STUDIES OF MOUNTAIN LAKE, VIRGINIA

WITH PARTICULAR REFERENCE TO

PHYSICAL LIMNOLOGY AND PROFUNDAL BOTTOM FAUNA

by

urtis
James C. Roth, B. S.

Thesis submitted to the Graduate Faculty of the

Virginia Polytechnic Institute

in candidacy for the degree of

MASTER OF SCIENCE

in

Zoology

May 20, 1963

Blacksburg, Virginia

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

TABLES

GENERAL

INTRODUCTION

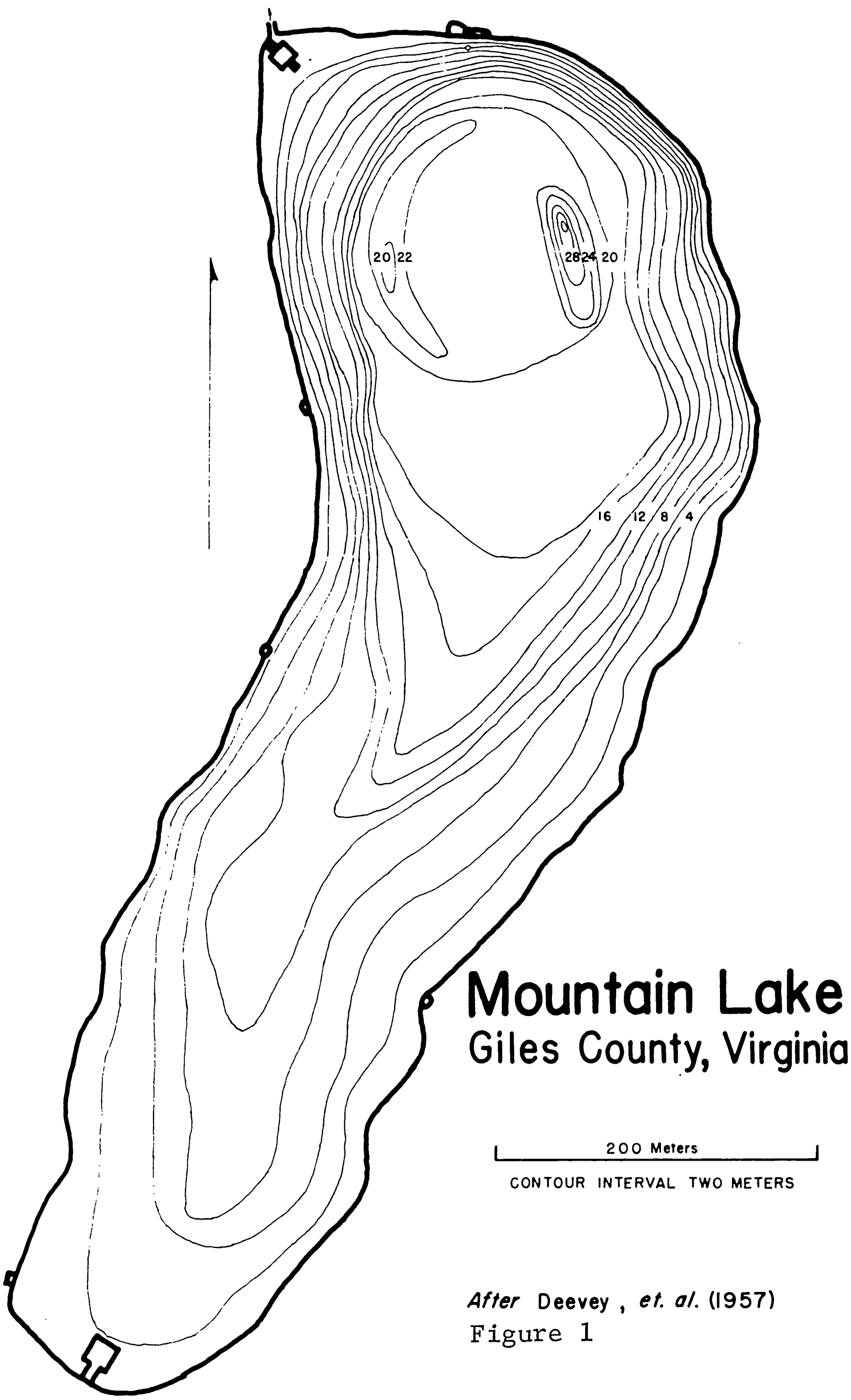
The present paper summarizes observations made on Mountain Lake, Virginia during 1961, 1962, and 1963. It includes data on the annual cycle of physical and chemical events occurring in the lake, and will serve as a point of departure for future, more specialized studies there. Observations made on the profundal bottom fauna of the lake during the same period are also reported.

