A QUALITATIVE SURVEY OF THE INVERTEBRATE BENTHOS OF WINTERGREEN LAKE, KALAMAZOO COUNTY, MICHIGAN

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Thomas F. Mitchell

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ABSTRACT

A QUALITATIVE SURVEY OF THE INVERTEBRATE BENTHOS OF WINTERGREEN LAKE, KALAMAZOO COUNTY, MICHIGAN

by Thomas F. Mitchell

During the summer of 1960, selected bottom areas in Wintergreen Lake on the W. K. Kellogg Bird Sanctuary, Hickory Corners, Michigan, were sampled for benthic invertebrates.

The morphometry, bottom deposits, aquatic vegetation, and water chemistries indicated that the lake was eutrophic. The lake was small (39 acres) and shallow (Figure 1). Bottom deposits were predominantly marl, organic ooze, and a marl-organic mixture. Aquatic vegetation was widespread and abundant, covering perhaps as much as 80 per cent of the basin. Phenolphthalein alkalinity was usually present in the shallower areas and the pH was usually above 9. Droppings from waterfowl which utilized the lake presumably contributed to its eutrophication.

A total of 168 genera were collected and identified. Of these, 81 were determined to species. The greatest diversity occurred in the Protozoa with 50 genera (13 identified to species), the Rotifera with 26 genera (11 identified to species), and the Tendipedidae with 15 genera (9 identified to species).

The Gastropoda and Pelecypoda were poorly represented. Heavy predation by waterfowl and possible toxic effects from waterfowl excreta were credited with reducing the fauna of snails and clams.

The vast majority of invertebrates were collected between the shore and the 11 foot depth.

The Protozoa, Rotifera, Oligochaeta, Turbellaria, Hirudinea, and Tendipedidae were qualitatively most diverse in stagnant situations. The Ostracoda, Gastrotricha, Amphipoda, Hydracarina, and Gastropoda were evenly distributed qualitatively.

A substrate composed of sand overlaid with detritus supported the largest number of species.

A gradient of increasing species diversity to the 11 foot depth was observed. Beyond this depth, there was an abrupt drop in diversity; only two species of Chaoborus predominated in the anoxic, severely polluted 21 foot deep hole in the north end of the lake. The unusual tolerance of these species is discussed.

A comparison of protected versus unprotected microhabitats showed no great difference in total species supported when protozoans were not considered. The modifying effects of vegetation and bottom substrate at the unprotected station seemed to explain this equality. Species composition at each station was different, however.

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I. INTRODUCTION

Wintergreen Lake represents an unusual type of habitat. Its waters contain large amounts of organic matter deposited by thousands of migratory waterfowl and by the permanent flocks which reside in the surrounding bird sanctuary.

The prime concern of this investigation was to qualitatively survey the benthic invertebrates found in the lake during the summer of 1960. An effort was also made to discover distribution patterns of the major groups of invertebrates within the lake, and to evaluate the factors which possibly influenced such patterns.

II. HISTORY AND DESCRIPTION OF WINTERGREEN LAKE

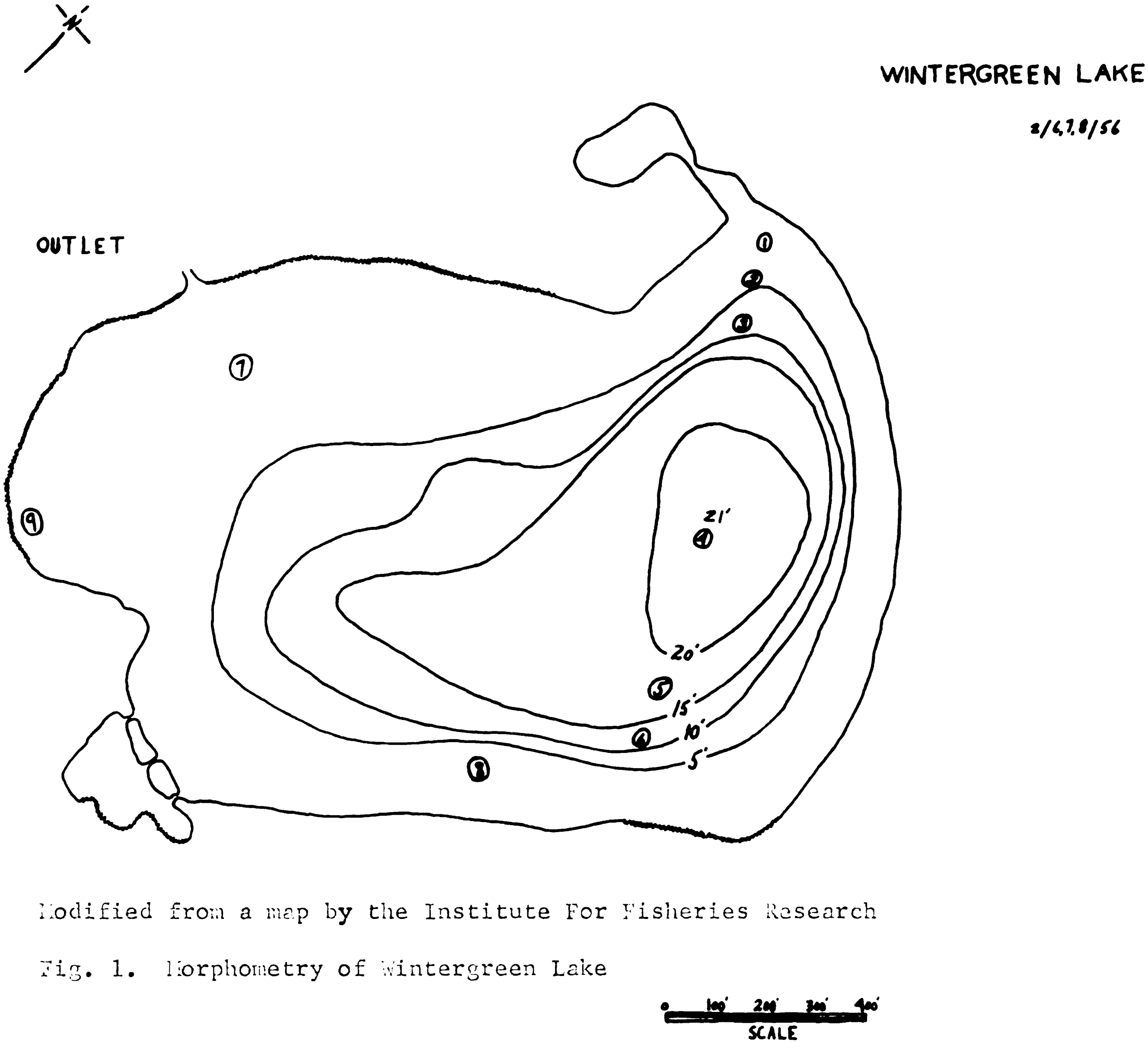
Wintergreen Lake (Figure 1) of the W. K. Kellogg Bird Sanctuary is located at T1S, R9W; Section 8 of Kalamazoo County, Michigan. This places it approximately one mile southeast of the W. K. Kellogg Biological Station of Michigan State University.

Prior to 1926, when W. K. Kellogg purchased the surrounding area, Wintergreen Lake had been fished extensively and had been known to yield larger fish on the average than lakes in the same vicinity. After this date, however, public fishing was prohibited so that a sanctuary for waterfowl might become established. Since that time, due to the large numbers of Canada geese and ducks which utilize the lake, tremendous amounts of natural fertilizer presumably have been added to the water.

The lake is consequently considered to be eutrophic and its morphometry, bottom deposits, and distribution of vegetation support this idea.

The lake is a pit lake of glacial origin and covers about 39 acres. Shallowness is its salient feature, although a hole reaching to 21 feet exists in the north end (Figure 1).

Springs on the north and northeast shores feed the lake. Drainage is by means of a small outlet on the west



Modified from a map by the Institute For Fisheries Research

Fig. 1. Morphometry of Wintergreen Lake

shore, but this seems to be extremely slow, at least during the summer months.

The major portion of the preceding information has been obtained from a master's thesis by C. Fetterolf which dealt with a population study of the fishes in the lake during the year 1951.

The bottom deposits of the lake are not very diverse. Shoal areas are sandy, but those on the west are protected from winds and consequently have a covering of detritus or pulpy peat. The unprotected east shoal has no such layer. Deeper areas have a marl bottom and this grades into a fine organic ooze in the hole at the north end.

