

WATER SOILS IN RELATION TO LAKE PRODUCTIVITY

Thesis for the Degree of Ph. D. MICHIGAN STATE COLLEGE Eugene W. Roelofs
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WATER SOILS IN RELATION TO LAKE PRODUCTIVITY

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INTRODUCTION

In June, 1938, an investigation of water soils in relation to the production of vegetation in lakes was begun by the Soils Section of the Michigan Agricultural Experiment Station. In September of that year, the project was formally organized with the following agencies cooperating: the State Department of Conservation, through the Institute for Fisheries Research at Ann Arbor, agreed to cooperate in the study to the extent of maintaining the author on their payroll as a Fisheries Research Technician, and lending assistance by making information in their files available, and by aiding otherwise in carrying out the investigation; the Conservation Institute at Michigan State College assumed the responsibility of providing field equipment and all field expenses; the Soils Section of the college provided laboratory, greenhouse, and office facilities.

The author is grateful to Director A. S. Hazzard of the Institute for Fisheries Research, Director L. R. Schoenmann of the Conservation Institute, and Dr. C. E. Millar, Head of the Soils Section, for their part in making this study possible through the cooperation of their respective organizations. Gratitude is also expressed to Professor J. O. Veatch, who originated the project and under whose immediate supervision the work was done, and to Dr. C. J. D. Brown of the Institute for Fisheries Research, who assisted in outlining and supervising the study. The author benefited greatly by frequent conferences with Dr. C. H. Spurway of the

Soils Section and Dr. H. T. Darlington of the Botany Department, who checked the identification of the aquatic plants.

The growth studies of fish were made by Mr. W. C. Beckman.

Mr. E. L. Cooper assisted with the more laborious field work during the past summer.

Biologists realize that any form of life in a lake, that is, the fish or the vegetation, is largely a product of environment. The objective of this investigation was to determine the importance of the soil factor in the environment, so that in subsequent studies of lake productivity or perhaps lake classification, the nature and extent of the various bottom types in a lake may receive due consideration in the light of their influence on the biota of that lake.

AVAILABLE PLANT NUTRIENTS IN LAKE SOILS *

In a classification of soils a wide range of conditions must necessarily be accommodated, particularly with regard to moisture content. This range includes desert conditions on one extreme and swamp or marsh conditions on the other. In the latter group are embraced many soils which may be seasonally inundated and are at or near the saturation point during all seasons of the year. A complete classification should be still more inclusive so as to include those soils which are permanently inundated—occurring in lakes, ponds, and streams. Veatch (10) proposed an extension of the soil taxonomic system which included these lake-bottom soils and applied to them the term "hydrosol".

The study of hydrosols, however, is not only the concern of the soil taxonomist but it has attracted the interest of the group whose objectives are to study and manage the aquatic life in the lakes--particularly fish and the "higher" vegetation. The aquatic biologists, then, have recently given more attention to hydrosols in conjunction with their more comprehensive studies of the lakes throughout the country. In our own state this work has been carried out by the Institute for Fisheries Research, the research branch of the Fish Division of the State Conservation Department. They have made, during the last several years, reconnaissance surveys of many lakes in all parts of the state, continuing and expanding the work previously suggested and initiated by the Land Economic Survey.

^{*} Material under this heading has been previously published as a part of the thesis in the Michigan Agricultural Experiment Station Quarterly Bulletin, Vol. 22, No. 4, May 1940, pp. 247-254.

At the outset of this investigation, it was believed that the relationship between the hydrosols and plant growth might be largely a matter of plant nutrient relationships, to the same extent as it is in agricultural soils and possibly more so since some other factors, particularly moisture content, do not fluctuate as widely in hydrosols as they do in agricultural soils. Hence the nutrient content of hydrosols might assume proportionately greater importance. The purpose was, then, to determine the nature and extent of the nutrient supply and the way in which differences in nutrient content are reflected by the nature and luxuriance of the plant associations.

Another aspect of the nutrient question investigated involved the quantitative analysis of a group of aquatic plants for phosphorus and a comparison between the phosphorus content of the plant and that of the hydrosol in which the plant was growing. Phosphorus in the plant material was determined by the standard Pemberton method (1) while all soil determinations were made by the Simplex Method designed by Dr. Spurway (9) of the Soils Department of Michigan State College. The object of this phase of the work was to learn something of the physiology of the aquatic vegetation and to determine the relationships between the content of a nutrient element in the plants and that of the soil. Phosphorus was selected because deficiencies of this element probably occur more generally in agricultural soils than do those of other elements. In relation to hydrosols, Pond (6) states that

"the primary cause of retarded growth of anchored plants is their inability to secure enough phosphorus and potassium, and possibly other elements".

The results of these two phases of the work (the nutrient content of a variety of hydrosols and the phosphorus content of aquatic plants and associated hydrosols) are reported here, while those phases requiring further and more intensive investigation will be reported later. Detailed field methods will be omitted. Soil samples were collected from various lake bottoms and brought into the laboratory to be tested. Data taken at each collecting station included the depth, pH, temperature, and turbidity of the water; a list of the vegetation; and evidences of the degree of wave action.

The lake-bottom soils have been divided into five broad types for the purpose of grouping the laboratory data. A brief description of the types used follows:

1. Sand. Soils included under this type are those whose outstanding characteristics are due to the sand content. Unless otherwise indicated a clean, compact, light-colored sand will be implied when the term is used. Sand may be found in conjunction with marl, peat, shells, or very finely divided particles of organic matter. It should be realized that innumerable combinations of the various components may and do occur in nature. As mentioned above, however, as long as the characteristics due to the sand are dominant, the soils will be included under this heading—the modifications when present will be given in a column provided for that purpose.

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- 2. Clay. This term is used to designate those soils which are composed of extremely finely divided particles of inorganic material. As such, clay is generally found as a bluish-gray, sticky, and rather homogeneous deposit.
- characterized by brown to black color, a semi-suspended condition of the components, and offering only a limited resistance to the passage of heavier objects such as sounding leads, anchors, etc. Here again, there are many possible intergrades between slime and the firmer deposits included under peat.

 Inclusions of all sorts may occur in slime. Some of the more common ones are marl, shells, sand, and clay. All degrees of decomposition of the plant fragments found in the slime also occur, giving a rather variable texture.
- 4. Peat. Included under this type are those soils which, like slime, are composed of plant remains. Unlike slime, however, peat deposits are more firm and when secured with sampling devices, relatively firm material is received. This soil varies with the nature of the parent plant material, environmental conditions under which decomposition has occurred, and the degree of decomposition. Three distinct divisions are recognized:

 (a) fibrous--including all those deposits whose composition is largely fragmented remains of the rooted aquatics, marsh plants, and bog plants such as mosses, cattails, and leather leaf, (b) woody--composed chiefly of woody material, and (c) gelatinous or pulpy--originating from semi-microscopic forms and from easily disintegrated rooted aquatics and characterized by a

uniform fine composition and a rather firm but gelatinous consistency. Inclusions may involve marl, shells, clay, etc.

5. Marl. This type includes those watersoils whose dominating characteristics are due to the marl content. Inclusions
or modifications are listed in a column describing the particular
deposit under consideration.

The series of tables (1 to 5 inclusive) gives the results of the rapid chemical tests made by the Simplex method, which was designed to give a rapid test for available plant nutrients in soils. Tests for the following nutrients are possible with this test: nitrates, nitrites, ammonia, aluminum, magnesium, manganese, phosphorus, potassium, calcium, iron sulphates, and chlorides. The tables presented give the amounts of some of the more important nutrients in the five broad bottom types. The nitrogen tests are omitted because when the sample is removed from the lake and allowed to remain in the laboratory, the state in which the nitrogen is present is undoubtedly changed and does not simulate its condition in the lake bottom. Hardness of the water is approximate and is expressed as grains per U. S. gallon.

An analysis of the data presented in these tables shows that lake soils vary widely in plant nutrient supply.

It is significant that the extremely acid peat and the pure, highly alkaline marl bottoms are almost completely deficient in available plant nutrients, particularly phosphorus and potassium. Observations show that lakes having a proportionately large percentage of these types of bottoms are low

Table 1. Available Nutrients	. in	-Sand.
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Sample	Modifications	Water		Soil	(Air-d	ry)			Rooted
No.	or Inclusions	Hard.	pН	ppm	K ppm	Ca ppm	Mg ppm	Fe ppm	Plants*
2	much dark organic matter	14	7.5	• • •	•••	100	•••	tr.	6 - b
7	abundance of shells	13	9.0	tr.	2	200	7	tr.	5 - a
15	none	13	7.5	tr.	• • •	100	6	•••	1 - a
27	none	12	7.8	• • •	• • •	200	6	10	2 - b
44	none	11	7.5	•••	tr.	200	8	•••	2 - b
45	none	11	6.3	0.75	•••	•••	5	•••	3 - b
60	much organic matter		8.0	•••	• • •	150	24	•••	1 - a
61	varying from dark gray to black organic matter		7.0	tr.	• • •	125	8	•••	1 - a
63	considerable organic matter		8.0	•••	•••	175	16	•••	3 - a
64	dark color	12	7.5	0.5	•••	175	8	•••	5 - b
65	brown color	12	7.2	0.5	• • •	• • •	4	•••	10 - b
67	marl mixed in	12	7.0	0.5	•••	•••	1	•••	2 - b
68	black, compact	8	5.5	tr.	20	•••	6	•••	6 - a
70	none	8	5.5	• • •	•••	•••	4	•••	•••
71	none	13	7.5	•••	•••	•••	1	•••	4 - b
72	none	11	5.0	tr.	• • •	100	7	•••	3 - a
	Range:	8 to 14	5.0 to 9.0	0 to 0.75	0 to 20	0 to 200	0 to 24	0 to 10	

^{*}The number indicates the number of plant species growing on the corresponding soil while the letters indicate the luxuriance of growth: a, very luxuriant growth, b, intermediate, and c, poorly developed. This has reference to thriftiness or luxuriance of growth--not density of stand.

In the data, blanks indicate that no test was made, while the symbol (...) means lack of response to test.

The foregoing procedures are carried out in tables 1 to 5, inclusive.

Table 2. Available nutrients in clay.

Sample		Modifications	Water	Soil (Air-dry)						Rooted
No.		or Inclusions	Hard	рH	ppm P	K ppm	Ca ppm	Mg ppm	Fe ppm	Plants
5	none		14	8.0	tr.	tr.	200	7	tr.	2 - b
9	none		13	8.2		•••	200	35		1 - b
10	none		13	9.0	tr.	•••	200	40		•••
13	none		13	7.5	tr.	•••	200	24	tr.	1 - a
16	none		13	7.5	•••	•••	200	10	•••	•••
		Range:	13 to 14	7.5 to 9.0	0 to	0 to tr.	0 to 200	7 to 40	to tr.	

Table 3. Available nutrients in slime.

Sample	- 1			Soil	(Air-d	ry)			Rooted
No.	or Inclusions	Hard	рĦ	P ppm	K ppm	Ca ppm	Mg ppm	Fe ppm	Plants
1	none	14	8.0	tr.	• • •	130	•••	•••	5 - b
6	none	14	7.5	tr.	2.0	175	6	tr.	5 - b
11	clay admixed	13	8.5	tr.	•••	200	4 0	tr.	3 - a
12	marl and shells	13	8.5	tr.	•••	200	24	•••	1 - a
14	none	13	7.0	tr.	•••	125	10	tr.	1 - a
17	marl at depth of 2 ft.	13	7.5	•••	•••	200	15	•••	4 - b
25	marl at depth of 4 ft.		7.8	tr.	5.0	200	10	tr.	6 - a
4 8	Green color, shells included	11	7.8	•••	•••	150	8	•••	3 - b
54	green color, very fluid	5	5.5	•••	•••	•••	8	•••	2 - c
102	marl and shells	14	8.0	1.5	•••	200	7	•••	9 - a
	Range:	5 to 14	5.5 to 8.5	0 to 1.5	0 t o 5	0 to 200	0 to 40	0 to tr.	

Table 4. Available nutrients in peat.

