since 1924 to have been on the whole in a downward direction, if we are to draw conclusions from recent changes upward in the dissolved oxygen supply at points below the Copperas Creek Dam. The movement of the population figures during these five years was of course upward, but in too small numbers to affect the sanitary indices noticeably. An apparently much more possible source of the recent improvement below Peoria seems to be in the improvement of the methods of waste disposal used by the Corn Products Refining Company at Pekin, which, it is presumed, made improved clarifying installations at Pekin at or near the same time it made them at Argo (Chicago).

The earlier of the natural reduction processes affecting the organic wastes from Chicago and its suburbs, so far as they occur in the Sanitary Canal and the Illinois River, take place now, as fifteen or more years ago, principally in the first hundred miles outside of the city.

The location of the great septic (polysaprobic) zone, or zone of *Sphaerotilus natans,* lies within this territory, above the city of LaSalle, and does not come within the boundaries of the studies undertaken in this paper. The 136 to 148 miles of the Illinois lying between LaSalle and Beardstown or Lagrange Dam (the latter point located about 77 miles above the mouth of the river) has in recent years been early pollutional to late sub-pollutional (early mesosaprobic *alpha* to late mesosaprobic *beta* in the sense of Kolkwitz and Marsson*), and is briefly characterized by sections and dates, in the paragraphs that follow.

LaSalle to Chillicothe This stretch of 45 miles, which in 1911-1912 was early pollutional to early sub-pollutional (early mesosaprobic *alpha* to early mesosaprobic *beta*) has all been early pollutional (early mesosaprobic *alpha*) since 1920; with bottom oxygen near or at the zero point and *Tubificidae* running into hundreds of thousands per square yard in the summer season.

Upper Peoria Lake If some relatively small areas near shore be excepted, the 7.7 miles of Upper Peoria Lake is apparently best described as early to late pollutional (mesosaprobic *alpha*) in years since 1920. Improvement in sanitary condition is relatively rapid in this short distance, under the influence of retarded current, widely and thinly spread waters, and accelerated growth of an incipient chlorophyllaceous phytoplankton, which had been held back by the conditions prevailing above Chillicothe. The same section marked the lower limit of the sub-pollutional zone (mesosaprobic *beta*) in 1913-1915.

Middle and Lower Peoria Lake Though conditions are mixed, particularly in the lower end of this reach of 12.2 miles, the section may be described, as of seasons since 1920, as principally early sub-pollutional (early mesosaprobic *beta*). The improvement in the bottom muds that took place in the 6.8 miles of the Middle Lake is checked, even in the greater part of the widewaters below Peoria Narrows by wind or wave-borne local pollution from the Peoria sewers. In both the Middle and the Lower Lake the dissolved oxygen, particularly at the surface, frequently goes quite high, but is not a good index of conditions on the bottom, in recent years. This territory was, if small areas near the Peoria water front on the Lower Lake be excepted, principally early clean-water (early oligosaprobic) in 1913-1915.

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* Marsson, M., Die Bedeutung der Flora und Fauna der natürlichen Gewässer für ihre Reinhaltung sowie ihre Beinflussung durch Abgänge von Wohnstätten und Gewerben. Mittlgn. d. Prüfungsanstalt. f. Wasservers. u. Abwbes. Heft. 14; 1911.

Kolkwitz, R., et al., Wasser und Abwasser: Die Hygiene der Wasserversorgung und Abwasserbeseitigung Leipzig, 1911, pp. 1-410; section on biology of sewage effluents, pp. 337-383, and plates.

P. P. U. Bridge to Havana This section of 40.6 miles also presents more or less mixed conditions: receiving the wastes of the Corn Products Refining Company's plants at Pekin, 7.6 miles down; and having a dam at Copperas Creek, at the end of the first 23.8 miles. Since 1920, conditions above the dam have ranged from pollutional to early sub-pollutional (mesosaprobic *alpha* to early mesosaprobic *beta*) over most of the area, and have apparently been largely early sub-pollutional (early mesosaprobic *beta*, in the same period below the dam. In 1913-1915 all this territory was clean-water (oligosaprobic) in the sense as usually understood. For a brief discussion of the visible increase since 1923 in the dissolved oxygen supply in the portion of this zone lying below Copperas Creek Dam, (without corresponding improvement being reflected in the small bottom fauna up to 1925) see the sections on dissolved oxygen, following.

Havana to Beardstown
or
Havana to Lagrange Dam The 31-mile section of river between Havana and Beardstown (corresponding to the 42.5 miles between Havana and Lagrange, 1913-1915) seems to have been mostly late sub-pollutional (late mesosaprobic *beta*) from 1920 to 1923, but to have shifted strongly, as indicated by the dissolved oxygen supply, toward early clean-water (oligosaprobic) between 1923 and 1925, though not yet very clearly so on the basis of the bottom fauna. This change, apparently largely a consequence of improvement in waste disposal at the Corn Products' plants at Pekin, is illustrated by the bottom dissolved oxygen figures in a subsequent section. All of this portion of the river was late oligosaprobic in 1913-1915.

The approximate equivalence of zones from the head of Peoria Lake south in the 1911-1915 and the 1920-1925 periods may be expressed finally as follows: Upper Peoria Lake in 1920-1925 about the same as LaSalle-Spring Valley in 1911-1912 (early pollutional); upper portion of Havana-Beardstown reach about the same in 1920-1923 as Upper Peoria Lake in 1913-1915 (late sub-pollutional); lower portion of reach Havana-Beardstown shifting after 1923 toward the condition of the best open water portions of Middle and Lower Peoria Lake in 1913-1915 (early oligosaprobic). The diagrammatic summary at the end of this section illustrates clearly the favorable effect of the first expansion of the river between Chillicothe and Spring Bay Narrows in checking the extension southward of the upper pollutional area between 1911-1912 and 1920-1925. Thus, the approximate boundary line between the pollutional and sub-pollutional zones *above Peoria* moved down stream not much if any more than 10 miles (or about the length of Upper Peoria Lake) between 1913-1915 and 1920; whereas the boundary between the late sub-pollutional and clean-water, lying in 1913-1915 much closer to the faster current of the Lower Lake, moved more than 50 miles (or from some point in Middle Peoria Lake to Havana or below) in the same time.

CHART SHOWING SHIFTING OF ZONES OF POLLUTION

	Miles below Lake Michigan	1913-1915	1920-1925
LASALLE	101.5	Early Pollutional in 1911-1912	Early Pollutional
SPRING VALLEY	108.6	Early Pollutional to Early Sub-pollutional in 1911-1912 (No collections above Chillicothe in 1913-1915.)	
CHILLICOTHE	146.5	Late Sub-pollutional	Early Pollutional to Late Pollutional
SPRING BAY NARROWS	154.0	Early Clean-water when not affected by local sewage	Principally Early Sub-pollutional (See Text)
PEORIA NARROWS	161.0	Principally Clean-water	Pollutional to Early Sub-pollutional above Copperas Creek Dam; largely Early Sub-pollutional below Copperas Creek Dam
HAVANA	207.0	Clean-water	Principally Late Sub-pollutional 1920-1923 Shifting to Early Clean-water after 1923
BEARDSTOWN	238.0		

Classification of the Species with Reference to Degree of Tolerance

In the comparisons later made in the present paper, illustrating changes in the composition of the small bottom fauna since 1915 in the Illinois River between Chillicothe and Beardstown, seven main groups of species have been recognized in the arrangement of the various kinds in order of tolerance, as follows:

I. **The pollutional group,** embracing seven or eight species that usually reached their highest figures 1920 to 1925 in or above Upper Peoria Lake. Here are included two genera and not less than five or six species of *Tubificidae* and at least two kinds of midge larvae.

II. **The sub-pollutional group, unusually tolerant subdivision;** fifteen species, including several each of *Sphaeriidae*, leeches, midge larvae, and *Bryozoa*. These have an unusually wide range of adaptability under changing conditions; all of them are apparently normal to the cleaner-water zones, but also quite capable of subsisting, and sometimes attaining very large numbers, either in pollutional or sub-pollutional territory. The most important of these from the point of view of numbers is the small bivalve mollusk, *Musculium transversum*, of which we have records in multiples of ten thousand per square yard under the widely varying conditions of the comparatively clean lower and middle Illinois River in 1913-1915, and of the lower pollutional to upper sub-pollutional territory of Upper Peoria Lake between 1920 and 1925. This small bivalve, as well as several midge larvae and leeches, is frequently very closely associated with the more pollutional *Tubificidae* where they occur in greater numbers; and it has been taken since 1920 in numbers around three hundred per square yard at points in the polluted Illinois fully 50 miles above those points in Upper Peoria Lake where the last zero oxygen readings have recently been taken as we pass downstream.

III. **The sub-pollutional group, unusually tolerant or doubtful subdivision.** Here are included several miscellaneous midge larvae, partly incompletely determined, which had a range 1920-1925 all the way from Henry (15.5 miles above the head of Peoria Lake) to Havana and farther south.

IV. **The sub-pollutional group, less tolerant subdivision,** a mixed lot of more than twenty species, largely *Chironomidae* and *Sphaeriidae;* and also including one gastropod, one leech, a few worms, and a few dwarf or young *Unionidae*. These ranged all the way from the upper end of Peoria Lake to Havana and south, under the cleaner-water conditions prior to 1920, but since 1920 have apparently done better under the sub-pollutional conditions between Chillicothe and the foot of Peoria Lake than in any part of the river between Peoria and Beardstown.

V. **Pulmonate snails and air-breathing insects,** five species. These are locally common, usually near the edge, or in unusual current, or in a situation combining both, in 1924 and 1925 collections as far north as Rome (upper end of Upper Peoria Lake); and we have taken them elsewhere in Illinois in similar situations under conditions that can be classed only as pollutional. The normal preference of all these surface and edge forms is for clean water, and they are wholly lacking in index value in connection with the study of stream pollution.

VI. **Current-loving species other than pulmonate snails and air-breathing insects,** with normal preference for cleaner water, but able to endure the conditions of the sub-pollutional zone in case there is unusual current. Here are placed a dozen or more kinds in all, including two *Pleuroceridae,* one isopod *(Asellus intermedius),* several sponges and *Bryozoa,* and several *Hydropsychidae,* the latter all undetermined, but of known habit and distribution. The index value of these species, though without question they are to be regarded for the most part as strictly clean-water forms, is poor, and their inclusion in lists without qualification is very likely to be misleading.

VII. **Cleaner-water species,** about thirty species in all, including a limited number of *Crustacea* and *Bryozoa;* several snails each of the families *Valvatidae, Amnicolidae,* and *Viviparidae;* a few kinds of dwarf or young *Unionidae;* a few kinds each of immature *Ephemeridae, Odonata,* and *Chironomidae;* an immature sialid; a few immature *Trichoptera;* and a few adult or larval *Coleoptera.* It has been convenient to subdivide this group, from the Illinois River 1920-1925, into a less sensitive and more sensitive subdivision, each including about half of the total as given.

Of the **less sensitive subdivision** we noted occasional occurrences 1920 to 1925 in the open water of the sub-pollutional zone (Middle Peoria Lake), though the majority of occurrences recorded at stations above Copperas Creek Dam in this period were from the edges. These species normally belong to the clean-water zones south of Peoria, but seem to have been largely exterminated there between 1915 and 1920, and not yet to have been reestablished in important numbers. The index value of the few occurrences in Peoria Lake recently is doubtful, because of the possible existence of springs under the lake bed there, as is known to be the case in the immediate vicinity of Spring Bay.

The **more sensitive subdivision** of the cleaner-water group includes species which have been confined in recent years to the edges or to unusual current, in cases where they do occur at all at points in Peoria Lake or elsewhere above Copperas Creek Dam. Most of these, like the less sensitive group, are recently absent or very rare in the reaches of river between Copperas Creek Dam and Beardstown, though most of them were common there, at least locally, in the period 1913-1915. Occurrences of members of this group at edges have no index value.

In the following list of small bottom invertebrates, upwards of one hundred kinds (if allowance is made for several cases of two or more undetermined forms grouped together) taken in the Illinois River since 1920 in the 136.5 miles between LaSalle and Beardstown are assigned places in one or another of the seven groups above outlined. Under each group, and to a considerable extent throughout the entire list, account is taken in each case of farthest northward occurrence in the more polluted sections of the Illinois River studied since 1920. Other considerations taken into account in determining the order of arrangement, of pollutional or unusually tolerant species in particular, have been: outside data on distribution and tolerance to pollution; association with other species of known pollutional or tolerant habit; survival under conditions of low dissolved oxygen supply, or where formerly-present clean water forms have been destroyed; and, in general, relative abundance or rarity before and since the great increase in pollution in and below Peoria Lake about ten years ago. All of the records have been considered in the light offered by data on the dissolved oxygen; as well as the usual or unusual physical or hydrographical factors that might be concerned. For just as the pollutional or unusually tolerant kinds may have an extreme range that carries them far outside of the pollutional or sub-pollutional zones downstream into relatively clean water, so may many of the clean-water species—under the protection of unusual current, or spring water, or proximity to aquatic vegetation, or to the margins (where the wash, or wind and wave effects, result in mechanical reaeration)—advance long distances upstream occasionally into the more polluted zones. These exceptional occurrences in all the more important instances, have been given separate listing; this is a point of especial importance in Peoria Lake recently in the case of several clean-water forms found sparingly in restricted situations outside of their general boundaries, and likely to mislead the inexperienced worker into assuming a much greater degree of improvement in sanitary condition than has actually occurred over the major part of the area in the time covered by the observations.

In the complete list of species of small bottom animals that follows, a half dozen of the names, among the first 12 entries, are marked with one or two stars (*;**), the latter number signifying unusual index value. The six starred kinds include all taken between 1920 and 1925 in the pollutional to late sub-pollutional territory between LaSalle and Beardstown that occurred in large enough numbers to be listed as common or abundant. Brief notes concerning the index value of these six species accompany their names in the running list. Some further discussion of main points concerning the value of the small bottom invertebrates as indicators of pollution, as based on our recent Illinois River data, will be found in the special section on that topic next following. The relatively few cleaner-water kinds taken at open-water stations in the sub-pollutional sections between Middle Peoria Lake and Beardstown since 1920 were in no case present in average numbers more than negligible as compared with the abundance of the same or similar kinds in the same territory in the 1913-1915 period.

TABLE III

LIST OF SPECIES OF SMALL BOTTOM ANIMALS TAKEN IN THE ILLINOIS RIVER, LASALLE TO BEARDSTOWN, 1920 TO 1925, ARRANGED IN APPROXIMATE ORDER OF TOLERANCE

Classification	Farthest upstream occurrence in open† water
I. **Pollutional**; in general, more common in the pollutional zone than below it.	
**1. *Tubifex tubifex.* A species of unusual index value; frequently reaches very large numbers in the lower end of the septic or upper end of the pollutional zone.	LaSalle
**2. *Limnodrilus hoffmeisteri.* Likely to occur in extremely large numbers throughout the pollutional zone. Index value somewhat less certain than that of the preceding species.	LaSalle
3. *Limnodrilus* sp. 3	LaSalle
4. *Limnodrilus* sp. 4	Hennepin
5. *Tubifex* sp.	Henry, above dam
**6. *Chironomus plumosus*, var., larva. Frequently occurs in very large numbers throughout the pollutional zone, though much less regularly so than *Limnodrilus hoffmeisteri.* Ventral blood gills vary in length as dissolved oxygen increases or decreases. Not taken by us in the septic zone of the Illinois River except at edges.	Henry, above dam
7. *Chironomus decorus*, larva	Lacon
8. *Limnodrilus claparedianus*	Chillicothe
II. **Subpollutional, unusually tolerant**; common to abundant at some stations in the pollutional zone; but with original natural preference for the subpollutional or cleaner water zones.	
*9. *Musculium transversum.* Extremely abundant in the pollutional zone in company with *Limnodrilus hoffmeisteri*, *Tubifex tubifex*, and *Chironomus plumosus*. No index value; equally common in some situations on clean bottom, and believed to be a case of recent adaptation.	LaSalle
*10. *Chironomus lobiferus*, larva. Occasionally or locally abundant in the pollutional zone; evidently has a distinct pollutional habit; but of too irregular occurrence to have great index value.	LaSalle
11. *Musculium truncatum*	Hennepin
*12. *Helobdella stagnalis.* Occasionally or	Hennepin

**;* For meaning of stars preceding names of species, see p. 405.
† With exceptions noted on p. 409.

TABLE III—*Continued*

locally abundant in the pollutional and subpollutional zones; but no definite connection with pollution, as such, apparent.	
13. *Dina microstoma*	Hennepin
14. *Glossiphonia complanata*	Hennepin
15. *Pisidium compressum*	Henry, above dam
16. *Tanypus* sp. 1, larva	Lacon
17. *Tanypus* sp. 3, larva	Lacon
18. *Plumatella princeps* var. *mucosa*	Lacon
19. *Dina parva*	Lacon
20. *Plumatella princeps* var. *fruticosa*	Chillicothe
21. *Erpobdella punctata*	Chillicothe
22. *Helobdella nepheloidea*	Chillicothe
23. *Hyalella knickerbockeri* [1]	Henry, below dam, in current
III. **Sub-pollutional, unusually tolerant or doubtful;** species undetermined; numbers not important.	
24. *Tanypus* sp., larva	Henry, below dam
25. *Chironominae*, gen. and spp., undetermined, larvae	Lacon
26. *Tanypinae*, gen. and spp., undetermined, larvae	Lacon
27. *Chironomus* sp., larva	Chillicothe
IV(a). **Sub-pollutional, less tolerant, more common species;** normally preferring clean water; but able to stand sub-pollutional conditions even where the current is slight.	
28. *Pisidium pauperculum* var. *crystalense*	Rome
29. *Pisidium complanatum?*	Rome
30. *Sphaerium striatinum* var. *corpulentum*	Rome
31. *Campeloma subsolidum*	Rome
32. *Pisidium* sp.	Spring Bay
33. *Sphaerium striatinum* var. *lilycashense*	Spring Bay
34. *Sphaerium stamineum*	Spring Bay
35. *Procladius concinnus*, larva	Spring Bay
36. *Cryptochironomus digitatus*, larva	Spring Bay
IV(b). **Sub-pollutional, less tolerant, less common species;** normally preferring clean water; but able to stand sub-pollutional conditions even where the current is slight.	
37. *Tanypus dyari*, larva	Rome
38. *Tanypus monilis*, larva	Rome
39. *Procladius sp.*, larva	Rome
40. *Oligochaeta*, gen. and spp. undetermined	Rome
41. *Palpomyia* sp., larva	Spring Bay
42. *Placobdella rugosa*	Spring Bay
43. *Anodonta imbecillis*	Mossville
44. *Lampsilis* sp., young.	Mossville
45. *Naididae*, gen. and spp. undetermined	Mossville

[1] This species was taken as far north as Spring Valley in 1911-1912.

TABLE III—*Continued*

Classification	Farthest upstream occurrence in open water
46. *Gordiidae*, gen. and spp. undetermined	Long Shore Beach
47. *Orthocladius* sp.	Wesley, strong current
48. *Lampsilis gracilis*, young.	Wesley, strong current
49. *Polypedilum* sp., larva	Seven Mile Island, strong current
V. **Pulmonate snails and air-breathing insects;** locally common near edges or in unusual current, of either pollutional or sub-pollutional zone; index value none; normal preference for clean water.	
50. *Physa sayi*	Rome
51. *Planorbis trivolvis*	Rome
52. *Arctocorisa* sp.	Peoria Narrows, strong current
53. *Lymnaea humilis*	Peoria Narrows, strong current
54. *Ferrissia rivularis*	Peoria Narrows, strong current
VI. **Current-loving or edge-dwelling, purely aquatic species,** able to endure conditions in the sub-pollutional zone provided there is more than usual current; numbers small; index value poor.	
55. *Planaria*, gen. and spp. undetermined	Spring Bay, current
56. *Asellus intermedius*	Spring Bay, current
57. *Dero* sp.	Peoria Narrows, current
58. *Spongilla fragilis*	Peoria Narrows, current
59. *Pleurocera acutum*	Peoria Narrows, current
60. *Goniobasis livescens*	Peoria Narrows, current
61. *Plumatella princeps* var. *mucosa-spongiosa*	Peoria Narrows, current
62. *Hydropsyche*, spp. undetermined (at least four), larvae	Peoria Narrows, current
63. *Urnatella gracilis*	McKinley Bridge, current
64. *Paludicella ehrenbergii*	McKinley Bridge, current
VII(a). **Cleaner-water species, less sensitive group;** occasional occurrences in open water in the sub-pollutional zone, but usually taken 1920 to 1925 only at or near edges in Peoria Lake and at other stations above Copperas Creek Dam; these species normally belong to the clean-water zones, below Havana, at present, but are rare and scattering even there since 1920. Index value of occurrences in open water in Peoria Lake doubtful in several cases, because of possibility of existence of springs under the lake bed. (See also pp. 454-458, on *Unionidae*.)	
65. *Valvata tricarinata*	*Mossville
66. *Valvata bicarinata* var. *normalis*	*Mossville

TABLE III—*Concluded*

67. *Caenis* sp. 1, nymph	*Mossville
68. *Valvata bicarinata*	*Maple Point
69. *Vivipara contectoides*	*Maple Point
70. *Amnicola emarginata*	*Maple Point
71. *Sialis infumata*, larva	*Long Shore Beach
72. *Pectinatella magnifica*	*Al Fresco
73. *Plumatella polymorpha* var. *repens*	*Wesley, current
74. *Gomphus plagiatus*, nymph	*Kingston
75. *Gomphus externus*, nymph	*Kingston
VII(b). **Cleaner-water species, more sensitive group;** occasional occurrences, at edges or in unusual current only, at stations between upper end of Middle Peoria Lake and Copperas Creek Dam. Most of them still absent or very rare in the reaches between Copperas Creek Dam and Beardstown, though most of them were formerly common there at least locally. Index value none when they occur at edge.	
76. *Tropisternus dorsalis*, adult	†Rome
77. *Ischnura verticalis*, nymph	†Rome
78. *Lampsilis parvus*	†Mossville
79. *Vivipara subpurpurea*	†Mossville
80. *Lioplax subcarinatus*	†Mossville
81. *Anax junius*, nymph	†Mossville
82. *Rhyacophila* sp., larva	†Mossville
83. *Amnicola limosa*	†Long Shore Beach
84. *Enallagma signatum*	†Al Fresco
85. *Somatogyrus subglobosus*	†Peoria Narrows, current
86. *Leptoceridae*, gen. and spp. undetermined, larvae	†Peoria Narrows, current
87. *Palaemonetes exilipes*	†Peoria Narrows, current
88. *Hexagenia bilineata*, nymph	‡†Pekin, one occurrence, 1923
89. *Cordylophora lacustris*	†Kingston, one occurrence, 1923
VII(c). **Cleaner-water species, more sensitive group;** not taken above Copperas Creek Dam at all in years since 1920; and only scattering occurrences below Copperas Creek Dam in recent period; the last named, *Chironomus ferrugineovittatus*, was very common in Illinois River black muds as far north as Copperas Creek Dam in 1913-1915.	
90. *Truncilla donaciformis*	Havana
91. *Truncilla elegans*	Matanzas
92. *Polycentropus* sp., larva	Copperas Creek Dam, below
93. *Molannidae*, gen. and spp. undetermined.	Havana
94. *Chironomus ferrugineovittatus*, larva	Matanzas

* Farthest north in open water.
† Farthest north at edges or in unusual current.
‡ This was the single occurrence in collections above Havana between 1920 and 1925; was taken in 1913-1915 as far north as Upper Peoria Lake.