Although Mountain Lake is in many ways ideally suited as a subject for limnological study, little work has been done there. A few papers have appeared which report data collected during the summer season. The earliest and most important of these, by Hutchinson and Pickford (1932), reported data collected in July and August, 1931. Coker and Hayes (1940) and Grover and Coker (1940) reported on the net plankton of Mountain Lake. Platt and Shoup (1950) used a thermistor to observe temperatures during the summer of 1947. In addition, local lists and notes have appeared, at irregular intervals, on the biota of the area. Reference to several of these is made in the present paper.

MORPHOMETRY

Figure 1 is a bathymetric chart of Mountain Lake, slightly modified from the one prepared by Deevey, Jones, and Daly (1957). Tables 1 and 2 summarize the morphometric and hydrographic details

Figure 1. Bathymetric chart of Mountain Lake, Virginia. After Deevey, Jones, and Daly (1957).



After Deevey , *et. al.* (1957)

Figure 1

of the lake. They are based on planimetric measurements of figure 1. Mountain Lake has an even, oval margin (shoreline development = 1.37) and a maximum length of about 0.9 kilometer. Maximum width is approximately 0.25 kilometer. The lake's surface covers an area of about 0.2 square kilometer. Figure 1 shows that the basin is regular in shape, being shallowest at the southern end, and sloping gently down to a single maximum depression (31.5 meters), which is located near the north end of the lake. Due to the small area occupied by this depression, the lake has a convex profile (volume development less than 1.0). Area and volume hypsographic curves for Mountain Lake (figure 2) illustrate its morphometry: Half of the volume and 60% of the lake's area lie above the 6 meter contour; 99% of both area and volume are contained in the upper 22 meters of depth. The smoothness of the curves in figure 2 is indicative of the regularity of the bottom slope. The mean slope of the basin is 15%. Mean depth is 9.75 meters. Maximum depths reported by various workers have varied rather widely, for reasons discussed below. The location of the lake and the area of the drainage basin were calculated from the map prepared by Caster (1958).

Table 1. Morphometric and Hydrographic Statistics for Mountain Lake.

Maximum Length	870 m
Maximum Effective Length	845 m
Maximum Width	266 m
Maximum Effective Width	344 m
Mean Width	218 m
Maximum Depth	31.5 m
Mean Depth	9.75 m