The higher aquatic vegetation is very dense. These plants are distributed rather characteristically. *Nuphar advena* Ait, occupies most of the protected west shore; *Chara* sp. predominates on the wave-swept east shore, *Myriophyllum* sp. occurring sporadically. Going deeper, one finds a wide band of *Potamogeton pectinatus* L. interspersed with some *P. Foliosus* Raf. and *Najas flexilis* (Wild) Rostk. et Schmidt. A band of *Cerotophyllum demersum* L. exists below this to a depth of 18 feet.

III. PROCEDURE

Sampling was confined to the summer, extending from June 25, 1960 to August 30, 1960. One sample was taken, however, on October 7.

On various dates, therefore, samples of lake water and of selected bottom deposits were taken at nine different points on the lake, six along a line transect and the remaining three in separate littoral areas (Figure 1). Table I contains data concerning the depth, bottom type, vegetation, and other features present at each station.

Water for chemical analysis was secured with a Kemmerer sampler and bottom samples were taken with an Ekman dredge. At the same time, weather conditions were noted.

Physico-chemical data for each station were determined by means of a Fahrenheit thermometer and a Hach water analysis kit. Calcium carbonate alkalinity and carbon dioxide concentration were obtained by titration methods, pH and oxygen concentration by colorimetric methods. Chemical tests were run within 20 minutes after the actual collecting.

Immediately after these tests, a finger bowl or two of bottom material was placed aside, allowed to settle, and later examined for microscopic organisms. While this material was settling, the remainder of the bottom deposit was run through #10 and #20 screens.

TABLE I. Description of sampling stations.

Sta.	Depth	Bottom	Vegetation	Other
1	2.5'	Sand, covered by pulpy peat.	Potamogeton pectinatus Ceratophyllum demersum, floating algal mats	Exposed to mild winds at times
2	5'	Marl.	Ceratophyllum beds	
3	8'	Marl-organic	Ceratophyllum beds	
4	21'	Organic ooze	Mat of Oscillatoria and Arthrospira coating sediments	Hydrogen sulfide present
5	16'	Organic ooze	Ceratophyllum sparse	Hydrogen sulfide present
6	11'	Marl-organic	Ceratophyllum sparse	
7	2'	Sand, pulpy peat layer	Isolated, floating algal mats	Protected
8	3'	Sand-marl mix	Chara sp. beds	Usually exposed to mild winds
9	.5'	Sand, detritus layer	Lemna sp.	Hydrogen sulfide; shaded by a willow

Hard bodied, non-contractile specimens were preserved in 70 per cent alcohol and were identified during the subsequent months. On the other hand, most microscopic specimens were identified while still alive, as suggested in Edmondson (1959).

With few exceptions, specimens were determined at least to genus using the following taxonomic keys: (1) B. D. Burks, 1953, the Mayflies, or Ephemeroptera of Illinois; (2) E. F. Cook, 1956, The Nearctic Chaoborinae; (3) W. T. Edmondson (ed.), 1959, Fresh-Water Biology; (4) R. R. Kudo, 1946, Protozoology; (5) R. W. Pennak, 1953, Fresh-Water Invertebrates of the United States; (6) S. S. Roback, 1957, The Immature Tendipedids of the Philadelphia Area; and (7) H. H. Ross, 1944, The Caddis Flies, or Trichoptera of Illinois.

IV. RESULTS

Physico-Chemical

In general, the data in Table II indicate that Wintergreen Lake was a warm, hard-water lake. Water temperatures were usually in the 70's; phenolphthalein alkalinity indicated carbonate radicals in solution. Reid (1961) has stated that hard-water lakes are characterized by pH values of 8.5 and above. Wintergreen Lake on the whole exhibited pH values above 9.

Although direct evidence of thermal stratification was not obtained, this can be inferred from the fact that chemical stratification did occur (Figures 2 and 3). Furthermore, two previous workers found thermal stratification in the lake. Fetterolf (1951) found the thermocline to begin at a depth of approximately 13 feet, and Scheibner (1958) reported a thermocline in the 21 foot deep hole at the north end of the lake.

Figure 2 shows that Wintergreen Lake exhibited a carbon dioxide-oxygen gradient typical of eutrophic lakes. The large amounts of carbon dioxide and small amounts of oxygen at the deepest station (#4) were caused by decomposition of organic sediments and lack of circulation of the water at that depth. Furthermore, Odum (1959) has stated that "productively rich lakes generally are subject

TABLE II. Physico-chemical data for Wintergreen Lake, Summer, 1960.

Station	Date	Temperature °F Air	Water	CO_2 p.p.m.	O_2 p.p.m.	pH	Alkalinity p.p.m. Phth.	M.O.
1	7/5/60	78	73	0	8.6	9.3	15	98
	8/5/60	81	77	0	6.7	9.3	10	95
2	7/8/60	80	75	0	8.8	9.4	12	95
	8/13/60	79	75	0	6.8	9.2	10	100
3	7/10/60	80	--	0	9.5	9.8	15	75
	8/19/60	84	--	0	7.8	9.2	8	105
4	7/13/60	73	--	16	1.6	7.2	0	150
	8/22/60	72	--	24	.7	7.1	0	173
5	7/15/60	70	--	8	5.0	7.5	0	130
	8/23/60	86	--	0	4.2	8.9	3	108
6	7/16/60	73	--	0	9.5	9.4	12	90
	8/24/60	75	--	0	---	---	15	100
7	6/25/60	72	68	0	7.9	9.2	10	95
	7/20/60	68	69	6	4.0	7.5	0	95
	8/29/60	88	74	2.6	---	---	0	108
8	6/28/60	76	70	0	11.2	9.6	22	98
	7/22/60	90	82	0	10.7	10.5	20	85
9	7/1/60	79	72	12	4.4	7.2	0	110
	7/26/60	74	70	16	1.8	7.1	0	105
	8/30/60	83	72	12	---	---	0	120
	10/7/60	63	51	--	---	---	--	---