Some Principal Points Regarding Index Value

Various extensive published lists, as well as questions frequently asked by workers newly interested, seem to imply, to say the least, an overconfidence in the simplicity and efficacy of the use of a few or many so-called index organisms in the determination of degrees of stream pollution. Less frequently are we asked to name those kinds, particularly of small bottom organisms, which are likely to be most useful for that purpose. This question often appears to be a definite reflection of the fact that various published lists, including our own, are much too long to be useful to the uninitiated worker without a good deal of explanation; as both it and other variations of inquiry seem to result from an impression that biological determinations of the extent of injury by sewage or other waste can be made by a more or less rule-of-thumb mechanical method, the practice of which calls for little by way of preliminary knowledge, except the names and identity of the species. As a matter of fact, the number of small bottom-dwelling species of the fresh waters of our distribution area that can be safely regarded as having even a fairly dependable individual index value in the present connection is surprisingly small; and even those few have been found in Illinois to be reliable as index species only when used with the greatest caution, and when checking with other indicators.

The septic zone is, however, as compared with the pollutional and sub-pollutional zones next below it, much the more easily recognizable, whether by chemical determinations, by its physical appearance and its odors, or by a limited number of characteristic organisms ordinarily found in quite large numbers in various situations within it. But, as illustrating the lack of fixed rules even in this zone, the most abundant and characteristic plankton species of all the septic kinds taken in the upper Illinois River in 1911-1912, *Sphaerotilus natans,* was wholly absent from the middle and lower end of the Chicago Sanitary Canal, where examined the same seasons, although those waters were and are also septic. Again, *Tubifex tubifex* and other associated *Tubificidae,* commonly regarded as characteristic of the septic zone, were distinctly most abundant toward the lower rather than the upper end of the septic zone of the upper Illinois in 1911-1912; while in the lower end of the Sanitary Canal, also septic, they were wholly absent in all bottom dredgings in those years.

The most serious limitations on the use of the members of the small bottom animal population as indices in the pollutional zone, which is at the same time unusually difficult to recognize either from its physical or chemical features, have to do both with their frequently very confusing latitude of distribution and with the fact that so few of them occur in numbers large enough to encourage their individual use as indicators. As an actual example, it is found that out of a total of more than 27 kinds of miscellaneous small bottom animals taken in the pollutional zone between LaSalle and the foot of Upper Peoria Lake in the four years of collecting between 1920 and 1925 only two, that is, one tubificid worm (*Limnodrilus hoffmeisteri*) and a single larval chironomid (*Chironomus plumosus*), could be said to have been generally common enough over wide ranges and to have fulfilled at the same time the other requirements necessary to encourage moderate confidence in their value as indicators when taken by themselves. But of these at least one, the pollutional chironomid, *Chironomus plumosus*, has usually been classified heretofore as septic; as has apparently also been the case a good deal of the time with *Limnodrilus hoffmeisteri*, a species very easily confused, in the absence of laborious microscopic examination, with *Tubifex tubifex*. A second pollutional or unusually tolerant chironomid larva, *Chironomus lobiferus*, occasionally has occurred recently in rather large numbers in the middle Illinois River, but at such widely separated points as to remove it from consideration as an important index species. The single remaining species, of the 27 kinds mentioned above, that has recently shown great abundance over wide territory, the small bivalve mollusk, *Musculium transversum*, in its turn, cannot be regarded as having any index value at all. Although necessarily listed as an occasional pollutional species, because of its close association with *Limnodrilus hoffmeisteri* and *Chironomus plumosus* in pollutional muds above Peoria, it is correctly regarded merely as a case of unusual adaptability in a form that normally reaches quite as large numbers under clean-water conditions as those recently recorded by us in the pollutional territory of Peoria Lake and the neighboring parts of the Illinois River.

Still confining ourselves for illustration to the pollutional zone, and assuming that both *Limnodrilus hoffmeisteri* and *Chironomus plumosus* have been recorded as present, we may inquire what standards, if any, are to be followed in striking the boundary line between numbers that are important and numbers that are best disregarded. It is as well to say at once that the question cannot be answered; for the interpretation of degrees of abundance, both of individual species and of small groups of kinds with similar habit, is extremely likely to be a wholly relative matter. Thus, in 1923-1925, we found the combined tubificid totals per square yard varying from under 1,000 to over 350,000 in the pollutional territory above Chillicothe at individual stations without having any ground for supposing conditions better at the one class of stations than the other. Likewise we have instances where *Chironomus plumosus* varied from near zero to more than one thousand per square yard in the same territory in the same season or between two seasons, without any evidence of change in sanitary condition appearing in the interval. Floods may carry away eggs or young midge larvae; severe winds may blow away swarms locally after emergence but before egg-laying; or bottom sampling may be done when the stages present are too small to be recognizable by the ordinary methods of recovery employed. On the other hand, numbers, whether of worms or midge larvae, that may appear low in comparison with some of the lowest we have mentioned may be significant of serious change in sanitary condition when compared with average previous rates of occurrence of the same forms in the same area.

Individual species quite unusable alone for various reasons as index organisms frequently acquire a cumulative value for that purpose as they come to be grouped together, particularly when there are lists of former inhabitants of the same area under presumably cleaner-water conditions for comparison. Here kind is very likely to become more important than numbers, and a knowledge of the previous history of the same or similar areas more important than any number of previously compiled lists of so-called key organisms graded according to index value. A good proportion of the conclusions presently drawn from the study of our recent Illinois River data are based upon this sort of grouping, as opposed to individual index value.

Not infrequently absence or much reduced numbers of formerly present clean-water species in an area may be quite as important or even more so than numbers of known pollutional forms found in determining degree of present or recent pollution. The pollutional forms themselves may be largely excluded by the nature of the original bottom, as was recently the case in several short hard-bottomed reaches of the Illinois River only a short distance below the foot of Peoria Lake. Still again, there may be other special invisible excluding factors, as toxic factory wastes, operating against the successful entrance of pollutional species in normal numbers into a polluted area. And, as a concluding illustration, in essentially late sub-pollutional territory, the condition of the bottom may be fairly good over a large portion of the year, and the absence or scarcity of cleaner-water forms may indicate the periodic incursion of pollution with sudden or prolonged increase of water levels. When a good supply of pollutional forms are present, on the other hand, the fact of absence of formerly present clean-water kinds may have considerable value as an additional check. And in the absence of any knowledge of the previous history of the same area, lists of species from similarly conditioned and located unpolluted territory may serve, to some extent, the same purpose.

An almost inextricable confusion of all zones from septic to clean-water is frequently met with in very shallow streams supplied with vegetation during the heated season, though scarcely less so than may sometimes occur very close to the margins of some large lakes and rivers. Herein lies the explanation of the comparatively rapid rate of self-purification found by Weston and Turner* in the Coweeset River below Brockton, Mass.; and by ourselves in 1914 in the Fox River below Aurora and below Elgin, where the transition in mid-channel, in each case below a dam, from late septic or early pollutional to practically a clean-water fauna was accomplished under midsummer low-water conditions in a distance of hardly more than 3 miles. In such very shallow areas

* Weston, Robert Spurr, and Turner, C. E. Studies on the digestion of a sewage filter effluent by a small and otherwise unpolluted stream. Contribution from San. Research Lab., Mass. Inst. Techn., vol. X, pp. 1-96; 1917.

the rate of reaeration from the plants customarily results in long continued supersaturation; and the various oxidizing and reducing processes, as well as the growth of the attendant organisms, are no doubt further accelerated both by the higher temperatures and the better access to light supplied.

Because of all of the various complexities above mentioned, and others, including those introduced by shifts from one to another distribution area, it can be seen that the individual student of the biological side of stream pollution in a new locality is bound sooner or later to be forced back upon his own resources to a large extent. He is very likely to find, in fact, that it is only after he has worked up his own species lists and arrived at his own conclusions as to index value and interpretations based upon it, whether as affecting individual species or groups, that previously published data from outside areas begin to fall into place and to serve a really practical use for final checking and comparison.

While certain strictures on the value of dissolved-oxygen readings as indicators are made in this paper, there has been no intention unduly to minimize the value either of that or the other usual chemical indices. The cases noted as calling for particular caution are those of lag of the bottom condition behind that of the plankton and the oxygen supply. These are most frequent in streams where there is a sudden and marked slowing up of current that continues long enough to permit the rapid multiplication of chlorophyll-bearing plant and animal plankton, without allowing a permanent and parallel improvement on the bottom in the same time over the same ground. Such instances aside, it must be said frankly that the simple procedure of listing side by side our recent dissolved-oxygen readings and the farthest upstream occurrences of our various Illinois River bottom species from the unwidened Illinois River and Peoria Lake channel both above and below Peoria has served as one of the most important general sources of aid in getting order out of the chaos that seemed to reign in all directions when the unorganized data were first spread out for study. Both for that and for other reasons the writer is strongly of the opinion that dissolved-oxygen determinations should hold a fixed place as accessory routine in all biological studies of stream pollution.

If the problem set involves nice determination for the first time of the boundary lines between zones in the Kolkwitz-Marsson* schedule of self-purification, figures for free ammonia and nitrates, particularly if expressed as percentages of total nitrogen, also will be found of value. Because of the wide range of error due to the variable mortality of the less pollutional plankton organisms during the incubation period and to other interfering factors likely to enter at any point below the septic zone, the usefulness of bio-chemical oxygen-demand determinations is quite likely to prove doubtful except as a test of the strength of raw sewage or relatively young effluents.

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* For bibliographical references, see p. 400.

Changes in the Number of Species Taken and Missing

Reduction in the total number of different kinds taken between 1913-1915 and 1920.

Severe downward changes in the total number of kinds of small bottom animals taken occurred in all sections of the river and Peoria Lake between Chillicothe and Beardstown between 1913-1915 and 1920. In the three subdivisions of Peoria Lake the reductions ran in all cases over 50 per cent: being 69 per cent in the Upper Lake, 72 per cent in the Middle Lake, and 50 per cent in the Lower. The largest percentage and absolute reduction of all, 83 per cent, occurred in the approximately 41 miles between the foot of Peoria Lake and Havana, where the total number of kinds taken dropped from 91 to 15 in the five-year period. In the 31 miles between Havana and Beardstown there was a decrease in the same time of 48 per cent, or from 43 to 22 kinds.

The largest decrease quite naturally took place in the section of river between the foot of Peoria Lake and Havana, where both the total number of all kinds and the number of cleaner-water kinds had been highest five years previously. The percentage losses in Upper and Middle Peoria Lakes were also not much less (69 and 72 per cent) than between the foot of Peoria Lake and Havana, though the absolute losses were conspicuously less, because of previous contraction of the lists in response to mild pollutional conditions that prevailed before 1920. The sizably smaller percentage loss in the Lower Lake (52 per cent) was no doubt in great part due to the much better protection afforded by the unusually rapid current that prevails over a large part of that area. The smallest loss of all, 48 per cent, in the section next below Havana, was probably due both to the tapering off of the pollution with distance and to the rather better average rate of current in a large portion of that section than in the 41-mile section just above.

Reasons why the reduction of the lists was not even more complete, particularly in the Peoria Lake region, and in the sections of river more immediately below Peoria, are to be found chiefly in the fact that in all of the subdivisions considered between Chillicothe and Beardstown a rather large but varying number of species were, even as early as 1913-1915, of such kinds as we might expect to show considerable tolerance. A table showing the total number of pollutional, ususually tolerant, and tolerant kinds contained in the 1913-1915 lists is given on page 419. Those figures show that 38 to 51 per cent of the total number of species present in the three sections of Peoria Lake in 1913-1915 were assignable to either one or another of the pollutional, unusually tolerant, or tolerant groups; while in the section Wesley to Havana the percentage was 24, and in Havana-Beardstown it was 32.

The increases in the total number of all kinds of small bottom species taken in the various reaches between 1920 and 1925 were due principally to increases in the more tolerant kinds, and are discussed in the sections immediately following.

TABLE IV

TOTAL NUMBER OF SPECIES TAKEN, EXCLUSIVE OF EDGE FORMS AND THOSE PROTECTED BY UNUSUAL CURRENT

Reaches	1913-1915	1920	Per cent decrease 1915 to 1920	1924	1925
Upper Peoria Lake	33	10	*69*	18	17
Middle Peoria Lake	36	10	*72*	34	33
Lower Peoria Lake	44	22	*50*	25	26
Foot of Peoria Lake to Havana	91	15	*83*	21	28
Havana to Beardstown	43	22	*48*	16	27

Reduction of the number of clean-water species taken between 1913-1915 and 1920; and slow rate of replacement since 1920.

Quite as good if not better than the totals of all kinds taken, as a measure of the effects of the wave of pollution of 1917*-1920 and the very mild improvement in sanitary condition that has taken place since, are the changes in the number of clean-water kinds of small bottom animals taken in the various sections of the river between 1913-1915 and 1925. The figures used in these comparisons are in all cases the numbers left after deduction of species found only at the edges or in unusual current. Summarized, these show: in Upper Peoria Lake a decrease from 11 clean-water kinds to none at all between 1913-1915 and 1920; in Middle Peoria Lake a decrease from 18 in 1913-1915 to none in 1920; in the Lower Lake a drop from 15 in 1913-1915 to none in 1920; in the 40 miles from Wesley to Havana a drop from 49 to 3; and in the 31 miles from Havana to Beardstown a drop from 17 in 1913-1915 to only 6 in 1920.

The very slow rate of replacement of clean-water species between 1920 and 1925 was most noticeable in Upper and Lower Peoria Lakes, where the number taken, after edge-forms are deducted, remained at zero throughout the four collecting years 1922-1925, with the single exception of one occurrence in the open water of Lower Peoria Lake in 1922. In the Middle Lake the number of clean-water species taken in open water remained at zero through 1922, but stood at 3 in 1923 and rose to and remained at 5 through 1924 and 1925. These were all isolated occurrences, in very small numbers, usually only a single specimen or two in a haul; and they may quite possibly mark the location of scattered springs under the lake bed, such as are known to occur in the lower part of the Upper Lake where several species of *Unionidae* were found unexpectedly surviving in 1924 and 1925.

* See p. 439 and reference mentioned in footnote on same page.

In the combined stretches of river between Peoria and Havana the number of clean-water kinds of small bottom animals taken varied rather widely between 1920 and 1925, but ended in 1925 with only 4 as compared with 3 in 1920 and 49 in 1913-1915. In the section between Havana and Beardstown, rather similarly, the number of clean-water kinds taken actually dropped between 1920 and 1924, and had risen only negligibly in 1925 as compared with 1920. It is of course to be kept in mind that the persistence of a small number of kinds is not so conclusive of continuing unchanged pollution, as the sharp reductions between 1913-1915 and 1920 were of its incidence; since it is quite within the possibilities for improvement to occur (as we think it has since 1923 below Copperas Creek Dam) at a visibly more rapid rate than the locally exterminated species are able by natural means to reestablish themselves.

TABLE V

NUMBER OF CLEAN-WATER SPECIES TAKEN, EXCLUSIVE OF EDGE-FORMS AND THOSE PROTECTED BY UNUSUAL CURRENT

Reaches	Total of all kinds taken 1913-1915 for comparison	1913-1915	Per cent of 1913-1915 total	1920	1922	1923	1924	1925
Upper Peoria Lake.....	33	11	*33*	0	0	0	0	0
Middle Peoria Lake....	36	18	*50*	0	0	3	5	5
Lower Peoria Lake....	44	15	*34*	0	1	0	0	0
Foot of Peoria Lake to Havana	91	49	*53*	3	no collections	8	0	4
Havana to Beardstown.	43	17	*39*	6	no collections	3	2	7

The species from the 1913-1915 lists missing 1920 to 1925. In all three sections of Peoria Lake and in the forty odd miles between Peoria and Havana the number of kinds of small bottom animals from the 1913-1915 lists that had shifted to the missing column by the summer of 1920 ran from nearly three-fourths to more than seven-eighths, in individual reaches, of the original 1913-1915 totals. The actual number of kinds missing and the percentage in each case was: Upper Peoria Lake, 26 missing, or 78 per cent; Middle Peoria Lake, 32 missing, or 88 per cent; Lower Lake, 32 missing, or 72 per cent; Wesley-Havana, 78 missing, or 85 per cent. The close agreement of the percentages missing in Peoria Lake and in the first forty odd miles below, in 1920 apparently results from the fact that in the three subdivisions of the Lake, where there were already in 1913-1915 relatively large numbers of tolerant or unusually tolerant kinds, the wave of pollution originating at Chicago was heaviest; while in the first 40 miles below Peoria, where the combined Chicago and Peoria load was probably on the average somewhere near the same, there was a visibly larger percentage of clean-water and less tolerant kinds.

The smallest of all the missing lists, that in the 30 miles between Havana and Beardstown, which stood at 27 in 1920, representing a loss of 62 per cent from the 1913-1915 total, was itself far from small. The moderately better showing made there in 1920 than in the sections of river immediately northward was of course largely a matter of the greater distance from the sources of pollution upstream.

The rate of replacement of missing species between 1920 and 1925 was fairly uniform over the three sections of Peoria Lake, and was more rapid in all three of them than in the next 70 miles of river below Peoria. Thus, the portion of the 1913-1915 lists missing dropped in the three subdivisions (Upper, Middle, and Lower Peoria Lake) from 78 per cent, 88 per cent, and 72 per cent to 57 per cent, 63 per cent, and 63 per cent, in order downstream. In rather sharp contrast, in the 40 miles between Peoria and Havana, the percentage missing dropped between 1920 and 1925 only from 85 per cent to 79 per cent. The difference in rate of replacement between this section of the river and Peoria Lake is clearly a consequence of the larger proportion of relatively sensitive species and the smaller percentage of unusually tolerant kinds found here in recent years, together with the naturally slower rate of reestablishment of the more sensitive forms. In the lowermost section of the river studied 1920 to 1925, Havana to Beardstown, as in the reach Peoria-Havana, and apparently in large part for similar reasons, the size of the missing list changed hardly noticeably during the five-year period, the percentage of the 1913-1915 list missing standing at 58 in 1925 as compared with 62 in 1920.

TABLE VI

TOTAL NUMBER OF SPECIES FROM 1913-1915 LISTS MISSING

Reaches	Total of all kinds taken 1913-1915 for comparison	1920 missing	Per cent of 1913-1915 total	1924 missing	1925 missing	Per cent of 1913-1915 total
Upper Peoria Lake...	33	26	*78*	21	19	*57*
Middle Peoria Lake...	36	32	*88*	20	23	*63*
Lower Peoria Lake...	44	32	*72*	30	28	*63*
Foot of Peoria Lake to Havana	91	78	*85*	76	72	*79*
Havana to Beardstown	43	27	*62*	28	25	*58*

The changes in the total number of pollutional, unusually tolerant, and tolerant kinds taken.

When we add together, for each section of the river and Peoria Lake studied, the pollutional, unusually tolerant, and tolerant kinds of small bottom animals taken in the 1913-1915 period of relatively clean water and compare with the totals of the same groups for 1920, immediately following the severe wave of pollution that destroyed most of the cleaner-water species, it is surprising at first to note that with but one short reach (Lower Peoria Lake) excepted, these numbers decreased also, rather than increased, as the clean-water species declined. Thus the total of pollutional, unusually tolerant, and tolerant kinds fell from 17 to 10 in the Upper Lake between 1913-1915 and 1920; from 15 to 10 in the Middle Lake; from 22 to 12 in the section between Wesley and Havana; and from 14 to 10 in the section between Havana and Beardstown. The only increase occurred in Lower Peoria Lake, where the total of pollutional, unusually tolerant, and tolerant kinds rose from 17 to 20 between 1913-1915 and 1920.

Next we notice that between 1920 and 1922, as conditions on the bottom became slightly, but only slightly, better, the total of pollutional, unusually tolerant, and tolerant species rose sharply in the two upper sections of Peoria Lake, and moderately (20 per cent) in Lower Peoria Lake. These increases were added to in all three sections of Peoria Lake between 1922 and 1923; and the change between 1923 and 1925 left the figures either larger or negligibly less than in 1922. In the river between Peoria and Havana also the total number of pollutional, unusually tolerant, and tolerant kinds nearly doubled between 1920 and 1923, dropped back again close to the 1920 figure in the severe flood summer of 1924, but rose again to the 1923 figure in 1925. In the section between Havana and Beardstown there was the least increase between 1920 and 1923 (only 10 per cent), but after remaining unchanged through the severe flood of 1924, it nearly doubled in 1925.