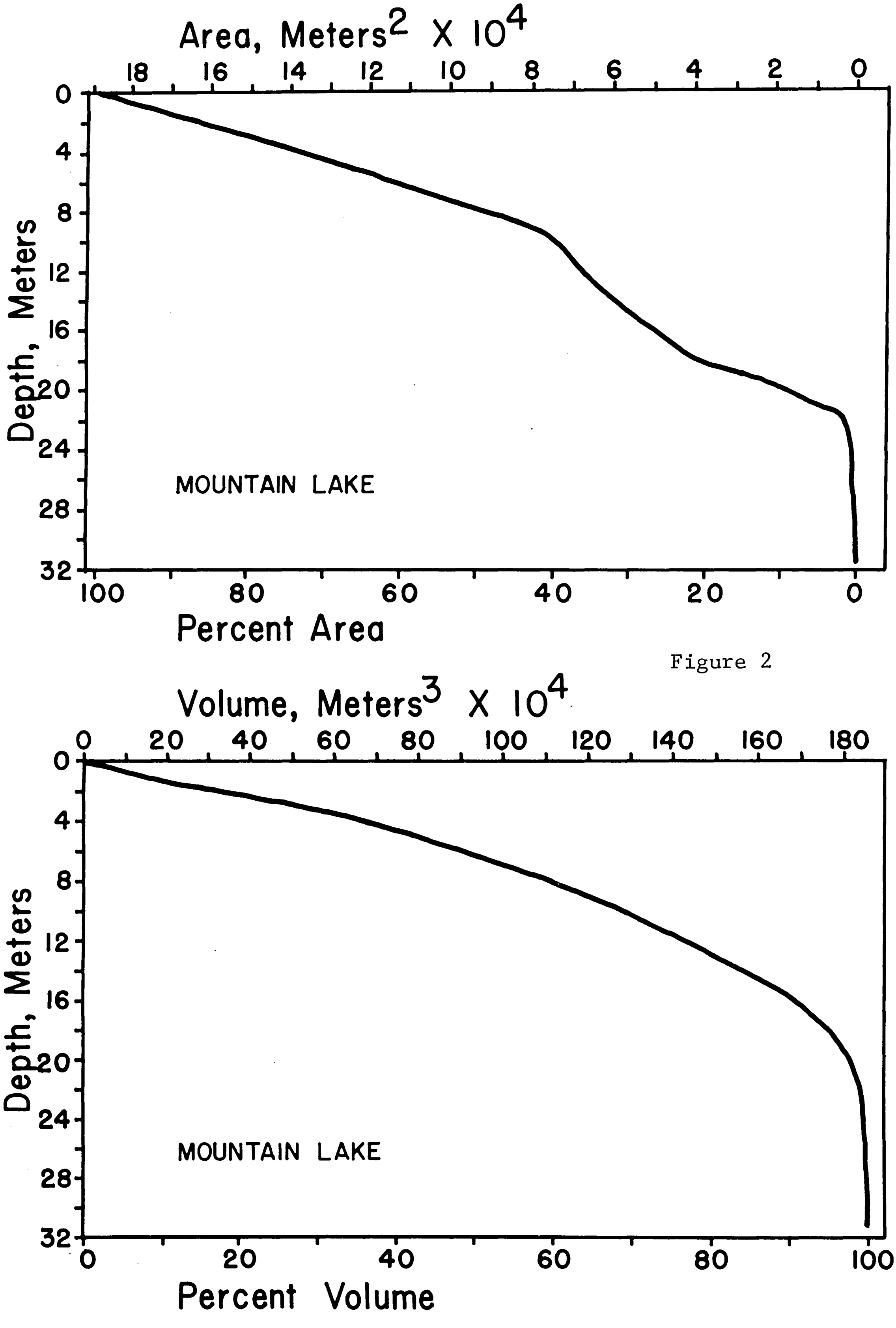
Table 1. Continued.

Mean Depth / Maximum Depth Relation	.310
Maximum Depth / Surface Area Relation	.073
Direction of Major Axis	NE-SW
Area	189,000 m^2
Length of Shoreline	2160 m
Shore Development	1.37
Volume	1,850,000 m^3
Volume Development	.93
Mean Slope of Basin	15.0 %
Elevation	1180 m
Location	37°21'56"N, 80°31'39"W
Area of Drainage Basin	0.95 km^2
Area of Drainage Basin/Area of Lake Relation	5.02

Table 2. Areas and Volumes of the Water at various levels in Mountain Lake.

Depth m	Area m^2	% Area	Volume m^3	% Volume	Length of Contour m
0	189,300	100.0	-------	------	2160
2	164,500	86.8	353,800	19.1	1980
4	137,200	72.5	301,400	16.3	1820
6	115,000	60.6	247,400	13.35	1755
8	93,300	49.2	208,000	11.25	1480
10	75,800	40.0	168,732	9.12	1168
12	67,800	35,8	143,400	7.75	1068
14	60,000	31.6	134,400	7.25	1000
16	50,650	26.8	110,566	5.97	955
18	40,600	21.4	91,100	4.93	1090
20	18,000	9.5	56,932	3.08	512
22	2,400	1.27	27,466	1.48	200
24	1,200	0.635	3,532	0.19	167
26	493	0.256	1,640	0.088	111
28	164	0.085	628	0.034	55
30	10	0.005	143	0.007	12

Figure 2. Hypsographic curves for Mountain Lake, Virginia, showing relationship of area (above) and volume (below) to depth. Based on planimetric measurements of figure 1.