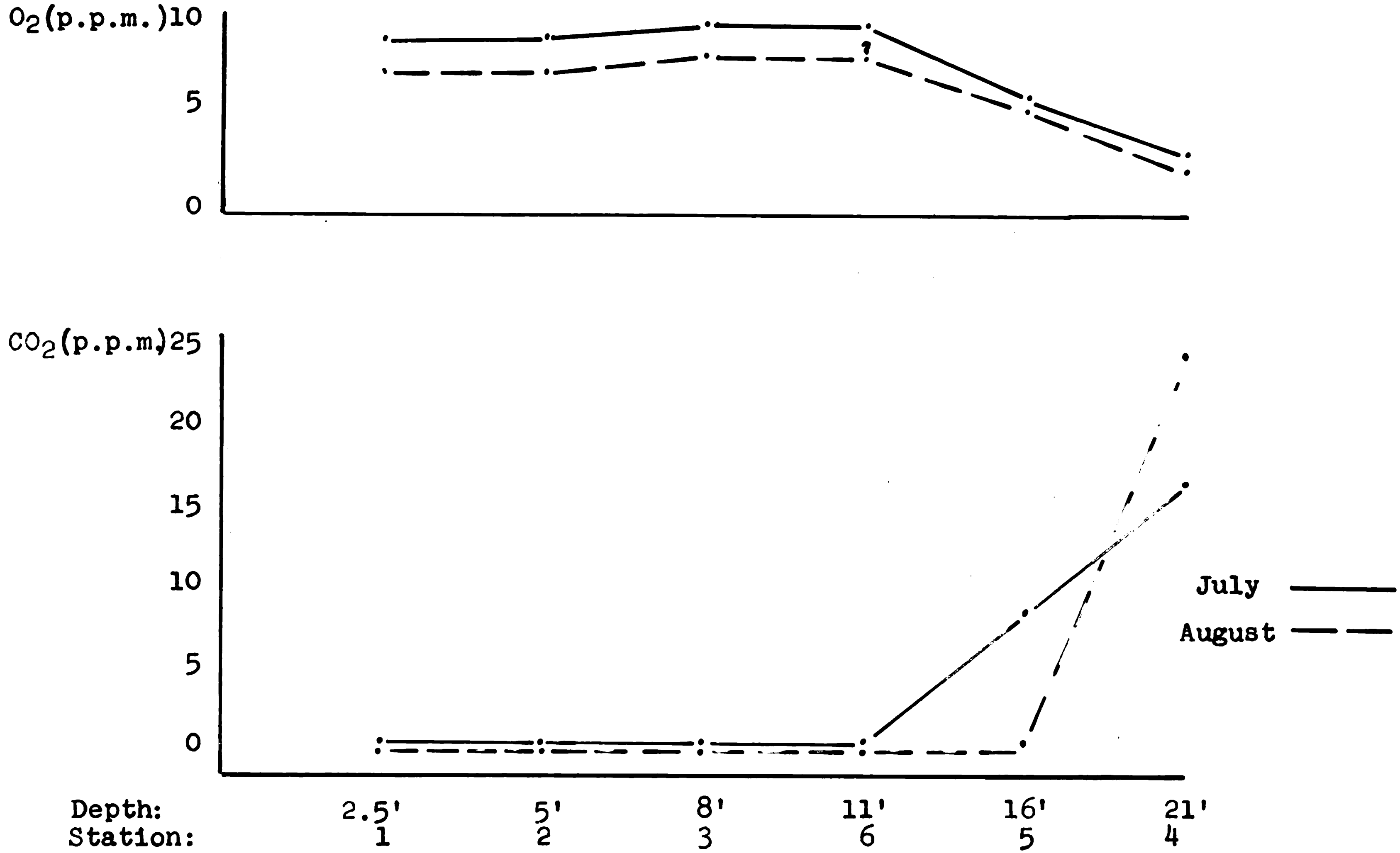


Fig. 2. Carbon dioxide and oxygen variations in Wintergreen Lake--Summer, 1960

to greater oxygen depletion . . . because the 'rain' of organic matter from the limnetic and littoral zones into the profundal is greater . . ." For this reason, station #4 was probably completely anaerobic and the oxygen recorded there was probably introduced into the sampling bottle from the atmosphere during the analysis in the lab. One large sampling bottle was used for other tests as well as for oxygen, and this necessitated uncorking the bottle and agitating the water several times.

Figure 2 also shows that oxygen concentration was lower in August than in July. This is best interpreted as caused by increased decomposition of accumulated dead plankton. Such an increase would also explain the higher concentration of carbon dioxide at station #4 in August.

Figure 3 illustrates alkalinity variations in Wintergreen Lake during the summer of 1960. Although not distinct, there was a gradient present; monocarbonates (phenolphthalein alkalinity) decreased with depth whereas bicarbonates (methyl orange alkalinity) tended to increase with depth. Moore (1950) has explained such a phenomenon being due to phytoplankton and higher vegetation (limited to shallower areas) extracting carbon dioxide from bicarbonates for photosynthetic activity. Such extraction consequently produced an increase of monocarbonates, forming marl. The irregularities in the gradient were probably due to local concentrations of vegetation.

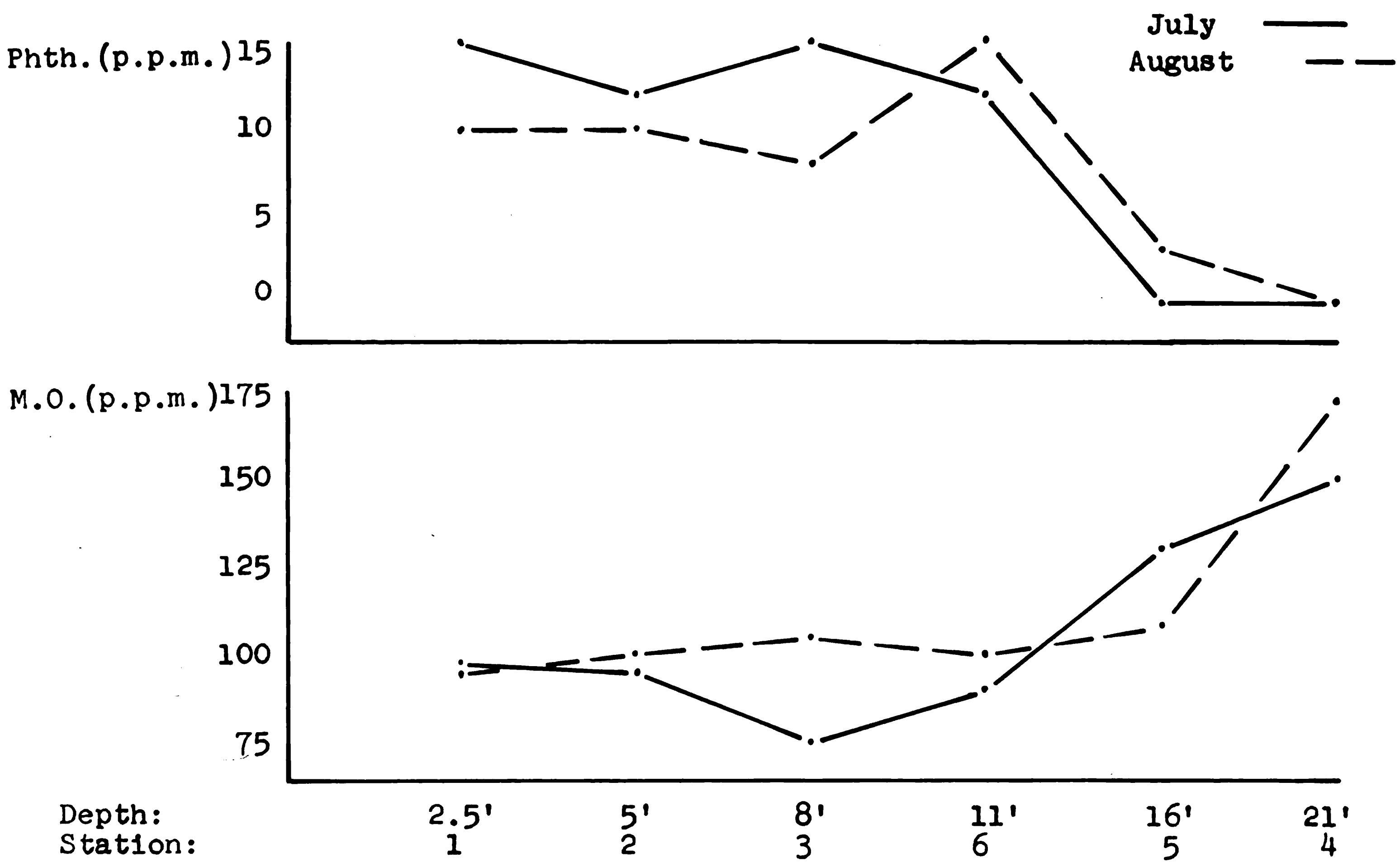


Fig. 3. Alkalinity variations in Wintergreen Lake--Summer, 1960

Methyl orange alkalinity in general increased in August because monocarbonates derived from dying and sinking phytoplankton combined with carbon dioxide to produce increased concentrations of bicarbonates (Moore, 1950). The exception to this pattern at station 5 was probably due to a local concentration of Ceratophyllum demersum.

Figure 4 illustrates temperature differences between protected and unprotected stations. The water temperature of the exposed area tended to follow the change in air temperature fairly closely, always remaining cooler than the air. Stirring of the water by wind action produced changes in temperature of the water paralleling changes in the air, but the high heat capacity of water always maintained its temperature below that of the air.

On the other hand, such a relationship was not seen for the sheltered area. Water temperatures did not fluctuate as greatly. Consequently, the water was warmer than the air at one point and at another point, the water was 14 degrees cooler than the air. Since water is a much more thermally stable substance than air, the former's temperature changes much more slowly than the latter's and thus the water was warmer than the air on July 20th at station 7. Furthermore, Welch (1952) has stated that in shallow, unusually protected areas, even in hot weather, only a thin layer of surface water may be warmed while the lowermost water may remain relatively cold. Thus, the 14 degree difference on August 29th.