The first reason to be noted in explanation of these changes is that neither the various sections of Peoria Lake nor the sections of the river proper studied between Peoria and Beardstown were even approximately clean five to seven years before 1920, though the latter two sections or at least the last one were relatively much more so than the lake. Second to be noted is that not merely the unusually tolerant and less tolerant species of our presently adopted classification, but also most of the pollutional species have an exceedingly wide range of distribution, which normally carries them, at least in moderate or small numbers, into relatively clean-water territory. In other words, the pollutional, unusually tolerant, and tolerant species were already there in 1913-1915, to decrease or increase as conditions might warrant. So, in the Upper Lake the combined number of pollutional, unusually tolerant, and tolerant kinds made up 51 per cent of the total of all kinds; in Middle Peoria Lake it made up 41 per cent; in the Lower Lake 38 per cent; and even

TABLE VII

CHANGES IN THE TOTAL NUMBER OF POLLUTIONAL, UNUSUALLY TOLERANT, AND TOLERANT KINDS TAKEN

Reaches	Total of all kinds taken 1913-1915 for comparison	1915 1913-	Per cent of 1913-1915 total	1920	1922	1923	1924	1925	Increase in total of all kinds 1920-1925	Increase in combined number of pollutional, unusually tolerant and tolerant kinds 1920-1925
Upper Peoria Lake..........	33	17	*51*	10	18	25	18	17	7	7
Middle Peoria Lake..........	36	15	*41*	10	20	31	29	28	23	18
Lower Peoria Lake..........	44	17	*38*	20	24	28	24	26	4	6*
Foot of Peoria Lake to Havana	91	22	*24*	12	no collections	23	15	20	13	8
Havana to Beardstown........	43	14	*32*	10	no collections	11	11	18	5	8*

* Figure larger than that in column before it because of decrease in number of cleaner-water kinds in the period.

in the reaches between Peoria and Havana and Havana and Beardstown, it made up 24 and 32 per cent of the totals of all kinds taken.

The noticeable decreases in the total number of pollutional, unusually tolerant, and tolerant kinds of small bottom animals recorded as pollution increased between 1913-1915 and 1920 in all sections of the river here compared were naturally greatest in the two last-named groups of the three. The very marked rise in the abundance of the *Tubificidae* in Upper Peoria Lake after 1920, as the condition of the bottom muds remained substantially unchanged or improved but slightly, however, suggests that even some of the pollutional kinds may at times be subjected to periods of low oxygen that are longer and more severe than they are equipped to stand.

The good increases in totals of pollutional, unusually tolerant, and tolerant kinds between 1920 and 1925 are believed to suggest improvement in the condition of the bottom muds as compared with conditions at a hypothetical apex of pollution shortly before 1920 rather than in that year. And the relatively slight improvement on the bottom indicated by the failure of the cleaner-water kinds of small bottom animals to increase and of the supply of bottom dissolved oxygen to improve above Copperas Creek Dam since 1920 is further confirmed by the fact that in all reaches above Beardstown the increase in the total number of kinds of small bottom animals taken was almost equalled or exceeded during the same five years by the increase in the combined number of pollutional, unusually tolerant, and less tolerant kinds. The cases (of Lower Peoria Lake and Havana-Beardstown) where the increase in pollutional, unusually tolerant, and tolerant kinds exceeded the increase in all kinds in the five years following 1920 result from the actual decrease in the total number of clean-water kinds taken in those two reaches during the period.

Changes in the Dissolved Oxygen Supply

Sharp decreases in the surface dissolved oxygen in mid-channel between Chillicothe and Beardstown between 1911-1912 and 1920.

In July-September, 1911 and 1912, the nearest years to 1913-1915 for which we have records, the dissolved-oxygen supply at all points between Chillicothe and Beardstown, as measured by surface figures in mid-channel, ruled moderately to well above the usually accepted minimum point for most of our fishes (or above 2.50 parts per million). Between 1911-1912 and 1920, the largest decline occurred at Chillicothe, where average figures of 3.72 and 3.0 parts per million in July-September, 1911-1912, gave way to an average of only 0.47 parts per million for four readings taken July-September, 1920. The readings obtained in the three sections of Peoria Lake in the summer of 1912 are so scanty, and so irregular (due probably to the coincidence of some of them with rich and some of them with poor phytoplankton periods) that they are of almost no value for comparison and are best here omitted. Dropping only ten miles below

Peoria to Pekin, the downward trend was clearly resumed, the decline there between July, 1912, and July-September, 1920, having been 2.4 parts per million, or from 5.4 to 3.0 parts per million. Above the Copperas Creek Dam the comparison between July, 1912, and July-September, 1920, was even more sharp, the figures dropping from 4.0 to 1.25 parts per million. At Havana there was a slump from 3.65 parts per million in July, 1912, to 2.25 in July-September, 1920; and at Beardstown from 4.8 to 2.35.

TABLE VIII

CHANGES IN SURFACE DISSOLVED OXYGEN, MID-CHANNEL, CHILLICOTHE TO BEARDSTOWN, 1911-1912 TO 1920; PARTS PER MILLION*†

Sampling stations	1911 July-Sept.	1912 July	1920 July-Sept.
Chillicothe	3.72^{8}	3.0	0.47^{4}
Upper Peoria Lake / Middle Peoria Lake / Lower Peoria Lake	see text		
Pekin	....	5.4	3.0^{3}
Above Copperas Creek Dam	....	4.0	1.25^{2}
Havana	....	3.65^{2}	2.25^{3}
Beardstown	....	4.8	2.35

* Exponent is number of readings averaged.
† Water levels, all years, about normal for season.

Slight or imperceptible increases in bottom dissolved oxygen figures in Upper and Middle Peoria Lake channel since 1920.

In general, the evidence afforded by the bottom dissolved oxygen figures from the channel indicates very little change either way in the sanitary condition of the bottom muds between Chillicothe and the foot of the Middle Lake between 1920 and 1925. If recent estimates* of increase in the population of the city of Chicago between 1920 and 1927 are at all to be relied upon, however, the persistence of low dissolved oxygen figures in this portion of the channel, in spite of recent enlargement of the fraction of the total population taken care of by the new sewage-treatment plants, can hardly be regarded as surprising.

For the purpose of the present comparisons we have taken a selection of the mid-channel stations covered in the summer work of 1920, 1923, and 1925; leaving out 1924 because of the abnormal diluting effect of the continuous summer-flood of that year. Taking Chillicothe and Rome as representing Upper Peoria Lake and vicinity, it is true that average bottom readings for the summer months showed a very slight rise at both stations between 1920 and 1925; from 0.2 to 0.53 parts per million at Chillicothe, and from 0.2 to 0.67 parts per million at Rome, to be particular. But when we examine the individual readings for 1920 and 1925 for the number of low points, we find at Chillicothe in 1920 one

* See p. 399.

reading under 0.3 parts per million out of a total of three; while in 1925 at the same station and approximately the same dates there were seven readings under 0.3 parts per million out of a total of twelve. At Rome the comparison was not quite so good, but there were two readings there under 0.3 parts per million out of a total of nine in the summer of 1925 (one of 0.2 and another of 0.1 parts per million), compared with one out of two at Rome in 1920.

In the upper part of the Middle Lake, represented by Mossville, the average of nine readings June-September, 1925, was not far from one point lower than the average of five readings at Mossville in July-August in 1920, the exact average figures being 1.98 and 1.07 parts per million, respectively. In the lower part of the Middle Lake, represented by Al Fresco Park, the dissolved oxygen supply is subject normally throughout the summer months to great variations, due to rapid and extensive changes in the amount of phytoplankton present. But even here, the average of six mid-channel readings taken in the summer of 1925 (3.06 parts per million) was hardly visibly larger than the average of seven samples (3.01 parts per million) taken in approximately the same season in 1920. When we take into account the frequency of low readings, we find at Mossville only two readings under two parts per million out of a total of five in mid-channel in July-August, 1920, compared with seven under 2 parts per million out of a total of nine in 1925. At Al Fresco Park the number of readings in July-August, 1920, under 2.5 parts per million was three out of a total of seven samples taken in mid-channel; and in 1925, July-September, three out of a total of six.

TABLE IX

CHANGES IN BOTTOM DISSOLVED OXYGEN, MID-CHANNEL, CHILLICOTHE TO NEAR FOOT OF MIDDLE PEORIA LAKE, 1920 TO 1925; PARTS PER MILLION*†

	1920	1923	1925
Upper Peoria Lake or vicinity:			
Chillicothe	0.2^{3} (July-Aug.)	0.15^{4} (June-Aug.)	0.53^{12} (June-Sept.)
Rome	0.2^{2} (July-Aug.)	0.44^{5} (June-Aug.)	0.67^{9} (June-Sept.)
Middle Peoria Lake:			
Mossville	1.98^{5} (July-Aug.)	1.73^{6} (June-Aug.)	1.07^{9} (June-Sept.)
Al Fresco Park	3.01^{7} (July-Aug.)	4.80^{2} (June-July.)	3.06^{6} (July-Sept.)

* Exponent is number of readings averaged taken in the months indicated.
† Water levels, all years, about normal for season.

Visible increases in the bottom dissolved oxygen in mid-channel between Copperas Creek Dam and Beardstown after 1923.

In Lower Peoria Lake and in the river between Wesley (opposite South Peoria) and points shortly above Copperas Creek Dam the midsummer dissolved oxygen readings since 1920 have generally been quite irregular and are best left out of the discussion at present. The first low, then high figures encountered, at various stations in this section of the river, sometimes reversed on the next round, are a consequence of the always varying mixture of fresh sewage received at Peoria and Pekin with more or less highly oxygenated water received from the frequently rich plankton-bearing wide-waters of the middle and lower sections of Peoria Lake. Omitting these figures, and dropping about 31 miles below the foot of Peoria Lake, to Liverpool, we find again for the 40-mile section of river between Liverpool and Beardstown readings that are as a rule much more regular and certain in significance, but have relatively fewer of them for the summer months since and including 1920, than were taken in Peoria Lake. Taking Liverpool, Havana, and Beardstown, 31, 40, and 71 miles below the foot of Peoria Lake, approximately, as representative stations for this section, we note little change upward, or actual decrease in the amounts of bottom oxygen present between 1920 and 1923; averages or single samples taken at the three stations in July-September of those two years running: Liverpool 1.75^{2} in 1920* and 0.0^{1} parts per million in 1923; Havana 2.16^{3} parts per million in 1920, and 1.1^{1} in 1923; and Beardstown 2.2^{1} in 1920 and 2.4^{1} in 1923.

Between 1923 and 1925, however, an emphatic upturn in the bottom dissolved oxygen is indicated by our rather limited number of mid-channel readings from these same three stations. The comparisons with 1920 stood: Liverpool, increase from 1.75^{2} to 4.45^{2} parts per million; Havana from 2.16^{3} to 4.60^{2} parts per million; and Beardstown from 2.2^{1} to 3.3^{1} parts per million. It appears likely, though not wholly certain, that the increases at Liverpool and Havana between 1923 and 1925 reflect improvement in methods of waste-disposal recently put into operation by the Corn Products Refining Company at Pekin; and that the moderate relapse in the dissolved oxygen figures at some stations below Havana in the summer of 1923, as in other recent years, is a consequence of delayed fermentation of some of the carbohydrate wastes still received at Pekin or Peoria.

TABLE X.

CHANGES IN BOTTOM DISSOLVED OXYGEN, MID-CHANNEL, LIVERPOOL TO BEARDSTOWN, 1920 TO 1925; PARTS PER MILLION*†

Sampling stations	1920	1923	1925
Liverpool	1.75^{1} (Aug.-Sept.)	0.0^{1} (Aug.)	4.45^{2} (July)
Havana	2.16^{3} (July-Sept.)	1.1^{1} (July)	4.6^{2} (July)
Beardstown	2.2^{1} (Sept.)	2.4^{1} (Aug.)	3.3^{1} (July)

* Exponent is number of readings averaged.

† Water levels, all years, about normal for season.

Uncertain index value of dissolved oxygen figures from the Peoria Lake wide-waters since 1920. In the summer months of 1920 and succeeding years dissolved oxygen readings from the wide-waters of Upper and Middle Peoria Lake have agreed mainly in the single point of showing great irregularity. This is, however, not wholly unexpected, as both these sections of expanded river lie in close proximity to the boundary line between the light and the heavy oxygen-producing plankton of the warm low-water period (in other words, the blue-green Algae and the chlorophyll-bearing Algae and Flagellata). The location of this line in 1920 and 1922 varied sometimes as much as the length of either lake in a few days or weeks, as there occurred shifts in water levels, temperature, wind, and sunlight. Under the most favorable conditions for the multiplication of the Chlorophyceae and the green Flagellata, we occasionally obtained in 1920, even in the wide-waters of the Upper Lake, surface readings of dissolved oxygen topping 6 or 7 parts per million. A few days or weeks later, as the lower limit of the largely colorless or blue-green plankton moved several miles further downstream, it was not unusual to get bottom readings under one part per million more than three-quarters of a mile from mid-channel in the Upper Lake; and readings under two parts per million at similar distances even in the lower part of the Middle Lake.

Because of this unusually great variability in dissolved oxygen figures, the minimum mid-summer readings are believed to be of more value than averages in estimating the fundamental or underlying sanitary condition in the Peoria Lake wide-waters. A short table of minimum dissolved oxygen readings taken at long distances from the mid-channel line in the Upper and Middle Lakes is shown on p. 425. For comparison with the location of these minimum readings, the approximate full recent low-water widths of the lake on the side beyond the mid-channel line from which they were taken are also given. These show that at times both in the summer of 1920 and 1922 comparatively low bottom dissolved oxygen was not infrequent at stations well toward the margins of the east wide-waters of these two subdivisions of Peoria Lake.

The 1924 figures are of no value for comparison because of excessive dilution due to flood conditions all summer. The 1925 unpublished figures by the State Water Survey are apparently deficient in readings from stations at long distances from the center of the channel, in all sections of Peoria Lake. Although this is the case, it is believed it may safely be assumed that, as there was practically no change in the channel supply of bottom oxygen in the Upper and Middle Lakes between 1920 and 1925, so there cannot have been any appreciable amount of change of a permanent nature in the wide-waters, at least where open and comparatively free from vegetation.

During the summer season, our recent records of dissolved oxygen, both surface and bottom, in the east wide-waters of Lower Peoria Lake have in general been more consistently high in comparison with the indications supplied by the bottom fauna than in either the Upper or Middle

Lake. But this advantage is probably largely nullified at other seasons, as in the late autumn, when the first northwest winds carry over local pollution from the Peoria water front. Effects of this wind- and wave-borne pollution are apparent, in fact, on comparison of the number of small bottom animals with lowest tolerance taken in recent years in the Middle and Lower Lake. It is found, in brief, that if a few species that have survived in the Lower Lake since 1920 by virtue of unusual current of the very wide channel be excepted, the Middle Lake has recently yielded a larger number of small bottom species with low tolerance than has the Lower.

TABLE XI.

BOTTOM DISSOLVED OXYGEN, MID-SUMMER LOW POINTS IN PEORIA LAKE WIDE-WATERS, 1920 AND 1922.*

Reaches and stations	Year	Approximate full width of lake east of mid-channel line at recent summer low water levels miles	Distance east of mid-channel line of low bottom dissolved oxygen readings miles	Low readings of bottom dissolved oxygen p. p. m.	
Upper Peoria Lake					
Rome	1920	0.87	0.75	1.5	July
Rome	1920	0.87	0.62	2.0	Aug.
Rome	1922	0.87	0.70	1.0	Aug.
Rome, 2½ mi. below	1920	0.87	0.62	2.7	July
Rome, 2½ mi. below	1920	0.87	0.83	0.4	Aug.
Middle Peoria Lake					
Mossville	1922	0.87	0.60	3.0	Aug.
Mossville	1920	0.87	0.75+	3.1–3.4	July
Mossville, ¾ mi. below	1920	1.00	0.62	2.0	Aug.
Al Fresco	1920	0.75	0.50	1.9	Aug.

* Water levels, both years, about normal for season.

Major Changes in Abundance of the More Important Groups

Decreases in all important groups except Tubificidae and Chironomidae between 1915 and 1920. On the basis of average numbers of individuals per square yard, all of the more important groups of the small bottom animals except two are shown to have suffered large decreases in all reaches of the river and Peoria Lake between Chillicothe and Beardstown in the period between 1913-1915 and 1920. The most important declining groups, in point of both numbers and bulk previous to 1920, were the *Gastropoda, Sphaeriidae* (represented principally by a single species), and *Ephemeridae* (also represented almost wholly by a single species). All of the non-current-loving *Gastropoda* except one *(Campeloma subsolidum)* have been proved by their later records of extremely slow replacement to belong among the more sensitive of the small bottom species; and the same is true of the single important burrowing mayfly nymph of the middle Illinois River *(Hexagenia bilineata)*. The most important of the several kinds of *Sphaeriidae (Musculium transversum)*, on the other hand, has since 1920 shown itself, by its rapid recovery to and above 1913-1915 figures in the worst polluted parts of the Peoria Lake channel and points above, to be unusually tolerant; and stands as one of our best items of biological evidence that at some time between* 1915 and 1920 conditions on the bottom in those portions of the Illinois River were even worse than we found them in the last-named year.

The declines in *Gastropoda* and *Sphaeriidae* between 1913-1915 and 1920 were heaviest in the previously very rich section of river which extends some nine or ten miles above the Spoon River bar at Havana. Here the drop in average numbers of *Sphaeriidae* between 1915 and 1920 was from 1,709 to only 46 per square yard when all areas are combined; and the average decline in total *Gastropoda* was from 496 to only 20. In the three sections of Peoria Lake the declines in both of these groups in the same period were also very marked, but were actually small enough, in part as a consequence of previous damage suffered, so that they were largely or wholly made up in 1920 by the simultaneous increase of the pollutional worms and midge larvae.

Other minor groups, in addition to the burrowing May-flies, that showed sharp declines in some or all reaches between 1915 and 1920 included the leeches, the caddis-flies *(Hydropsychidae)*, the *Odonata, Planaria,* and *Amphipoda,* to name only the more important entries in a much larger list. Of these the leeches, the *Odonata,* the *Planaria,* and *Amphipoda* had enjoyed a wide distribution, in all reaches, (with the exception of the last two, usually in moderate numbers) previous to 1920. The *Hydropsychidae* had been confined principally to those sections of the river with hardest bottom and swiftest current in the 1913-1915 period.

Increases in Tubificidae and Chironomidae 1915 to 1920. The two groups of small bottom animals that showed large increases in numbers in all sections of the river between Upper Peoria Lake and Beardstown as pollution became heavier between 1915 and 1920 were the *Tubificidae* and the *Chironomidae.* Both septic and pollutional *Tubificidae* of at least two genera and several species, including *Tubifex tubifex* and several species of *Limnodrilus,* always had been represented under the cleaner-water conditions of 1913-1915 and earlier, at least in moderate numbers in the muddier sections of the middle and lower Illinois River; though they then attained large numbers in the sections of river here considered only in restricted localities subject to constant or occasional local pollution. The *Chironomidae* before 1920 included more than a dozen species, several of which have since turned

* See p. 439 and reference mentioned in footnote on same page.

out to be of unusually tolerant habit; and two or three which seem easily to stand pollutional conditions. Most important among the latter are: a variety of *Chironomus plumosus,* with ventral blood gills of adaptable length for living under high or low oxygen concentration; *Chironomus lobiferus;* and a small form much like *Chironomus plumosus* that has been recorded from Illinois previously as *Chironomus decorus.*

The increases in both the *Tubificidae* and the *Chironomidae* between 1915 and 1920 were greatest in the three sections of Peoria Lake and in the formerly rich gastropod territory lying in the first ten miles above Havana; these comprising the principal reaches with practically continuous soft black-silt bottom originally best adapted as habitats for these two groups as represented. The extreme average increase in *Tubificidae* in numbers (in Upper Peoria Lake) was from 16 to 2,463 per square yard between 1915 and 1920; and in *Chironomidae,* in the same lake from 10 per square yard to 733.

Below Peoria, the *Tubificidae* at 46 per square yard, were about 30 times as numerous in the section between Liverpool and Havana as they were in the same area in 1915. Such an increase, however, is relatively small as compared with the more than 150-fold increase in *Tubificidae* in the same time in Upper Peoria Lake. In strong contrast with the relatively much greater increase of *Tubificidae* than of *Chironomidae* in the Upper Lake between 1915 and 1920, in the formerly rich gastropod territory just above Havana the rate of increase of the *Chironomidae* in the five years greatly exceeded that of the *Tubificidae.* Here the *Chironomidae* were multiplied more than 190-fold between 1915 and 1920, as compared with 30 times for the *Tubificidae.*

Continued increase of the Tubificidae and Sphaeriidae since 1920, and increase of leeches after 1924.

It was noted in 1922 that the increase in *Tubificidae,* begun before 1920, had gained momentum and that a very rapid rise in *Sphaeriidae* was also under way in both of the two upper subdivisions of Peoria Lake. These gains were held, up to 1923, in both places, and between 1924 and 1925 were extended in these or other reaches to still larger figures for both groups. Comparing the 1924 or 1925 figures with those of 1920 (or 1915) the most striking increases took place in Upper Peoria Lake, where these worms rose from 2,463 to 39,182 per square yard in four or five years; in the Lower Lake, where the rise was from 78 to 6,919 per square yard; and in the section of the river from the Peoria and Pekin Union Railway bridge to Pekin, where there was an increase from none in 1915 (no collections in 1920) to 19,819 in 1925. Increases in the *Tubificidae* in the Liverpool-to-Havana and the Havana-to-Beardstown sections between 1920 and 1925 were less, but in both of these sections the figures moved up from under 50 to around 2,000 per square yard.

The increases in the *Sphaeriidae* from 1920 to 1925 were more irregular than in the *Tubificidae,* very possibly in part because this group is a preferred fish food to a much greater extent than the worms. Quite consistently, also, the *Sphaeriidae* reached their greatest numbers in or near two of the best commercial fishing reaches (Upper Peoria Lake and Liverpool to Havana) in the continuous summer flood year 1924 (instead of 1925), when large numbers of the fishes were probably feeding in the "brush". In Upper Peoria Lake average numbers in all areas combined rose from 57 per square yard in 1920 to 18,114 in 1924; in the Middle Lake, from 3 in 1920 to 4,497 in 1925; and in the Lower Lake from 1.5 in 1920 to 1,122 in 1925. Just above Havana the gains approached those in Upper Peoria Lake—swinging from 46 per square yard in 1920 to 12,785 in 1924. Between Havana and Beardstown, in an always less favorable, because harder, bottom, the rise was only from 7 to 112 up to 1924, and to 2,561 in 1925.