				Soil	(Air-	·dry)			
Sample No.	Modifications or Inclusions	Water Hard.	pН	P ppm	K ppm	Ca ppm	Mg ppm	Fe ppm	Rooted Plants
11.5	gelatinous, green	13	7.0	tr.	•••	125	3	•••	3 - a
20	fibrous, prolific Chara growth, pH of water-8.5	13	5.5	0.5	•••	125	14		5 - b
23	gelatinous, containing many small shells		8.0	1.5	•••	200	8		3 - a
41	fibrous, containing many small shells	18	7.6	•••	•••	200	24	tr.	7 - a
47	gelatinous	11	7.0	0.5	•••	125	16	•••	4 - a
50	gelatinous	11	6.0	0.5	•••	125	8		3 - b
52	gelatinous	5	5.0	•••	•••	•••	8	•••	3 - c
53	fibrous	5	5.0	•••	•••.	•••	8	•••	2 - b
66	fibrous	12	6.5	tr.	•••	1 50	20	•••	2 - b
69	fibrous	8	6.5	0.75	•••	150	10	•••	5 - a
100	fibrous, marl under shore but not under bottom	16	8.0	•••	•••	200	24	•••	5 - b
101	gelatinous	16	7.7	•••	•••	125	7	•••	5 - b
107	fibrous	8	5.5	•••	2.5	125	14	•••	7 - a
130	fibrous, containing marl	8	8.5	•••	•••	200	7	•••	•••
Range:		5 to 18	5.0 to 8.5	0 to 1.5	0 to 2.5	0 to 200	3 to 24	0 to	

Table 5. Available nutrients in marl

Comple	Madigiantian	717 - A		Soil (Air-dr	y)			Rooted	
Sample No.	Modifications or Inclusions	Water Hard.	•	P ppm	K ppm	Ca ppm	Mg ppm	Fe ppm	Rooted Plants	
3	impure	14	9.0	tr.	• • •	160	•••	•••	2 - b	
4	composed chiefly of very small shells	14	8.0	•••	•••	200	•••	•••	2 - b	
8	none	13	8.5	•••	•••	200	7	•••	1 - b	
18	none	13	8.5	•••	•••	200	8	•••	•••	
19	impure, much organic matter	13	8.0	•••	•••	200	24	•••	2 - b	
21	none		8.0	•••	•••	200	16	•••	4 - b	
22	considerable organic matter		7.8	•••	•••	200	6	•••	6 - a	
24	numerous plant fibers		8.0	•••	tr.	200	8	•••	•••	
26	none		8.0	•••	•••	200	8	•••	2 - b	
28	none	12	e . 2	•••	•••	200	4	•••	3 - с	
40	impure	18	7.8	•••	•••	200	24	•••	4 - a	
43	gelatinous peat admixed	9	8.5	•••	•••	200	8	•••	5 - a	
46	impure	11	8.5	•••	•••	200	8	•••	4 - a	
49	none	11	8.2	•••	•••	200	8	•••	3 - c	
51	none	11	8.5	•••	•••	200	8	•••	•••	
	Rang e:	9 to 18	7.8 to 9.0	o to tr.	0 to tr.	160 to 200	0 to 24	0		

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in productivity, not only with respect to vegetation but also with respect to plankton and fish production. Similar observations are recorded by Raymond (7) and Welch (11). Among the other types of bottoms, there seems to be no correlation between nutrient supply and the type and luxuriance of the plant communities. Certain plants prefer given types of soils, but the preference seems to be based on physical characteristics, such as firmness of the bottom and subjection to wave action, rather than on the chemical constituency of the bottom.

Table 6 presents the results of the analysis of several different species of aquatic plants-giving the phosphorus content as determined by the standard Pemberton method. The soils upon which the plants were found have been tested for phosphorus by the Simplex method and those data are also included in the table. The reason for selecting phosphorus has been previously mentioned.

An examination of Table 6 indicates that there is a wide variation in the phosphorus content of aquatic plants. The percentages of P_9O_5 range from 0.189 to 1.105.

Different species of plants growing on the same soil absorb different amounts of phosphorus. In one case <u>Potamogeton</u> amplifolius, <u>Anacharis</u>, <u>Myriophyllum</u>, and <u>Naias</u> were found growing together and contained the following percentages of P_2O_5 respectively: 0.400, 0.479, 0.816, and 0.727.

A single species of plant does not show a uniform phosphorus content but varies widely when grown in different lake soils, although the phosphorus content of the plant shows no

Table 6. Comparison of phosphorus content of aquatic plants and that of associated soils.

Lake	Soil	Phos- phorus in soil (ppm)	P ₂ O ₅ in plants (percent)	Plant(s)	Sample No.
Pine L. Barry Co.	fibrous peat	0.0	•508	Brasenia	P - 1
Pine L. Barry Co.	fibrous peat	0.0	•351	Naias	P - 2
Craig L. Branch Co.	firm fibrous peat	0.5	.256	Potamogeton pectinatus	P - 3
Craig L. Branch Co.	fibrous peat no sample taken		.227	Chara	P - 4
Fish L. Oakland Co.	green gelatinous peat	0.0	•534	Potamogeton amplifolius	P - 5
Fish L. Oakland Co.	slime too thin to get with sampler		•359	Brasenia	P - 6
Square L. Oakland Co.	gray soft gelatinous peat and marl	0.0	.452	Potamogeton spp., Chara	P - 7
Pleasant L. Oakland Co.	green organic slime and shells	0.0	•441	Potamogeton sp.	P - 8
Pleasant L. Oakland Co.	sand	0.75	. 283	Potamogeton sp.	P - 9
Pond on U.S. 10, 3 mi. N.W. of Clarkston	sand and clay	0.0	•762	Myriophyllum, Chara & algae	P - 10
Mona L. Muskegon Co.	thin layer of fib- rous peat over sand	tr.	1.098	Lemna, Spirodela	P - 11
Pigeon L. Ottawa Co.	semi-fluid fibrous peat	0.75	•757	Chara	P - 12
Cook L. Livingston Co.	brown fibrous peat	0.0	•833	Heteranthera	P - 13
Bennett L. Livingston Co.	thin layer of black slime over sand	1.5	.296	Chara	P - 14
Kawbawgam L. Marquette Co.	brown gelatinous peat	0.0	•363	Pontederia	410-A
Kawbawgam L. Marquette Co.	brown gelatinous peat	0.0	. 496	Potamogeton praelongus	410 - P

Table 6. Continued.

Lake	Soil	Phos- phorus in soil (ppm)	P ₂ O ₅ in plants (percent)	Plant(s)	Sample No.
Ross L. Marquette Co.	sand	0.0	•309	Isoetes	413-B
Ross L. Marquette	sand	0.0	•663	Sparganium	413-A
Kawbawgam L. Marquette Co.	sand and fibrous peat	0.0	.254	Scirpus sp. Giant Bulrush	421 - B
Little Bradford L. Otsego Co.	sand and gelatinous peat	0.5	•160	Chara	431 - C
Little Bradford L. Otsego Co.	sand and gelatinous peat	0.5	.263	Potamogeton sp.	431 - P
Little Bradford L. Otsego Co.	sand and gelatinous peat	0.5	.521	Nuphar	431-W
Heart L. Otsego Co.	dark sand	3.0	.281	Potamogeton natans	43 2- N
Witch L. Marquette Co.	sand	0.0	.219	Scirpus sp.	43 3- S
Houghton L. Roscommon Co.	slime and gelatinous peat		•304	Vallisneria	439-C
Houghton L. Roscommon Co.	slime and gclatinous peat		•534	Zizania	439 - R
Big Perch L. Marquette Co.	dark sand	0.0	-262	Nuphar	445 - L
Big Perch L. Marquette Co.	dark sand	0.0	•360	Potamogeton Richardsonnii	445-P
Little Perch L. Marquette Co.	sand	0.0	•491	Potamogeton gramineus	446-P
Little Perch L. Marquette Co.	sand	0.0	•791	Polygonum	146 - S
Otsego L. Otsego Co.	sand, marl, and sawdust	5.0	•400	Potamogeton amplifolius	468-A
Otsego L. Otsego Co.	sand, marl, and sawdust	5.0	•479	Anacharis	468 - E
Otsego L. Otsego Co.	sand, marl, and sawdust	5.0	.816	Myriophyllum	468-M
	l	1	ı	l	ı

Table 6. Continued.

Lake	Soil	Phos- phorus in soil (ppm)	P ₂ 0 ₅ in plants (percent)	Plant(s)	Sample No.
Otsego Co.	sand, marl and sawdust	5.0	•727	Naias	468 - N
Buttonbush Pond St. Joseph Co.	clay and organic matter	tr.	. 526	Polygonum	504-A
Buttonbush Pond St. Joseph Co.	clay and organic matter	tr.	. 760	Utricularia	504 - B
Buttonbush Pond St. Joseph Co.	clay and organic matter	tr.	•738	Tolypella	504 - F
Buttonbush Pond St. Joseph Co.	clay and organic matter	tr.	•904	Potamogeton natans	504-N
Buttonbush Pond St. Joseph Co.	clay and organic matter	tr.	•730	Potamogeton obtusifolius	504 - P
Buttonbush Pond St. Joseph Co.	clay and organic matter	tr.	1.105	Sagittaria	504 - S
Prairie River L. St. Joseph Co.	gelatinous peat and marl	0.0	. 656	Ceratophyllum	507-C
Prairie River L. St. Joseph Co.	gelatinous peat and marl	0.0	. 639	Peltandra	507-P
Silver L. Washtenaw Co.	sand, marl, and organic matter	tr.	.189	Chara	512-C

relation to that of the lake soil. Potamogeton natans, for instance, contained 0.281 per cent P₂O₅ when growing on a soil containing 3.0 p.p.m. while another sample from a different lake contained 0.904 per cent P₂O₅ when growing on a soil containing only a trace of phosphorus. If aquatic plants obtain nutrients from the soil, they must have greater extracting powers than is generally supposed since the Simplex method is able to detect available phosphorus in concentrations of less than 0.5 parts per million, and in many cases plants showed a relatively high percentage of phosphorus when the corresponding soil failed to show even a trace by this test. However, if the nutrients were absorbed directly from the lake water, then a very minute amount of phosphorus in the lake water might supply the amount required by the plant for its metabolism.

It is interesting, in this connection, to note that two floating plants, <u>Lemna</u> and <u>Spirodela</u>, contained a higher percentage of phosphorus than all of the rooted plants, except for a sample of <u>Sagittaria</u> from Buttonbush Pond in St. Joseph County.

FERTILIZER PLOTS AT ROSE LAKE

Following some preliminary pot tests in the greenhouse, which were made to determine the feasibility of the use of commercial fertilizers. it was considered desirable to make some fertilizer applications on a larger scale and under more natural conditions. Through the cooperation of the Game Division of the Michigan Conservation Department, experimental plots were constructed in the floating bog surrounding Rose Lake in Bath Township, Clinton County, Michigan. The mat of vegetation here is about 18 inches thick and is underlain by varying depths of semi-fluid fibrous material of the same nature as that comprising the bottom of Rose Lake. Excavations were made during the winter, when the ground was frozen, to a depth of three feet. Wood cribs were placed in the pools to prevent the soft material from filling them in. Plots of two different sizes were made -- three of 15 feet square and nine which were ten feet square. The plots were placed 25 feet apart.

Before adding fertilizers to the plots, it was necessary to know the rate and amount of diffusion of salts which would take place in order to be certain that the application of fertilizer in one pool would not affect the adjoining pools. An experiment was established in the bog to determine this. A series of holes three inches in diameter were bored through the surface mat at the following intervals from the hole in which the salt was to be placed: 1, 3, 5, 10, 15, and 25 feet.

The salt (1500 grams of KCl) was put in the end hole after a sample of the water and soil had been tested for potassium and found to be very low--less than five parts per million.

Tests were frequently made to determine the amount of diffusion.

After two weeks, a slight increase occurred in the first hole-one foot distant, while the others remained unchanged. Throughout the period of a year, tests have indicated that the salt did
not diffuse to an appreciable extent and that applications of
soluble salts in one plot would not affect the nutrient content
of adjacent plots.

The original nutrient content of the soil was: phosphorus--0.0 p.p.m.; potassium--less that 5 p.p.m.; and nitrates--0.0 p.p.m.

Equivalent amounts of vegetation were introduced into each pool. Plants used were two species of Potamogeton and Utricularia vulgaris.

The following treatments were made in duplicate, using two plots as controls: 500 pounds per acre metaphosphate; 2000 pounds per acre metaphosphate; 500 pounds per acre muriate of potash; 500 pounds per acre ammonium nitrate; and 500 pounds per acre metaphosphate, plus 1500 pounds per acre muriate of potash. These applications were made in May, 1939, and the experiments are still in progress.

The plants were not harvested, but some data were obtained regarding their growth. Figures 1 to 4 inclusive show differences in growth in various pools.

Within a week, following the fertilizer applications, algal growth was enormous in the plots receiving a phosphorus



Fig. 1. One of the control plots. Water lilies have come in naturally.



Fig. 2. Plot receiving muriate of potash.

Vegetation is not as abundant as in the control plot.



Fig. 3. A plot receiving 2000 pounds per acre of metaphosphate. <u>Utricularia</u> is very prolific. Duckweeds naturally introduced.



Fig. 4. A plot receiving both metaphosphate and muriate of potash. Vegetation about as abundant as in Fig. 3.

treatment. This condition persisted for two weeks, after which the algae were present, but not in such large quantities. The Uticularia in these same pools grew very rapidly and at the end of the second season is still prolific--see Fig. 4. Duck-weeds and water lilies have been naturally introduced.

Other treatments seemed to have little effect, since a noticeable difference in plant growth could not be detected.

These results indicate that where definite nutrient deficiencies exist, the condition can be remedied by the addition of commercial fertilizers. However, in lakes the problem is complicated considerably. First, it is difficult, in a lake, to attribute the complete absence or even scarcity of vegetation solely to nutrient deficiencies because of the presence of numerous other factors--probably chiefly physical in nature. The method of application would undoubtedly require modification. Diffusion of the nutrients into the water would occur more rapidly in a lake where water movement occurs. Experiments involving these problems should prove both interesting and valuable to the fisheries biologist.

GREENHOUSE FERTILIZER TESTS.

During the winter and spring of 1939-1940, a series of fertilizer tests were made in the greenhouse. The soils used in the tests were collected from the bottom of lakes throughout the state and were taken from areas which seemingly should be producing vegetation but were not. The soils were tested for plant nutrient content and the treatments made on the basis of the original fertility.

The soil samples were placed in 2-gallon jars, filling the jar to a depth of three inches. The jars were then filled with distilled water.

(Anacharis canadensis). This species was used because it grows rather rapidly under favorable conditions, and it develops roots readily so that anchorage is not a problem. The fresh weight of the plants was measured for each jar. The plants were allowed to grow for three days, at the end of which time the few that had died were replaced. The fertilizers were then added. During the growing period of ten weeks, the jars were kept full by adding distilled water. Algal growths were treated with copper sulfate, but in many cases a treatment with sufficient strength to kill the algae damaged the plants to such an extent that they did not recover. At the end of 10 weeks, the plants were harvested and weighed.