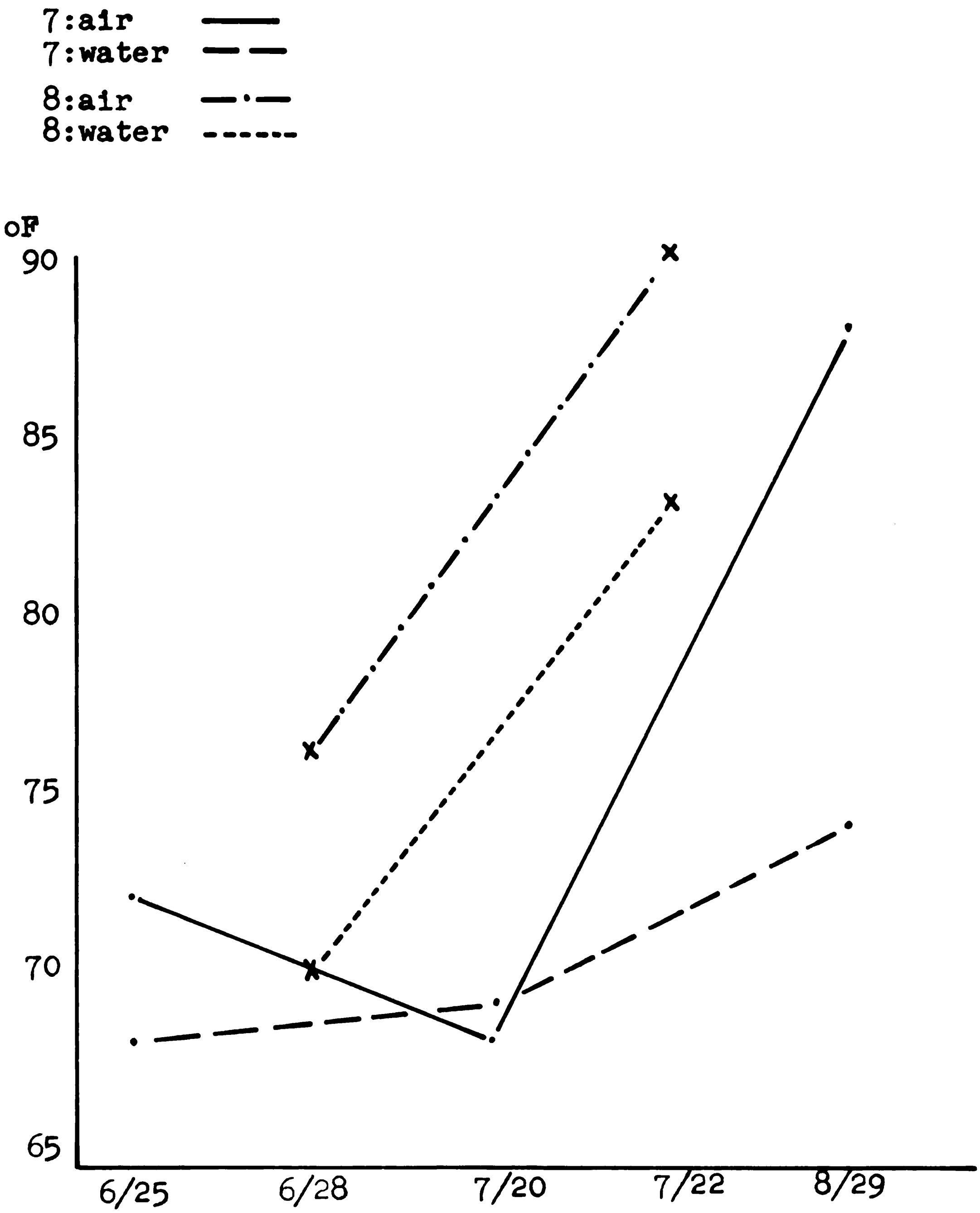


Fig. 4. Temperature differences between protected (7) and unprotected (8) stations

In addition to temperature differences, the protected and unprotected stations exhibited dissimilarities with respect to carbon dioxide and oxygen concentration (Figure 5). The exposed station never had carbon dioxide in solution and always recorded very high oxygen concentrations. Welch (1952) found that under conditions of calm, sunny days, the water surrounding dense vegetation beds may sometimes produce supersaturations of oxygen of considerable magnitude. The dense beds of Chara sp. at the exposed station were apparently functioning to this effect.

The sheltered station, on the other hand, eventually showed presence of carbon dioxide and a corresponding change in oxygen (Figure 5). Lack of stirring by wind and decomposition of organic matter seem to have produced such changes.

Biological

The benthos is commonly defined as those organisms which inhabit or are closely associated with the bottom substrate of a lake. This definition is, however, too facile since "the facts of ecological life histories show that the line of demarcation between benthos and plankton is, to a great extent, hazy and poorly defined" (Cole, 1955). In other words, as Welch (1952) has said, ". . . some of the plankters are facultative benthic inhabitants . . ." In addition to plankton, it is conceivable that forms normally on higher vegetation may, through accident or choice, become incorporated into the benthic community.

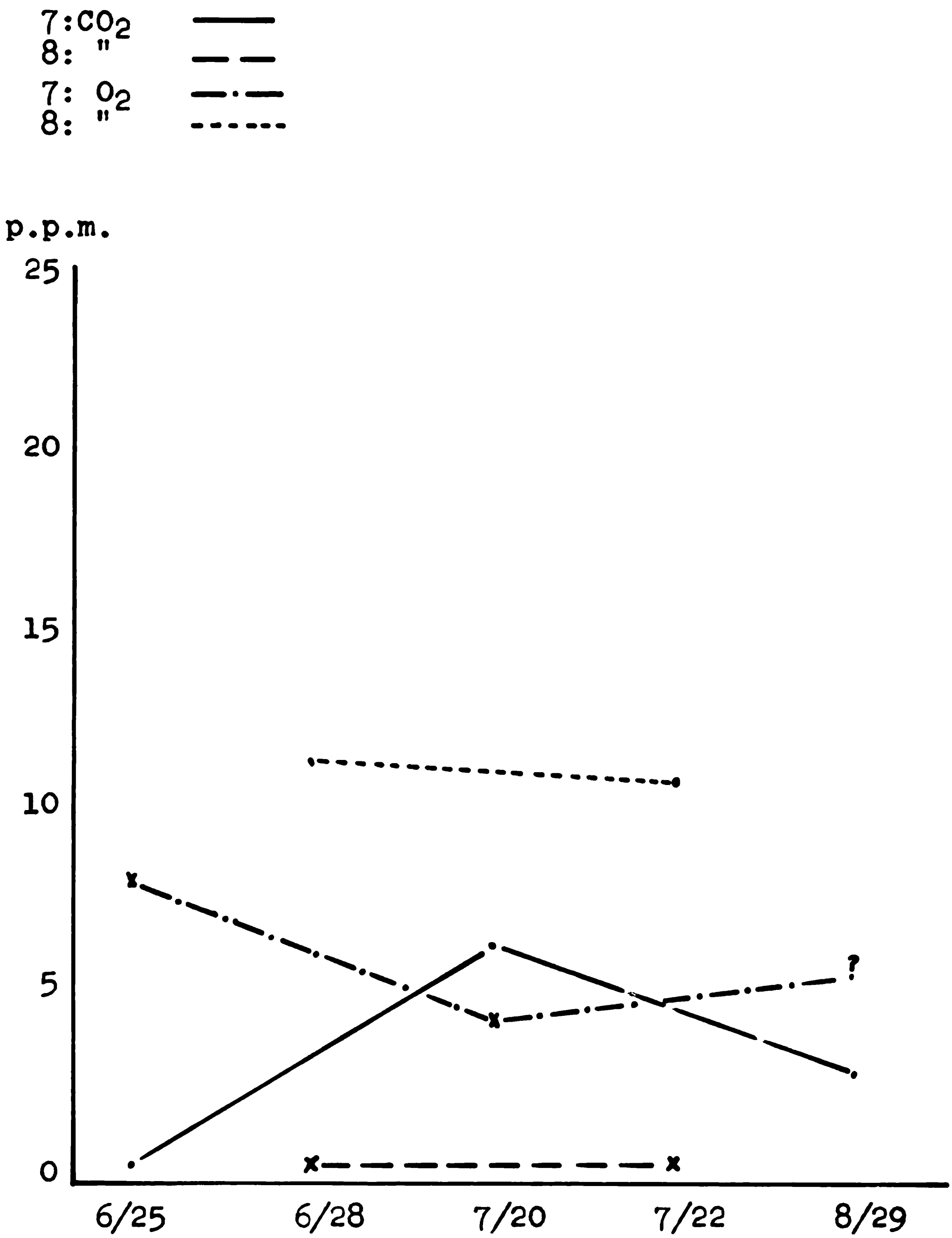


Fig. 5. Carbon dioxide and oxygen differences between protected (7) and unprotected (8) stations

This idea of invasion by atypical species is substantiated in the lists of invertebrates compiled in this work (Table III). For example, Euglena sp., Halteria sp., Synura sp., and Volvox sp. are considered more planktonic than benthic. The rotifers, Lecane sp., Macrochaetus sp., Polyarthra sp. and Testudinella patina are also thought to be planktonic. The cladoceran, Daphnia sp., is similarly regarded.