The leeches, after declining in numbers only moderately, from 1915 to 1920, as practically all the Illinois River species are of unusually tolerant or even occasionally pollutional habit, rose hardly appreciably till 1924 or after. The largest part of their increase came between 1924 and 1925 and was most conspicuous in three short reaches: in Middle Peoria Lake, where they rose from none in 1920 to 548 per square yard in 1925; in the section between the foot of Peoria Lake and Pekin, where they rose from 58 in 1915 (no collections in 1920) to 1,511 in 1925; and in the ten miles immediately above Havana, where they increased from under 20 per square yard to more than 10,000 per square yard between 1920 and 1925. Below Havana increases were negligible in the five years following 1920.

The marked increases, rather than decreases, noted in the total *Tubificidae* between 1920 and 1925 are in apparently significant agreement with the bottom dissolved-oxygen figures from the channel above Peoria in indicating little or no change in sanitary condition in the bottom muds since 1920. It should be kept clearly in mind, however, that the rich tubificid territory below Chillicothe has been referable to the pollutional, or sub-pollutional, and not the septic zone since that time. The leading member of the family in abundance there, also, has been a species of *Limnodrilus (Limnodrilus hoffmeisteri),* and not *Tubifex tubifex;* though comparison of incomplete counts of samples from stations in the river above Chillicothe in 1923 with a few counts from Peoria Lake showed considerably larger ratios of *Tubifex tubifex* at the up-river, and so more heavily polluted, stations.

The recent changes in abundance in an upward direction in and above Upper Peoria Lake both of *Limnodrilus hoffmeisteri* and the dominant sphaeriid, *Musculium transversum,* which seems able to thrive almost equally with that worm in polluted bottom, may well be, for anything that we know to the contrary, illustrations of an unusual adaptability more or less recently and locally acquired. In other words, we may perhaps suppose that both of these two species found the strength of the pollution over most of Peoria Lake rather too much for them at the crest of the pollutional wave that seems to have reached its height shortly before* 1920; but have since found conditions just about to their liking. So far as their sources of food are concerned, it cannot be believed that there was any lack in that respect at any time in recent years; the *Tubificidae* utilizing the bacteria and fine organic detritus of the bottom, and the *Sphaeriidae* using a wide range of living or dead microorganisms, most of which are diatoms, unicellular algae, protozoa and the like, from the always rich plankton population overhead.

The enormous increase in leeches in the section of river between Liverpool and Havana from 1924 to 1925, which seems to have attained the proportions of a veritable epidemic for whatever organisms they were living upon, occurred in a section where one of their preferred food organisms (small bivalve *Mollusca* of the family *Sphaeriidae*) was present in very great numbers; and as the leeches increased the *Sphaeriidae* declined heavily. The more abundant species of leeches taken between Chillicothe and Havana from 1920 to 1925, as likewise before that time, have been five or six in number *(Helobdella stagnalis, Helobdella nepheloidea, Dina microstoma, Erpobdella punctata, and Glossiphonia complanata)*, and are all known to feed upon snails, worms, various insect larvae, and other smaller bottom animals; the first two and the fourth also being scavengers. The most abundant one of all in recent collections from the middle Illinois River, *Helobdella stagnalis*, has been noted particularly by Dr. J. P. Moore as being partial to *Sphaeriidae*. A special table showing the rise in leeches alongside the decline in *Sphaeriidae* (principally *Musculium transversum*) in the 10-mile stretch above Havana, 1924 to 1925, follows.

TABLE XII

INVERSE CHANGES IN ABUNDANCE OF LEECHES AND *Musculium transversum*, FROM 1924 TO 1925 IN THE SECTION OF RIVER BETWEEN LIVERPOOL AND HAVANA; AVERAGE NUMBERS PER SQUARE YARD

Areas	Year	*Musculium transversum*	Total leeches
Channel	1924	17,952	1,660
	1925	12,528	24,336
Extra-channel	1924	11,446	132
	1925	4,388	5,593
Channel and extra-channel areas combined	1924	12,785*	441
	1925	6,465*	10,275

* Total *Sphaeriidae*, consisting almost wholly of *Musculium transversum*.

Various instances (see tables on pp. 460-468) of apparently inconsistent trends of leeches and *Sphaeriidae*, 1924 to 1925, in other sections of the river are all readily harmonized with the case above considered or are easily explained as the result of other influences. The case of heavy decrease in *Sphaeriidae* in Upper Peoria Lake, while leeches remained substantially unchanged can have been due to unusually heavy

* See p. 439 and reference mentioned in footnote on same page.

feeding by carp in the early spring of 1925; or even possibly to unusually heavy mortality among the *Sphaeriidae* as a result of overcrowding consequent upon their exceptionally rapid rate of increase between 1923 and 1924. The case, between the foot of Peoria Lake and Pekin, in which the leeches rose from only 5 to 341 pounds per acre while the *Sphaeriidae* increased slightly, calls merely for the comment that if the leeches had not increased so much very probably the *Sphaeriidae* might have gone much higher. Comparisons as between the years 1920 and 1925 also show a few instances where both leeches and *Sphaeriidae* rose simultaneously over the five-year period, from more or less negligible to important numbers. Even if the correctness of the predator-victim relation be granted, however, it is reasonable to assume, up to a certain point, that the leeches might increase sharply as the species preyed upon increased; the point at which increase gave way to decrease in the small bivalves depending upon the time of attainment of an unbalance in the multiplication rates of the two groups.

Small or negligible increases, 1920 to 1925, in the Gastropoda and other cleaner-water groups. In the cleaner-water 1913-1915 period the *Gastropoda* had bulked large both in numbers and weight in all reaches of the river and Peoria Lake between Chillicothe and Beardstown. The group at that time included in all reaches not less than half a dozen species of unusually sensitive habit that were either generally abundant or abundant to common locally: *Vivipara contectoides; Vivipara subpurpurea; Lioplax subcarinatus; Amnicola emarginata; Amnicola limosa;* and *Somatogyrus subglobosus;* all of which were practically wiped out in the deeper open water all the way from Chillicothe to Beardstown by the wave of pollution that reached its climax shortly before 1920. Two other important members of this group, *Campeloma subsolidum* and *Pleurocera acutum* were also destroyed in great numbers, but much less completely so than the six first-named species; *Pleurocera,* particularly, holding out in fairly good numbers in all portions of the Peoria Lake channel where there was unusual current.

The recovery in the total *Gastropoda* in the three sections of Peoria Lake between 1920 and 1925 was so small as to be practically unmeasurable; the maximum rate of distribution (in the Middle Lake) being only 12 per square yard in 1925, consisting wholly of *Campeloma subsolidum,* which is unusually tolerant, and comparing with 49 to 130 per square yard of mixed species in 1915. Below Peoria, in the 10 miles between Havana and Liverpool, where the combined *Gastropoda* had averaged 496 per square yard in 1915, they rose in 1925 to a bit less than 40, from just half that number at the recorded low point five years before. The fact that more than half of the specimens taken in this section in 1925 were *Vivipara contectoides,* however (the rest being *Campeloma subsolidum*) seems to reflect to some extent the results of the previously mentioned improvement in the bottom dissolved oxygen supply below Copperas

Creek Dam since 1923. Below Havana, to Beardstown, still greater variety was presented: two-thirds of the average consisting of three of the more sensitive species (*Vivipara contectoides; Amnicola emarginata;* and *Amnicola limosa*) and only one-third of them being the tolerant *Campeloma subsolidum.* Here average numbers per square yard had been 79 in 1915; had dropped to 22 in 1920; and risen to 40 in 1925.

Next after the *Gastropoda* the burrowing May flies of the genus *Hexagenia* were by all odds the most important of the cleaner-water species of the muddy reaches of the middle Illinois River in the 1913-1915 period and earlier. At that time they were taken as far north as Upper Peoria Lake, and were present practically everywhere between that section and the lower end of the river, though their habit of depositing their eggs in swarms, often quite widely separated, sometimes resulted in their appearing rather scatteringly in a fixed program of collections. In the summer of 1920 the common species, *Hexagenia bilineata*, did not appear at all in collections above the foot of Matanzas Lake, 4 miles below Havana; since that year it has been taken but a single time, and then in very small numbers, and very close to the edge, at one of the stations between Peoria and Havana. Below Havana, as we would expect, the species has been taken a little more frequently in the last few years: but did not occur at all in collections above Beardstown either in 1924 or 1925.

Among the more important minor groups of the cleaner-water small bottom fauna of 1913-1915 that have shown slight if any recovery at all since 1920 may be noted: the *Hydropsychidae* and *Odonata*, among insects; and among lower forms the *Planaria*. While all of these groups except the *Odonata* occasionally attained quite large numbers around ten years ago they did not either then or later amount to a great deal in averages, and need not occupy time here for discussion. *Coleoptera*, represented almost solely in recent years in the deep open water by a species of *Stenelmis*, have been principally confined to the vegetation near the margins both before and since 1920; the latter statement being also true of most of the *Odonata*. The principal *Crustacea* and *Bryozoa* of the open water are more or less tolerant and have received mention in that connection in another place.

Irregularity of abundance of the Chironomidae since 1920. The larvae of midges, or *Chironomidae*, have been noticeably irregular in abundance in all of our recent collecting in the Illinois River. As illustrating some of the more important changes, we found large decreases occurring between 1920 and 1925 in Upper Peoria Lake and in the ten miles above Havana, large increases in Middle and Lower Peoria Lake, and slight increases between Havana and Beardstown.

Most of the species taken in the sections of the river covered since 1920 are pollutional or more than ordinarily tolerant; their natural food supply, of settled and bottom plankton and organic detritus, is almost everywhere abundant; and there can be, therefore, hardly any question concerning the general suitability of conditions. Because of the frequency of new broods, of the same or different species during the warm season, it is not to be supposed that the time of making collections would, in the long run, make much difference. This was verified in the case of the common *Chironomus plumosus* in Middle Peoria Lake in 1922 and 1923, the average number of individuals per unit area of lake bottom not varying seriously from one month to another between July and September.

The *Chironomidae* also have shown themselves more susceptible than any of the other larger groups of small bottom animals to the effects of floods in the Illinois River in recent years: dropping sharply between 1923 and 1924 in nearly all reaches between Chillicothe and Beardstown, as a consequence, with hardly any doubt, of the unusually long continued and severe summer floods of the latter year; and rising again sharply in the same areas between 1924 and 1925, as the river came back to normal warm season levels.

Fuller details, with tables, of the changes in abundance of *Chironomidae* accompanying and following the 1924 high water are given on pp. 448-453, and tables showing the abundance of midge larvae in all reaches in a series of years will be found on pp. 463-465.

Changes in Valuation as Fish Food and in Per Cent Composition by Weight

Average poundage and composition of total stocks, by reaches, in 1915. In 1915, average valuations of the small bottom fauna between Chillicothe and the Lagrange Dam, about eleven miles below Beardstown, did not much exceed 350 pounds per acre in any area of open water except the short reach of less than ten miles immediately above Havana, during the June-to-September season. Between Chillicothe and the Copperas Creek Dam the figures ran from around 170 to a little under 370 pounds per acre, and below Havana did not exceed 270 pounds. Quite in contrast with these records, the upper eight miles of the section between Copperas Creek Dam and Havana showed over 1,000 pounds per acre, and the lower nine miles, next above Havana, more than 2,700. At that time even the lower figures were not considered unexpectedly poor or unfavorable, in view of the generally rather hard or sandy bottom in which they were taken excepting in Peoria Lake; and because in both the same and other sections of the river vastly richer areas were to be found in the connecting lakes and other backwaters. The comparatively low averages obtained in the three sections of Peoria Lake have since appeared, so far as they arose from shortage of a considerable number of cleaner-water species, to reflect measurable injury there by pollution before 1915.

The composition of the average total haul in 1915 in all the open-water reaches, including Peoria Lake, was made up always largely, and frequently almost wholly, of some half-dozen species of large and small *Gastropoda*, all but one of which have since almost completely disappeared from the areas above the Copperas Creek Dam. The average per cent by weight of the total haul made up by these *Gastropoda* in various reaches is shown in the table that follows, which includes percentage showings as high as 95 and only one lower than 60. In the Peoria Lake area rather less than a third of the totals of *Gastropoda* belonged to the unusually tolerant viviparid species, *Campeloma subsolidum;* and in the Liverpool-Havana section a not very different fraction; pollution at that time not yet having affected seriously any of the more sensitive members of this group of snails.

In 1915, *Sphaeriidae* occurred in numbers large enough to affect valuations importantly in only three of the eight sections here recognized; viz., in Upper Peoria Lake, where they made up 13 per cent of the total on the average; in the first section below Peoria Lake (Peoria and Pekin Union Railway bridge to Pekin) where they contributed 31 per cent; and in the rich Liverpool-to-Havana section, where the percentage was also 31.

TABLE XIII

PERCENTAGES BY WEIGHT CONTRIBUTED TO TOTALS OF ALL SMALL BOTTOM ANIMALS IN 1915 BY MOLLUSCA.† CHANNEL AND EXTRA-CHANNEL AREAS COMBINED

Reaches	Av. lbs. per acre	Gastropoda per cent	Sphaeriidae per cent
Upper Peoria Lake	170	51	43
Middle Peoria Lake*	.....	..	..
Lower Peoria Lake	330	95	
P. P. U. Bridge to Pekin	230	62	31
Pekin to Copperas Creek Dam	367	80	
Copperas Creek Dam to Liverpool	1,064	80	
Liverpool to Havana	2,757	68	31
Havana to Lagrange Dam	263	86	

† Unimportant percentages of *Sphaeriidae* disregarded.
* Included in Upper Peoria Lake, 1915, when collections in the Middle Lake were confined to its upper third.

The change in composition of the fauna and the decline in poundage in most reaches between 1915 and 1920.

The principal collecting of the summer of 1920 was done in the region between Chillicothe and the foot of Lower Peoria Lake. Below Peoria, the two sand-and-shell reaches between Wesley and Pekin and next below Copperas Creek Dam, as also the short, more or less muddy section between Pekin and the dam, were passed over, and the bottom collecting was confined to the previously very rich short section next above Havana and the stretch of about 20 miles of sand-and-shell or clay bottom immediately below Havana and above the foot of Hickory Island (about 10 miles above Beardstown).

Both in the three subdivisions of Peoria Lake and in the first 20 miles below Havana, all of which areas had been only moderate producers before 1920, the reversal in composition of the fauna and the substitution of pollutional or unusually tolerant *Tubificidae*, *Chironomidae*, and *Sphaeriidae* since 1915 for the *Gastropoda* and other cleaner-water species formerly dominant there, offered more striking and significant evidence of the increased pollution than the declines in poundage in the five years. Even the average poundage in the Lower Lake was cut down to about a third of the 1915 average, though the replacement of the cleaner-water by the pollutional and unusually tolerant forms served actually to increase the average poundage in Upper Peoria Lake and the upper portion of the Middle Lake in the five year interval of increasing pollution that ended in 1920. The outstanding decline in average poundage, accompanied by radical change in the composition of the small bottom fauna, occurred in the nine miles between Liverpool and Havana, where the high average of 2,757 pounds per acre in 1915 gave way to an average of only 195 pounds five years later.

The shifts in the composition of the fauna between 1915 and 1920 in the three sections of Peoria Lake reduced the *Gastropoda* almost 100 per cent, or practically to zero. The only surviving members of the group showing a trace in open water in 1920 belonged to the single unusually tolerant stagnant-water form, *Campeloma subsolidum*, or, where there was unusual current, to the only slightly less tolerant current-loving *Pleurocera acutum*. Here, as the *Gastropoda* fell, the combined pollutional and unusually tolerant *Chironomidae* and *Tubificidae* rose to figures, in terms of weight per acre, equal to 85 to 95 per cent of the average total haul.

In the sections of the river between Liverpool and Havana and between Havana and Beardstown the average poundage of *Gastropoda* was cut in the five years 80 to 98 per cent and the *Chironomidae* (principally the pollutional *Chironomus plumosus*) in the first-named section

TABLE XIV

PRINCIPAL CHANGES IN VALUATION AND PER CENT COMPOSITION BY WEIGHT OF ALL SMALL BOTTOM ANIMALS, 1915 TO 1920. CHANNEL AND EXTRA-CHANNEL AREAS COMBINED

Reaches	Average lbs. per acre		Gastropoda per cent	Chironomidae per cent	Tubificidae per cent	Gastropoda per cent
Year	*1915*	*1920*	*1915*	*1920*	*1920*	*1920*
Upper Peoria Lake.....	170	256	51	52	33	3.5
Middle Peoria Lake.....	*	42	*	78	18	
Lower Peoria Lake.....	330	72	95	89	4	
Liverpool to Havana....	2,757	195	68	53		19
Havana to Beardstown..	263	119	86	30		42

* Included in Upper Peoria Lake, 1915, when collections in the Middle Lake were confined to its upper third.

made up 53 per cent of the average haul. The only surviving *Gastropoda* in the first nine miles above Havana belonged to one or the other of the two unusually tolerant species above mentioned; and the more sensitive large *Viviparidae* and the smaller *Amnicolidae*, which had been a prominent feature of this stretch of river in 1913-1915, were not taken at all. Below Havana the changes were less severe, though even here the *Gastropoda* dropped from 86 per cent of the average total haul to considerably less than half of it; while all *Gastropoda* that were found in 1920 belonged to the tolerant species of *Pleurocera* above mentioned. Here also the *Chironomidae*, which had made up a negligible portion of the total poundage in 1913-1915, had multiplied until they contributed more than 30 per cent of it; and the bulk of them belonged to the pollutional species, *Chironomus plumosus*.

Great increases in poundage in all reaches since 1920, due to multiplication of the pollutional or unusually tolerant groups.

While in 1920 valuation figures higher on the average than in 1915 were obtained only in Upper Peoria Lake, where the gains in the pollutional and unusually tolerant *Tubificidae*, *Chironomidae*, and *Sphaeriidae* had already outstripped the losses in *Gastropoda* and other cleaner-water species, it was clear by 1922-1923 that the continued rise of the single unusually tolerant sphaeriid, *Musculium transversum*, was rapidly lifting average poundages to formerly unknown levels also in Middle Peoria Lake and in the 9-mile stretch of formerly very rich bottom just above Havana. The full extent of the change was not realized till the summer of 1924. At that time the returns from Upper Peoria Lake showed an average poundage more than twenty-five times that of 1920 and more than thirty-nine times that of 1915; the Middle Lake more than twenty-six times the average of 1920; and the Liverpool to Havana section almost twice the average poundage of 1915, and more than twenty-five times that of 1920. These great production averages, in 1924, of 6,737 pounds per acre in the Upper Lake, 1,110 pounds in the Middle Lake, and 4,996 pounds in the short section just above Havana, were almost wholly due to the rapid multiplication of unusually tolerant *Sphaeriidae* (principally *Musculium transversum*), of which the contributions to the average total haul ran 80.4 per cent, 92 per cent, and 94.3 per cent, respectively.

Although there was a sharp decline in *Sphaeriidae* in Upper Peoria Lake between 1924 and 1925 (still leaving the total poundage about six times the 1920 figures and more than nine times the 1915 figures), the rise in total poundage continued strongly upward after 1924 in the Middle Lake, going in that area from 1,100 pounds per acre to 2,014 pounds, due largely to increase in *Sphaeriidae*. It rose moderately also in the Liverpool-Havana section between 1924 and 1925, from 4,996 pounds to 5,355 pounds, in spite of a decline of large proportions in *Musculium transversum*, accompanied by a great increase in leeches known to be predatory with reference to many of the other small bottom species, and of small bivalve *Mollusca* in particular. The decrease in *Sphaeriidae* in the Upper Lake between 1924 and 1925 was not accompanied by a corresponding rise in the leeches; and it may have been a consequence of temporarily increased feeding by fishes in that area, following a summer of almost continuous flood, which could easily bring large fish up the river in good numbers, but keep them occupied in the shallower, temporarily overflowed, or "brush", areas during its continuance.

Perhaps the most remarkable change of all between 1924 and 1925 was the extension of the rapid gains in average total poundage to Lower Peoria Lake and to the previously comparatively poor sand-and-shell or lightly silted reaches between Wesley and Liverpool, and below Havana. In the summer following 1924 the average poundage of the Lower Lake had risen from 230 to 1,009 pounds per acre, due to large increases in three of the pollutional or unusually tolerant groups,—*Tubificidae, Chironomidae* and *Sphaeriidae.* In the two short sections between the foot of the Lower Lake and Copperas Creek Dam the rise in average weight was from less than 250 pounds per acre to the neighborhood of 1,300; in the first case this was due principally to an enormous increase in *Tubificidae;* in the second, to still greater increase in the midge larvae. Between Havana and Beardstown in the same twelve months the average total haul was multiplied more than eight times, standing in 1925 at 1,135 pounds per acre, or almost ten times the average 1920 figure and almost five times the average of 1915.