Table 7 presents the results from the experiment. It is interesting to note that some applications produced enormous

increases in growth over the control. Others seemed to produce conditions very favorable to algal growth, with the result that the <u>Anacharis</u> was either choked out or killed by copper sulfate treatments. In one case-soil 479-the treatment seemed to inhibit algal growth.

From the practical standpoint, it may be important to point out that the majority of the large increases were obtained by using natural materials as fertilizers. The addition of an acid muck to highly alkaline marl bottoms lowers the reaction and probably makes available some nutrients which are unavailable in a strongly alkaline condition. Additions of marl to acid soils seems to give the same response in plant growth by reversing the conditions of reaction and availability of plant nutrients. Marl and muck or peat are plentiful in the state, and if the productivity of lakes can be increased by artificial means, it seems that these two sources of fertilizing material should prove valuable. It must be pointed out, however, that in some cases actual nutrient deficiencies may occur, and that in these cases, additions of commercial fertilizers may prove to be the solution.

Table 7. Results of Greenhouse Fertilizer Tests.

Soil*	pH of soil	P	K	Treatment** lbs./acre	***Hd	Growth (Awe. of duplicate treatments) 100% dec. 0 100% inc. 200% 500%
500S, G	7.8	0.5	4.0	Control 1000M	7.8	
506M, PP	7.9	0.5	0.0	Control 500-N, 500-K	8.5	
520FP	5.7	tr.	0.0	Gontrol 1000-M1	5.6	
431S, FP	7.3	0.5	7.5	Control 500-P, 500-K	8.0	
479M	7.8	0.0	tr.	Control	7.8	
M613	7.7	0.0	0.0	Control 500 ea. N. P. K	8.5	
511S, M	7.5	0.0	0.0	Control 500-K 500-P 500-N 500-M	0.0000000000000000000000000000000000000	
445S	6.4	0.0	4.0	Gontrol 1000-M1	0.0	
505S, M	7.4	1.0	0.0	Control 500-K 500-M	88.7 7.95	
441WP	4.5	0.0	0.0	Control 1000-M1, 500 ea. P, K	4. T.	
413S, PP	ຄ	0.0	0.0	Gontrol 500-P, 500-K 500-N	4 4 4 8 0 0 1 0	

This test was made * Symbols for soil: S--sand, G--gravel, M--marl, PP--pulpy peat, FP--fibrous peat, WP--woody peat. **Symbols for treatments: M--muck, M1--marl, P--superphosphate, K--muriate of potash, N--ammonium nitrate. three weeks after application of fertilizers. *Plants choked out by algae.

A COMPREHENSIVE STUDY OF FOUR LAKES

During the summer and fall of 1940, a detailed study was made on four lakes in the northern part of the Lower Peninsula of Michigan. The objective here was to study the natural distribution of vegetation in different lakes, and to determine the importance of water soils in the ecology of the larger aquatic plants.

Lakes were chosen from this part of the state for two reasons: first, the Hunt Creek Experiment Station of the Institute for Fisheries Research, located at Lewiston, made an excellent headquarters since all of the lake conditions desired could be found within a radius of 10 or 12 miles; second, the problems of private ownership of surrounding lands and that of conflict with sportsmen and resort owners are less intense in the northern part of the state.

Methods.

The methods used in this investigation are essentially the same as those used for similar studies by Wilson (12) on Sweeney Lake, Wisconsin, and Rickett (8) on Green Lake, Wisconsin. Transects were arbitrarily chosen on the basis of natural shoreline zones or types, assuming that opposite a uniform shoreline, there is a corresponding uniform zone of off-shore vegetation. These transects extend from the shore through the zone of vegetation. In the lakes studied, the vegetation never extended to a depth exceeding six meters.

Plant and soil samples were collected along the transects with the Peterson dredge, which gives perhaps a better quantitative sample than do other available sampling devices. Samples were taken at depth intervals varying from one-fourth to one meter, depending on the degree of slope of the bottom-the steeper the slope, the larger the interval.

The entire sample, plants and soil, was discharged into a large pan. The plants were transferred to a wire basket hanging over the side of the boat, washed, packeted in wax paper, and properly labeled. A sample of the soil was placed in glass jars provided for that purpose, and each jar labeled. These samples were taken into the laboratory for further study and treatment. See Fig. 5 for field equipment.

In the laboratory, each plant sample was separated into species; each species sample was washed free from debris, drained and blotted to remove the excess water, and then carefully weighed. An index card was filled out for each species, recording the transect, collecting station within the transect, depth, and fresh weight. Dry weights were not measured, chiefly due to lack of time and space. Moreover, since the larger aquatic plants, with a few exceptions, do not vary over eight or ten percent in water content, it seems that taking both fresh and dry weights is impracticable. If, for any lake, the total weed crop is desired on a dry weight basis, one needs only to multiply the fresh weight figures by 12 or 13% since the plants average 87% or 88% water. Using this technique on the data from the Green Lake, Wisconsin, study, the result is

probably not different enough to warrant the additional labor. In this lake, the total crop is given as 13,002,500 kg. fresh weight and 1,527,900 kg. dry weight. Twelve percent of 13,002,500 is 1,560,300. If considering only the emergent plants, the factor used would have to be increased because emergent plants contain a lower percentage of water.

The soil samples were tested for reaction; and available phosphorus, potassium, calcium, and iron. These tests were made with the Simplex Soil-testing System designed by Dr. C. H. Spurway (9). Briefly, this consists of making a .135 N. acid soil extraction from each sample, dividing the extracted solution into 1 cc. portions, and using colorimetric tests for each nutrient. The acid extraction is used as an arbitrary means of determining the readily soluble salts in the soil and it is believed that these salts are available to the plant. The results of the analyses were recorded on index cards, together with the information regarding the collecting station and a description of the soil.

A small sample of each soil was oven-dried at 110° C. for organic matter determinations. The hydrogen peroxide method was used to determine the organic matter.

Tabulation and treatment of data:

The discussion will be restricted to the methods involved in tabulating the data rather than a presentation of the results.

In all computations, except that of the frequency of occurrence and relative abundance of various plant species

on different soil types, the method used was the same. The transects were divided into zones on the basis of depth of water. Zone 1 includes all readings between the shore and a depth of one meter (0 - 1 m.); zone 2, those between one and three meters (1 - 3 m.); and zone 3, from three meters through six meters (3 - 6 m.).

Since the number of samples varied, the measurements from each zone were averaged. Plant weights, then, are obtained as the mean weight per sample. These means were converted into grams per square meter, kilograms per hectare, and, to give the maps (Figs. 8b, 12b, 16b, and 21b) more popular usage, into pounds per acre.

Total yields were computed by multiplying grams per square meter by the area (in square meters), which was obtained from a large base contour map.

The average yield by zones (Figs. 9, 13, 17, 22, and 24) was determined on the basis of the total yield and the total area of the zone.

Fertility and organic matter determinations of soils were averaged by zones; the mean reading was used in all calculations.

In Tables 10, 13, 15, and 19, showing the frequency of occurrence and relative abundance of plant species on different soil types, the individual plant and soil samples were considered.

The derivation of the fertility figure or nutrient content warrants explanation. On the basis of some 3,200

tests, it was found that each of the nutrients occurred in quantities within a given range--this range varying with each element. In deriving a standard fertility figure, each element received equal weight or importance. Using a factor, based on the highest reading for that element, the nutrient could be properly proportioned. The following table illustrates:

Standard

Nutrient	Maximum Value (ppm)	Factor	Equiv. Value	(ppm) Reading	Equiv. Value
Phosphorus	2.5	8	20	1.5	12.0
Potassium	20.0	1	20	6.0	6.0
Calcium	200 *	1/10	20	75.0	7.5
Iron	40.0	$\frac{1}{2}$	20	15.0	7.5

Maximum nutrient content -- 80 N.C. of sample 33.0

The value of the figures obtained by this method and other possible methods will be discussed later.

In tables dealing with plants, some species which occur in the list of plants for a given lake are omitted. In such cases there were not enough data to warrant the inclusion of those species which are omitted.

When a species was observed but not taken in a sample, it was recorded as a trace (tr.).

^{*}In marl samples the calcium content is greater than 200 ppm. Exact readings would require dilution of the soil extract--a process requiring more time than was available. Moreover, it is doubtful that calcium in excess of 200 ppm. adds to the fertility of the bottom.



Fig. 5. Sterm of boat with field equipment in place.

The outlines and contours of the maps in this manuscript were obtained from maps furnished by the Institute for Fisheries Research.

Data Presented.

The data will be presented for each lake individually, with a general discussion following.

<u>Lake Fifteen:</u> Situated in sections 14, 15, and 22 of Briley Township, Montmorency County.

This lake occupies an 88 acre basin in the Thunder Bay River valley, the river flowing through the western part of the lake. The basin lies in a rather narrow strip of outwash plain situated between two moraines of the Port Huron system. The lake margin is swampy around practically the entire circumference (Fig. 8a). The swamp or bog is underlain by marl at a depth varying from three to fifteen feet. The lake is still a marl-producing lake--pebble marl being unusually abundant.

The lake basin is characterized by a narrow shoal, which is terminated abruptly by a rapid "drop-off". See Figure 8a for further hydrographic information.

The water in Lake Fifteen is clear and relatively hard; it measures 18 grams calcium carbonate per U. S. gallon.

Twenty-one species of plants (Table 8) are represented in the lake.

Table 9 shows the distribution of the flora with regard to depth. Zone 1 (the area between the shore and the

one-meter contour) contains 36.4% of the total vegetation. The plants comprising the bulk of the flora in Zone 1, in order of their abundance, are Chara sp., Nuphar advena, and Myriophyllum heterophyllum.

In Zone 2 (the area between the 1 and 3-meter contours) M. heterophyllum, Chara sp., Potamogeton amplifolius, P. zosteriformis, and smaller amounts of other species comprise 46.6% of the total crop.

The vegetation in Zone 3 (the area between the 3 and 6-meter contours) accounts for 17.0% of the total crop; the chief contributing species, in order of their abundance, are M. heterophyllum, P. zosteriformis, and Chara sp.

The distribution of the flora with respect to bottom types is shown in Table 10.

The relationship between yield of plants, the organic matter content of the bottom, and the nutrient content of the bottom is shown in Figure 9.

The density of the vegetation and the bottom types occurring in the lake are given in Figures 8b and 8c respectively.



Fig. 6. View showing the uniformity of the east shore of Lake Fifteen.



Fig. 7. A protected bay at Transects A & B. Picture taken in May. In July and August, vegetation here is abundant.

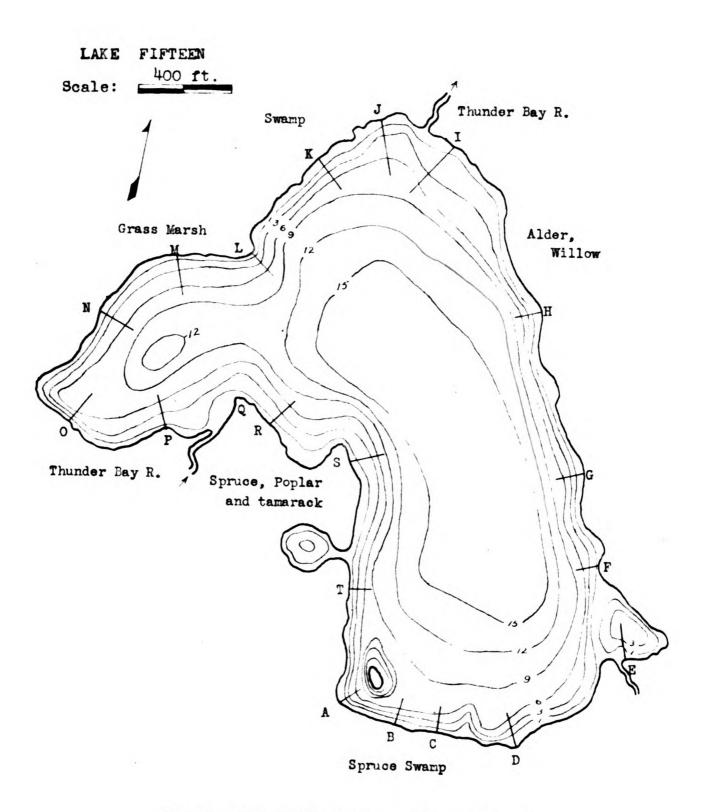


Fig. 8a. Map showing contours (in meters) and transects along which samples were collected.