It must be stressed that these lists are not meant to be complete since a selected number of microhabitats were sampled and these primarily during the summer. As Eggleton (1939) has stated "in typical, eutrophic, temperate lakes of the second order, the qualitative composition of the benthic forms will vary considerably with the seasons . . .," although Pennak (1953) claimed that "summer and winter species lists [of protozoans] from the same habitat are often strikingly similar." Table III indicates that a total of 168 genera were collected and identified of which 81 were determined to species.

Based on estimates of numbers, the most abundant macroscopic organisms observed during the summer were Limnodrilus udekemianus (Oligochaeta), Cypridopsis vidua (Ostracoda), and Hyalella azteca (Amphipoda).

The collection made at station 9 in October contained an excessive number of Frontonia sp. (Protozoa) and Simocephalus serrulatus (Cladocera) compared to the population sizes of these organisms observed during the summer.

TABLE III. Invertebrate benthos--Wintergreen Lake, Summer, 1960

Invertebrate benthos	Stations
1. Protozoa:	
Acanthocystis sp.	6
Acropisthium mutabile Perty	3
Actinobolina sp.	9
Actinophrys sp.	6
Actinosphaerium sp.	9
Amoeba sp.	6
Amphileptus claparedei Stein	9
Arcella dentata Ehrenberg	2,3
Arcella vulgaris Ehrenberg	9
Balladyna sp.	6
Centropyxis aculeata (Ehrenberg) Stein	6
Coleps sp.	2,3,6,9
Cristigera sp.	3
Difflugia corona Wallich	9
Difflugia oblonga Ehrenberg	6,9
Difflugia sp.	2,3,9
Dileptus sp.	2,7
Epistylis sp.	7
Euglena spp.	3,9
Frontonia sp.	3,6,7,9
Halteria sp.	1,2,3,6, 7,8,9
Histrio sp.	9

TABLE III (continued)

Invertebrate benthos	Stations
1. Protozoa: (continued)	
Lionotus sp.	6
Loxocephalus sp.	9
Loxodes sp.	7,9
Loxophyllum sp.	3
Merotrichia sp.	3
Nassula sp.	2,3,6,7
Onychodromopsis Flexilis Stokes	6
Ophyroglena sp.	3
Paramecium caudatum Ehrenberg	9
Phacus spp.	3,7,9
Physalophyra sp.	6
Pompholyxophrys sp.	3
Pontigulasia sp.	9
Prorodon sp.	1,7
Pseudomicrothorax sp.	6
Scyphidia sp.	9
Spirostomum sp.	1,3,6, 7,8,9
Stentor coeruleus Ehrenberg	1,2,6,7
Stichotrichia sp.	7
Strombidium sp.	3
Strongylidium sp.	3,6,7
Stylonychia sp.	6,9
Synura sp.	9

TABLE III (continued)

Invertebrate benthos	Stations
1. Protozoa: (continued)	
Systylis sp. ?	9
Trachelius ovum Ehrenberg	2,6,9
Trichodina sp.	8
Trichotaxis sp.	6
Urocentrum turbo (O. F. Muller)	3,6,7
Urozona butschlii Schewiakoff	6
Volvox, sp.	2,3,9
Vorticella sp.	2,3,6, 7,8,9
Unidentified Flagellate	4,5
2. Porifera:	
None collected.	
3. Coelenterata:	
Hydra sp.	6,8
4. Turbellaria:	
Dalyelliidae	6,9
Dugesia tigrina (Girard)	1,2,3,8,9
Mesostoma ehrenbergii (Focke)	7,9
Stenostomum sp.	3,6,7,9
Unidentified Rhabdocoel	9
5. Nematoda:	
Unidentified spp.	2,3,9
6. Gastrotricha:	
Chaetonotus formosus Stokes	3,6,9

TABLE III (continued)

Invertebrate benthos	Stations
6. Gastrotricha: (continued)	
Chaetonotus sp.	1,3
Lepidodermella squamatum (Dujardin)	7
Polymerurus rhomboides (Stokes)	9
7. Rotifera:	
Cephalodella sp.	2,3
Colurella sp.	6,8,9
Cyrtonia tuba Ehrenberg	2,6,7,9
Dicranophorus sp.	6
Erignatha sp.	2
Euchlanis sp.	2,3,6,9
Harringia sp.	2,6
Itura sp.	9
Lecane luna Muller	2
Lecane sp.	2,9
Lepadella sp.	3,6
Lindia sp.	3
Macrochaetus sp.	8
Monommata sp.	3
Monostyla closterocerca Schmarda	6
Monostyla quadridentata Ehrenberg	3
Monostyla sp.	2,3,6,9
Mytilina sp.	6
Philodina sp.	2,3,9

TABLE III (continued)

Invertebrate benthos	Stations
7. Rotifera: (continued)	
Platyias patulus (Muller)	2,3,7,9
Polyarthra sp.	9
Resticula sp.	3
Rotaria sp.	3,6
Scaridium longicaudum (Muller)	8
Sinantherina semibullata	9
Stephanocerus fimbriatus (Goldfuss)	6
Synchaeta sp.	3
Testudinella patina	6
Trichocerca porcellus	2
Trichocerca similis	6
Trichocerca sp.	2,3
8. Bryozoa:	
Cristatella mucedo Cuvier	3
Lophopodella carteri (Hyatt)	9
9. Tardigrada:	
None collected.	
10. Oligochaeta:	
Aeolosoma hemprichi Ehrenberg	6
Aulophorus vagus Leidy	9
Chaetogaster langi Bretscher	2,3,6
Chaetogaster limnaei K. von Baer	6,9
Dero digitata (O. F. Muller)	3,6,9

TABLE III (continued)

Invertebrate benthos	Sections
10. Oligochaeta: (continued)	
Limnodrilus udekemianus Claparede	2,5,8,9
Lumbriculus inconstans (F. Smith)	9
Naidium breviseta (Bourne)	2
Nais communis Piquet	9
Pristina longiseta leidyi Smith	3
Pristina osborni (Walton)	3,6
Pristina schmiederi Chen	9
Stylaria Fossularis Leidy	9
Stylaria lacustris (Linnaeus)	3,6
11. Hirudiaea:	
Erpobdella punctata (Leidy)	9
Helobdella stagnalis (Linnaeus)	2,3,7,9
Placobdella parasitica (Say)	9
12. Cladocera:	
Alona guttata Sars	6
Ceriodaphnia quadrangula (O. F. Muller)	3,9
Chydorus sphaericus (O. F. Muller)	3,6
Daphnia sp.	4,5,7
Pleuroxus denticulatus Birge	3
Pleuroxus procurvus Birge	3,6
Simocephalus serrulatus (Koch)	2,3,6, 7,8,9
Unidentified sp.	2,7

TABLE III (continued)

Invertebrate benthos	Stations
13. Ostracoda:	
Cypria palustera Furtos	9
Cypria sp.	3
Cypridopsis vidua (O. F. Muller)	1,2,3,6 7,8,9
Herpetocypris sp.?	9
Paracandona euplectella (Brady and Norman)?	9
Physocypria pustulosa Sharpe	1,5,6, 7,8,9
Unidentified sp.	2,3,6
14. Copepoda:	
Canthocamptus vagus Coker and Morgan	9
Eucyclops agilis (Koch)	3,9
Macrocyclops albidus (Jurine)	2,3,6, 7,8,9
Unidentified calanoid	4
Unidentified cyclopoid	9
15. Isopoda:	
None collected.	
16. Decapoda:	
None collected.	
17. Amphipoda:	
Hyalella azteca (Saussure)	1,2,3,6, 7,8,9
18. Ephemeroptera:	
Ameletus sp.	7
Caenis sp.	1,3,6, 7,8,9

TABLE III (continued)