Area, Meters^2 X 10^4
18
16
14
12
10
8
6
4
2
0
Depth, Meters
0
4
8
12
16
20
24
28
32
MOUNTAIN LAKE
100
80
60
40
20
0
Percent Area
Volume, Meters^3 X 10^4
0
20
40
60
80
100
120
140
160
180
Depth, Meters
0
4
8
12
16
20
24
28
32
MOUNTAIN LAKE
0
20
40
60
80
100
Percent Volume

Figure 2

PHYSIOGRAPHY

Mountain Lake, Giles County, Virginia (37° 21' 56" N, 80° 31' 39" W), is located between the peaks of Salt Pond, Doe, and Bald Knob Mountains, in the ridge and valley province of western Virginia. The surface of the lake is 1180 meters above sea level. As Dietrich (1957:7) remarked, it stands "nearly 1000 feet [305 meters] above most of the surrounding ridge tops." Platt and Shoup (1950:487) likened Mountain Lake's situation with that of a high Alpine lake. Mountain Lake has a drainage basin whose area is 5 times the area of the lake itself. The source of the water is apparently partly seepage from the small drainage basin, and partly from underwater springs. The possible influence of these springs on the annual temperature cycle in the lake is discussed below. The lack of suspended matter in Mountain Lake water is undoubtedly related to its drainage basin being composed of ancient, resistant rock, which is covered by a dense, virgin hemlock forest. The basin is largely used as a game preserve and bird sanctuary. Mountain Lake is a place of rare scenic beauty, which is enhanced by the fact that the area remains relatively uncommercialized.

The lake basin is located in a breach in the crest of an anticline of Silurian Clinch sandstone, which pitches roughly northeast. The long axis of the basin is nearly parallel to the axis of the anticline, and the valley formed in the breach lies in the Martinsburg shale (Sevier shale), of Ordovician age.

The thickness of the Martinsburg in this area is thought to be well over 300 meters (Hubbard and Croneis, 1924:339; Sharp, 1933:637). Underlying the shale are Shenandoah and Chickamauga limestones, which are highly soluble. Figure 3A is a diagrammatic cross-section of the lake basin and its adjacent ridges.

At the north end of the lake, Pond Drain, a tributary of Little Stony Creek (New River Drainage), and the lake's only outlet, cuts through the Clinch sandstone. Here the lake bottom is composed of great blocks of Clinch, which do not occur in other areas of the lake. These blocks "are continuous in occurrence with those above water near the eastern side of the outlet," according to Sharp (1933:638). It is in this area that the maximum depression occurs, and that author (1933:638) pointed out that "the depth here may vary several feet within a horizontal distance of a few inches according to whether the lead strikes or just misses the edge of one of these great blocks." A longitudinal profile of the lake, with the vertical scale exaggerated, is presented as figure 3B.

Coker and Hayes (1940:192) remarked that Mountain Lake is the only lake of substantial size in the unglaciated Appalachians. Several hypotheses of origin have been suggested for the lake, by geologists and laymen alike. Of those modes of formation discussed by Dietrich (1957), only two are worth considering here. The theory advanced by Holden (1938:73) is that the lake represents a limestone solution sink. While limestone solution caves are common in the immediate vicinity, it is unlikely that the basin of Mountain Lake

Figure 3. Vertical sections through Mountain Lake.

Figure 3A. Generalized geological section through Mountain Lake and the adjacent ridges. Section line is approximately east-west, as seen from the south.

Figure 3B. Longitudinal profile of Mountain Lake, obtained from figure 1. Taken along a curved line passing through the maximum depression.