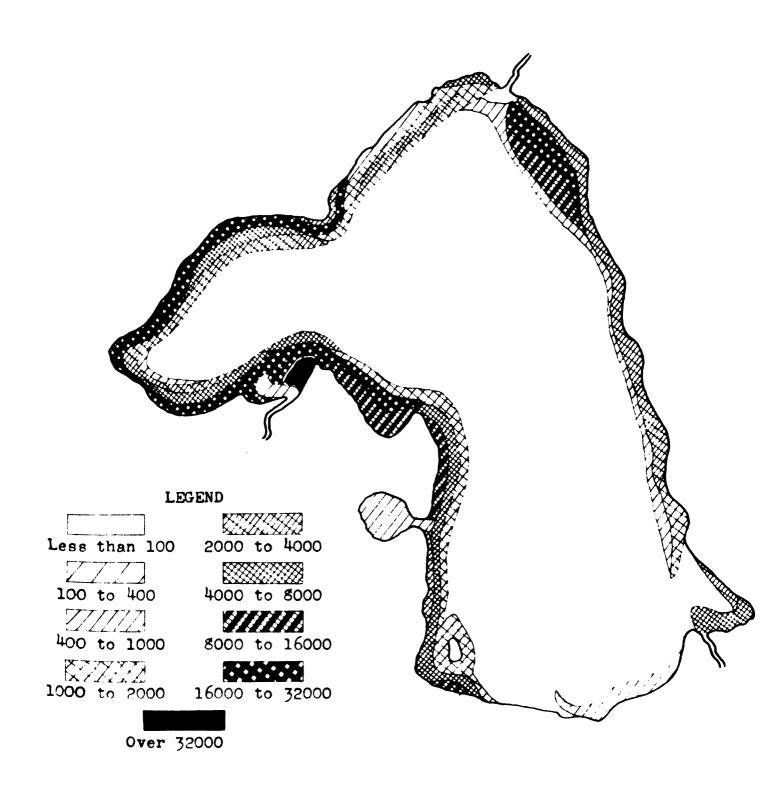


Fig. 8b. Map showing vegetation density in lbs. per A.

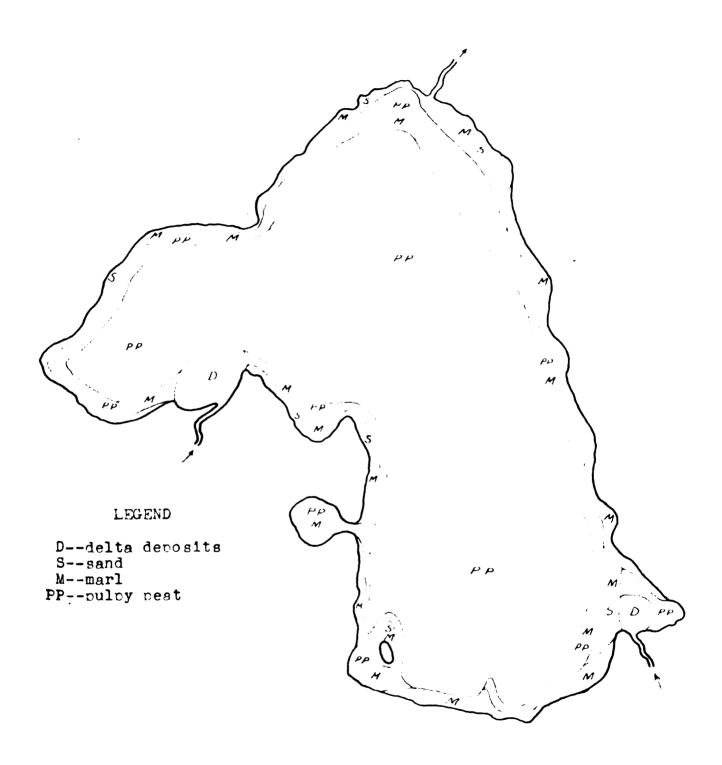


Fig. 8c. Map showing bottom types.

Table 8. Plants Occurring in Lake Fifteen.

Carex lasiocarpa Sedge

Carex rostrata Sedge

Ceratophyllum demersum Coontail

Chara spp. Muskgrass; Stonewort

Dulichium arundinaceum Three-way Sedge

Myriophyllum heterophyllum Water Milfoil

Naias flexilis Bushy Pondweed

Nuphar advena Yellow Water Lily

Nymphaea odorata White Water Lily

Potamogeton amplifolius Large-leaf Pondweed; Bass Weed

P. angustifolius Pondweed

P. filiformis var. borealis Pondweed

P. foliosus Leafy Pondweed

P. interior Pondweed

P. natans Floating-leaf Pondweed

P. pectinatus Sago Pondweed

P. praelongus Whitestem Pondweed; Muskie Weed

P. zosteriformis Flat-stemmed Pondweed

Scirpus acutus Hardstem Bulrush

Typha latifolia Common Cattail

Utricularia vulgaris var. Eladderwort

americana

Table 9. Total Weight and Percentage of Each Species by Zones.

<u>Lake Fifteen</u>

	Zone	1.	Zone	2.	Zone	3.	Total
Species	Weight kg.	%	Weight kg.	90	Weight kg.	c.70	Weight kg.
Carex lasiocarpa	529	1.7					529
Chara spp.	17,715	56.4	5,639	14.0	2,748	18.1	26,102
Myriophyllum heterophyllum	4,423	14.1	23,601	58.5	8,592	56.7	36,616
Naias flexilis	387	1.2	396	1.0			783
Nuphar advena	5,663	18.0	1,175	2.9			6,838
Potamogeton amplifolius	1,639	5.2	4,185	10.3	41	0.3	5,864
P. angustifolius	291	0.9	263	0.7	1		554
P. interior	111	0.4	190	0.5			301
P. natans	62	0.2	120	0.3			182
P. poetinatus	278	0.9		,			2 73
P. praclongus	tr.		644	1.6			644
P. zosteriformis	210	0.7	3,301	8.2	3,275	21.6	6,786
Scirpus acutus	71	0.2					71
Typha latifolia	26	0.1					26
Utricularia vulgaris	7	0.0	799	2.0			808
Total	31,393		40,313		14,656	<u> </u>	86,380
Percent of Grand Total in each Zone	36.4		46.	6	17.0		

Table 10. Frequency of Occurrence and Relative Yield of Certain

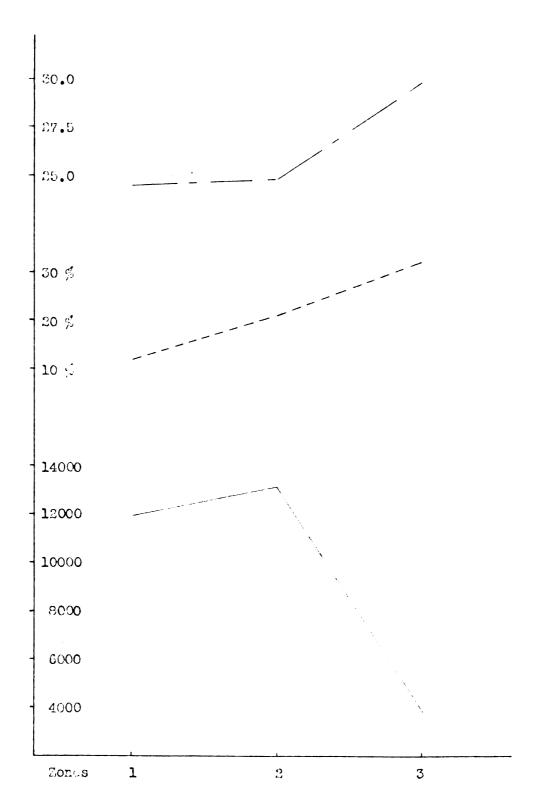
Plant Species on Different Bottom Types. Lake Fifteen

	Bottom Type.								
Species	M	PP	S,M	M,PP	PP,D,M	S,M,PP			
Carex lasiocarpa			75* 25**						
Carex rostrata	25*		75*						
Ceratophyllum demersum	50*			50*					
Chara spp.	25**	1*	5* 18**	9** 38***	1**	3***			
Dulichium arundinaceum	45*		55*						
Myriophyllum heterophyllum	12* 2**	2**	4* 17**	12** 50***	1*				
Naias flexilis	2*		9*	40* 45**	4*				
Nuphar ad v ena	9*		40* 3 3**	15*	1*	2*			
Potamogeton amplifolius	2*		6*	56* 37**	1*				
P. angustifolius .	4*			72* 15**	1*	8*			
P. interior			45*	33* 22**					
P. natans				16*	84.*				
P. pectinatus					67* 33***				
P. praelongus	3*		17*	80*					
P. zosteriformis			2*	33* 40** 21***	4*				
Scirpus acutus			95* 5**						
Typha latifolia						100*			
Utricularia vulgaris	4*			55* 10**	18*	13*			

¹ Frequency of occurrence on each bottom type stated in percent of total number of collections of given species. Relative yield: *, less than 300 gms./ sq. meter; **, 300 to 1000 gms./ sq. meter; ***, over 1000 gms./ sq. meter. Bottom types: M--marl; PP--pulpy peat; S--sand; D--detritus.

Example: 100% of the collections of Carex lasiocarpa were taken from a sand and marl bottom; 75% of the collections measured less than 300 gms. per square meter, 25% measured between 300 and 1000 gms./sq. meter.

Fig. 9. Graphs showing average yield of plants (kg./hectare ——), percentage of organic matter in bottom (———), and nutrient content of bottom (———) by zones in Lake Fifteen.



* <u>Lake Twenty-two</u>: Situated in section 22 of Vienna Town-ship, Montmorency County.

This lake is a good example of a "kettle" type, occupying a basin of 109 acres in the Port Huron moraine. Its shores rise rather abruptly so that only a narrow wave-built terrace is found. Exception to the above occurs along the south side for a short distance and in the bay constituting the western end of the lake.

The filling in of this large bay was undoubtedly hastened, or perhaps may be accounted for, by the existence of a large sawmill there in the lumbering days.

The shoreline is characterized by fallen trees and an accumulation of logs, sticks, and all manner of debris.

A list of the plants is given in Table 11.

Table 12 shows the distribution of the flora with regard to depth. In Zone 1, the most abundant plants are, in order: Chara sp., Nymphaea odorata, and Potamogeton amplifolius. In Zone 2, they are: Chara sp., P. obtusifolius, and P. amplifolius, and in Zone 3, P. amplifolius and P. obtusifolius comprise the total crop.

Zone 1 produces 16.0% of the total crop; Zone 2 produces 42.2%; and Zone 3 produces 41.8% of the total.

Figures 12a, 12b, and 12c give the maps of the lake corresponding to those of Lake Fifteen.

^{*}The land surrounding Lake Twenty-two is owned by the Kneeland-Bigelow Lumber Company. Their permission for access to the lake is greatly appreciated.

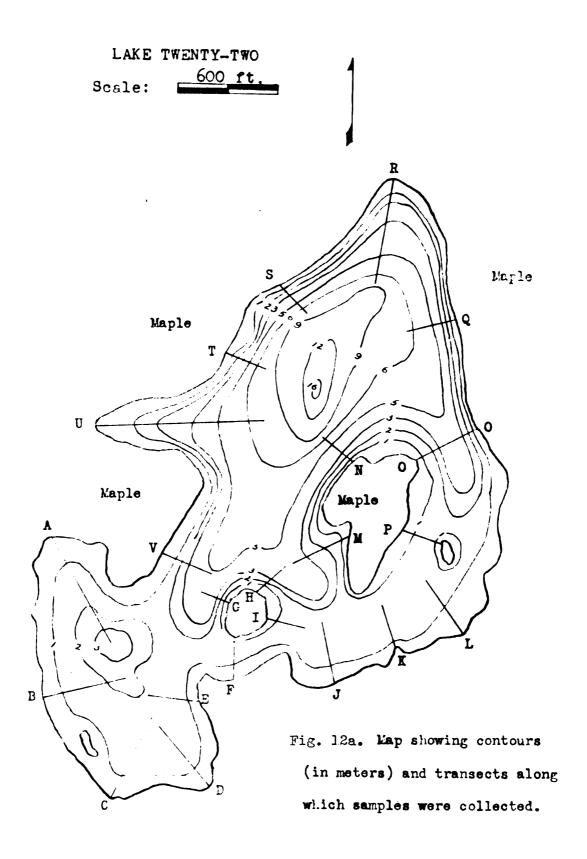
The relationship of plants to different bottom types is given in Table 13. Figure 13 shows the graphs or curves for yield, organic matter content of the bottom, and the nutrient content of the bottom by zones.



Fig. 10. A swampy shoreline.



Fig. 11. A rather steep, wooded shoreline, characteristic of the east and northwest sides of the lake.



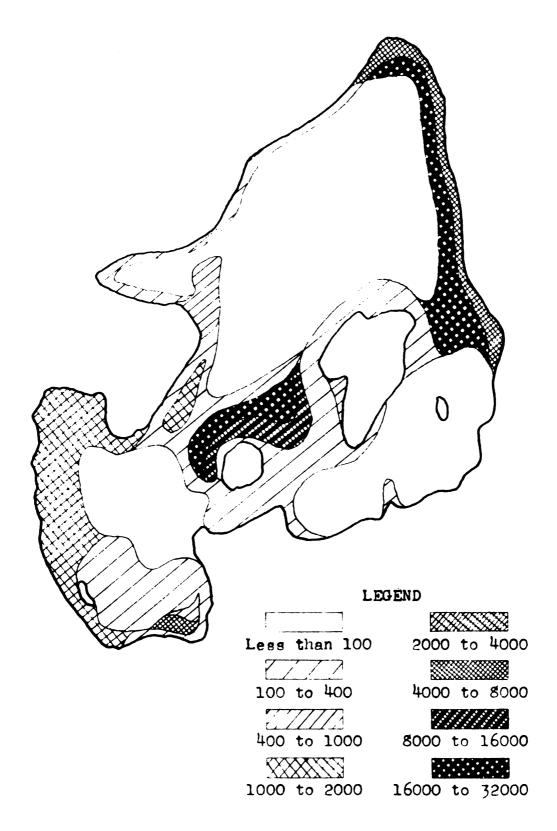


Fig. 12b. Map showing vegetation density in lbs. per A.