Invertebrate benthos	Stations
18. Ephemeroptera: (continued)	
Edmundsius sp.	9
Neocloen sp.	8
Siphlonurus sp.	9
19. Odanata:	
Epicordulia sp.	3
Ischnura sp.	1,2,3,6,9
Nehalennia sp.	7
20. Plecoptera:	
None collected.	
21. Hemiptera:	
Tenegobia sp.	9
22. Neuroptera:	
None collected.	
23. Coleoptera:	
Berosus sp.	9
Copelatus sp.	9
Haliplus sp.	9
Hydrovatus sp.	2,8
Peltodytes sp.	9
24. Trichoptera:	
Leptocerus americanus (Banks)	1,2,3,6
Mystacides sepulchralis (Walker)	8

TABLE III (continued)

Invertebrate benthos	Stations
24. Trichoptera: (continued)	
Oecetis sp.	1,2,6,8
Orthotrichia sp.	3
Polycentropus sp.	2,3,6,7
Triaenodes tarda Milne	3
25. Lepidoptera:	
Acentropus sp.	3
26. Diptera:	
A. Culicidae:	
Aedes sp.	9
Chaoborus Flavicans (Meigen)	3,4,5,6,7
Chaoborus punctipennis (Say)	4,5
B. Heleidae	
Palpomyia sp.	2,3,6, 7,8,9
C. Tendipedidae:	
Anatopynia sp.	6,7,9
Calopsectra sp.	3,6,9
Clinotanypus sp.	9
Cryptochironomus digitatus (Malloch)	8,9
Glyptotendipes sp.	3,6,8
Harnischia sp.	9
Hydrobaenus (*Trichocladius*) sp.	6,7,9
Lauterborniella sp.	9

TABLE III (continued)

Invertebrate benthos	Stations
C. Tendipedidae: (continued)	
Pentaneura flavifrons Johannsen	8
Pentaneura monilis (Linnaeus)	2,3,9
Pentaneura sp.	7,8,9
Polypedilum illinoense (Malloch)	3,7
Procladius riparius Malloch	5,6,7,9
Procladius sp.	7,8
Psectrocladius sp.	9
Pseudochironomus sp.	3,6,8
Tanytarsus sp.	3,6
Tendipes decorus	3,9
Tendipes nervosus (Staeger)	3,6,8
Tendipes plumosus (L.)	5,6,9
Tendipes staegeri (Lundbeck)	3
Tendipes sp.	1,3,6,8,9
27. Hydracarina:	
Albia sp.	3
Arrenurus spp.	2,3,6,7
Diplodontus (*Hydrodroma*) *despiciens* (Muller)	2,3,7
Hydrozetes sp.	2,8,9
Hydryphantes sp.	9
Koenikea sp.	2,6
Limnesia sp.	2,7

TABLE III (continued)

Invertebrate benthos	Stations
27. Hydracarina: (continued)	
Neumania spp.	3,5,6,7
Piona sp.	6
Unionicola sp.	7
Immature sp.	9
28. Pelecypoda:	
Sphaerium spp.	1,2,6,8
29. Gastropoda:	
Gyraulus deflectus (Say)	9
Gyraulus parvus Say	2,3,5, 6,8,9
Lymnaea sp.	9
Physa sp.	1,2,3,6, 7,8,9
Promenetus exacuous Say	9
Valvata sincera Say	1,2,3,8

V. DISCUSSION

Physico-Chemical

The physico-chemical data for Wintergreen Lake (Table II) indicate that it was a eutrophic lake, that is, one which exhibited warm water temperatures, experienced oxygen depletion in the hypolimnion, and contained fairly large amounts of calcium carbonate and bicarbonate. The lake was shallow (Figure 1) and was, therefore, readily warmed during the summer. Since the hole at the north end of the lake (Figure 1) dropped off abruptly and furthermore was surrounded by a wide band of Ceratophyllum demersum, any subsurface currents produced by wind action were ineffective in circulating the water in the hole (station 4). This, plus the fact of decomposition of the organic bottom sediments, accounted for the anaerobic condition found there. Deposits of glacial drift around the lake probably explain the hard nature of the lake water.

Of the chemical factors noted in Table II, the most biologically important is oxygen. Most of the stations had sufficient amounts of oxygen to support most forms of life. This was primarily due to the photosynthesis of the dense vegetation at these stations. On the other hand, station 4 was virtually anaerobic for reasons already discussed.

Station 9 also showed low oxygen concentrations; this was because (1) there was little vegetation present, (2) the area was choked with decaying detritus, and (3) the area was shaded throughout most of the day by a willow tree.

Other biologically important chemical factors not included in Table II, but which nevertheless were undoubtedly present in fairly large quantities, were hydrogen sulfide, ammonia, and other toxic organic breakdown products. The thousands of waterfowl which utilized the lake apparently contributed these toxic substances by depositing their "urine" and feces in the lake. Such toxic substances might quite possibly have played an important role in the occurrence and distribution of many of the invertebrate groups.

Biological

The complete absence of several groups and of certain typical benthic species may have been due to any of the following: (1) inadequate sampling, e.g. the Isopoda, Tardigrada, and Neuroptera are not uncommon in lakes; (2) physiological limits, e.g. the Porifera are more sensitive to environmental variations than are other fresh-water invertebrates (Pennak, 1953), in this case perhaps toxic organic waste products; (3) habits, e.g. the Plecoptera are mostly stream-dwellers and the Decapoda are chiefly nocturnal (all collecting was done during the day); (4) predation, e.g. the Decapoda are a prime fish food; or (5) the existence of a narrow concentration zone of the absent forms. Alona quadrangularis, Drepanothrix sp. and Ilyocryptus sp. are typical benthic cladocerans, and yet were never found.

Furthermore, Hexagenia limbata, a burrowing mayfly nymph, was not collected, either by the author during his research or by R. H. Scheibner who conducted a year-long quantitative study on the insect bottom fauna of the lake in 1957. The latter's sampling stations were along a different transect and at different depths for the most part than those in this study. However, during an excursion around the lake on July 6, 1961, this species was collected in a very limited area on the west shore. This area had not been sampled by Scheibner or the author during their investigations. Hunt (1953) observed that H. limbata preferred a marl-organic mixture and that ". . . fewer nymphs existed in thickly vegetated bottom. . ." Such a condition seemed to exist in this locality and may account for the presence of this organism.

Another evidence for the existence of concentration zones in the lake was the fact that both Scheibner and the author during their work, had witnessed large emergences of the mayfly Caenis sp. However, neither worker found this organism in large numbers in the bottom sediments.

The paucity of species among several insect groups and in the molluscan groups likewise may have been due to any of the causes mentioned above. Inadequate sampling undoubtedly produced only one species of Hemiptera. Scheibner (1958) collected Notonecta sp. and Plea striola (Hemiptera) in 1957. He also found two beetles, Bidessus sp. and Tropisternus sp., which were not present in the author's samples.

It is well known that lakes lose much of their insect population through the emergence of adults usually in the spring and early summer. Scheibner (1958) collected the following odanate nymphs primarily in the winter--Basiaeschna janata, Enallagma sp., Libellula sp., Perithemis sp., and Tetraganeuria sp. He also collected Leptocella sp. and Phryganea sp. (Trichoptera). The author did not find the nymphs of these genera during the summer.

Three facts account for the qualitative paucity of pelecypods in the lake. Pennak (1953) has stated that, ". . . small lakes, especially seepage lakes, contain few species" and that "customarily, mussels inhabit substrates free of rooted vegetation. . . . The Sphaeriidae are less specific in their occurrence. . . ." Reid (1960) has stated that ". . . pelecypods are eaten by various fishes and other animals including muskrats and waterfowl."

Similarly, the snail fauna in Wintergreen Lake was rather limited. Several factors may have been responsible for this. Small bodies of water usually have few species compared to larger bodies of water because there are fewer microhabitats specific for each particular species (Pennak, 1953). Predation by fish, birds, and the snail leech Helobdella stagnalis is common (Pennak, 1953). The larger species of snails apparently did not exist in the lake. The extremely large numbers of fish and waterfowl in the lake may have "overgrazed" the more easily detected larger snails. Another factor in reducing the snail fauna may have been the toxic waste products produced by the droppings of the waterfowl which utilized the lake. Boubjerg and Ulmer (1960) found only 11 species in Lake Okoboji, Iowa, compared to 36 species found there by Shimek 25 to 30 years previously. These workers cited pollution by sewage as the major cause of this gap.