The increase between 1924 and 1925 below Havana was almost wholly in the unusually tolerant single kind of *Sphaeriidae (Musculium transversum)* that has recently been contributing so heavily to poundage figures in Peoria Lake, and that neither in the 1913-1915 period nor since 1920 until 1925 had contributed at all importantly to totals between Havana and Beardstown. The very sudden appearance in 1925 of this small bivalve in such large numbers at stations in the first 31 miles below Havana, where in 1913-1915 the greater part of the bottom was sand and shell, or otherwise harder than bottom usually selected by that species,

TABLE XV

AVERAGE VALUATION, IN POUNDS PER ACRE, ALL SMALL BOTTOM ANIMALS; CHANNEL AND EXTRA-CHANNEL AREAS COMBINED*

Reaches	1915	1920	1924	1925
Upper Peoria Lake	169.7	255.8	6,737.8	1,565.7
Middle Peoria Lake	......	41.8	1,110.6	2,014.0
Lower Peoria Lake	329.9	72.1	230.4	1,009.2
Foot of Peoria Lake to Pekin	230.0	.....	229.9	1,356.3
Pekin to Copperas Creek Dam	367.5	.....	143.0	1,275.3
Copperas Creek Dam to Liverpool	1,063.7	.....	51.5	......
Liverpool to Havana	2,756.7	195.0	4,995.9	5,351.1
Havana to Beardstown	263.2	119.0	142.3	1,135.8

* The composition of these totals is shown in the tables on pp. 460-468.

can be explained only as in large part probably a special consequence of the unusual and long-continued summer flood of 1924. It seems almost necessary to assume, in fact, that the flood not only carried down and deposited unusual amounts of rich sediment in certain parts of the Havana-Beardstown section, but that it also actually moved good numbers of very young individuals of *Musculium* in the midsummer season of their greatest abundance, along with the sediment, many miles downstream. It is not, in fact, at all likely that a similar effect, both in enrichment of the bottom deposits and in the multiplication of this particular species, could have been accomplished within the space of twelve months if the 1924 flood had been confined to the usual short spring period. That has ordinarily been in recent years somewhere between the end of January and the end of April, when collections of *Musculium transversum* usually show practically all adults, which are much better able to hold their anchorage in soft bottom than the very young.

In the section of this paper immediately following, the recent strong upward surge in abundance and valuation of the *Sphaeriidae* is shown with a fair degree of probability to be a normal phase of a pollutional cycle or succession that evidently takes at times several years to complete itself. Various uneliminable factors may also be concerned. In particular, it should be pointed out that a portion of the recent very great poundage increases in the polluted sections of river above Beardstown may reflect permanent reduction since 1913-1915 in the population of bottom-ranging fishes, with consequently decreased inroads, for securing food, on the small bottom animal population. At least we can hardly assume that the increases have been wholly due in all areas to an abnormal multiplication rate under the stimulus of a richer food supply, of its kind, that goes with a more polluted river. The comparison of commercial fisheries' census data of 1908 to 1914 with those of 1921 and 1922 to some extent bears out these strictures.

Temporal Succession of the Leading Groups of Pollutional or Unusually Tolerant Forms in the Polluted Reaches Below Chillicothe

Between 1920 and 1925 an accumulation of very suggestive evidence has come into our hands bearing on the order in which the more important pollutional and unusually tolerant groups of the small bottom animals came into prominence as or after the more sensitive *Gastropoda* and other groups had disappeared from most of the reaches above Beardstown shortly after 1915. For various reasons, however, comparisons based on the per cent composition of the average haul expressed in numbers per unit of bottom area have not been found as satisfactory for the purpose intended as those based on weight. On the basis of abundance, to take only a single example, the *Tubificidae* were shown to be the leading group in Upper Peoria Lake in 1920, with an average of 2,463 individuals per square yard, although the *Chironomidae,* with decidedly smaller numbers (only 733 per square yard, to be exact), contributed much more heavily to average poundage over the same area at the same time. Next, it is found that by that method of comparison the *Tubificidae* continued to hold their dominance in that section of river continuously (except for 1921, when we made no collections) from 1920 to 1925, though in both 1924 and 1925 and possibly also in 1922 and 1923 the *Sphaeriidae* had risen to the leading place, on a bulk and weight basis, having in fact a margin of around 300 per cent over the *Tubificidae* in 1924.

By scheduling the various groups on a basis of per cent composition by weight, on the other hand, we obtain a picture of the true "complexion" of the small bottom fauna rather than its population-distribution expressed in confusingly different sized units, and see the main features of a succession that seems to have a real biological basis. Using this method of comparison, we find that the *Chironomidae,* represented very largely by the single pollutional species *Chironomus plumosus,* led in all reaches between Chillicothe and Beardstown in 1920 where *Gastropoda* had fallen to less than 20 per cent of the average valuation total, this including the three sections of Peoria Lake, and the nine-mile section immediately above Havana; and that *Tubificidae* were following instead of leading in the two sections of Peoria Lake in which they were most abundant that year.

In 1924, an essentially changed picture is presented; with the *Sphaeriidae,* in all subdivisions of Peoria Lake and part of the river reaches above Havana, holding the place that was held by the midge larvae in 1920; and with the *Tubificidae* holding first place in two of the river reaches between Peoria and Havana and in the 31-mile section between Havana and Beardstown. In 1925, the *Sphaeriidae* still held their lead in the three subdivisions of Peoria Lake and in the section next above Havana; and the *Tubificidae* were still first in weight between the foot of the Lower Lake and Pekin, though they had lost their lead to the *Chironomidae* between Pekin and the Copperas Creek Dam and to the *Sphaeriidae* between Havana and Beardstown.

It is evident that we have in the above data strong hints of some kind of a cycle. In order for this cycle to emerge into full light, however, it is necessary to have in mind a few additional features of the biology not yet mentioned. The first of these is that, in very badly polluted muds in streams already infected with those worms farther up, *Tubificidae* are ordinarily the first of the pollutional or unusually tolerant groups to attain not only dominant numbers but dominant bulk and weight as well. This was well illustrated in work in the upper Illinois in 1911-1912, and more recently in studies on some less important water-courses in the State. The reason for it is not at all obscure, being the simple fact, apparently, that the worms can float or roll into the new area; whereas the *Chironomidae* must ordinarily make their entrance from the outside, on the wing; and the *Sphaeriidae,* excepting those times (as in 1924) when unusual summer floods seem to have moved their young and half grown, depend principally on the slow process of creeping over the bottom.

If the above is a substantially correct view, the three sections of Peoria Lake and the ten-mile stretch of mud bottom next above Havana are seen to have been very probably in the second (chironomid) stage instead of the first (tubificid) stage of the pollutional-biological cycle in the summer of 1920. This would ordinarily also mean that a short time before 1920 *Tubificidae* were probably the dominant group in bulk and weight in all or most of those areas. Though it is not necessary, in order for this to have been the case, (at least in Upper Peoria Lake) to assume that the pollution was greater in these parts of the river shortly before than during 1920, it is noted that the tendency of the data on the volume of business done by the Chicago Packers from 1916 to 1920 and of other evidence* is to suggest that it was at least for a time measurably more so.

The third (sphaeriid) phase of the cycle had attained full swing in the three subdivisions of Peoria Lake and in some reaches farther down river by or before 1924, incomplete valuation figures for 1922 and 1923 suggesting that the *Sphaeriidae* had attained the lead in point of weight in Upper Peoria Lake as early as 1922 or 1923. It is necessary to point out also that dominance of the *Sphaeriidae* (as represented almost wholly by the single species *Musculium transversum*) in areas where *Tubificidae* and *Chironomus plumosus* had previously held the lead, does not necessarily imply improvement in sanitary condition. That species, in fact, accompanied the *Tubificidae* as far up river as LaSalle in both 1924 and 1925; often attaining large numbers side by side with tens to hundreds of thousands of *Tubificidae* per square yard. The evidence from the bottom dissolved-oxygen readings, already presented, indicates also that there was no important change in the underlying sanitary condition above Copperas Creek Dam between 1920 and 1925.

Evidence of a minor succession of *Tubificidae-Chironomidae-Sphaeriidae* in several reaches below Peoria Lake in the two years 1924-1925 is also little less clearly implicit in the data. The sudden elevation of the *Tubificidae* to first place in weight between the foot of Peoria Lake and Pekin, between Pekin and Copperas Creek Dam, and between Havana and Beardstown in 1924 was without much doubt in great part the result of an involuntary migration downstream of the worms during the heavy and continuous summer floods of that year. It stands also as corroborative evidence of considerable value that putrescible sediment is carried during floods far past its normal resting place under more stable hydrographical conditions; and goes far toward explaining the lag not infrequently noted between the condition of the bottom sediments and the dissolved oxygen and plankton in the moving water overhead. It was very probably largely due to the temporary

* Richardson, R. E., Bull. Ill. Nat. Hist. Survey, Vol. XV, Art. V. pp. 328-332, Aug. 1925.

nature of this minor wave of pollution in the section of river between Havana and Beardstown that the *Sphaeriidae* displaced the *Tubificidae* as dominants there by the next summer. In the short section of river between the foot of Peoria Lake and Pekin, on the other hand, the *Tubificidae* still held the lead in 1925; and between Pekin and Copperas Creek Dam the cycle had progressed only to the second stage (that of *Chironomidae*) by the summer of that year.

The succession above described is essentially temporal in character, representing the order of attainment of dominance of three groups of substantially equal tolerance, within the limits of the zone (mesosaprobic, or pollutional to sub-pollutional) between that of septic and cleaner-water organisms; and in territory where no changes sufficiently great as to have altered zonal boundaries are known to have taken place between the dates of its inception and completion. It has no essential connection with the broad zonal succession from septic to clean-water forms that occurs over a period of years in a circumscribed area as pollution gradually decreases; or from the upper to the lower reaches of a stream septic at its upper end but long enough to permit fairly complete biological self-purification in the run to its mouth.

While leeches came near exceeding either *Tubificidae, Chironomidae,* or *Sphaeriidae* in weight per unit of bottom area between Liverpool and Havana in 1925, their numbers and weight were as a rule irregular and unimportant in all other sections of river covered by the collections since 1920. They seem, so far as represented by the five or six commoner species participating in the unusually large leech totals of 1925, to have no necessary connection with pollution, although apparently able to stand about as much of it on occasion as the other three groups named. Their sudden appearance within a limited area in very large numbers that year does not fit into the succession above described at any point, but may have had some connection with the floods of the summer of 1924 and the further fact that at least three of the commoner ones, including the most abundant of all, *Helobdella stagnalis,* are scavengers. Leeches have been observed recently in Rock River swimming near the edges in strong current after rapid rises of water level, and similar observations have been made on the Illinois River. The long-continued summer floods of 1924 may have given rise to considerable dispersal of leeches and at the same time seem to have favored an unusual rate of multiplication of the small bivalve *Mollusca (Sphaeriidae)* on which several of the leeches feed. Floods also wash in various dead animals, terrestrial and otherwise, which might add to the food supply of the scavengering kinds; and unusual mortality among the *Sphaeriidae,* following the unusual multiplication rate and resultant crowding mentioned, may to some extent have served the same purpose.

In the following table illustrating succession, based upon average weight figures in pounds per acre, the small numbers at upper right of group names represent the percentages of average total hauls contributed by the groups; groups with percentages under 5 being ignored. The larger figures at left preceded by letter A are the phase numbers of the groups constituting the long pollutional cycle that started shortly before 1920; phase number 1 (*Tubificidae* dominant) having been missed, and apparently falling somewhere between 1917 and 1920. The large figures at left preceded by letter B are the phase numbers of the minor and apparently temporary pollutional cycle that started in certain reaches below Peoria Lake during the severe summer floods of 1924.

TABLE XVI

TABLE SHOWING SUCCESSION OF LEADING GROUPS OF SMALL BOTTOM ANIMALS, BASED ON PERCENTAGE COMPOSITION BY WEIGHT OF THE AVERAGE HAUL; 1915 TO 1925

Exponents are percentages of the average total poundages per acre contributed by the leading groups of small bottom animals

1915

Upper Peoria Lake..................	*Gastropoda*[illegible]	*Sphaeriidae*[illegible]
Middle Peoria Lake†		
Lower Peoria Lake..................	*Gastropoda*^{95}	
P. P. U. R. R. Bridge to Pekin........	*Gastropoda*^{62}	*Sphaeriidae*^{34}
Pekin to Copperas Creek Dam........	*Gastropoda*^{80}	*Sphaeriidae*^{16}
Copperas Creek Dam to one mile above Liverpool	*Gastropoda*^{80}	*Sphaeriidae*^{19}
One mile above Liverpool to Havana.	*Gastropoda*^{65}	*Sphaeriidae*^{31}
Havana to Lagrange Dam...........	*Gastropoda*^{86}	*Sphaeriidae*^{12}

1920

Upper Peoria Lake......	A2	*Chironomidae*^{52}	*Tubificidae*^{33}	
Middle Peoria Lake......	A2	*Chironomidae*^{78}	*Tubificidae*^{18}	
Lower Peoria Lake......	A2	*Chironomidae*^{98}		
P. P. U. R. R. Bridge to Pekin..................		no collections		
Pekin to Copperas Creek Dam....................		no collections		
Copperas Creek Dam to one mile above Liverpool...................		no collections		
One mile above Liverpool to Havana	A2	*Chironomidae*^{53}	*Gastropoda*^{19}*	Leeches^{18}
Havana to Beardstown...		*Gastropoda*^{45}*	*Chironomidae*^{30}	Leeches^{23}

* Holdover from 1913-1915.

† Collections from upper third of Middle Peoria Lake included with Upper Lake in this part of the table.

TABLE XVI—Concluded.

1924				
Upper Peoria Lake.........	A3	*Sphaeriidae*^{60}	*Tubificidae*^{19}	
Middle Peoria Lake........	A3	*Sphaeriidae*^{92}		
Lower Peoria Lake.........	A3	*Sphaeriidae*^{57}	*Tubificidae*^{19}	Leeches^{13}
P. P. U. R. R. Bridge to Pekin	B1	*Tubificidae*^{80}	*Sphaeriidae*^{17}	
Pekin to Copperas Creek Dam	B1	*Tubificidae*^{33}	Leeches^{32}	*Sphaeriidae*^{22}
Copperas Creek Dam to one mile above Liverpool.....	A3	*Sphaeriidae*^{91}	*Tubificidae*^{6}	
One mile above Liverpool to Havana	A3	*Sphaeriidae*^{91}		
Havana to Beardstown.....	B1	*Tubificidae*^{45}	*Sphaeriidae*^{30}	*Gastropoda*^{17}*
1925				
Upper Peoria Lake	A3	*Sphaeriidae*^{51}	*Tubificidae*^{36}	*Chironomidae*^{10}
Middle Peoria Lake	A3	*Sphaeriidae*^{85}	*Chironomidae*^{6}	Leeches^{5}
Lower Peoria Lake	A3	*Sphaeriidae*^{35}	*Chironomidae*^{34}	*Tubificidae*^{22}
P. P. U. R. R. Bridge to Pekin.	B1	*Tubificidae*^{48}	Leeches^{35}	*Sphaeriidae*^{15}
Pekin to Copperas Creek Dam	B2	*Chironomidae*^{84}	Leeches^{6}	
Copperas Creek Dam to one mile above Liverpool.			No collections	
One mile above Liverpool to Havana	A3	*Sphaeriidae*^{47}†	Leeches^{47}	
Havana to Beardstown	B3	*Sphaeriidae*^{84}	*Tubificidae*^{6}	*Gastropoda*^{6}*

† The leeches are apparently preying upon the *Sphaeriidae*, which are just abdicating first place, which they held over from 1924.
* Largely holdover from 1913-1915.

Competitive Relations Among the Small Bottom Animals

Among the three groups of small bottom invertebrates that have figured largest in abundance and valuation in the muddy reaches of the Illinois River above Havana since 1920 *(Tubificidae, Sphaeriidae,* and *Chironomidae),* it cannot be said that competition for food has been at any time an important influence on numbers. Insofar as these three groups use the same food, namely, the living bottom plankton and bacteria and the settled plankton and fine organic detritus, they are competitors in a general sense. But by reason of the practically limitless amounts of those materials available, at least in the reaches of the Illinois River with less current, competition for food is probably non-existent in actual practice, although all three groups have often in recent years been found associated in large numbers over the same bottom area.

The gastropod *Mollusca,* embracing several species of large snails capable of ingesting objects as large or larger than the eggs of many insects, and having the habit of taking in practically everything that lies in the path of their tongues as they crawl over the incrusted surface of sticks, or stones, or dead or living shells, have bulked so small in the Illinois River bottom fauna above Beardstown in recent years that depredation by them on egg or very immature stages of other organisms may be regarded as little if any more than negligible. In years previous to 1920, on the other hand, the fact that they once became dominant in an area seems to have given them a more or less permanent and, if abundant, often almost undisputed foothold there. This was with little doubt in some part due to the inability of other bottom invertebrates, which plaster minute eggs on solid objects on the bottom, to multiply in great numbers where the rasping tongues of hundreds or thousands of *Campeloma* and *Vivipara* per square yard were in daily operation. The hold of the larger *Gastropoda* on the territory once occupied by them in great numbers was doubtless also strengthened against some otherwise likely associates, by the smothering blanket of slime spread over and binding together the fine bottom ooze and shutting off the air over large areas from eggs or very young stages of other species living therein; and against still others (as possibly *Tubificidae* and young *Chironomidae*) by the sheer bulk, weight, and slow motion of these snails, which could easily result in smothering many small organisms of other species unfortunate enough to be in their way.

Thus it is no surprise to find that our older data, obtained when large *Gastropoda* led in abundance in many reaches of the Illinois River, strongly suggest that great numbers of these snails act as a bar against the increase in large numbers in their immedite neighborhood of either *Chironomidae, Sphaeriidae,* or *Tubificidae.* Only those *Tubificidae* of less pollutional habit are here referred to, *Tubifex tubifex* being unlikely, because of its more distinct preference for very foul bottom, to reach great numbers in muds inhabitable by the more sensitive *Viviparidae* even if the large snails were not there.

Of the larger species of *Sphaeriidae* it was noted in years prior to 1920 that *Musculium transversum* was frequently comparatively abundant along with considerable numbers of large *Viviparidae,* though not likely to be present at all where *Viviparidae* reached maximum numbers. The indicated greater immunity to both direct and indirect injury by the large snails exhibited by this small bivalve, than by *Chironomidae* and *Tubificidae,* quite possibly had some connection with the fact that they are born alive with a fully formed shell, and of a size rather larger than that of food objects usually taken by the large *Gastropoda.*

Leeches, concerning whose depredations on *Sphaeriidae* mention has been made in a preceding section, are also known to prey upon *Tubificidae,* but we find no positive evidence of that in our recent bottom fauna data. In the stretch of river between Liverpool and Havana the *Tubificidae* in fact increased about 20 per cent between 1924 and 1925, as the small bivalves, thought to be the object of leech depredation, declined. Other strictly predaceous bottom species that are known to affect the abundance of the less well protected small bottom organisms in many waters, such as certain larval *Coleoptera* and *Odonata,* have not been represented in important numbers in recent Illinois River and Peoria Lake collections from the deeper open-water areas.

Accessibility, Quality, and Extent of Use as Fish Food

Probably quite as effective as competition among themselves in keeping down numbers of some groups of the small bottom animals is their use as food by the more common bottom-feeding fishes. Also there is not lacking circumstantial evidence that neglect of some groups by the fishes permits them at times to increase while the stocks of others are being drawn down.

The evidence from Professor Forbes studies on the food of the buffalo, red-horse, and carp-suckers from scattered localities in Illinois; those of Cole on German carp in Lake Erie; and those of the State Natural History Survey in the past three years on the feeding habits of carp, buffalo, and other sucker-mouthed fishes of Rock River, strongly suggests that, in general, these fishes prefer small bivalve mollusca *(Sphaeriidae)*, various kinds of larval midges *(Chironomidae)*, the burrowing May-flies *(Ephemerinae)*, and the larval caddis-flies *(Hydropsychidae)* to *Tubificidae,* leeches, and large *Gastropoda.* The evidence as respects avoidance of the *Tubificidae* by the large bottom-ranging fishes is of course not conclusive at present, consisting in their almost total absence from more than a thousand stomachs examined (from Illinois waters only), although the worms are known in a good portion of the cases to be present in at least moderate numbers in the areas from which the fishes came.

Several possible reasons for this seeming neglect of the *Tubificidae* by the principal large bottom-feeding fishes suggest themselves. For one thing, the *Tubificidae* are generally quite small, and are accustomed to withdraw themselves instantaneously into their tube-like burrows, excavated in the bottom mud, at the least disturbance. This habit may easily afford effective protection to them when their numbers are moderate and when they are interspersed between larger, more accessible, and more acceptable small bottom kinds, as is apparently most frequently the case where much feeding by the large bottom-ranging commercial fishes goes on. When they are extremely abundant, on the other hand, the dissolved-oxygen supply is likely to be so low that little feeding by the fishes can be believed to take place during the active warm season in their territory. For the discussion of data that suggest, on the other hand, that the large bottom-ranging fishes do occasionally under unusual conditions, and perhaps more or less accidentally, eat large quantities of *Tubificidae,* see page 450.

The complete exclusion of the *Tubificidae* from the dietary of the bottom-feeding fishes, even if it were to occur where they are most abundant, would cut down the total stocks of small bottom animals available, measured in pounds per acre, much less than the exclusion, under recent conditions, of the *Sphaeriidae;* but, on the average, apparently, not much if any less than the exclusion of the *Chironomidae*. Thus, in Upper Peoria Lake in 1924, the *Tubificidae* amounted on the average to approximately 1,300 pounds out of a total of all kinds of small bottom animals of somewhat more than 6,000 pounds per acre; while the *Sphaeriidae* averaged well over 5,000 pounds. Their occurrence in average poundages over 500 to the acre during the years 1924 and 1925, was confined to three sections of the Illinois River, all above Pekin. In most of the few cases since 1920, in fact, where the percentage of the total weight of all small bottom animals made up of *Tubificidae* was high, the total weight of all kinds was low, and the average weight of the worms was considerably under 200 pounds per acre.

In rather marked contrast to the *Tubificidae,* the four more important of the apparently preferred groups in Illinois streams, the *Sphaeriidae*, the *Chironomidae*, the *Ephemeridae* and the *Hydropsychidae*, are all visibly larger; and they are accustomed, even when burrowers (as are some of the *Chironomidae* and all of the formerly common *Ephemeridae* of the Illinois River), to remain for considerable times outside of their burrows. Even the larvae of the more abundant caddis flies of the Illinois and Rock Rivers (the *Hydropsychidae*) live a free life upon the bottom much of the time, though they show a preference for cracks or crevices in rock or other hard bottom when it is available, and withdraw into a hard case made of sand grains just before pupation. In spite of the rather large degree of protection afforded them by such habits they are not a small element in the food of several of the larger bottom-feeding fishes of these rivers.