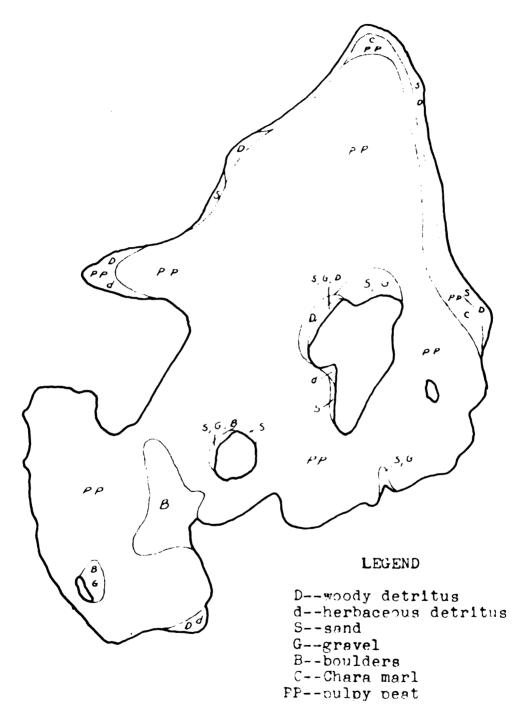


Fig. 12c. Map showing bottom types.

Table 11. Plants Occurring in Lake Twenty-two.

Carex Lasiocarpa

Chara spp.

Dulichium arundinaceum

Eleocharis palustris

Equisetum fluviatile

Eriocaulon septangulare

Myriophyllum heterophyllum

Nymphaea odorata

Potamogeton amplifolius

P. gramineus var.

P. g. var. graminifolius

f. myriophyllus

P. obtusifolius

P. pusillus

Sagittaria latifolia

Scirpus acutus

Sparganium eurycarpum

Typha latifolia

Sedge

Muskgrass; Stonewort

Three-way Sedge

Creeping Spike Rush

Horsetail; Scouring Rush

Pipewort

Water Milfoil

White Water Lily

Large-leaf Pondweed; Bass Weed

Variable Pondweed

Variable Pondweed

Pondweed

Pondweed

Duck Potato; Arrowhead

Hardstem Bulrush

Bur Reed

Common Cattail

		•	

Table 12. Total Weights and Percentage of Each Species by Zones

<u>Lake Twenty-two</u>

Chaoing	Zone	1.	Zone 2.		Zone 3.		Total	
Species	Weight kg.	%	Weight kg.	%	Weight kg.	%	Weight kg.	
Chara spp.	8,844	40.7	40,192	69.8	tr.		49,036	
Eleocharis palustris	138	0.6					138	
Equisetum fluviatile	316	1.5					316	
Eriocaulon septangulare	803	3.7					803	
Nymphaea odorata	5,412	24.8	tr.				5,412	
Potamogeton amplifolius	4,762	21.9	7,086	12.3	36,074	63.3	47,922	
P. gramineus war. gramini- folius f. myriophyllus	200	0.9	297	0.5			497	
P. obtusifolius	753	3.5	8,854	15.4	20,951	36.7	30,558	
P. pusillus			1,164	2.0			1,164	
Scirpus acutus	104	0.5					104	
Sparganium eurycarpum	418	1.9					418	
Total	21,750		57,593		57,025		136,368	
Percent of Grand Total in each zone	16.0		42 .2		41.8			

Table 13. Frequency of Occurrence and Relative Yield of Certain

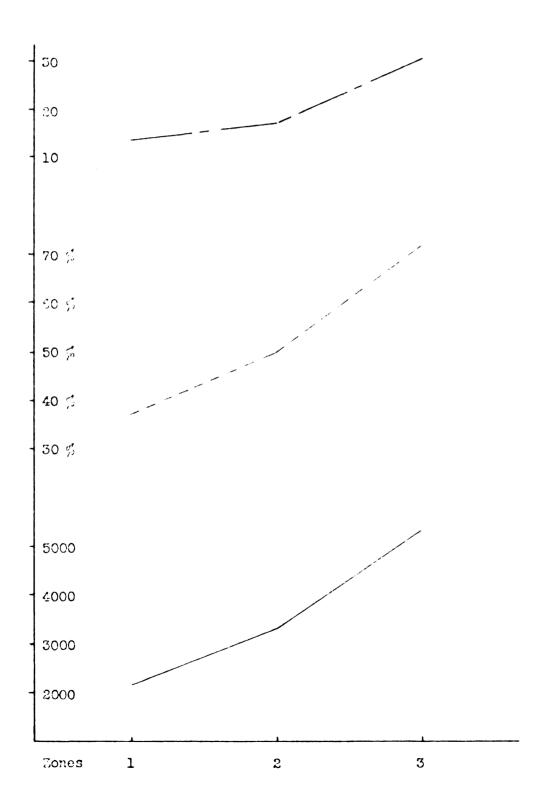
Plant Species on Different Bottom Types. Lake Twenty-two.

	Bottom Type								
Species	S	s,D	PP	PP,C	s,G				
Carex lasiocarpa	65*	3 5*							
Chara spp.	2*	6**		12** 80***					
Eleocharis palustris	87*	13*							
Equisetum fluviatile	80*	<u>1</u> 5*			5*				
Eriocaulon septangulare	66 * 30**	4*							
Nymphaea odorata			72* 18**						
Potamogeton amplifolius		2*	6* 12***	5** 75***					
P. gramineus var. gramin- ifolius f. myriophyllus		2*	7* 4**	87*					
P. obtusifolius			33* 67**						
P. pusillus			65* 35**						
Sagittaria latifolia	25*	75*							
Scirpus acutus	45* 22**	24 * 6**			3*				
Sparganium eurycarpum		85* 10**							
Typha latifolia	90*	10*							

¹ Bottom types: S--sand; D--detritus; G--gravel; PP--pulpy peat; C--chara marl.

For explanation of table, see Table 4.

Fig.1". Craphs showing average yield (kg./ hoct. ——), percentage organic matter (— ——), and nutrient content (————) by zones in Lake Twenty-tuo.



<u>Little Wolf Lake</u>: Located in sections 34 and 35 of Albert Township, Montmorency County, and sections 2 and 3 of Greenwood Township, Oscoda County.

This lake is unique in that it is composed of two basins, separated only by a narrow channel in which the water does not exceed a depth of 18 inches. The two basins differ widely, in that one is deep and contains little vegetation, while the other is shallower and rich in vegetation. The entire lake is 87 acres. Other information concerning the hydrographic aspect of the lake may be found in Fig. 16a.

A rapid lowering of the water level--a phenomenon which has attracted considerable attention in recent years--is an interesting feature of this lake, as well as of many others in the surrounding, level outwash plain. In Little Wolf Lake, boat-docks have been left high on the shore as the water receded. The outlet, which formerly flowed into Big Wolf Lake and several years ago was capable of accommodating a boat equipped with an out-board motor, no longer functions during any part of the year. The small bay at Transect K., formerly a favorite bass-fishing spot for the local sportsmen, is now dry and has grown up to marsh grasses.

Only two definite types of shorelines are present. A sand beach extends around nearly the entire lake. See Fig. 14. Exception occurs in the vicinity of Transect F, where a gravel pavement has been formed. See Fig. 15.

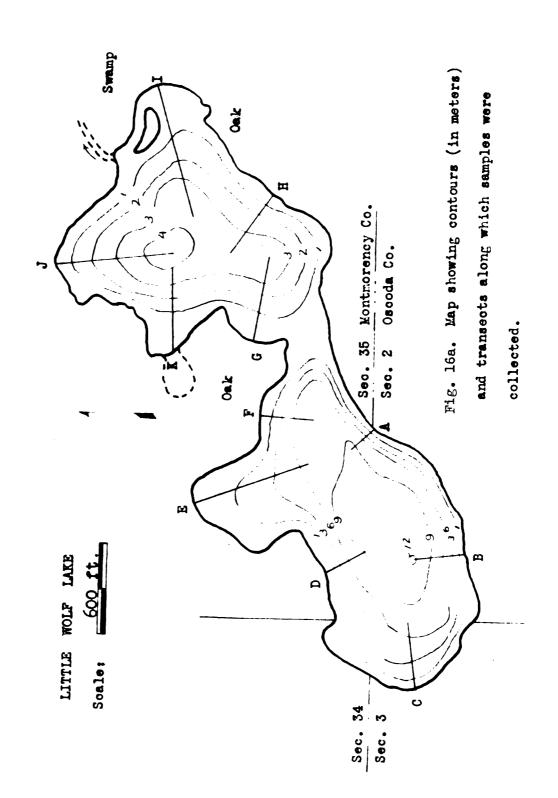
The data for this lake have been tabulated in figures and tables corresponding to those of the two lakes discussed previously.



Fig. 14. A wave-swept sand beach as found around nearly the entire lake.



Fig. 15. Gravel pavement situated in the vicinity of Transect F_{\bullet}



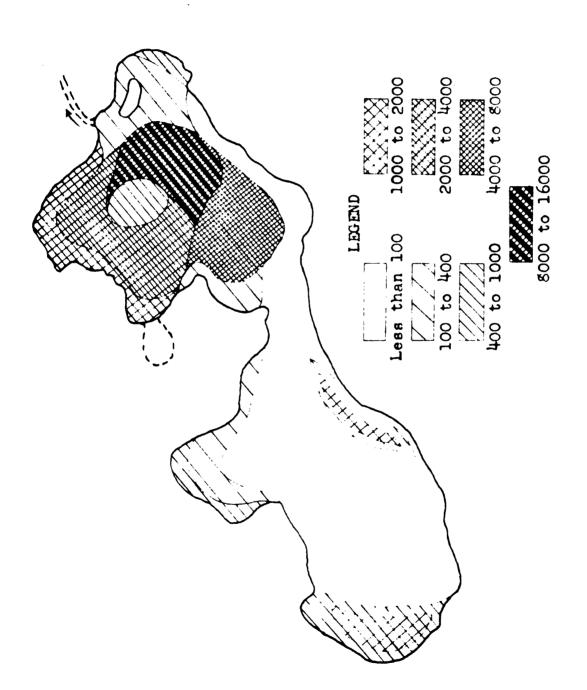


Fig. 16b. Map showing vegetation density in lbs. per A.

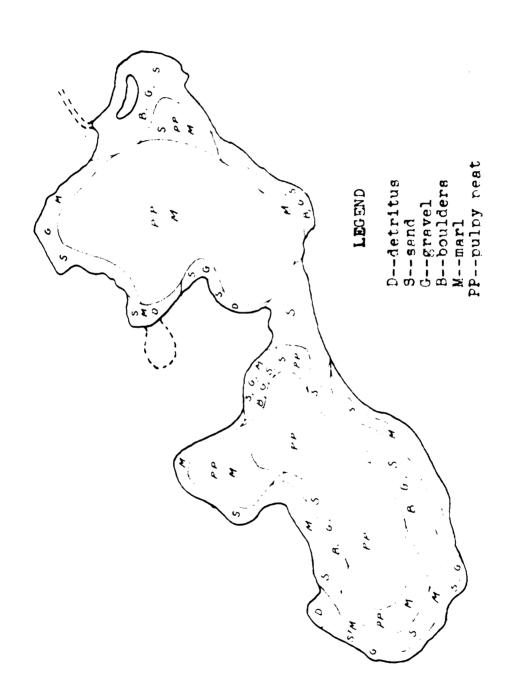


Fig. 16c. Map showing bottom types.

Table 14. Plants Occurring in Little Wolf Lake.

Chara spp. Muskgrass; Stonewort

Myriophyllum heterophyllum Water Milfoil

Naias flexilis Bushy Pondweed

Nuphar advena Yellow Water Lily

Nymphaea odorata White Water Lily

Potamogeton gramineus var. Variable Pondweed

P. praelongus "Mnitestem Pondweed

P. natans Floating-leaf Pondweed

Scirpus acutus Hardstem Bulrush

Table 15. Frequency of Occurrence and Relative Yield of Certain Plants on Different Bottom Types 1. Little Wolf Lake.

Bottom Type									
Species	s,M	s,G	s,G,M	S,B,G	S,PP	S,D	S,M,D	PP,M	
Chara spp.	16*	4*	16*	2*	2*	4*	11* 33**	4* 8**	
Myriophyllum heterophyllum							12*	65* 23**	
Nymphac a o dorata					54* 3 3** 13***				
Potamogeton praelongus					4**		6**	3** 87***	

¹ Bottom Types: S--sand, M--marl, G--gravel, B--boulders, PP--pulpy peat, D--detritus

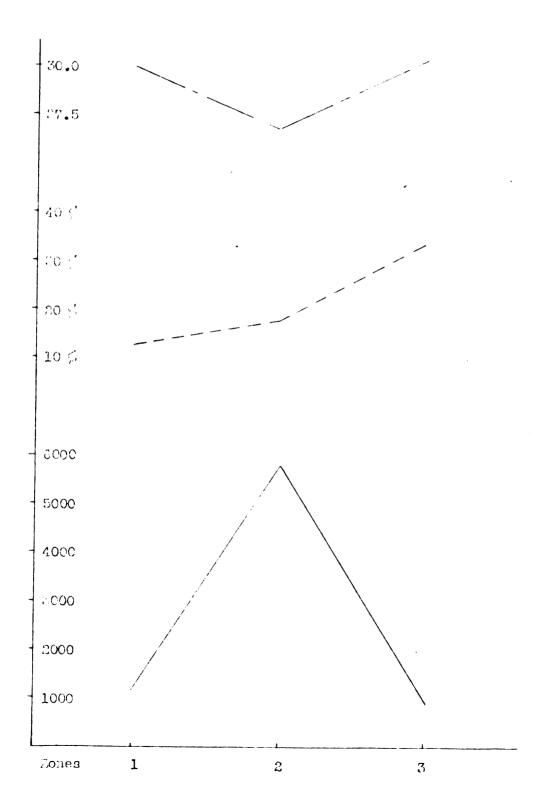
For explanation of table, see Table 4.