Table IV illustrates the distribution of each major group collected and identified. Where gaps exist between depths, it may be assumed that the group in question was present at that depth, but not necessarily at the station shown. Examination of the locations of the sampling stations in Figure 1 provides an explanation for this situation. Furthermore, physico-chemical properties of individual stations may be limiting to certain groups. These gaps can be attributed to sampling error and/or insufficient examination of the samples from that depth.

Obviously, the distribution of each group may not be complete since there were depths which were never sampled. However, the range as shown for each group may be of some value in portraying approximate depth limitations.

These limitations, furthermore, cannot be considered as absolute since "the depth distribution [of various benthic

TABLE IV. Qualitative distribution of benthic invertebrates.

Station	9	7	1	8	2	3	6	5	4
Depth	.5'	2'	2.5'	3'	5'	8'	11'	16'	21'
Bottom Types*	S.D.	S.P.	S.P.	S.M.	M.	M.O.	M.O.	O.	O.
Protozoa(54)	25spp.	14	3	4	10	20	23	1	1
Coelenterata(1)	--	--	--	1	--	--	1	--	--
Turbellaria(5)	5	2	1	1	1	2	2	--	--
Gastrotricha(4)	2	1	1	--	--	2	1	--	--
Rotifera (31)	10	2	--	3	12	13	13	--	--
Bryozoa (2)	1	--	--	--	--	1	--	--	--
Oligochaeta(14)	8	--	--	1	3	5	6	1	--
Hirudinea (3)	3	1	--	--	1	1	--	--	--
Cladocera (8)	2	3	--	1	2	5	4	--	1
Ostracoda (7)	5	2	2	2	2	3	3	1	--
Copepoda (5)	4	1	--	1	1	2	1	--	1
Amphipoda (1)	1	1	1	1	1	1	1	--	--
Ephemeroptera(5)	3	2	1	2	--	1	1	--	--

*S--Sand; D--Detritus; P--Peat; M-Marl; O--Organic.

TABLE IV. (continued)

Station	9	7	1	8	2	3	6	5	4
Depth	.5'	2'	2.5'	3'	5'	8'	11'	16'	21'
Bottom Types	S.D.	S.P.	S.P.	S.M.	M.	M.O.	M.O.	O.	O.
Odanata (3)	1	1	1	--	1	2	1	--	--
Hemiptera (1)	1	--	--	--	--	--	--	--	--
Coleoptera (5)	4	--	--	1	1	--	--	--	--
Trichoptera (6)	--	1	2	2	3	4	3	--	--
Lepidoptera (1)	--	--	--	--	--	1	--	--	--
Culicidae (3)	1	1	--	--	--	1	1	2	2
Heleidae (1)	1	1	--	1	1	1	1	--	--
Tendipedidae (22)	14	6	1	8	1	10	10	2	--
Hydracarina (10)	3	5	--	1	5	4	4	1	--
Pelecypoda (1)	--	--	1	1	1	--	1	--	--
Gastropoda (6)	5	1	2	3	3	3	2	1	--
TOTAL (199)	99	45	16	34	49	82	79	9	3

groups] found at one time of the year cannot be assumed to be the distribution typical of that type of lake or even that individual lake at all other times of the year" as has been stated by Eggleton (1935).

Table IV indicates that the great majority of the invertebrate groups penetrated to at least the 11 foot depth, but usually not to the 16 foot depth. Table I shows that at 16 feet, the substrate was an organic ooze, vegetation was sparse, and hydrogen sulfide was present. Table II shows that this depth also exhibited fairly low concentrations of dissolved oxygen. This complex of unfavorable conditions was apparently limiting to most species.

Some species, however, were more tolerant of unfavorable conditions. A small green flagellate was found at 21 feet along with two species of Chaoborus (Culicidae). Hall (1953) has stated "chlorophyll-bearing species [of protozoa] are often saprozoic and some can grow in darkness." Cole (1955) noted that "Phacotus sp. was the only green flagellate found regularly in the anoxic hypolimnion. . . ." Chaoborus sp. is a typical profundal inhabitant and will be discussed below.

The cladoceran and copepod at 21 feet were probably recently dead or dying, having sunk from the upper limnetic zone.

Clench (in Edmondson, 1959) observed that many pulmonate (lung-bearing) snails can remain submerged in water for indefinite periods of time, exchanging gas through the body surfaces. This adaptation may have accounted for the presence of Gyraulus parvus at the 16 foot depth. It was surprising, however, to find this snail there when carbon dioxide and oxygen concentration were 8 p.p.m. and 5 p.p.m., respectively. Pennak (1953) indicated that pulmonate snails require rather high concentrations of dissolved oxygen.

Later in August at this depth, Limnodrilus udekemianus, Physocypria pustulosa, and Neumania sp. occurred there when carbon dioxide was absent and oxygen was 4.2 p.p.m

The Coleoptera were not found beyond the 5 foot depth. Most adults in this group must obtain their oxygen from the surface and must, therefore, remain in relatively shallow water.

On a more specific level, an examination of Table III shows that the most widely distributed species in the lake were the following: Halteria sp., Spirostomum sp., Vorticella sp. (Protozoa); Dugesia tigrina (Turbellaria); Simocephalus serrulatus (Cladocera); Cypridopsis vidua, Physocypria pustulosa (Ostracoda); Macrocyclops albidus (Copepoda); Hyalella azteca(Amphipoda); Chaoborus flavicans (Culicidae); Palpomyia sp. (Heleidae); Tendipes sp. (Tendipedidae); Gyraulus parvus, and Physa sp. (Gastropoda).

The proportion of species within a major group found at any one station (microhabitat) may be used in ascertaining the microhabitat requirements of that group. Presumably, most species within a group are found in that environment which is most favorable for growth and reproduction of that group.

Protozoan diversity was greatest at station 9, 6, and 3, in that order(Table IV). Kudo (1946) has said that the majority of fresh-water protozoans "live in waters in which active oxidation and decomposition of organic matter are taking place." The quantities of carbon dioxide and oxygen at station 9 corroborated this statement. However, no such corroboration held for stations 6 and 3 (see Table II). The sediments and immediate overlying water at stations 6 and 3 were probably more stagnant than the data indicate, because the Kemmerer sampler was lowered to a depth one foot above the bottom so as not to stir up the sediments. Welch (1952) has stated "bottom deposits, through their decomposition processes, consume oxygen, exhausting it . . . not only within themselves but also in a thin layer of water lying immediately above the bottom, thus producing a microstratification."

Although not quite as striking, the rotifers and oligochaetes seemed to require a microhabitat similar to that required by the protozoans.

The Turbellaria, Hirudinea, and Coleoptera were qualitatively concentrated at station 9. Pennak (1953) has noted that many rhabdocoels are characteristic of microhabitats of much decay and low oxygen and that most flatworms are photonegative. Station 9 was low in oxygen and was shaded during most of the day; hence the flatworm diversity there. Although planarians require high oxygen concentrations, Dugesia tigrina was found at Station 9. This species may have been obtaining oxygen at the air-water interface.

Pennak has further noted that leeches prefer warm protected shallows with much vegetation and debris. Clampitt et al. (1960) reported that leeches showed definite preference for sand substrates except Helobdella stagnalis which was widely distributed. The findings of this investigation coincide closely with these observations (see Tables III and IV).

Most species of Bryozoa avoid direct sunlight and "Lophopodella carteri is probably the species that is most tolerant of decay and stagnation" (Pennak, 1953). Thus this species was found at station 9 (see Table III).

In general, copepods are more tolerant of a deficiency of oxygen than are cladocerans (Pennak, 1953). Four of the five species of copepods were taken at station 9, whereas only two of the eight species of cladocerans were taken there.

Pennak has stated that ostracods "tolerate wide ranges of ecological factors" and that the nature of the substrate is not important in their distribution. As seen in Table IV, this group was fairly evenly distributed. The Gastrotricha, Amphipoda, and Hydracarina were similarly distributed.

The Gastropoda likewise were fairly evenly distributed and this, Boubjerg and Ulmer (1960) also discovered in Lake Okoboji, Iowa. However, these workers never found snails in or about Chara sp. beds, whereas this worker did (at station 8). Although pulmonate snails are usually not found in stagnant water (Pennak, 1953), such species were found at station 9 (which was stagnant). Since this station was quite shallow (6 inches), these forms were probably obtaining oxygen from the atmosphere at the surface.