Because in the season of 1925 the total weight of the leeches in the reach Liverpool to Havana rose to the unprecedented figure of over 2,500 pounds per acre, it is of interest, next, to inquire whether this rather large supply of potential animal food was likely to be of any important actual value to the large commercial fishes that range the bottom of the open Illinois River where the leeches were found. Such answer as is afforded by the study of data from a variety of sources is not in favor of placing a high value on the leech crop as fish food. It is true that Professor Forbes* more than forty years ago found leeches in the stomachs of 3 out of 113 channel cat examined from Illinois waters, and also in the stomachs of 6 out of 49 bullheads; and large leeches are reported as being used occasionally as bait for channel cat in Rock River. But channel cat and bullheads made up then as now only a rather small percentage of the total fish catch, whereas the more important group, from the point of view of bulk and weight and numbers, including the bottom-feeding

* Various papers on the food relations of fresh-water fishes, published between 1877 and 1888 by this laboratory.

buffalo, red-horse, and suckers, furnished only a single specimen which had eaten a leech out of a total of 107 specimens examined. Cole†, in studying the food of carp in Lake Erie (1903) found no leeches at all in 33 specimens examined, but did find an abundance of small bivalve *Mollusca* and *Chironomidae,* much vegetation, and other minor materials. In our examination of the food of the larger bottom-feeding fishes of Rock River, not completed, 92 specimens of carp have shown no leeches taken as food; 109 buffalo, of three species, showed only one leech eaten (by a mongrel buffalo); 116 suckers and red-horse and silver carp of various species showed no leeches eaten at all; and over 900 channel cat and 40 other catfishes of various species showed no leeches eaten at all. Leeches evidently play a more important part in the food of shore fishes, particularly those that feed among vegetation—including sunfishes, perch, black bass, some perch-like fishes, sculpins, and bullheads, as is shown by Pearse‡ in his studies (1915-1916) on the food of fishes in some of the inland Wisconsin Lakes.

The younger and thinner-shelled specimens of the large gastropod *Mollusca* are known to be used as food by the large species of red-horse, but did not appear in the food of buffalo, suckers, or silver carp examined by Professor Forbes from Illinois Waters. Neither have they been found by us in any of the specimens (upwards of 300) of carp, buffalo, red-horse, etc., examined in the last three years from Rock River. These snails, it is true, are comparatively rare in most of the Rock River. But in those reaches of the Rock River about and above Rockford, where large *Viviparidae* are common, while they do not appear in the buffalo, suckers, red-horse or carp stomachs, they are found frequently in the stomachs of channel cat, the only fish we at present know of which seems capable of handling them. Professor Forbes called attention to this nearly 40 years ago, and today we find, as he did then, that the large channel cat are able to withdraw the bodies of full-grown heavy-shelled specimens of *Campeloma* and *Pleurocera* from the shells and swallow them with no hard parts attached except sometimes the operculum. The value of these larger snails as fish food thus appears to be quite limited, much as that of the several kinds of common leeches; both entering into the food, for the most part, of a single minor group of the large bottom-ranging fishes (the catfishes), and being avoided by the more important, carp, buffalo, and allied kinds. From the point of view purely of accessibility, then, of the more important constituents of the small bottom fauna as fish food, the destruction of the large *Gastropoda* in the Illinois River by pollution since 1915, and their replacement by still larger numbers and greater total bulk of the more acceptable and more accessible small bivalve *Mollusca* *(Sphaeriidae),* may be regarded as a benefit rather than an injury to the commercial fishery, at least in those areas where the pollution which ac-

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† Cole, L. T., The German Carp in the United States. Rept. U. S. Bureau of Fisheries, year ending June 30, 1904, Appendix, pp. 523-641.

‡ Pearse, A. S., The Food of the Shore Fishes of Certain Wisconsin Lakes. Bull. U. S. Bureau of Fisheries, Vol. XXXV, 1915-1916, pp. 247-291.

complished the change does not hold the oxygen down to or below the danger point for the fishes during the active feeding season.

On the score of quality—including both healthfulness and suitability for producing edible quality in fishes which consume it—the recent "rich" food supply in the more polluted sections of the Illinois River both above and for some distance below Peoria seems open to indictment on more than one count. While "gassy" fish have been complained of at various places along the Illinois River for many years, these complaints have become much more insistent in the Peoria Lake region since 1920. Since that time eastern receivers have been accustomed to make price discriminations against Illinois River fish, more particularly, carp, for that reason. The local complaints have agreed that the "gassy" taste is more pronounced in winter, when the river and lakes are frozen over, without, however, advancing a satisfactory explanation why that should be so; the putrefactive processes in the bottom sludges being clearly much less active and productive of nuisance under winter temperatures than during the warm season. On reflection it is seen that a very simple and purely physical theory satisfactorily accounts both for the central fact of "gassiness" and for its stronger expression under winter conditions. Direct absorption by the tissues of odors from some varieties of food eaten is well known in man. The possibilities in fishes, such as carp, which, if they do not actually take up by choice appreciable quantities of foul-smelling sludge, do at times feed heavily upon small bottom organisms that have done so, need only to be mentioned to be realized. In the fouler areas ranged over by carp, not only the small oligochaetes, which swallow mud or sludge in large quantities, but also the small bivalves, certain snails, and other bottom species that take bottom detritus accidentally along with the bottom plankton or incrusting plant and animal growths, are likely to develop strong odors, which in turn will be reflected later on in the odor and taste of the fishes. During the summer season, of course, decompositions in the muds are likely to be much nearer their end points than in winter; and the exhalation of such odors through blood-stream and skin is doubtless at a relatively high rate, corresponding with the degree of activity of the fish. Another point of possible importance is the ordinary habit of the larger commercial fishes of feeding much farther away from the channel in spring and summer than in late fall and early winter. Fishes, on the other hand, which continue to feed a a short time after the bottom is chilled, are likely to take in directly or indirectly material capable of producing especially offensive odors, as its temperature is raised to that of the body of the late feeder. And those fishes which go into winter dormancy immediately after a heavy feeding on chilled bottom will retain such odors as are absorbed more fully and longer because of the lessened exhalation rate that accompanies inactivity.

Among the carp taken since 1920 at and above Peoria, also, a very high rate of disease has been observed; the percentages of affected fish to totals recently examined going above 50 at most stations. There are some grounds for believing that the most prevalent of the diseases noted may be connected with the character of the food supply. As the carp is the only surviving commercial kind that is now able to maintain fair numbers in these polluted areas, comprising probably more than nine-tenths recently of all fishes taken, it can be seen that a large part of the entire local fishery is affected. Dr. David H. Thompson was engaged for some time in a special study of the diseased carp in the middle Illinois River, and his report on this subject is published in this bulletin.*

Changes in Abundance of the Principal Groups During and Just After the Continuous Summer Floods of 1924

Of the six summer seasons, 1920 to 1925, all except that of 1924 had the crest of the spring freshet not later than the middle of May, with gage height at Peoria dropping to between 11 and 9 feet before the end of June, and continuing within a range of 8 to 10 feet through July, August, and September. The warm season of 1924 was characterized by continuous summer floods, with the Peoria gage ranging 14 to 18 feet in June, 18 to 19 feet in July, and 19 to 20 in September. What appear to be direct effects of these very unusual flood conditions are seen in the figures of abundance of midge larvae for the season of 1924, which almost uniformly showed decreases, some of them quite large, over the figures of the year of more normal summer rainfall preceding. The largest decreases were shown in the three reaches (Middle and Lower Peoria Lake, and foot of Peoria Lake to Pekin) where *Chironomidae* had been most abundant the year before. The single section, in fact, of those examined, in which average numbers of midges went above the figures of 1923 was that between Havana and Beardstown, where *Chironomidae* had been comparatively rare in previous collecting seasons, and into which it is possible that the flood of 1924 introduced them in somewhat more than usual numbers.

Evidence tending further to confirm our supposition that the decreases in the *Chironomidae* in 1924 were due to the washing away of successive broods in the egg or early larval stage, is furnished by the data of abundance of the larvae in the summer season of 1925. Under the normal summer gages of that year large increases in midge larvae were shown in almost all reaches, with the largest increases falling mainly within the territory of largest decreases in the year preceding, if a single case of very unusual increase, in the short reach between Pekin and Copperas Creek Dam, be excepted. The latter quite possibly reflected the result of some unusual attraction furnished temporarily by the odors from the Peoria and Pekin wastes.

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* Vol. XVII, Art. VIII, The "knothead" carp of the Illinois River.

TABLE XVII

CHANGES* IN ABUNDANCE OF TOTAL CHIRONOMIDAE DURING AND IMMEDIATELY FOLLOWING THE CONTINUOUS SUMMER FLOODS OF 1924; AVERAGE NUMBERS PER SQUARE YARD

Reaches and subdivisions	1923 to 1924		1924 to 1925	
	Channel	Extra-channel	Channel	Extra-channel
Upper Peoria Lake...	—57	—145	—6	+466
Middle Peoria Lake..	—557	—383	+760	+629
Lower Peoria Lake...	—1,059	—117	+303	+1,264
Foot of Peoria Lake to Pekin	—400	—57	+280	+256
Pekin to Copperas Creek Dam	—104	—11	+54	+10,497
Copperas Creek Dam to Liverpool........	—62	no collections 1923	no collections 1925	no collections 1925
Liverpool to Havana..	—36	—23	no change	—26
Havana to Beardstown.	+4	+22	+8	+139

* Increases are represented by the + sign, decreases by the — sign.

Examination of the figures of abundance for the other two leading groups among the small bottom animals, the *Sphaeriidae* and the *Tubificidae*, fails entirely to disclose similar trends in those groups in the periods 1923-1924 and 1924-1925. Quite to the contrary, in 1924, while midge larvae were sharply declining, both *Musculium transversum* (which made up more than 90 per cent of the *Sphaeriidae* in most reaches) and total *Tubificidae* were showing fair to heavy increases in numbers, or declines that (relatively to the largest increases) were unimportant. Again, while *Chironomidae* in 1925 were rising sharply in almost all reaches, far the largest changes in the *Sphaeriidae* were downward, and several of the largest changes in the *Tubificidae*, itemizing by reaches and areas, were in the same direction.

While the effects of a variety of factors, impossible wholly to separate from each other, may be concerned here, the most reasonable explanation of the principal changes in abundance of these two groups (*Sphaeriidae* and *Tubificidae*) between 1923 and 1924 seems to be to regard them as largely indirect effects of the wide shift in water levels during the period. At least it is clear that similar effects easily could be obtained through the medium of lessened, followed by increased, foraging in the deeper open waters by the bottom-ranging fishes; the amount of feeding, in its turn, being influenced by gage heights. It is well known that, throughout the spring and summer season as there arises opportunity, the fish depart to a great extent from the deeper water to feed in the "brush"—or in other words, territory into which our collecting has not taken us since the close of field operations in the region of Havana before 1920. It is evident that changes in abundance of the small bottom animals, provided they are of kinds not so easily washed away as the majority of the commoner *Chironomidae* of the Illinois River seem to be, would be in some measure during a growing season of continuous flood in proportion to the extent of this migration.

Evidence confirmatory to some extent of this view of the case seems to be furnished in the fact that the *Sphaeriidae* showed the largest increases during the flood of June to September, 1924, in Upper Peoria Lake and from Liverpool to Havana, where, in each case, that group had been most abundant the year before, and where, in the case of the first area mentioned, there is a very large acreage of "brush" territory contiguous to the area represented by our collecting stations. Likewise, the large decreases in the *Sphaeriidae* between 1924 and 1925, along with the presumable re-entrance of the fishes into the deeper and more open waters for spring and summer feeding, also took place in the same two sections of river (i. e., Upper Peoria Lake and Liverpool to Havana), where the greatest increases had occurred the year before. This finding is, in its turn, at least consistent with the popularly held supposition that large fishes which move about considerably are alert to discover and utilize the richest feeding grounds, provided of course, that the oxygen supply is adequate. In order for the latter to have been the case in Upper Peoria Lake in 1925, it seems necessary to assume that the bulk of the cutting down of the surplus stores of *Sphaeriidae* laid up there in 1924 was done from April to June rather than in July and August.

TABLE XVIII

CHANGES* IN ABUNDANCE OF *MUSCULIUM TRANSVERSUM* DURING AND IMMEDIATELY FOLLOWING THE CONTINUOUS SUMMER FLOODS OF 1924; AVERAGE NUMBERS PER SQUARE YARD

Reaches and subdivisions	1923 to 1924		1924 to 1925	
	Channel	Extra-channel	Channel	Extra-channel
Upper Peoria Lake...	+16,977	+14,533	—15,242	—14,828
Middle Peoria Lake..	+1,844	+1,044	+3,164	+1,596
Lower Peoria Lake...	+130	+49	+1,238	+327
Foot of Peoria Lake to Pekin	+40	+132	+1,064	+36
Pekin to Copperas Creek Dam	—82	+124	+34	+38
Copperas Creek Dam to Liverpool........	—26	no collections 1923	no collections 1925	no collections 1925
Liverpool to Havana.	+17,928	+7,200	—5,424	—7,058
Havana to Beardstown	—199	+40	+5,290	+1,843

* Increases are represented by the + sign, decreases by the — sign.

Just why it was that the *Sphaeriidae* increased rather than declined in most of the other reaches, between the Middle Lake and Beardstown (except the Liverpool-to-Havana reach) in 1925 is not wholly clear. The figures stand about as they would, however, if two assumptions are granted: first, that an excessive rather than merely normal amount of feeding by the fishes is likely to occur where the bottom fauna is richest, with the limitations above noted; and, second, that the normal rate of increase in the *Sphaeriidae* in recent years, both in the areas of its greatest abundance and elsewhere, may have been in excess of normal demands from the present fish population.

Our data on abundance of *Tubificidae* from 1923 to 1925 in the reaches between Chillicothe and Beardstown, if the single instance of Upper Peoria Lake be excepted, reflect an irregularity that can be ascribed only to the operation or effects of several influences. In the first place, these worms increased greatly, both in the channel and extra-channel zones in Upper Peoria Lake, during the heavy floods of the summer of 1924, and decreased in the same part of Peoria Lake in 1925; in both instances in quite a similar way to the changes of the *Sphaeriidae*. In this part of Peoria Lake, the stronghold of both the *Sphaeriidae* and *Tubificidae* between Chillicothe and Beardstown since 1920, and where, in fact, the worms reach vast numbers in close juxtaposition on the lake bottom with the small bivalves, it is probable that for several years the large bottom-feeding fishes, when they have fed there at all, have been forced to take large quantities of the small worms as food in order to get the *Sphaeriidae*. This being so, the explanation of the rise

Table XIX

Changes* in Abundance of Total Tubificidae During and Immediately Following the Continuous Summer Floods of 1924; Average Numbers per Square Yard

Reaches and subdivisions	1923 to 1924		1924 to 1925	
	Channel	Extra-channel	Channel	Extra-channel
Upper Peoria Lake...	+51,476	+23,158	—42,824	—10,494
Middle Peoria Lake..	—1,892	+46	+1,086	+78
Lower Peoria Lake...	+339	+1,873	+931	+7,782
Foot of Peoria Lake to Pekin	+3,098	+5,758	—2,992	+25,245
Pekin to Copperas Creek Dam	—164	—352	+160	—220
Copperas Creek Dam to Liverpool........	—9	no collections 1923	no collections 1925	no collections 1925
Liverpool to Havana.	—461	+2,988	+504	+688
Havana to Beardstown	—27	+1,209	+4,888	—1,934

* Increases are represented by the – sign, decreases by the — sign.

in numbers of the worms under the flood conditions of 1924, and the sharp decline in the much more settled summer following, is probably largely the same as that offered above for the changes in the common small bivalve, *Musculium transversum.*

The unusually larger increases in *Tubificidae* in 1925, following the flood year 1924, in several of the reaches below Upper Peoria Lake, and including even Havana to Beardstown, seem to call for a less simple explanation. In the first place, in none of the reaches of river below Upper Peoria Lake could it be said that the *Tubificidae* and the *Sphaeriidae* were so crowded together on the bottom in the years before 1925 that the carp and buffalo would be compelled to take them in order to get the ordinarily preferred *Sphaeriidae;* that is, the *Sphaeriidae* could be more readily foraged for separately in these areas than in Upper Peoria Lake, and the *Tubificidae* to the same extent left alone. Again, as has been mentioned in a preceding section, there are strong reasons for supposing that the unusual all-summer floods of 1924 brought down "seeding-stock" of the worms themselves, along with a rich supply of organic sediment, into several reaches of river between Peoria and Beardstown that had been poor bottom fauna and fish producers for many years before because of prevailingly hard sand-and-shell or lightly silted clay bottom.

The sharp spurt upward of the *Tubificidae* in the extra-channel areas of the reach between the foot of Peoria Lake and Pekin in 1925 seems most probably to have resulted from a concentration of local pollution on the east side of the river at Pekin. The richest hauls of *Tubificidae,* which account largely for the high average, were taken on the Pekin side, above the Corn Products Refining Company's plant, and might have originated either at Pekin or at South Peoria.

We may now return again to the *Chironomidae* to inquire what may have caused that group, previously listed with evidently good reason among the preferred foods of several of the most important of the bottom-feeding fishes, to increase its numbers, either sizably or heavily in all reaches above Copperas Creek Dam in 1925, while the *Sphaeriidae* declined sharply in Upper Peoria Lake and showed relatively small or negligible increases in all the other reaches in the same distance. The answer is probably to be found partly in the fact that, in the case of the *Chironomidae,* we are dealing with a larger number of kinds and a much wider distribution of broods over the growing season; whereas close to 99 per cent of the *Sphaeriidae* in many sections of the river has recently been made up of *Musculium transversum,* a species whose single heavy bearing season has in recent years in the Illinois River usually come as late as July or August. Even more important, perhaps, is the fact that the edible-sized larval *Chironomidae* periodically leave the river, actually for two weeks or more between emergence and egg-laying, and effectively for longer periods; while the small bivalves are permanent residents on the river floor. As a consequence, largely of one or the other of these considerations, the large schools of carp and buffalo that made their way upstream in the early spring of 1925 could conceivably have made heavy inroads into the stocks of gravid *Sphaeriidae* at a point of especial vulnerability, antedating the normal time of heaviest birth rate by several weeks. The same schools of bottom-feeding fishes, however, could have passed up the river easily between dates of pupation and emergence of some of the earlier broods of the *Chironomidae* and so have had relatively little effect on abundance of those particular kinds through the rest of the same summer. Or, in an unusually late spring, the same effect, in greater or less degree, could have been produced several weeks later in the season.

Comparative Abundance in the Channel and Extra-channel Areas, 1920 to 1925

Comparisons of channel and extra-channel figures of abundance of the *Tubificidae* for all collecting years 1920 to 1925 shows that in all the reaches above and below Peoria Lake, and in that part of Peoria Lake which most nearly resembles unwidened river in its average rate of flow (i. e., Lower Peoria Lake) they usually reached both their highest average numbers and their maxima in the extra-channel areas. This was noted and commented upon in 1922 and 1923, and is believed to express the preference of these worms for the ordinarily more stagnant conditions prevailing in those areas and for the consequently more frequently renewed supply of rich bottom sediments, following freshets, in such situations.

In both Upper and Middle Peoria Lakes, however, quite the reverse of these conditions is found to hold: both greatest average abundance and maxima occurring in recent years almost without exception in the main stream-channel rather than in the wide-waters. Both of these lakes have an average low-water rate of flow both in the steam-boat channel and in the wide-waters considerably under that of the Lower Lake, and it is quite apparent that sufficient sedimentation takes place within the channel itself to supply the worms with nearly if not quite optimum soil conditions. As an additional influence on abundance of the worms in the direction noted, the fact may be mentioned that the principal part of the feeding by the large commercial fishes ordinarily takes place in the areas outside the channel; and in these two sections of Peoria Lake the close mingling of great numbers of *Tubificidae* and *Sphaeriidae* could easily result in the consumption of unusually large quantities of the worms by bottom fishes while in quest of the bivalves.

The large *Sphaeriidae*, as represented by the single extremely abundant species of Peoria Lake, *Musculium transversum*, have not been observed to follow the rule of the small worms, but rather, with only two or three unimportant exceptions, reached their largest average numbers per square yard in the period 1920 to 1925 in the deeper-channel areas, both in the three sections of Peoria Lake and in the more important river reaches above and below it. This recent distribution of the *Sphaeriidae* as between channel and extra-channel areas quite reverses the rule that prevailed in 1913-1915, when, in the sections of river most richly supplied with those small mollusks, much the largest numbers were taken in the extra-channel areas. The rule of distribution at that time seems to have reflected, indirectly, the fact of preference for, and preemption of the channel territory by, the large *Viviparidae* and *Pleuroceridae* which have been for the most part a missing element in the small bottom fauna since 1920. Though the figures of abundance for total chironomid larvae over the period 1920 to 1925 are mixed and in many cases quite indefinite as to trend, there appears a clear tendency both in all the unwidened river reaches and in Lower Peoria Lake to reach greatest numbers in the areas outside the channel—in this respect, following the rule observed of the *Tubificidae*. In the Upper and Middle Lakes, on the contrary, as in the instance of the worms, the highest average figures and the maxima both fell without exception in the deeper channel areas, for reasons no doubt not substantially different from those just cited as probably affecting the *Tubificidae*.

Changes in the Mussel Fauna of Peoria Lake, 1912 to 1925

Danglade*, in the course of his examination of the Illinois River for the United States Bureau of Fisheries in 1911-1912, found a total of forty-one kinds of mussels in Peoria Lake (with Chillicothe, slightly above the upper end, included) but did not publish separate lists for the three subdivisions. Nineteen of these were commercial species regularly salable, of which at least ten were then easy to obtain in paying numbers. The mussels died out rapidly in all three sections of the lake during and after 1917 until commercial clamming entirely ceased because of failure to obtain shells. In the summer of 1920 a single clammer operated a bar for a few days in the channel of the Lower Lake opposite the center of Peoria, but took nothing but dead shells except for an occasional live specimen of *Amblema rariplicata* or still less frequently *Quadrula pustulosa*. In 1920-1922 the Natural History Survey took single examples of three species (*Amblema rariplicata*, *Anodonta imbecillis*, and *Quadrula pustulosa*) with the Petersen bottom sampler incidentally to the collection of the small bottom fauna of the Lower Lake. Commercial clamming on a scale much reduced from that of the pre-1920 period began again in 1924 and has been continued sporadically by a few clammers since. The only commercial species obtained since then in salable quantity, however, has been the common three-ridge, *Amblema rariplicata*. Following out the suggestion from the commercial clammers, the Survey in the summers of 1924 and 1925 operated with a standard clammer's dip-net over fairly extensive areas between Peoria Narrows and the vicinity of Spring Bay,

* Danglade, Ernest, The Mussel Resources of the Illinois River. Report U. S. Bureau of Fisheries for 1913, Appendix VI, pp. 1-48.

near the foot of the Upper Lake, and took, in all, during the two seasons, 16 species. Of the sixteen kinds taken, only one, the common three-ridge, as in the recent commercial clamming in the Lower Lake, was found in more than small and scattering numbers.