Table 16. Total Weights and Percentage of Each Species by Zones.

Little Wolf Lake

	Zone 1.		Zone 2.		Zone 3.		*
Species	Weight kg.	%	Weight kg.	%	Weight kg.	%	Total Weight kg.
Chara spp.	2,254	22.1	1,341	2.5	245	3.5	3,840
Myriophyllum heterophyllum	847	8.3	2,347	4.3			3,194
Naias flexilus	2,214	21.7	6,370	11.7	664	9.6	9,248
Nymphaea advena	3,862	37.7					3,862
Potamogeton praelongus	1,038	10.2	44,225	81.5	6,003	86.8	51,266
Total	10,215		54,283		6,912		71,410
Percent of Grand Total in each zone	14.3		76.0		9.7		

Fig. 1". Graphs chowing average yield (kg./hect.____),
percentage organic matter (_ _ _ _), and nutrient
content (_ _ _) by zones in Little Folf Lake.



Tee Lake: Sections 2, 3, 10, and 11 of Greenwood Township, Oscoda County.

This lake occupies a 210 acre basin in a relatively flat outwash plain area. Due to its peculiar shape, it has an unusually long shoreline as well as a wide variety of shoreline types. These vary from swampy margins to rather steep shores, and from extremely soft bottoms to gravel and boulder shorelines. As a consequence, the plant zone is very irregular and variable, resulting in a greater number and variety of plant species than any of the other lakes.

Due to the extent of the gradually sloping sand shoreline, a dense growth of sedges and bulrushes prevails. (See Figure 20.) As a result, this is the only lake in which Zone 1 produces a greater quantity of vegetation than do Zones 2 and 3. (See Table 18)

The data are presented in the same manner as are those of the other three lakes.



Fig. 18. A steep shoreline with coarse gravel bottom. Characteristic of entire east side of the main body of the lake.



Fig. 19. A swampy margin—at the north end of the lake.



Fig. 20. A gently sloping shoal with a zone of bulrushes and sedges. This type of margin characterizes the long narrow arm composing the southeast part of the lake.

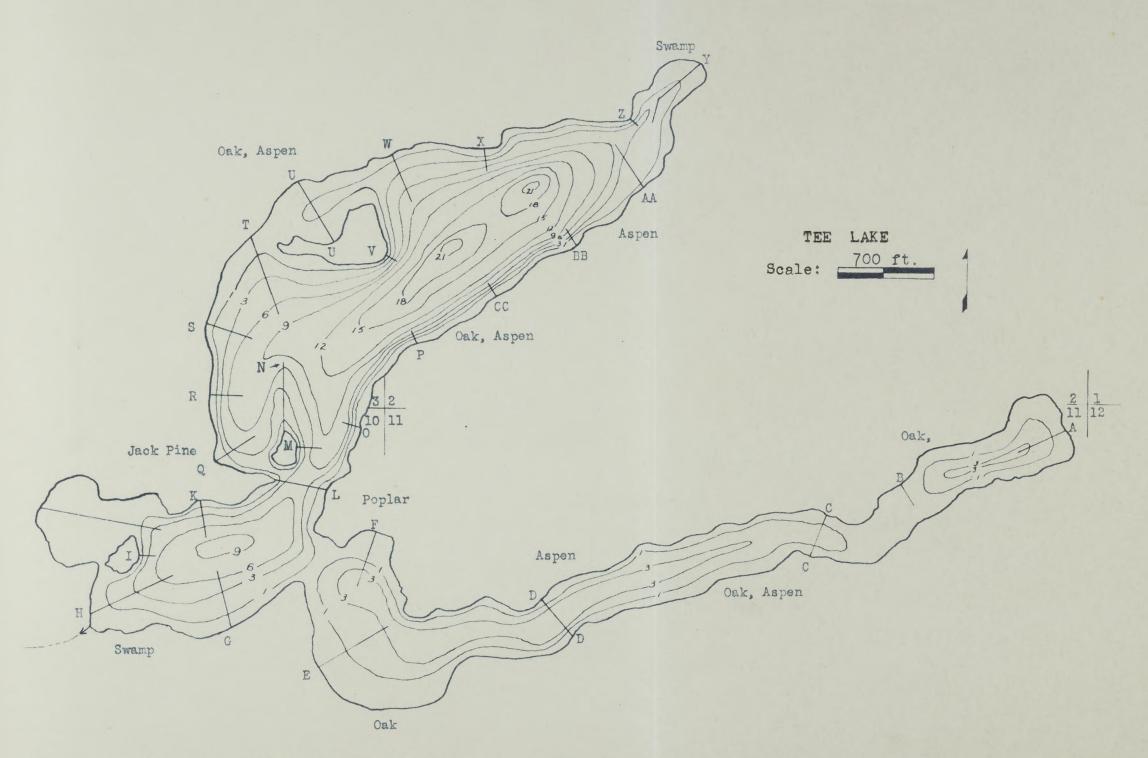


Fig. 21a. Map showing contours (in meters) and transects along which samples were collected.

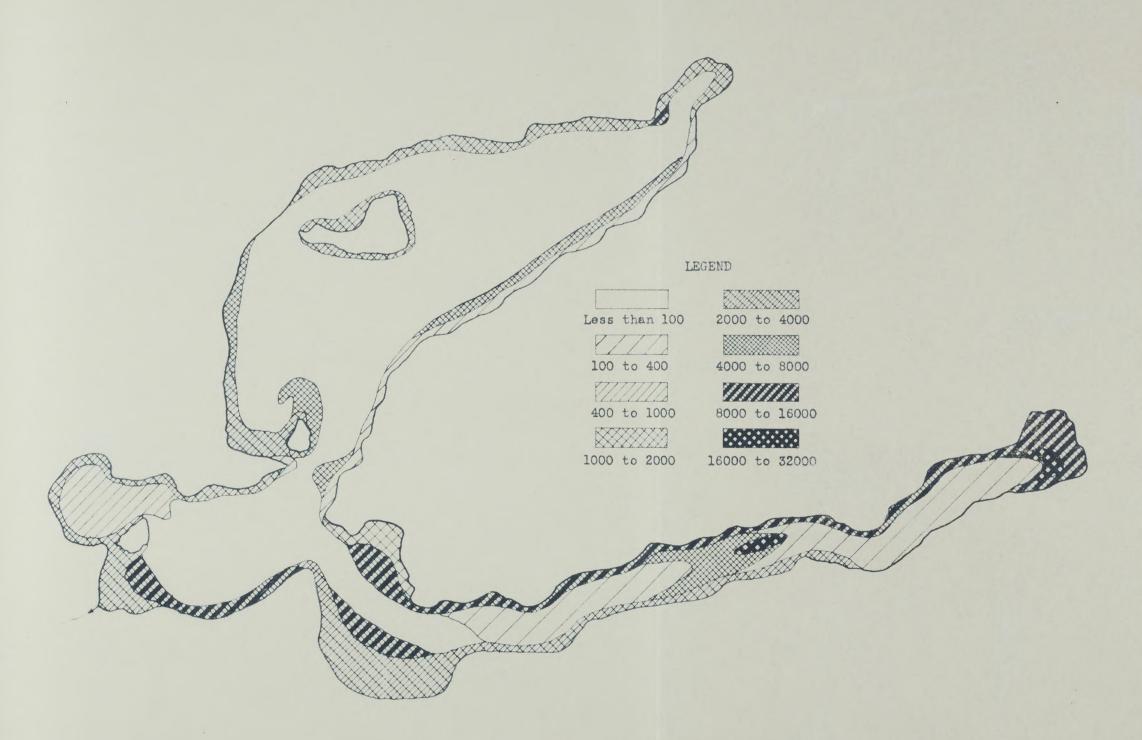


Fig. 21b. Map showing vegetation density in 1bs. per A.

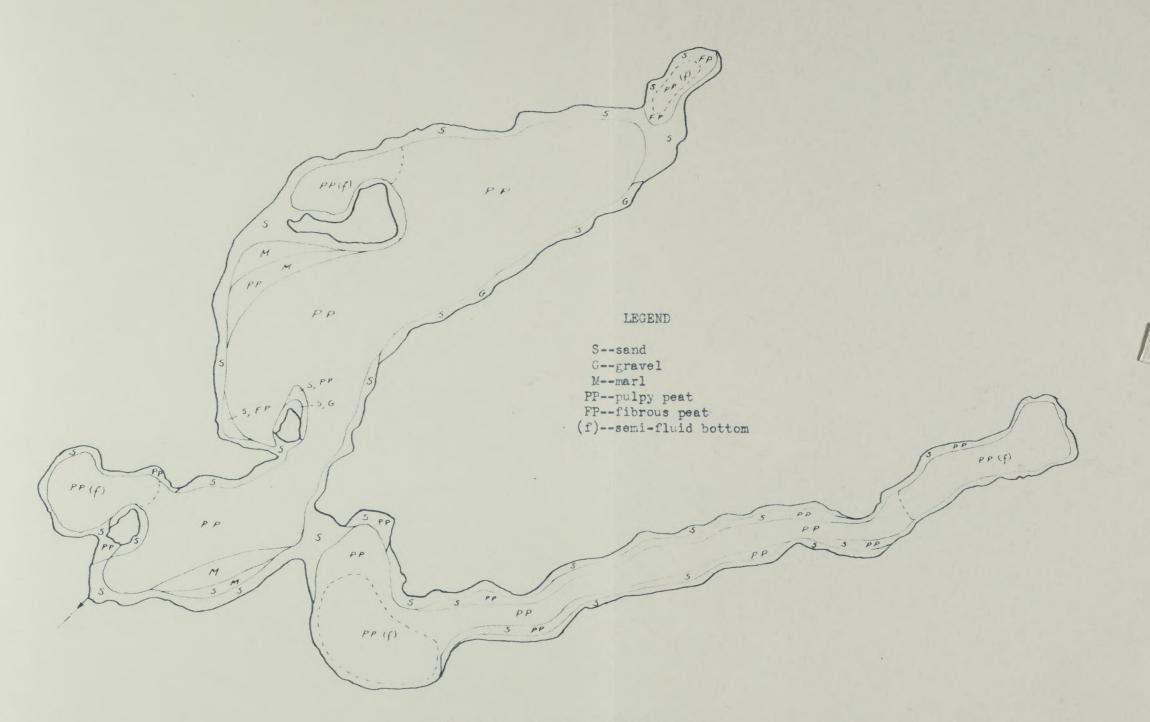


Fig. 21c. Map showing bottom types.

Table 17. Plants Occurring in Tee Lake.

Calla palustris Water Arum

Carex lasiocarpa Sedge
Carex Pseudo-Cyperus Sedge

Ceratophyllum demersum Coontail

Chara spp. Muskgrass; Stonewort

Cladium mariscoides Twig Rush

Dulichium arundinaceum Three-way Sedge

Eleocharis palustris Creeping Spike Rush

Equisetum fluviatile Horsetail; Scouring Rush

Eriocaulon septangulare Pipewort

Iris versicolor Blue Flag

Lemma minor

Myriophyllum heterophyllum

Water Milfoil

Naias flexilis

Bushy Pondweed

Nuphar advena Yellow Water Lily

Nymphaea odorata White Water Lily

Potamogeton amplifolius Large-leaf Pondweed; Bass Weed

Pondweed

P. angustifolius Pondweed

P. gramineus var. graminifolius f. longipedunculatus

P. g. g. f. myriophyllus Pondweed
P. g. g. f. terrestris Pondweed

P. natans Floating-leaf Pondweed

P. praelongus Whitestem Pondweed

P. pusillus Pondweed

P. zosteriformis Flat-stemmed Pondweed
Sagittaria latifolia Duck Potato; Arrowhead

Scirpus atrovirens Bulrush

Scirpus acutus Hardstem Bulrush

Sparganium minimum Bur Reed

Typha latifolia Common Cattail

Table 18. Total Weights and Percentage of Each Species by Zones. $\underline{ \text{Tee Lake} }$

	Zone	1.	Zone	2.	Zone	3.	
Species	Weight kg.	%	Weight kg.	%	Weight kg.	%	Total Weight kg.
Carex lasiocarpa	8,816	6.9					8,816
Chara spp.	549	0.4	77	0.1	192	7.1	818
Cladium mariscodies	14,952	11.6					14,952
Dulichium arundinaceum	275	0.2					275
Eleocharis palustris	4,090	3.2					4,090
Eriocaulon septangulare	10,708	8.3					10,708
Naias flexilus	13,207	10.3	13,845	11.0			27,052
Nuphar advena	4, 696	3.8					4,696
Nymphaea odorata	3,968	3.1					3,968
Potamogeton amplifolius	2,069	1.6	63,420	50.3		!	65,489
P. angustifolius	774	0.6	574	0.5			1,348
P. gramineus var. gramini- folius f. myriophyllus	1,274	1.0	54				1,328
P. natans	22,077	17.3	905	0.7			22,982
P. praelongus	10,945	8.5	45,362	35.9	800	29.3	57,107
P. pusillus	155	0.1	1,641	1.3	1,735	63.6	3,531
P. zosteriformis	51		314	0.2			365
Scirpus acutus	27,014	21.0					27,014
Typha latifolia	2,730	2.1					2,730
Totals	128,350		126,192		2,727		257,269
Percent of Grand Total in each zone	49.9		49.1		1.0		

Table 19. Frequency of Occurrence and Relative Yield of Certain Plants on Different Bottom Types. Tee Lake.