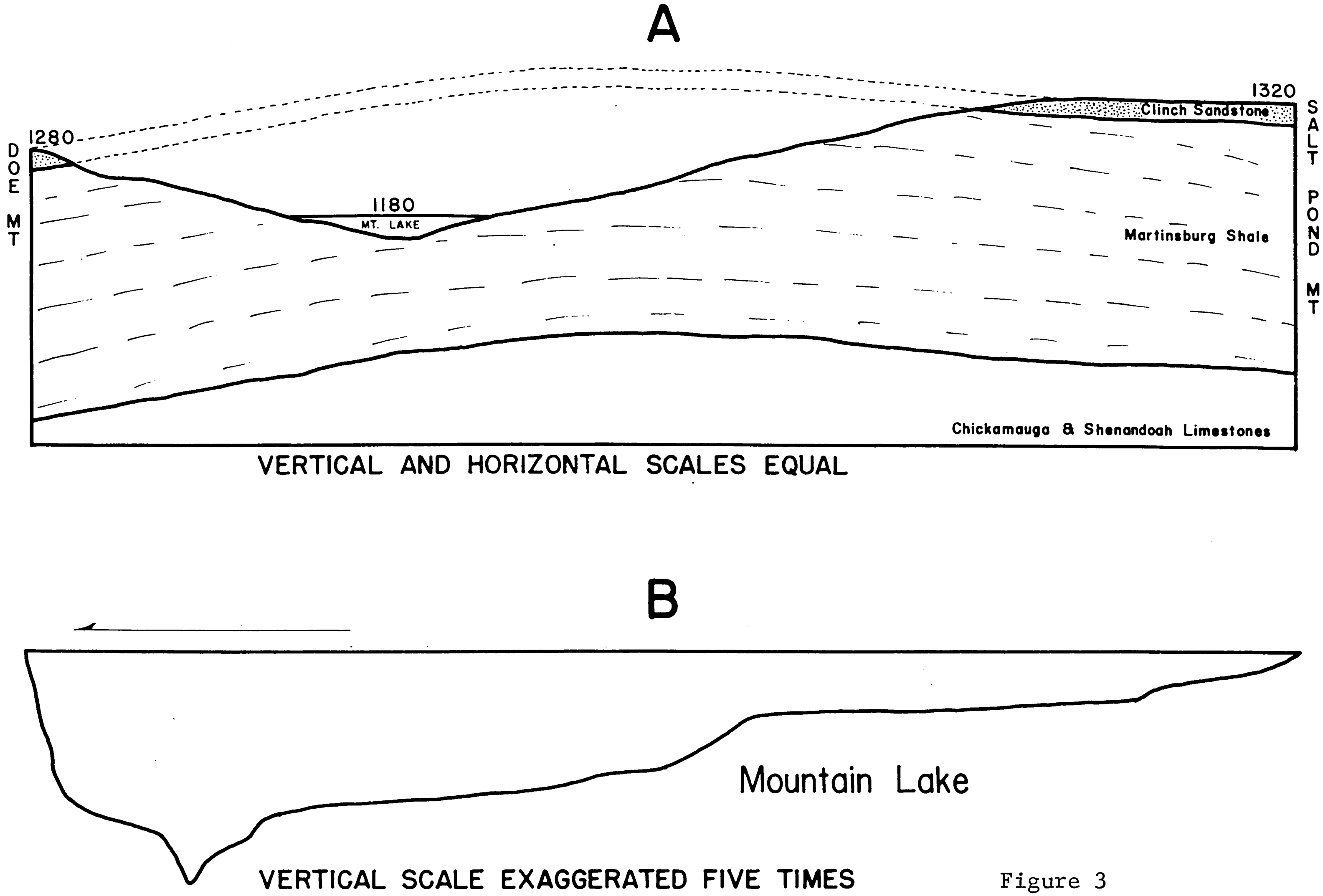

A
1280
DOE MT
1180
MT. LAKE
1320
Clinch Sandstone
SALT POND MT
Martinsburg Shale
Chickamauga & Shenandoah Limestones
VERTICAL AND HORIZONTAL SCALES EQUAL
B
Mountain Lake
VERTICAL SCALE EXAGGERATED FIVE TIMES