Allee and Schmidt (1951) have noted that "contrary to a condition frequently found in terrestrial insects, the aquatic insects are seldom limited to definite plants." An exception to this is the habitation of the tips of Ceratophyllum demersum by Leptocerus americanus (Ross, 1944).

Considering tendipedid larvae, Procladius riparius and Tendipes plumosus were the only midge larvae which penetrated to the 16 foot depth. The midges in general exhibited a distribution similar to that of the Protozoa and Rotifera (see Table IV). This was not surprising since it is well known that many midge larvae can withstand rather low concentrations of dissolved oxygen (Surber, 1958). Curry (1954) noted that the largest number of species was found in the littoral zone and was "directly associated with the dense plant growth of this region." Hence, the concentration of this group at stations 9, 6, and 3. The following species of midges were found exclusively at Station 9 (a fairly stagnant area): Clinotanypus sp., Harnischia sp., Lauterborniella sp., and Psectrocladius sp.

Figure 6 illustrates the influence of depth and bottom type on species diversity. Eggleton (1939) has stated that, in general, the benthic fauna increases qualitatively with depth to an optimum level somewhere within the lower littoral or upper sublittoral and then decreases with depth to a minimum in the deepest regions. This relationship was observed along the transect (stations 1-6) in the lake.

Station 9, however, supported the greatest diversity of species. This was probably due for the most part to the nature of the substrate there. Cole (1955) noted that a detritus-like bottom likewise supported the largest number of species.

The extreme paucity of species at 21 feet (see Figure 6) was also noted by Scheibner (1958). In addition to Chaoborus sp., he also found Palpomyia sp., Tendipes sp., and Tanytarsus sp. However, these additional forms were present only during April, May, and December and then only in very low numbers. Forms quite often found in deeper waters, e.g. Oligochaeta and Sphaeriidae, were never collected at station 4. It would seem, therefore, that the chief limiting factor, rather than absence of oxygen, was decomposition products, especially hydrogen sulfide.

The occurrence of Chaoborus sp. under such adverse conditions has not been fully explained. It is well known

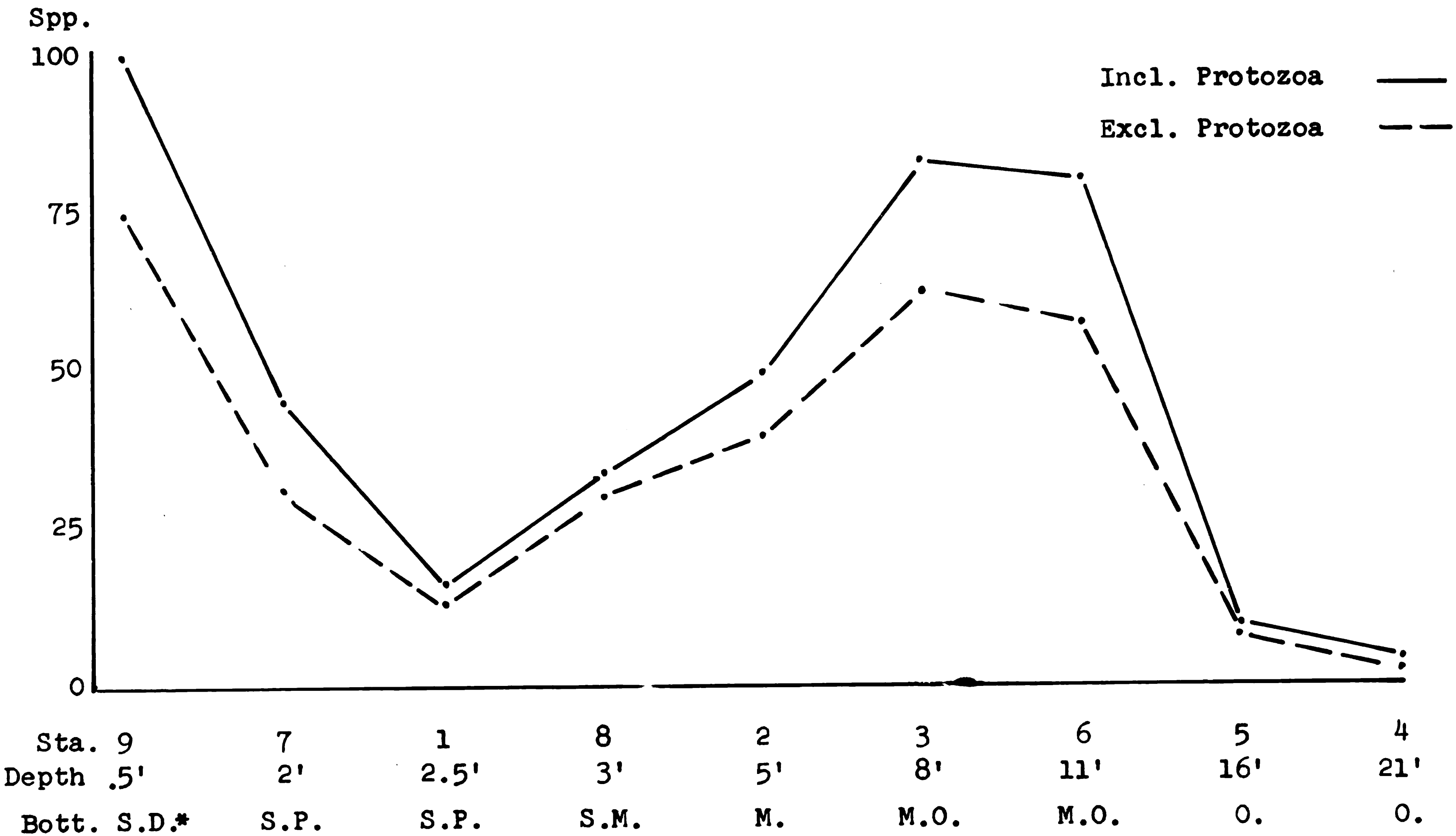


Fig. 6. Species diversity vs. depth and bottom type

* S--Sand; D--Detritus; P--Peat; M--Marl; O--Organic

that *Chaoborus* sp. larvae migrate to the surface at night and might thereby obtain temporary relief. However, Eggleton (1932) has observed *Chaoborus* sp. migrating nocturnally (1) during the winter when the lake was covered with ice and snow, and (2) during the autumnal overturn when the lake was completely aerated from surface to bottom. These observations seem to indicate that the determining factors of such migrations are not light or oxygen requirement, although these both may be operable.

Although a sandy, wave-swept shore usually supports the fewest number of species (Allee and Schmidt, 1951), the thick *Chara* sp. beds at station 8 were probably preventing any molar action by the waves and thus a relatively large number of species was collected there (Figure 6). Furthermore, the marl mixed with sand probably served to stabilize the latter and to give the sand some consistency.

Figure 6 shows that the protected station (7) had a greater number of different species than the unprotected station (8). This difference in total number of species supported was due to the larger number of protozoans present at station 7; most protozoans occupy stagnant situations; station 7 was stagnant and station 8 was not. The protozoans excluded, the two stations supported almost the same number of species.

Station 7 was also qualitatively richer in cladocerans and water mites whereas station 8 supported a greater diversity of tendipedids and snails. Chara sp. may possibly have influenced the former groups adversely. Many snails are known to forage on aquatic plants and the midges apparently found the more stable substrate of station 8 a more favorable one in which to burrow.

VI. SUMMARY

1. Wintergreen Lake on the W. K. Kellogg Bird Sanctuary was found to be eutrophic, rendered so primarily by the droppings of thousands of waterfowl in and around the lake. Such natural fertilization presumably contributed large amounts of nitrates, phosphorus, and other important trophic substances.

2. A total of 168 genera were collected and identified. Of these, 81 were determined to species. Qualitative diversity was greatest in the Arthropoda, Protozoa, and Rotifera.

3. The molluscan fauna in the lake was qualitatively meager.

4. The Protozoa, Rotifera, Oligochaeta, Turbellaria, and Tendipedidae were best represented in situations low in oxygen and rich in organic matter.

5. A substrate composed of detritus supported the greatest number of different species.

6. *Chara* sp. beds present in an unprotected area allowed a greater number of species to exist there than otherwise would have been possible.

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