		Bottom	n Types	
Species	S	PP	S,G	S,PP
Carex lasiocarpa	20* 25**		5*	15* 35**
Chara spp.	48*		8*	44*
Cladium mariscoides	12* 54***		4*	30*
Eleocharis palustris	75 * 10 * *	·		12* 3**
Equisetum fluviatile	75*		8*	17*
Eriocaulon septangulare	67* 25**		4*	4*
Naias flexilis	18*	22* 48** 8***		4**
Nuphar ad v ena		87* 13**		
Nymphaea odorata		65* 22**		13*
Potamogeton amplifolius	2*	25* 33** 40***		
P. angustifolius	2*	95*		3*
P. gramineus var. gramini- folius f. myriophyllus		13*		87*
P. natans	8* 4**	20* 22** 40***		
P. praelongus	4*	15* 56** 21***		4*
P. pusillus		17* 33** 50***		
P. zosteriformis			·	95* 5**
Scirpus acutus	17* 43** 25***		2* 13**	

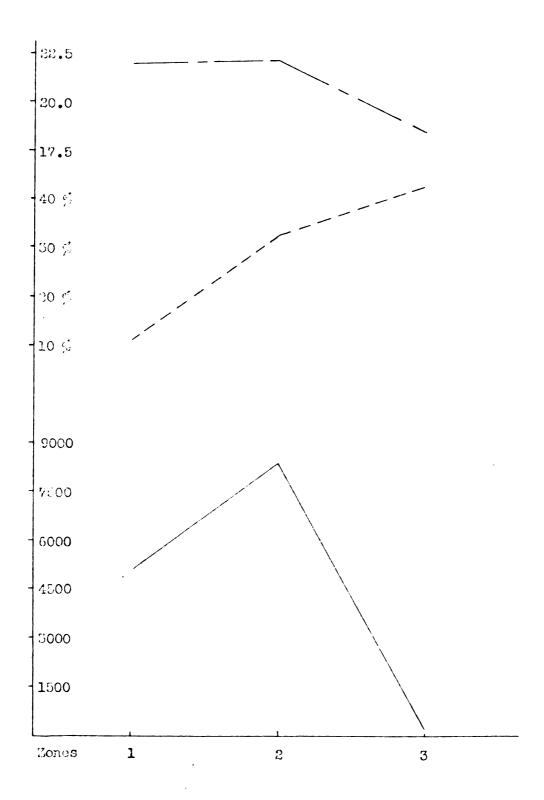
¹ Bottom types: S--sand; PP--pulpy peat; G--gravel.

For explanation of table, see Table 4.

Fig. 12. Craphs showing average yield (kg./hect. ____),

percentage organic matter (- - -), and nutrient

content (_____) by zones in Tee Lake.



DISCUSSION

In addition to the presentation of the quantitative data, a discussion of some important ecological problems is warranted. These problems are reviewed in the light of, and with constant reference to, the data already presented.

Bottom Fertility:

Before a discussion of fertility is undertaken, the term requires definition. The common definition is—the ability of a soil to produce vegetation, if seeded. Hence, the more vegetation a soil produces, the more fertile is the soil. In other words, soil fertility can only be measured in terms of its productivity. Fertility, then, embodies all of the factors responsible for plant growth.

Fertility in lake soils, when considered from this viewpoint, becomes extremely complicated. There is no way to measure total fertility except by determining the plant yield, since fertility implies plant production. In such event, there must be a direct correlation between fertility and plant yield.

In this study, the term "fertility" is used in a restricted sense. The phase of fertility studied was the nutrient content of the soils. As described previously, this included a determination of the supply, in readily soluble form, of four elements, namely, phosphorus, potassium, calcium, and iron. It was assumed that these are the most important nutrients, and that if a correlation existed between nutrient content and plant production, it would be revealed

by this method. Further studies may show that other elements are important. Perhaps the minor soil elements such as boron, copper, zinc, and manganese have an active role in lake soil fertility. Pond (6) concludes, from a study of six aquatic plant species, that "the primary cause of the retarded growth of anchored plants is their inability to secure enough phosphorus and potassium, and possibly other elements".

Due to the quantity of data accumulated in this study, it became necessary to apply statistical methods. In order to do this, some means of expressing the nutrient content by a single figure had to be devised. This has been described previously. The validity of the method is subject to question. All the elements were given equal weight or importance. This was done because our knowledge of the physiology of aquatic plants has not progressed sufficiently so that we are able to say that one element is more important than any other.

Another question which might arise in this connection is, "Does an increased nutrient content necessarily result in increased fertility?" It is possible that an increase of a given element beyond a certain point might prove toxic rather than beneficial. But in the soils tested, it is not likely that any element has been toxic. It is possible, however, that the depressing effect of the high calcium content, in Lake Fifteen, on the solubility of the other nutrients has resulted in a much lower nutrient content figure than would otherwise be the case.

The chief objection to the method is that the figure itself gives no information regarding the individual constituents. Table 20 shows the mean nutrient content by zones, as well as the individual constituents. The table bears out the truth of the opening statement of the paragraph.

Still another weakness is the fact that the figures from one lake can not be compared with those of another. For example, all of the nutrient content figures for Lake Fifteen are higher than those of the first two zones of Lake Twentytwo, and yet in the writer's opinion, the soils in Lake Twenty-two are better from the standpoint of nutrient content because they have enough calcium to supply the plants' needs, and they have a higher content of the other three elements. However, when considering one lake at a time, or comparing values within a single lake, the method is difficult to improve upon since, in every case, a higher figure means better conditions for plant growth from the standpoint of nutrient content. It is the writer's belief that this system, or any system embracing tests for several elements, can not be applied in comparing different lakes because, as this study points out, lakes vary widely in total nutrient content from one another while soils within a given lake tend to vary much less markedly. See Table 20.

An attempt was also made to determine whether or not the test for any single element might prove to be an index of the nutrient content. An examination of the data indicated that if such an index existed, it would be the phosphorus

Table 20. Individual Constituents of Nutrient Content*.

Lake	Zone	Phosphorus ppm.	Potassium ppm.	Calcium ppm.	Iron ppm.	Nutrient Content
L. Fifteen	1	.14	1.1	200	0.0	24.5
	2	•46	1.1	200	0.0	24.7
	3	.80	3.4	200	0.0	29.8
L. Twenty-two	1	•74	4.6	17.3	1.95	13.2
	2	•85	4.4	47.7	1.77	16.9
	3	1.80	11.0	58.0	3.00	32.7
Little Wolf L.	1	•18	9.4	188.0	0.65	30.0
	2	•04	6.5	200	0.0	26.8
	3	•18	10.7	182.0	0.71	30.7
Tee L.	1	1.00	4.9	25.2	12.33	21.6
	2	.72	5.2	39 .9	13.57	21.7
	3	•59	4.6	27.5	14.00	19.0

^{*} See text for determination of nutrient content figure.

determination. Table 21 shows the correlation coefficients between phosphorus and nutrient content. While a significant correlation exists in the majority of cases, it is not likely that phosphorus could be used as an index. The difficulty again is that, while there is a correlation within a single lake, a phosphorus content of a given amount in one lake does not mean that the same amount in another lake has the same corresponding value. For example, in Table 20, a phosphorus content of .46 ppm. in Zone 2 of Lake Fifteen has a corresponding nutrient content value of 24.7, while in Zone 2 of Little Wolf Lake, a phosphorus reading of .04 ppm. has a corresponding nutrient content of 26.8. On the other hand, there seems to be a relationship between the readings or measurements within a single lake. However, a large number of measurements would have to be taken in order to determine whether or not, for a given lake, phosphorus could be used as an index. Hence, it would be advisable to assume that it could not be used, and to proceed with the more complete examination as used in this study.

Organic Matter Content:

Organic matter in a lake bottom is extremely important from the standpoint of carbon dioxide production. Brown (3) believes that the plants, by being rooted, show greater growth chiefly because they are held closer to the supply of carbon dioxide and can utilize it before it is taken out of solution by algae, marl precipitation, etc. Bourn (2) takes a median position between Pond and Brown by concluding that

Table 21. *Correlation coefficients between nutrient content and yield (N.C.--Y.), phosphorus content and yield (P.--Y.), organic matter and yield (O.M.--Y.), phosphorus content and nutrient content (P.--N.C.), and organic matter and nutrient content (O.M.--N.C.).

Lake	Zone	M.CY.	PY.	O.MY.	PN.C.	0.MN.C.
Lake Fifteen	ı	.371**	.315**	•978	•742	•675
	2	.572	•499	•789	•781	•640
	3	•500	•644	•389**	•546	None
Lake Twenty-two	1	•738	•699	None	. 859	None
	2	.725	•705	None	•913	None
	3	•693	•569	•48 0**	.814	None
Little Wolf Lake	1	None	None	•449**	None	None
	2	None	***	•609	***	None
	3	None	***	•58 0	***	None
Tee Lake	ı	None	None	None	•580	None
	2	None	None	.694	None	None
	3	None	None	None	None	None

^{*} The correlation coefficients are based on the averages from measurements in each transect in each zone. Each average represents from 3 to 5 measurements.

^{**} Correlation coefficients not statistically significant.

^{***} Not sufficient data for statistical analysis.

"while a deficiency of carbon dioxide is found to be an important factor limiting the growth of aquatic plants, --a constant supply of carbon dioxide does not eliminate the difference between plants rooted in soil and those merely anchored in solutions".

peroxide method. While this method is considered unsatisfactory in agricultural soils work because it does not determine total organic matter but rather, the more easily decomposed organic matter, it is believed to be entirely satisfactory for use on lake soils. Since bacteria in a lake are concentrated at the bottom soil-water interface, and since organic matter is constantly accumulating, only the more easily decomposed organic matter is in a position to be decomposed. Hence a better picture of what might be termed the "effective organic matter"-- that available for carbon dioxide production--is obtained by the hydrogen peroxide method than by methods which give total organic matter.

Organic matter not only functions as a source of carbon dioxide, but also as a source of nutrients. Statistical analyses, however, do not show a significant correlation coefficient between organic matter and nutrient content, except in Zones 1 and 2 of Lake Fifteen. The reason for the correlation here is probably due to the fact that an accumulation of organic matter reduces the effect of the calcium ion in rendering the other elements unavailable. In other words, in a mixture of marl and organic matter, the nutrients are avail-

able from the organic matter whereas in the marl they are present in a relatively insoluble form. No reason for the lack of a significant correlation in the other lakes can be offered at present.

The Ecology of Aquatic Plants:

The study of plant distribution in lakes has received some attention in this country and in Europe. Our knowledge of the factors involved, however, is far from being complete. Any study along this line adds to the fund of general information and perhaps aids in correlating the results of the scattered workers.

The present study dealt with plant distribution in relation to depth, bottom, type, bottom fertility, and organic matter content of the bottom.

Figure 23 summarizes the distribution of plants in the four lakes with regard to depth. The total weights, as given in this figure, do not reflect the actual productivity of the bottom since the zones vary in size. When considered on a yield per unit area basis, the result is quite different.

Figure 24 shows the average yield by zones, in the four lakes. Here it will be noted that in three of the lakes, Zone 2 is the most productive. There is also a wide variation between lakes. This variation is probably exaggerated, however, due to the fact that nearly all of the plants in Lake Fifteen were coated with a fine marl or lime deposit which could not be washed off; consequently, the weights of these samples were affected considerably. Hence, Lake Fifteen is

Fig. 2.. Total weights and percentage of vegetation in each zone. From tables 3, 6, 10, 8 13.

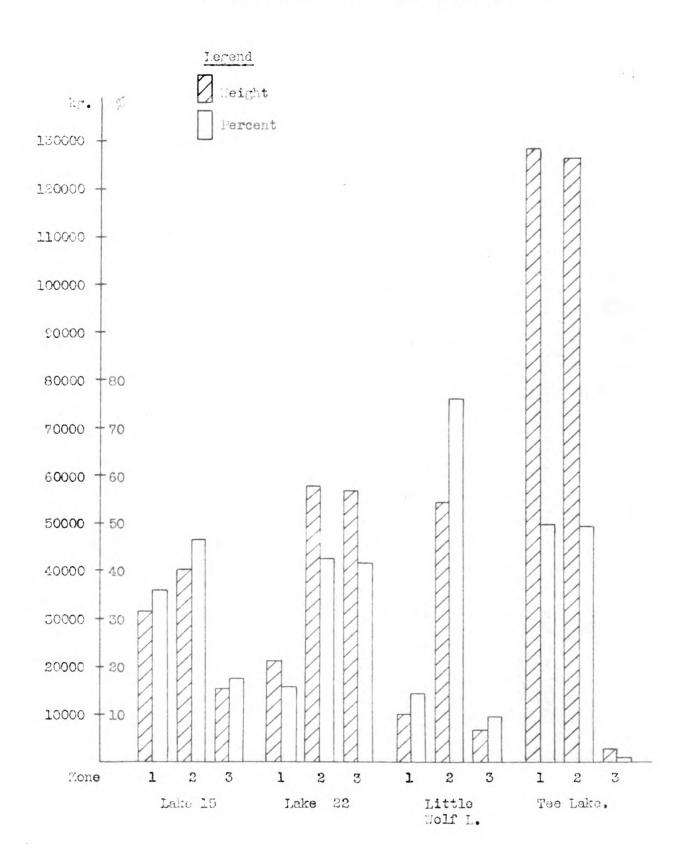
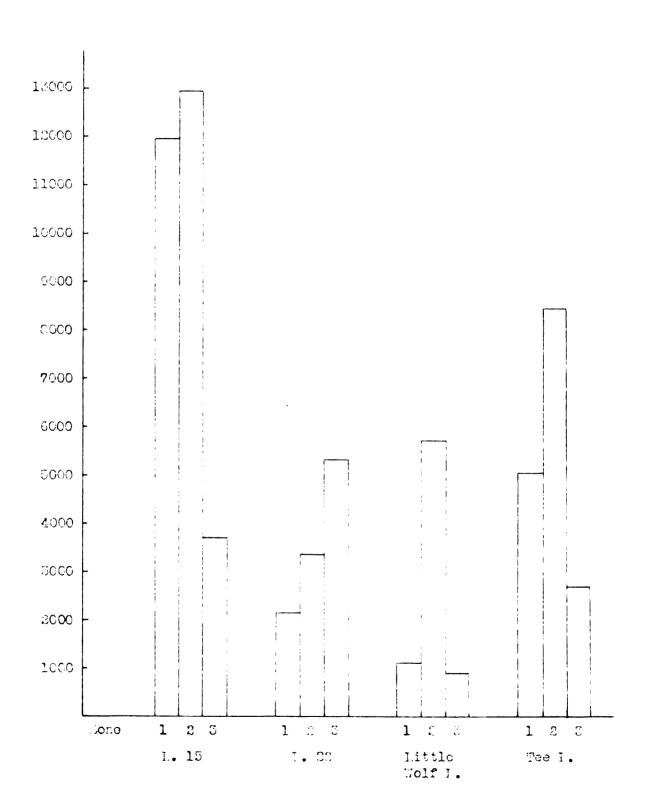


Fig. 7. Average field of plants for tack zero in the four lakes. Stated in km./ hectare.



not as productive as the graphs indicate, but it is undoubtedly more productive than any of the other lakes.