The eight species taken by us in the Upper Lake in 1924 and 1925 all came from two stations at its lower end, in both cases in unusually favorable situations: either opposite the foot of Partridge Island, on the east side, and only shortly below the outlet of Partridge Creek; or in the unusually strong current in Spring Bay Narrows. Springs under the bed of the river are known to exist in the lower end of this section of Peoria Lake, in the vicinity of Spring Bay, their occurrence there giving the name to the old village.

At various stations in the Middle Lake, between Mossville and Towhead Island, eleven kinds were taken in 1924-1925. The most of the remnant beds in the Middle Lake were located on the west (or bluff) side, but some successful drags were made as much as 500 to 700 feet from shore on either side of the channel. Springs are very frequent along the west bluff and quite possibly exist in this section of the lake under the river and lake bed in some places. Unless this is true, or unless these species are able to bury themselves in the mud during the hot season for considerable periods (a supposition which is thought doubtful), it is hard to understand how even these unusually tolerant species can have survived the destruction by pollution that occurred generally in this lake between 1916 and 1920. For the recent findings, either in the Upper or Middle Lake, are not to be looked upon as any new development, the specimens having probably remained alive in substantially their recent locations through the worst of the wave of pollution that destroyed the more sensitive *Mollusca* about ten years ago.

TABLE XX

UNIONIDAE OF PEORIA LAKE, 1924-1925

Upper Peoria Lake	Middle Peoria Lake	Lower Peoria Lake
Foot of Partridge Island, Spring Bay Narrows	Mossville to Towhead Island, miscellaneous stations	Peoria Narrows, south of bridge
Fusconaia undata		*Fusconaia undata*
Quadrula quadrula	*Fusconaia undata*	*Quadrula pustulosa*
Amblema rariplicata	*Quadrula quadrula*	*Quadrula quadrula*
Lasmigona complanata	*Amblema rariplicata*	*Amblema rariplicata*
Anodonta corpulenta	*Anodonta corpulenta*	*Elliptio dilatatus*
Anodonta imbecillis	*Anodonta suborbiculata*	*Anodonta corpulenta*
Lampsilis fallaciosa	*Anodonta imbecillis*	*Anodonta imbecillis*
Lampsilis siliquoidea	*Obliquaria reflexa*	*Obliquaria reflexa*
	Leptodea fragilis	*Leptodea laevissima*
	Carunculina parva	*Leptodea fragilis*
	Lampsilis fallaciosa	*Proptera alata*
	Lampsilis siliquoidea	*Lampsilis fallaciosa*
		Lampsilis siliquoidea

The thirteen kinds of mussels taken in 1924-1925 at the head of the Lower Lake, just below the Peoria Narrows wagon bridge, require no explanation, as the current is unusually swift there, and the dissolved oxygen under the worst conditions in the warm season usually ranges between 4 and 5 parts per million and, when the green plankton is the most abundant and active, sometimes exceeds 8 parts per million.

Comparison with our own 1912 records of occurrence in the Illinois River above Chillicothe, when about 3 parts per million, instead of zero, as recently, was the usual lower limit of the dissolved oxygen at Chillicothe, shows that it is largely the same list of species now showing unusual tolerance in Upper and Middle Peoria Lake, that ranged farthest up stream in the badly fouled river above the Upper Lake (and Chillicothe) in 1912. We find, in fact, that all of the eight species found in Upper Peoria Lake in 1924-1925 ranged at least as far north as Hennepin (27 miles above the head of Upper Peoria Lake) in 1912; that two of them *(Amblema rariplicata* and *Lasmigona complanata)* were taken at Starved Rock (50 miles above Chillicothe) in 1912; and that two others *(Anodonta corpulenta* and *Quadrula quadrula)* ranged then as far north as Spring Valley (38 miles above the head of the Upper Lake). It is also noteworthy that *Amblema rariplicata,* one of the two species found as far north as Starved Rock in 1912, was the only one of the entire sixteen taken in Peoria Lake in 1924-1925 that occurred in more than very scanty numbers.

The 1924-1925 list of mussels from the Middle Lake had among its eleven species one that occurred as far north as Starved Rock in 1912 *(Amblema rariplicata);* one that was taken above Peru that year; and two that then occurred as far north as Spring Valley. Of the remaining seven, four occurred as far north as Hennepin in 1912; one between Chillicothe and Henry; and two not at any of the 1912 collecting points.

Though the conditions of current and dissolved-oxygen supply are unusually good at Peoria Narrows, it seems also that to a great extent only the hardier mussels have been able to hold out there through and since the 1917-1920 period of destructive pollution. So we find that the 1924-1925 list of thirteen kinds from there includes three species with a northward range between Peru and Starved Rock in 1912; three with northward range to Spring Valley in 1912; five others with occurrences as far north as Hennepin then; and the other two with older records from between Chillicothe and Henry.

Combining our 1912 lists from the river between Chillicothe and Starved Rock with the 1924-1925 lists for the three sections of Peoria Lake, we now have a total of 28 species that may be regarded as showing considerably more tolerance than the various species of middle Illinois River *Unionidae* not included in it. A useful subdivision of these 28 kinds on the basis of relative sensitiveness is feasible if we regard Spring Valley in 1912 as marking about the lower limit of pollutional conditions, much as those portions of the Upper Peoria Lake bed not especially protected by spring water or unusual current have done in more recent years. Subdividing the list in this way as best possible, and taking account of relative abundance, and the possibility of special protection afforded by spring water or current, we find that eleven of them may be classed as conditionally pollutional, with a single one of that group *(Amblema rariplicata)* much less sensitive than the other ten; while about 17 others may be classed as possibly early or late sub-pollutional, or in other words, as more or less tolerant. In addition to the list of 28 less sensitive species immediately following, we also present here the complete list of the 41 species taken by Danglade between Chillicothe and the foot of Peoria Lake under the decidedly cleaner-water conditions of 1912.

TABLE XXI

LIST OF LEAST SENSITIVE UNIONIDAE, ILLINOIS RIVER, WITH FARTHEST NORTHWARD STATIONS OF OCCURRENCE, 1912 AND 1924-1925

Species	Farthest north 1912	Farthest north 1924-1925
1. *Amblema rariplicata*	Starved Rock	Upper Peoria Lake, lower end
2. *Lasmigona complanata*	Starved Rock	Upper Peoria Lake, lower end
3. *Leptodea fragilis*	above Peru	Middle Peoria Lake
4. *Proptera alata*	above Peru	Peoria Narrows
5. *Actinonais carinata*	above Peru	
6. *Quadrula pustulosa*	Spring Valley	Peoria Narrows
7. *Quadrula quadrula*	Spring Valley	Upper Peoria Lake
8. *Anodonta corpulenta*	Spring Valley	Upper Peoria Lake, lower end
9. *Megalonaias gigantea*	Spring Valley	
10. *Tritogonia tuberculata*	Spring Valley	
11. *Anodonta grandis*, var. *gigantea*	Spring Valley	
12. *Fusconaia undata*	Hennepin	Upper Peoria Lake, lower end
13. *Anodonta imbecillis*	Hennepin	Upper Peoria Lake, lower end
14. *Leptodea laevissima*	Hennepin	Peoria Narrows
15. *Lampsilis fallaciosa*	Hennepin	Upper Peoria Lake, lower end
16. *Lampsilis siliquoidea*	Hennepin	Upper Peoria Lake, lower end
17. *Strophitus edentulus*	Hennepin	
18. *Carunculina parva*	Hennepin	Middle Peoria Lake
19. *Lampsilis ventricosa*	Hennepin	
20. *Lampsilis occidens*	Hennepin	
21. *Anodontoides ferrusacianus*	Hennepin	
22. *Elliptio dilatatus*	Henry to Chillicothe	Peoria Narrows
23. *Obliquaria reflexa*	Henry to Chillicothe	Middle Peoria Lake
24. *Fusconaia ebena*	Henry to Chillicothe	
25. *Truncilla truncata*	Henry to Chillicothe	
26. *Plagiola lineolata*	Henry to Chillicothe	
27. *Lampsilis anodontoides*	Henry to Chillicothe	
28. *Anodonta suborbiculata*		Middle Peoria Lake

TABLE XXII

LIST OF MUSSELS REPORTED BY DANGLADE* FROM PEORIA LAKE, INCLUSIVE OF CHILLICOTHE, IN 1911-1912; NOMENCLATURE REVISED BY MR. F. C. BAKER; ORDER OF DANGLADE'S LIST UNCHANGED

1. *Cyclonais tuberculata*	21. *Anodonta suborbiculata*
2. *Fusconaia ebena*	22. *Anodonta imbecillis*
3. *Pleurobema plenum*	23. *Strophitus rugosus*
4. *Pleurobema catillus* var. *solida*	24. *Obliquaria reflexa*
	25. *Tritogonia tuberculata*
5. *Pleurobema catillus* var. *coccinea*	26. *Truncilla donaciformis*
	27. *Truncilla truncata*
6. *Pleurobema cordatum*	28. *Plagiola lineolata*
7. *Fusconaia undata*	29. *Obovaria olivaria*
8. *Fusconaia flava*	30. *Leptodea laevissima*
9. *Quadrula pustulosa*	31. *Leptodea fragilis*
10. *Quadrula fragosa*	32. *Proptera alata*
11. *Quadrula quadrula*	33. *Carunculina parva*
12. *Quadrula metanevra*	34. *Ligumia recta* var. *latissima*
13. *Megalonaias gigantea*	35. *Lampsilis fallaciosus*
14. *Amblema costata*	36. *Lampsilis anodontoides*
15. *Amblema rariplicata*	37. *Lampsilis higginsii*
16. *Elliptio crassidens*	38. *Lampsilis orbiculata*
17. *Elliptio dilatatus*	39. *Actinonais carinata*
18. *Lasmigona complanata*	40. *Lampsilis siliquoidea*
19. *Arcidens confragosus*	41. *Lampsilis ventricosa*
20. *Anodonta corpulenta*	

* Danglade, Ernest, The Mussel Resources of the Illinois River. Report U. S. Bureau of Fisheries for 1913, Appendix VI, pp. 1-48.

Explanation of General Tables

As a matter of convenience, full valuation figures in pounds per acre are given for only four of the eight collecting years beginning with 1913. In the tables of abundance and of numbers of species present and missing, much more nearly complete data for all the various years are given. The years selected for complete valuation mark all the important turning points in the 12 years; 1913-1915 showing substantially no change; 1922 being little different from 1920; and 1923 little different from 1924 and 1925.

In the tables of abundance of leading groups of small bottom animals, for similar reasons of convenience or importance, all-area averages are given only for the four years for which valuation data are presented, and only for the reaches from Upper Peoria Lake southward. Channel and extra-channel averages for the *Tubificidae* are given for the section of river between LaSalle and Chillicothe for the years 1923, 1924, and 1925, only, but not for 1920 and 1922 because no quantitatively comparable collections were taken above Upper Peoria Lake until 1923. Further restriction of figures in the case of leeches and *Gastropoda* relates to their importance for the purposes in hand.

The lists of species on which the summaries of numbers of kinds taken and missing are based have been somewhat extended by additional determinations in several groups, particularly leeches, since the publication of earlier papers in this series. The complete tabulations used in making up the summaries are in the files of the Natural History Survey, but are too voluminous and complex for present publication in detail.

In the valuation tables the weights given in the case of *Mollusca* are those remaining after deduction of weight of shells, and in the case of all groups, after correction for an ascertained average body shrinkage in alcohol, in instances of the use of that preservative.

In various tables zero is used to indicate the fact of absence in reaches where collections were made; while a blank space indicates that no collections were taken.

In the valuation and abundance tables contractions of mixed group titles are made use of as follows at heads of the vertical columns:

Sphaeriidae, for same plus unimportant numbers of young or dwarf *Unionidae*.

Gastropoda, for same plus unimportant numbers of *Pulmonata*.

"Others", meaning other groups than *Tubificidae*, *Chironomidae*, *Sphaeriidae*, Leeches, and Gastropoda; and including (except in 1920, when leeches were included under this head), as the most important: burrowing *Ephemeridae; Hydropsychidae; Odonata; Turbellaria;* and *Amphipoda*.

Bryozoa, and other incrusting or attached forms, although given places in the species lists, are excluded from the quantitative data in all cases.

TABLE XXIII.

NUMBER OF KINDS OF SMALL BOTTOM ANIMALS, ILLINOIS RIVER, 1913-1925; CHANNEL AND EXTRA-CHANNEL AREAS COMBINED

LaSalle to Chillicothe

Years	Number of collections	Pollutional	Unusually tolerant	Tolerant or doubtful	Air-breathing and current-loving	Clean-water	Total
			Species taken				
1913-1915	no collections above Chillicothe						
1920	no collections above Chillicothe						
1922	no collections above Chillicothe						
1923	30	5	9	5	0	0	19
1924	16	2	10	3	0	0	15
1925	16	5	4	1	0	0	10

Upper Peoria Lake

Years	Number of collections	Pollutional	Unusually tolerant	Tolerant or doubtful	Air-breathing and current-loving	Same after deduction*	Clean-water	Same after deduction†	Total	Same after deduction†
					Species taken					
1913-1915	23	1	6	10	5	5	11	11	33	33
1920	8	5	1	4	..	..	..	..	10	10
1922	23	5	5	8	..	..	1	0	19	18
1923	21	6	8	11	..	..	2	0	27	25
1924	25	3	9	6	2	0	..	..	20	18
1925	7	3	7	7	3	0	2	0	22	17
					Species missing that were present in 1913-1915					
1920	..	..	5	5	5	..	11	..	26	..
1922	..	..	1	2	5	..	11	..	19	..
1923	..	..	1	3	5	..	11	..	20	..
1924	..	..	1	4	5	..	11	..	21	..
1925	..	..	1	2	5	..	11	..	19	..

Middle Peoria Lake										
Species taken										
1913-1915	15	1	7	7	3	3	18	18	36	36
1920	8	4	2	4	..	..	..	..	10	10
1922	30	4	5	11	..	..	..	..	20	20
1923	30	5	9	17	.	..	5	3	36	34
1924	38	4	11	14	..	..	8	5	37	34
1925	18	3	10	15	2	0	9	5	39	33
Species missing that were present in 1913-1915										
1920	..	..	5	5	3	..	19	..	32	..
1922	..	..	2	5	3	..	19	..	29	..
1923	..	..	1	2	3	..	19	..	25	..
1924	..	..	1	2	3	..	14	..	20	..
1925	..	..	1	3	3	..	16	..	23	..
Lower Peoria Lake										
Species taken										
1913-1915	22	1	6	10	12	12	15	15	44	44
1920	19	4	8	8	4	1	..	..	25	22
1922	18	4	10	10	3	1	1	1	28	26
1923	26	5	12	11	9	0	1	0	38	28
1924	23	3	8	13	3	1	1	0	28	25
1925	10	4	12	10	11	0	4	0	41	26
Species missing that were present in 1913-1915										
1920	..	..	2	4	11	..	15	..	32	..
1922	..	..	1	4	12	..	15	..	32	..
1923	..	..	..	3	11	..	15	..	30	..
1924	..	..	1	3	11	..	15	..	30	..
1925	..	..	..	4	9	..	15	..	28	..

* Number left after deducting kinds found only at edge.
† Number left after deducting kinds found only at edge or in unusual current.

TABLE XXIII—*Concluded*

Years	Number of collections	Pollutional	Unusually tolerant	Tolerant or doubtful	Air-breathing and current-loving	Clean-water*	Total
Wesley to Havana							
Species taken							
1913-1915	108	1	5	16	20	49	91
1920	14	4	4	4	..	3	15
1922	no collections						
1923	36	6	8	9	7	8	38
1924	23	3	7	5	6	..	21
1925	15	2	9	9	4	4	28
Species missing that were present in 1913-1915							
1920	..	..	1	13	17	47	78
1922	no collections						
1923	..	..	1	10	14	44	69
1924	..	..	..	13	16	47	76
1925	..	..	..	11	17	44	72
Havana to Beardstown							
Species taken							
1913-1915	69	2	5	7	12	17	43
1920	22	3	4	3	6	6	22
1922	no collections						
1923	15	3	5	3	2	3	16
1924	12	2	5	4	3	2	16
1925	9	3	7	8	2	7	27
Species missing that were present in 1913-1915							
1920	..	1	3	3	6	14	27
1922	no collections						
1923	..	..	2	5	10	16	33
1924	..	..	..	3	9	16	28
1925	..	..	..	2	10	13	25

* Collections on which number of species is based in all cases from open water, some distance from edges.

TABLE XXIV.

AVERAGE WEIGHT IN POUNDS PER ACRE, ALL SMALL BOTTOM ANIMALS
CHANNEL AND EXTRA-CHANNEL AREAS COMBINED

Reaches	*Number of collections averaged*	Tubificidae	Leeches	Sphaeriidae	Gastropoda	Chironomidae	Others	Total
				1915				
Upper Peoria Lake......	*33*	0.5	3.2	73.6	87.1	4.2	1.1	169.7
Middle Peoria Lake......		collections taken opposite Mossville here included with those from Upper Lake						
Lower Peoria Lake......	*12*	0.6	3.6	10.6	315.0	0	0.1	329.9
P. & P. U. R. R. Bridge—								
Pekin	*8*	0	9.8	72.5	142.3	3.5	1.9	230.0
Dam	*30*	0.04	9.2	61.3	294.1	2.3	0.6	367.5
Pekin—Copperas Creek								
Copperas Creek Dam—								
Liverpool	*12*	0	6.3	202.1	854.2	1.1	0	1,063.7
Liverpool—Havana	*27*	0.04	17.4	858.5	1,880.3	0.4	0.1	2,756.7
Havana—Lagrange	*58*	0.1	1.2	32.1	226.5	0.4	2.9	263.2
				1920				
Upper Peoria Lake......	*8*	85.8	here	28.5	9.0	132.5	0	255.8
Middle Peoria Lake.....	*8*	7.7	included	1.5	0	32.6	0	41.8
Lower Peoria Lake......	*19*	3.2	under	0.7	4.1	64.1	0	72.1
P. & P. U. R. R. Bridge—			column					
Pekin	..	....	headed	....	....	.....	....	.....
Pekin—Copperas Creek			"Others"					
Dam	..	....		....	....	.....	....	.....
Copperas Creek—Liver-								
pool	..	....		....	....	.....	....	.....
Liverpool—Havana	*14*	1.5		16.0	38.0	104.5	35.0	195.0
Havana—Hickory Island	*22*	0.5		3.5	51.0	36.0	28.0	119.0

TABLE XXIV—*Concluded*

Reaches	*Number of collections averaged*	Tubificidae	Leeches	Sphaeriidae	Gastropoda	Chironomidae	Others	Total
1924								
Upper Peoria Lake......	*25*	1,292.0	23.7	5,417.2	4.5	0.3	0.1	6,737.8
Middle Peoria Lake......	*38*	34.5	31.7	1,021.8	14.7	7.6	0.3	1,110.6
Lower Peoria Lake......	*23*	66.6	29.6	131.2	0.8	1.7	0.5	230.4
P. & P. U. R. R. Bridge—Pekin	*7*	184.4	5.1	38.5	0	1.9	0	229.9
Pekin—Copperas Creek Dam	*9*	47.8	46.4	31.5	7.8	2.8	6.7	143.0
Copperas Creek—Liverpool	*2*	3.1	1.1	47.3	0	0	0	51.5
Liverpool—Havana	*5*	79.2	181.7	4,715.3	0	1.5	18.2	4,995.9
Havana—Beardstown ...	*12*	64.5	7.6	42.5	24.0	1.2	2.5	142.3
1925								
Upper Peoria Lake......	*7*	563.9	32.0	805.2	0	164.6	0	1,565.7
Middle Peoria Lake......	*18*	42.9	101.6	1,706.7	29.2	133.3	0.4	2,014.1
Lower Peoria Lake......	*10*	228.6	53.3	352.1	4.8	343.2	27.2	1,009.2
P. & P. U. R. R. Bridge—Pekin	*5*	654.0	341.8	204.2	91.2	63.3	1.8	1,356.3
Pekin—Copperas Creek Dam	*6*	44.7	74.2	45.6	33.7	1,068.7	8.4	1,275.3
Copperas Creek—Liverpool	..	.....	......	......	.....	......	....	......
Liverpool—Havana	*4*	95.4	2,551.6	2,503.4	189.0	4.5	7.2	5,351.1
Havana—Beardstown ...	*9*	65.9	8.9	950.7	69.8	30.1	10.4	1,135.8

TABLE XXV

AVERAGE NUMBERS PER SQUARE YARD, TOTAL CHIRONOMIDAE.*

Year	LaSalle to Chillicothe	Upper Peoria Lake	Middle Peoria Lake	Lower Peoria Lake	P. P. U. R. R. Bridge to Pekin	Pekin to Copperas Creek Dam	Copperas Creek Dam to Liverpool	Liverpool to Havana	Havana to Beardstown
				Channel and extra-channel areas combined					
1915	.....	10	....	0	25	10	8	3	3
1920	.....	733	124	197	...	......	...	587	113
1924	.....	8	38	25	24	38	0	33	26
1925	.....	333	694	774	288	7,048	...	12	128
				Channel					
1920	.....	1,216	36	88	...	......	...	950	36
1922	.....	0	240	18	...	......	...	...	...
1923	.....	63	585	1,090	456	104	62	36	12
1924	.....	6	28	31	56	0	0	0	16
1925	.....	0	788	334	336	54	...	0	24
				Extra-channel					
1920	.....	326	148	236	...	......	...	225	190
1922	.....	196	124	121	...	......	...	...	...
1923	.....	159	422	135	57	69	...	65	22
1924	.....	14	39	18	0	58	0	42	44
1925	.....	480	668	1,282	256	10,555	...	16	183

* Chiefly *Chironomus plumosus* in all reaches, 1920 to 1925.