Figure 3

is a result of such activity, for several reasons. First, the lake basin is situated near the top of the Martinsburg shale, which is insoluble or only slightly soluble, and over 300 meters thick. Second, the margin and bottom slopes are notably regular, which is highly atypical of solution basins, according to Sharp (1933:639-640). Third, such an hypothesis would fail to explain how the Clinch sandstone, which is extremely resistant, was initially penetrated. It is possible (although improbable) that the maximum depression of the lake penetrates through the Martinsburg into the limestones below. Partial drainage through such a sink would help to explain the marked variations in water level which the lake has experienced, and which are discussed below. The initial formation of the basin, however, must be explained in another way.

A far more likely explanation, and one which was advanced by Rogers (1835:110), expanded by Sharp (1933) and Stose (in Hutchinson and Pickford, 1932:253), is that the lake basin was cut by a resequent stream (Sharp, 1933:637), which was probably the ancestral Pond Drain. The source of such a stream would have been at the top of the anticline the remains of which form Salt Pond and Doe Mountains. As the stream cut its way through the rock strata, forming the lake basin, the Clinch sandstone near the present outlet of the lake was undercut, being more resistant than the underlying Martinsburg shale. This undercutting finally caused great blocks of Clinch to break off and creep down the shale slopes, filling the stream-cut valley bottom, and eventually completely damming the valley, creating the lake. This explanation is consistent with the morphometry of the lake. Sharp (1933:640) wrote "the longitudinal profile of the basin with its gradual descent down valley to a point of sudden ascent [figure 3B] is that of a stream valley dammed by debris, the dam causing the reversal in slope." It is not known whether the lake basin penetrates the limestones which underlie the Martinsburg. It probably does not. Certainly if it does, it is only in that small area which forms the lake's maximum depression, in which case the sink thus formed would be a result rather than a cause of the lake basin formation. Dietrich has stated (1957:8) that the intermittent character of the lake can be explained in terms of factors other than solution, including periods of drought, "periodic increase of discharge through the . . . talus and sliderock dam," or a combination of these things.

HISTORICAL REMARKS

Although popular folklore and historical fact concerning Mountain Lake are often closely mixed, the following data seem to be sufficiently well documented to be admitted as historical evidence. The lake was discovered in 1751 by Christopher Gist, a surveyor who was commissioned by the Ohio Company to explore lands south of the Ohio River (Summers, 1903:47-48). At that time the lake was approximately its present size. The following passage is taken from Gist's diary, as found in Summers (1929:56).

> Saturday 11 [May 1751] . Set out S 2 M, SE 5 M to a creek and a Meadow where we let our horses feed, then SE 2 M, S 1 M, SE 2 M, to a very high Mountain upon the top of which was a Lake or Pond about 3/4 of a Mile Long NE & SW, and 1/4 of Mile wide. the water fresh and clear, and a clean gravelly shore about 10 yds. wide with a fine Meadow and six fine springs in it, then S about 4 M, to a branch of the Conhaway called Sinking Creek.

Some historians have expressed doubt that Gist actually saw Mountain Lake in 1751 (see Johnston, 1906:12-13; Pendleton, 1920:183). This opinion is unreasonable, in view of the fact that there are no other bodies of water of similar size in the vicinity.