It is interesting to note that Lake Fifteen produces the smallest crop, and yet, on the basis of yield per unit area, is the most productive. The reason, of course, is that the plant zone is relatively small but the vegetation is dense where it is able to grow.

In Lake Twenty-two, a very productive Zone 3 is found. The shape of the basin is believed to be largely responsible. A gradually sloping bottom is found around a good share of the lake; this is usually accompanied by greater growth in deeper waters. This phenomenon undoubtedly is an important factor in determining the total productivity of a lake.

Table 21 shows the results of a statistical analysis pertaining to yield as influenced or related to the nutrient content and organic matter content of the bottom. In Lake Fifteen there is not a significant correlation in Zone 1 between nutrient content and yield, while there is in Zones 2 and 3. Wave action, which is severe in this lake, is likely responsible for inhibiting vegetative growth in Zone 1. Wherever organic matter has an opportunity to accumulate, however, vegetation gets a "foot-hold" and grows well. In Zone 3, of course, the organic matter content is high and rather uniform so a significant correlation does not exist.

In Lake Twenty-two, there is a good correlation between nutrient content and yield, whereas there is not between organic matter and yield, chiefly because the organic matter content is rather uniformly high. In Little Wolf Lake, however, where there is a lower average organic matter content, there is a correlation between the organic matter and plant yield.

prom a consideration of the data presented, it can be pointed out again that the distribution of vegetation is the result of the interplay of many factors. Physical factors are, in the opinion of the writer, of primary importance.

Wave action, where it is extreme, prevents plants from growing abundantly, in spite of the possible available nutrients. Deeper water generally means a more fertile bottom, from the standpoint of nutrient content. But again, light penetration and perhaps temperature inhibit plant growth. The consistency of the bottom is important from the standpoint of the rooting ability of the aquatics. Organic matter content, considered both physically and chemically, is important, and determines the nature and quantity of plant growth under certain conditions.

In a lake with a sand or marl bottom, such as is found in Little Wolf Lake and Lake Fifteen, respectively, an addition or accumulation of organic matter in a region of suitable depth has a very noticeable effect on plant growth. This is undoubtedly due to a change in consistency of the bottom, the production of carbon dioxide, and the release of plant nutrients.

On the other hand, if the organic matter reaches a certain limit, it seems that the further addition of organic

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matter has little or no effect. This explains why, in Lake Twenty-two, there is no correlation between organic matter and plant yield.

This same principle seems to apply in relation to nutrients. A deficiency of any one nutrient may retard plant growth, but addition or presence of a small amount of the same nutrient will give a substantial increase. Addition beyond a given point will have no effect, until so much has been added that toxicity results. Referring back to the Rose Lake plots, the addition of 500 pounds per acre of phosphorus fertilizer yielded excellent growth; the addition of 2000 pounds per acre yielded no better. This proves a phosphorus deficiency, which was previously indicated by chemical tests, and its remedy by the addition of phosphorus.

Another phase of the ecology of aquatic plants is the relation between various species of plants and their growth on different bottom types. Tables have been presented for each lake to show the distribution of vegetation with respect to bottom type, and also with respect to depth of water. It may be pointed out that for most plants, there is one, or possibly two, bottom types on which the plant is found most frequently and in the greatest abundance. The same is true for depth—the majority of plant species tend to be concentrated in one depth zone.

An examination of separate items reveals some interesting facts which are obscured in condensed and summarized data. It is found that a given type of bottom, which a plant

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occupies most frequently, is generally situated or located at the depth at which the given plant usually grows. This brings up the question, then, "Does the plant 'prefer' that type of bottom, or does that bottom just happen to occur at the depth which the plant 'prefers'"?

This question has received attention in the past. Lakes in England have been studied by Pearsall (5) and Misra (4). They have both pointed out the different kinds of vegetation associated with different bottom soils, and have worked out plant successions beginning from rock bottoms and continuing through the dominantly organic bottoms. In their discussion of plant succession, the general trend is to consider succession the result of chemical and physical changes in the bottom. This is undoubtedly the case, but it seems that too much emphasis has been placed on the chemical nature of the bottom, and not enough/the physical nature of the bottom or the other components of the water soil profile as proposed by Veatch (10), chiefly the nature of the aqueous horizon. This horizon constitutes a major part in the environment of aquatic plants; the lake bottom--accumulative horizon--serves, in some cases, merely for anchorage. The parent material -- the original lake bottom--functions in plant distribution only when the accumulative layer is absent or very thin, so that roots penetrate through it to the parent material.

While most of the work is being done on the lake bottoms, the above conception of the soil profile must not be neglected because the chemical and physical nature of the water above

the bottom are equally as important, in the ecology of aquatic plants, as is the type of bottom.

of Michigan which are as primitive as some of the lakes studied in England by Pearsall and Misra. There are few lakes, for instance, whose bottom is 70 percent rocky to a depth of thirty feet. In the lakes studied, however, almost all conceivable bottom types are represented, ranging from a clean sand or marl to those which are highly organic and semi-fluid in consistency.

As pointed out above, most plants are found more frequently on a given type of bottom than on others. But, it seems that plant distribution is affected more by physical factors than by those that are chemical, since a careful study of the data from the four lakes fails to show any indication of a consistent "preference" on the part of any plant with regard to the chemical nature of the bottom as determined by the method used. The writer's inference is that physical factors, wave action in particular. determine to a large extent the distribution of bottom types in the portion of the lake in which vegetation can be produced. The bottom types, then, together with the active physical forces, determine the distribution of the vegetation. Under conditions of extreme wave action, this force plays a more active role in plant distribution than does the type of bottom; under such conditions, a wide variety of bottom types will not be formed, except as the parent material varies. When conditions with respect to wave action are less pronounced and temperature,

depth, and light penetration are adequate, the character of the bottom type occupies the determinant role in plant distribution. Factors involved here are: nutrient content, when one or more plant food elements approach the point where they are either deficient or toxic; consistency of the bottom, determining the penetrability by roots; and organic matter content of the bottom, which affects the consistency and the nutrient content as well as the production of available carbon dioxide.

Relative productivity of the four lakes:

As pointed out by Welch (11), an adequate index of productivity has not been determined. Total vegetation was considered but did not prove satisfactory. Perhaps, however, a consideration of the yield per acre, figuring the entire lake, together with the percent of the lake which produces vegetation, would give a fair index to the productivity.

The following table summarizes the information suggested above:

adove:	L. 15	L.22	Wolf L.	Tee L.
Area (acres)	88	109	87	210
% productive bottom	31	48	54	52
Yield/acre of lake (lbs)	1,220	2,750	1,780	2,695
* Shoreline development	1.4	2.0	1.75	3.4

^{*} The shoreline development is the ratio between the circumference of the lake and the circumference of a circle having the same area as that of the lake. This measurement is considered to be of value because it indicates the relative amount of shoreline and shallow water, which is important biologically.

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From these data it might be concluded that Tee Lake and Lake Twenty-two would be the most productive. Little Wolf Lake has a higher percentage of the bottom producing vegetation but the average yield is lower and the shoreline development is less. Lake Fifteen would be considered the least productive, in spite of its being most productive on the basis of the average yield of the vegetation zone. (Fig. 24)

On the basis of shoreline development, Tee Lake would probably rank higher than Lake Twenty-two.

Productivity as indicated by fish growth studies:

Productivity, to the fisheries biologist, is naturally measured by the production of fish. Hence, an attempt was made to determine the growth rate of the fish in the four lakes. Unfortunately, large enough samples of fish could not be taken in the fall of the year to make a satisfactory study. However, the data obtained will be presented since they at least may be indicative of the actual condition in the lake. See Table 22.

Indications are that the perch in Lake Twenty-two are growing much faster than are those in any other lake. The data on bluegills is rather scant but it is interesting to note the difference in growth between the two basins of Little Wolf Lake. Although only one specimen was taken from any age group in the north basin, there were no specimens from the corresponding groups in the south basin which reached the length of the north basin specimen. If this

condition exists generally, it reveals a contrast undoubtedly brought about by the difference in the two basins, since the north basin is shallow and rich in vegetation while the south basin is deep and contains little vegetation. It is doubtful that migration occurs through the shallow channel between the two basins.

More work on the comparison of the fish production in these four lakes would prove extremely interesting and valuable. It would be an opportunity to learn whether or not there is a direct relationship between the amount or extent of the vegetation and fish production. The data presented here may be indicative, and do agree for the most part with the popular viewpoint, which is often fairly accurate. Lake Twenty-two is considered by far the best perch-fishing lake in the vicinity; Tee Lake is a popular bass and bluegill lake, and sizable catches are reported; Little Wolf Lake is fairly popular for its bluegills; Lake Fifteen attracts fewer anglers than do the others and the catches are reported to be very small.

Total Lengths of Fish From the Four Lakes. (Stated in millimeters) Table 22.

		Age	Group (Years)	rs)			
Lake & Species	ı	II	III	ΔI	Δ	VI	VII
Lake Fifteen							
Perch			155 (1)				
Lake Twenty-two							
Perch (males)	154.2 (6)	172.0 (7)	,			278.0 (3)	
(females)	160 (1)				283.2(9)	290.8(10)	294.3 (3)
Bluegill	106.0 (3)	147.5 (2)					
Little Wolf Lake							
Perch	91 (1)	153 (1)	163 (1)				
North Basin							
Bluegill		129 (1)		177 (1)		205 (1)	
South Basin							
Bluegill	68.3 (13)	95.5 (2)	128.7 (3)	145.7 (7)			
Tce Lake							
Perch		163,5 (24)	175.0(43)	180.6(14)	182,5(2)		
Bluegill	72 (1)						

Figures in parentheses indicate the number of specimens which the average represents.

SUMMARY

A study has been made of water soils in relation to the productivity of lakes. Reconnaissance studies were first made on bottom soils from lakes throughout the state. Pot tests were made to determine the effect of fertilizing materials on plant growth; these were followed by similar tests on plots at Rose Lake. The final phase of the investigation consisted of a comprehensive study of the soils and vegetation of four lakes in the northern part of the Lower Peninsula.

Conclusions reached as a result of the work are:

- 1. As shown by the Rose Lake plots, definite nutrient deficiencies may occur in lake soils, and these deficiencies can be remedied by the addition of fertilizer. Modification of the method of application would probably be necessary for lake improvement work.
- 2. The greenhouse tests show that the addition of fertilizing materials, in some cases, favors the growth of algae to such an extent that they interfere with the growth of the higher plants. It is doubtful that the problem would be as acute in lake work as it is in the greenhouse, but there would be competition for nutrients between algae and the higher aquatics.
- 3. The study of four lakes shows a variety of conditions and an attempt has been made to interpret or understand the importance of various factors and their effect on lake productivity.

- 4. On the basis of the fertility tests, it is found that the average nutrient content of the bottom soils varies considerably between different lakes, and that the method used can not be safely applied in comparing different lakes but is quite satisfactory in evaluating the comparative fertility of the soil samples from the same lake.
- 5. There seems to be no single test which will serve as a satisfactory index to the nutrient content of the bottom soils.
- 6. Lakes vary in plant distribution; Zone 2 is generally the most productive of vegetation, however.
- 7. Plant distribution is governed largely by physical factors, including shape of the basin, wave action, light penetration, and consistency of the bottom. Under conditions of low nutrient content or low organic matter content, there is a direct relationship between these factors and plant yield, but when there is a relatively high organic matter content and nutrients are available in sufficient quantities, changes in these two factors do not result in corresponding changes in plant yield.
- 8. Bottom type distribution is determined to a great extent by wave action; the character of the bottom, together with the other active physical forces, then control the plant distribution. The extent to which the bottom type or other factors influence plant distribution varies locally.
- 9. Although there is no satisfactory index of productivity in lakes, from the standpoint of the fisheries biologist,

indications are that a consideration of the shoreline development; the percent of the bottom producing vegetation; and the average yield of vegetation, considering the entire lake, will give a fair index to the productivity.

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