TABLE XXVI

AVERAGE NUMBERS PER SQUARE YARD, TOTAL SPHAERIIDAE OR *Musculium transversum*

Year	LaSalle to Chillicothe	Upper Peoria Lake	Middle Peoria Lake	Lower Peoria Lake	P. P. U. R. R. Bridge to Pekin	Pekin to Copperas Creek Dam	Copperas Creek Dam to Liverpool	Liverpool to Havana	Havana to Beardstown
	Channel and extra-channel areas combined (total Sphaeriidae)*								
1915	.....	161	.....	36	144	121	404	1,709	64
1920	.....	57	3	1.5	.....	...	...	46	7
1924	.....	18,114	2,890	653	113	88	144	12,785	112
1925	.....	2,839	4,497	1,122	568	134	...	6,465	2,561
	Channel (Musculium transversum)								
1920	.....	112	0	0.1	.....	...	...	34	2
1922	.....	27,920	3,956	30	.....	...	...	......	.....
1923	.....	1,097	1,368	44	0	90	26	24	207
1924	.....	18,074	3,212	174	40	8	0	17,952	8
1925	.....	2,832	6,376	1,412	1,104	42	...	12,528	5,298
	Extra-channel (Musculium transversum)								
1920	.....	14	2	1	.....	...	...	58	11
1922	.....	25,688	1,013	15	.....	...	...	......	.....
1923	.....	3,109	657	8	12	0	...	4,246	180
1924	.....	17,642	1,701	57	144	124	252	11,446	220
1925	.....	2,814	3,297	384	180	162	...	4,388	2,063

* Chiefly *Musculium transversum* in all reaches and years.

TABLE XXVII

AVERAGE NUMBERS PER SQUARE YARD, TOTAL TUBIFICIDAE.*

Year	LaSalle to Chillicothe	Upper Peoria Lake	Middle Peoria Lake	Lower Peoria Lake	P. P. U. R. R. Bridge to Pekin	Pekin to Copperas Creek Dam	Copperas Creek Dam to Liverpool	Liverpool to Havana	Havana to Beardstown
				Channel and extra-channel areas combined					
1915	......	16	.....	6	0	2	0	1.4	3.5
1920	......	2,463	220	78	......	.....	.....	46	16
1924	......	39,182	1,045	2,018	5,592	1,448	96	2,400	1,954
1925	......	17,094	1,300	6,919	19,819	1,354	.....	2,892	1,997
				Channel					
1920	......	4,960	540	183	......	.....	.....	89	2
1922	......	2,733	536	61	......	.....	.....	.....	.....
1923	2,328	8,628	3,358	570	230	184	81	461	479
1924	14,661	60,104	1,466	909	3,328	20	72	0	452
1925	4,809	17,280	2,552	1,840	336	180	.....	504	5,340
				Extra-channel					
1920	......	964	31	64	......	.....	.....	4	30
1922	......	18,800	438	159	......	.....	.....	.....	.....
1923	32,068	2,076	807	542	1,538	2,514	.....	12	1,942
1924	15,095	25,234	853	2,415	7,296	2,162	120	3,000	3,151
1925	42,144	14,740	931	10,197	32,541	1,942	.....	3,688	1,217

* Chiefly *Limnodrilus hoffmeisteri* in all reaches below Chillicothe.

TABLE XXVIII

AVERAGE NUMBERS PER SQUARE YARD, TOTAL LEECHES*

Year	LaSalle to Chillicothe	Upper Peoria Lake	Middle Peoria Lake	Lower Peoria Lake	P. P. U. R. R. Bridge to Pekin	Pekin to Copperas Creek Dam	Copperas Creek Dam to Liverpool	Liverpool to Havana	Havana to Beardstown
				Channel and extra-channel areas combined					
1915	.....	19	...	21	58	40	38	103	5
1924	.....	58	167	114	13	48	6	441	17
1925	.....	137	548	194	1,511	252	...	10,275	36

* Chiefly *Helobdella stagnalis* 1924 and 1925.

TABLE XXIX

AVERAGE NUMBERS PER SQUARE YARD, TOTAL GASTROPODA*

Year	LaSalle to Chillicothe	Upper Peoria Lake	Middle Peoria Lake	Lower Peoria Lake	P. P. U. R. R. Bridge to Pekin	Pekin to Copperas Creek Dam	Copperas Creek Dam to Liverpool	Liverpool to Havana	Havana to Beardstown
				Channel and extra-channel areas combined					
1915	.....	49	....	130	54	92	276	496	79
1920	.....	3	0	21	...	...	...	20	22
1924	.....	0.9	8	0.2	0	2.6	0	0	8
1925	.....	0	12	1.6	77	15	...	39	40

* Chiefly *Vivipara contectoides*, *Lioplax subcarinatus*, and *Campeloma subsolidum* in 1915; *Campeloma subsolidum* and *Pleurocera acutum* principally, 1920 to 1925.

Summary

The present paper is based on a study of 1,308 biological collections made by the Natural History Survey between 1913 and 1925, inclusive, over a 225-mile stretch of the Illinois River and in its connected bottom-land lakes. For convenience in discussion, this stretch of water is divided into eight reaches, as follows: Beginning at LaSalle, which is 101.5 miles below Lake Michigan, the first reach extends downstream to Chillicothe, a distance of 45 miles; the second, from Chillicothe to the foot of Peoria Lake, 20 miles; the third, to Copperas Creek Dam, 24 miles; the fourth, to Liverpool, 9 miles; the fifth, to Havana, 8 miles; the sixth, to Beardstown, 31 miles; the seventh, to Lagrange Dam, 11.5 miles; and the eighth a distance of 77.5 miles, to Grafton at the mouth of the river.

The upper part of the river is powerfully affected by pollution from the Sanitary District of Chicago, the effect of which diminishes slowly downstream and varies considerably with the stage of water and time of year. This pollution has increased, of course, with the population of the contributing cities and with the growth and activity of certain industries, the most important of which are those of the Chicago stockyards. During the six years from 1914 to 1920, tangible wastes of Chicago, including those of its stockyards, increased by about 11 per cent, and to these was added the sewage from minor but increasing sources at various points down the river, especially at Peoria and Pekin. A notable upward rush of pollutional ratios and effects, due to war-time activities of the stockyards, culminated in 1918 in a sewage contribution from this source equivalent to that of a population of 1,390,000 people, but fell off during the first two years of peace by about 25 per cent.

An effort is made to distinguish septic, pollutional, sub-pollutional, and clean-water conditions by the plant and animal species characteristic of each, and from these to select an index series of species whose abundance marks the grade of pollution in which each species predominates; but this classification of degrees of pollution is difficult because the several divisions fade into each other gradually with no well-marked boundaries, and different grades intermingle in the same locality, those of the main current of the stream differing from those dominating in comparatively sluggish, shallow, and weedy marginal waters; and these differing again from those of still more sluggish, broad expanses of shallow water. Even in the channel of the river itself the organisms suspended in the flowing stream differ, often widely, both in relative abundance and in sensitivity, from those of the bottom sediments, and the conclusion is reached that a dependable classification can be arrived at only by the supplementing of chemical data with a comprehensive study of the dominant fauna and flora in each situation.

Increase of pollution between 1913 and 1920 is shown by the advance downstream of stages of pollution. Clean-water conditions, which in 1913 extended upstream within 53 miles of LaSalle, had receded by 1920 to a point 53 miles still farther down, an average recession of about 8 miles a year.

Deterioration of the condition of the river bottom during this interval is shown also by a reduction in the number of species represented in the bottom fauna, amounting to an average of 64 per cent in the Peoria Lakes, 83 per cent in the river between these lakes and Havana, and 48 per cent between Havana and Beardstown.

Another measure of increased pollution is found in the number of characteristically clean-water species that disappeared during the same interval. The Peoria Lakes, for example, were entirely cleared of these species by 1920. In the 49 miles next below they had been reduced from 49 species to three, and in the next 31 miles from 17 species to six. Corresponding data are given for an increase in the number of pollutional and sub-pollutional species during the same interval and over the same sections of the river, but there was some slight recovery of clean-water species after the end of the world war. The dissolved oxygen data constitute a similar record of rapid decline from 1912 to 1920 and of a partial recovery in the Peoria Lakes by 1925.

The effect of increasing pollution upon the more important groups of the bottom fauna is reflected in a general and often very large decrease in average numbers per square yard in all of these groups except the pollutional sludge worms (Tubificidae) and midge larvae (Chironomus), which multiplied enormously in this period. In a 10-mile section of the river just above Havana, for example, where there were 1,709 Sphaeriidae (small bivalve mollusks) per square yard in 1915, there were only 46 per square yard in 1920 and the numbers of Gastropoda (snails) declined from 496 to 20; but where there were 16 sludge worms and 10 midge larvae per square yard in 1915 there were 2,463 sludge worms and 733 midge larvae in 1920, and in the following four or five years the numbers of sludge worms had still further multiplied to 39,182 per square yard. From 1920 to 1925, however, the Sphaeriidae, which had been diminishing so rapidly under the heavier pollution of the war period, recovered quickly as pollution diminished, rising in the 10-mile section just mentioned from 46 per square yard in 1920 to 12,785 in 1924. This uprising of Sphaeriidae appears to have been checked and reversed by an epidemic outbreak of predaceous leeches preying on them, the leeches themselves multiplying from 441 to 10,275 per square yard, while the Sphaeriidae fell from 12,785 to 6,465.

Valued by *total weights* instead of *numbers of organisms,* the small bottom fauna (mostly gastropod mollusks) ranged in 1915 from 170 to 360 pounds per acre between Chillicothe and the Lagrange Dam except in a 17-mile section above Havana where it rose to 1,000 pounds per acre in the upper 8 miles and 2,700 pounds in the lower 9 miles; but by 1920 these snails were virtually exterminated in the Peoria Lakes, where, on the other hand, the sludge worms and midge larvae of a polluted water rose to 86 per cent of the total weight. Between Liverpool and Havana gastropod mollusks were reduced to 19 per cent of the average haul, and midge larvae were increased to 53 per cent.

Following upon prolonged and destructive floods in the summer of 1924, which presumably carried down and distributed great quantities of up-the-river sludge and its inhabitants, there was an enormous increase of the total product made up mostly of sludge worms, midge larvae, and *Musculium transversum* (a little bivalve mollusk unusually tolerant of pollutional conditions). In the three Peoria Lakes and in the Liverpool-to-Havana section of the river, the total weight rose in 1924 to 25 or 26 times that of 1920, composed in the lakes almost wholly of the little Musculium, which made 80 per cent to 94 per cent of the product of an average haul.

Study of the competitions and depredations of the more important groups of the bottom animals shows that under clean-water conditions snails, by their feeding methods, tend to dominate and, where they become abundant, to suppress midges, sludge worms, and the smaller Sphaeriidae, and that sucker-mouth fishes draw heavily upon small mollusks and larvae of midges, mayflies, and caddis flies, preferring these to sludge worms, leeches, and the larger snails. Only catfishes (and sheepsheads) prey extensively upon the larger snails. The destruction of the latter by pollution and the release by this means of the small Sphaeriidae affords to "coarse fish" an increased available food supply and so may be a benefit rather than a detriment to commercial fisheries. On the other hand, the frequently gassy taste and, in the case of the carp, the diseased condition of as many as 50 per cent, due to the effects of pollution upon their food, diminishes the market value of Illinois River fishes.

The numbers of midge larvae and of Musculium were at first diminished and afterwards increased by the floods of 1924, and the numbers of sludge worms were at first increased and afterwards diminished. These contrasting variations and those of Musculium, as a consequence of the floods, are described and discussed in detail with suggested explanations; and a study is reported of the comparative abundance of these same groups in the river channel and in the shallow waters adjoining. The effect of pollutional conditions on the river mussels is shown by a comparison of a list of 41 species found in Peoria Lake in 1911 and 1912 with the 15 species remaining in 1924 and 1925, eight of them in the upper lake, eleven in the middle, and thirteen in the lower.

The lag of the small bottom animals behind the dissolved oxygen (and also the plankton and bacteria of the epilimnion) appears to be due principally to two causes—the naturally slow rate of re-spread upstream of cleaner-water forms, as against the easier downstream movement of the pollutional and unusually tolerant bottom species; and the delivery, with every flood, into territory that would otherwise remain reasonably clean, of fresh loads of incompletely oxidized organic sediment.

From the preceding statement, and others in the body of this paper, the inference is drawn that the small bottom animals, except where the pollution is very heavy, on the whole furnish a better index of the fundamental or permanent sanitary condition than the frequently rapidly changing dissolved oxygen or plankton.

Bearing in mind the popular distinction between "coarse" fishes and "fine" fishes, which may usefully be extended for the moment to the small bottom animals, it is to be emphasized that the increases in pounds-per-acre averages between Chillicothe and Beardstown since 1920 represent almost wholly enlargement in quantity at the expense of quality, and have occurred for the most part without corresponding permanent improvement in sanitary condition. Such food is available only to the fishes which are able to live under the conditions prevailing where it is produced; and large portions of those areas are still subject in the warm season to spells of oxygen depletion that are likely to exclude from these rich feeding grounds all except the most tolerant of the bottom feeding fishes.

APPENDIX TO ARTICLE XII

The following is a list of publications of the State Natural History Survey and its predecessor, the State Laboratory of Natural History, dealing in whole or in part with investigations of the Illinois River. The asterisk marks articles relating to Illinois River biology as such, to distinguish them from others of a more general nature which contain some information on this subject.

Bulletin Series

1876. List of Illinois Crustacea. S. A. FORBES. Vol. I, No. 1, pt. 1. (25 pp., 1 pl.)

1876. A partial catalogue of the fishes of Illinois. E. W. NELSON. Vol. I, No. 1, pt. 4. (30 pp.)

1877. A catalogue of the fishes of Illinois. DAVID STAR JORDAN. Vol. I, No. 2, pt. 4. (34 pp.)

1877. The food of Illinois fishes. S. A. FORBES. Vol. I, No. 2, pt. 5. (19 pp.)

1880. The food of fishes. S. A. FORBES. Vol. I, No. 3, pt. 2. (48 pp.)

1880. On the food of young fishes. S. A. FORBES, Vol. I, No. 3, pt. 3. (14 pp.). *Second edition, 1903. Reprint, 1919.*

1883. The food of the smaller fresh-water fishes. S. A. FORBES. Vol. I, No. 6, pt. 3. (30 pp.)

1888. Studies of the food of fresh-water fishes. S. A. FORBES. Vol. II, Art. 7. (41 pp.)

1888. On the food relations of fresh-water fishes: a summary and discussion. S. A. FORBES. Vol. II, Art. 8. (63 pp.)

*1895. On the entomology of the Illinois River and adjacent waters. C. A. HART. Vol. IV, Art. 6. (125 pp., 12 pl.)

*1896. Descriptions of new species of Rotifera and Protozoa from the Illinois River and adjacent waters. ADOLPH HEMPEL. Vol. IV, Art. 10. (8 pp., 5 pl.)

1897. Contribution to a knowledge of the North American fresh-water Ostracoda included in the families Cytheridae and Cyprididae. RICHARD W. SHARPE. Vol. IV, Art. 15. (71 pp., 10 pl.)

*1897. Plankton studies. I. Methods and apparatus in use in plankton investigations at the Biological Experiment Station of the University of Illinois. C. A. KOFOID. Vol. V, Art. 1. (25 pp. 7 pl.)

1897. A contribution to a knowledge of the North American fresh-water Cyclopidae. ERNEST B. FORBES. Vol. V, Art. 2. (56 pp., 13 pl.)

1897. The North American species of Diaptomus. F. W. SCHACHT. Vol. V, Art. 3. (111 pp., 15 pl.)

*1898. Plankton studies. II. On *Pleodorina illinoisensis*, a new species from the plankton of the Illinois River. C. A. KOFOID. Vol. V, Art. 5. (21 pp., 2 pl.)

*1899. A list of the Protozoa and Rotifera found in the Illinois River and adjacent lakes at Havana, Illinois. ADOLPH HEMPEL. Vol. V, Art. 6. (88 pp.)

*1899. A statistical study of the parasites of the Unionidae. H. M. KELLY. Vol. V, Art. 8. (20 pp.)

*1899. Plankton studies. III. On Platydorina, a new genus of the family Volvocidae, from the plankton of the Illinois River. C. A. KOFOID. Vol. V, Art. 9. (22 pp., 1 pl.)

1901. The Hirudinea of Illinois. J. PERCY MOORE. Vol. V, Art. 12. (69 pp., 6 pl.)

*1903. Plankton studies. IV. The plankton of the Illinois River, 1894-1899, with introductory notes on the hydrography of the Illinois River and its basin. Part I. Quantitative investigations and general results. C. A. KOFOID. Vol. VI, Art. 2. (535 pp., 50 pl.)

1904. A review of the sunfishes of the current genera Apomotis, Lepomis, and Eupomotis, with particular reference to the species found in Illinois. R. E. RICHARDSON. Vol. VII, Art. 3. (9 pp.)

1906. A catalogue of the Mollusca of Illinois. F. C. BAKER. Vol. VII, Art. 6. (84 pp., 1 map.)

1907. On the local distribution of certain Illinois fishes: an essay in statistical ecology. S. A. FORBES. Vol. VII, Art. 8. (31 pp., 15 maps, 9 pl.)

*1908. The plankton of the Illinois River, 1894-1899, with introductory notes upon the hydrography of the Illinois River and its basin. Part II. Constituent organisms and their seasonal distribution. C. A. KOFOID. Vol. VIII, Art. 1. (360 pp., 5 pl.)

*1913. Observations on the breeding of the European carp in the vicinity of Havana, Illinois. R. E. RICHARDSON. Vol. IX, Art. 7. (19 pp., 1 map.)

*1913. Observations on the breeding habits of fishes at Havana, Illinois, 1910 and 1911. R. E. RICHARDSON. Vol. IX, Art. 8. (13 pp., 1 pl.)

*1913. Studies on the biology of the upper Illinois River. S. A. FORBES and R. E. RICHARDSON. Vol. IX, Art. 10. (95 pp., 21 pl.)

*1915. The Chironomidae, or midges, of Illinois, with particular reference to the species occurring in the Illinois River. JOHN R. MALLOCH. Vol. X, Art. 6. (269 pp., 24 pl.)

1918. Ways and means of measuring the dangers of pollution to fisheries. VICTOR E. SHELFORD. Vol. XIII, Art. 2. (18 pp.)

*1919. Some recent changes in Illinois River biology. S. A. FORBES and R. E. RICHARDSON. Vol. XIII, Art. 6. (18 pp.)

*1919. Acanthocephala from the Illinois River, with descriptions of species and a synopsis of the family Neoechinorhynchidae. H. J. VAN CLEAVE. Vol. XIII, Art. 8. (33 pp., 7 pl.)

*1921. The small bottom and shore fauna of the middle and lower Illinois River and its connecting lakes, Chillicothe to Grafton: its valuation; its sources of food supply; and its relation to the fishery. R. E. RICHARDSON. Vol. XIII, Art. 15. (161 pp.)

*1921. Changes in the bottom and shore fauna of the middle Illinois River and its connecting lakes since 1913-1915 as a result of the increase, southward, of sewage pollution. R. E. RICHARDSON. Vol. XIV, Art. 4. (43 pp.)

1923. The determination of hydrogen-ion concentration in connection with fresh-water biological studies. VICTOR E. SHELFORD. Vol. XIV, Art. 9. (17 pp.)

*1925. Changes in the small bottom fauna of Peoria Lake, 1920 to 1922. R. E. RICHARDSON. Vol. XV, Art. 5. (61 pp.)

*1925. Illinois River bottom fauna in 1923. R. E. RICHARDSON. Vol. XV, Art. 6. (31 pp.)

*1925. Some observations on the oxygen requirements of fishes in the Illinois River. DAVID H. THOMPSON. Vol. XV, Art. 7. (15 pp.)

1928. The biological survey of a river system—its objects, methods, and results. S. A. FORBES. Vol. XVII, Art. 7. (8 pp.)

*1928. The "knothead" carp of the Illinois River. DAVID H. THOMPSON. Vol. XVII, Art. 8. (36 pp.)

*1928. The bottom fauna of the middle Illinois River, 1913-1925: its distribution, abundance, valuation, and index value in the study of stream pollution. R. E. RICHARDSON. Vol. XVII, Art. 12. (86 pp.)

Reports of the Director of the Illinois State Laboratory of Natural History S. A. Forbes, Director

1888. Report for 1887-1888, pp. 2-4: General program of aquatic zoology.

1894. Report for 1893-1894, pp. 3-26: Zoological exhibit at the Columbian Exposition, establishment of the Illinois River biological station at Havana, etc. (15 pl.)

*1896. Report for 1895-1896, pp. 7-31: Special report of the biological experiment station. (20 pl.)

*1898. Report for 1897-1898, pp. 4-7: Personnel, equipment, summer school, etc.; also pp. 8-25: Report of the superintendent of the biological station, C. A. KOFOID; pp. 25-27: Report on water analysis, by ARTHUR W. PALMER, professor of chemistry; and pp. 29-31: Report on the summer school of 1898, by FRANK SMITH, assistant professor of zoology. (10 pl.)

1901. Report for 1899-1900, pp. 3-11: Study of Illinois fishes and care of collections; study of the plankton, aquatic insects, and leeches; expansion of the library and its exchange list; etc.

1915. Report for 1913-1914, pp. 7-10: Continuation of operations on the Illinois River and its tributary waters.

Final Reports on the Natural History Survey of Illinois

1908. The fishes of Illinois. S. A. FORBES and R. E. RICHARDSON. Vol. III of the final reports on the natural history survey of Illinois. (cxxxvi+357 pp., 68 pl., 76 text fig.; 103 maps in a separate atlas.) *Second edition, 1920.*

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