The lake has, according to the information available, experienced radical fluctuations in water level, the probable causes of which have been discussed. It was reported by Kercheval (1925:389) that in 1804 the lake was reduced to a small pond at the lower end of the lake basin. Local farmers reputedly took their cattle to the pond for watering and "salting." Hence the name "Salt Pond" was applied to the lake, wrote Dietrich (1957:8), and is still applied to the mountain. Trees were said to have taken root at this time in what had been the shallow parts of the lake. By 1835, when the noted geologist, W. B. Rogers visited the lake, it was again at approximately its present level, and he wrote (1835:110) that "trees and shrubs that grew upon its margin [were then] seen sometimes standing erect at a considerable depth beneath the surface." Except for lesser fluctuations (of up to 3 meters) the lake basin has been "filled" since that time (Dietrich, 1957:8). Pendleton (1920:183) reported that submerged trees were seen in the lake in 1861. Pollard (1871:147) made a similar observation around 1870. Dietrich (1957:8) cited a letter to R. J. Holden, dated "7/1/44" written by one B. Ellison, in which it is claimed that in 1902-03 "the lake was more than 15 vertical feet [4.6 meters] lower than usual, at which time trees up to 18 inches [46 centimeters] in diameter were removed from the lake basin." On the basis of these data, it seems possible to the present writer that if complete or nearly complete drainage of Mountain Lake has occurred at all since 1751, it has occurred only once, around 1804. However, various reports are to be found in the literature. For example, Platt and Shoup (1950:487) stated that complete drainage had occurred at least four times during the last 250 years.

Misinformation concerning the history of Mountain Lake is widespread. One popular legend has it that during the "salt pond" period the lake was formed when cattle inadvertently stamped earth into the limestone sink through which drainage was supposed to have been occurring (previous to this time, the water "made its escape by sinking into the earth"). Thus, the lake was said by Nicklin (1837:66-67) to have been "made without hands, within the [span of?] memory of the mountaineers." The persistence of the belief that Mountain Lake is (or was) a source of "salt" is itself interesting in that Hutchinson and Pickford (1932:258) have remarked that its waters contain very low concentrations of dissolved inorganic materials. As is often the case with all except the very shallowest of lakes, Mountain Lake is considered by many (none of whom have sounded the lake) to be "bottomless." Adherents to both the "formed-by-feet" theory and the "bottomless" view ignore the mutual exclusiveness of the two. Also prominent in the local tradition is the theory that the lake has been drained (or indeed, formed) by earthquake activity. Evidence to support this contention is lacking. (Cf. Campbell, 1938; Chapman, 1949)

METHODS

Sampling of the lake was begun on 13 October 1961. By 13 January 1962, a regular series of visits to the lake was undertaken and these were continued twice a month until 19 January 1963. A sampling station was established at the north end of the lake, where the water was 22 meters deep. Both bottom samples and physical and chemical observations were often taken at the same spot. Reasons for the selection of this spot are given below.

A regular procedure for sampling was established, and on each day the following data were collected.

1. A vertical series of temperature and conductivity observations from the surface to the bottom, at intervals of one meter;
2. Water samples for hydrogen ion concentration, dissolved oxygen, and alkalinity determinations, at depths of 0, 5, 10, 15, and 20 meters;
3. The Secchi disc limit of visibility and turbidity, or ice thickness, when present;
4. The water level, measured from an arbitrary landmark;
5. Bottom materials.

Temperature and conductivity measurements were made with a Whitney Thermistor and Conductivity Meter, manufactured by Whitney Underwater Instruments, San Luis Obispo, California. The instrument was read to the nearest 0.05° C. Batteries were renewed once.

Water samples for chemical analyses were collected with a Kemmerer water sampler. Dissolved oxygen concentrations were determined by the unmodified Winkler method (Welch, 1948:207-209). This method was selected since the concentration of dissolved materials which might influence the results seem to be extremely low in Mountain Lake. Gravimetric and colorimetric determinations by Hutchinson and Pickford (1932:257-258) support this. Reagents were added to the sample bottles in the field, and titrations were made upon return to the laboratory.

Alkalinities were estimated in the laboratory by titration with N/50 H_2SO_4, using phenolphthalein and methyl orange as indicators. In addition, methyl purple was used, as a check, since its end point is more easily detected than that of methyl orange.

Hydrogen ion concentrations were determined in the field, using the Hellige Pocket Comparator, and Hellige indicators Brom-thymol Blue-D and Phenol Red-D.

Instruments were standardized twice during the course of the study. The thermistor was compared with an ice water solution; sodium thiosulfate used in the Winkler determinations was standardized against a potassium dichromate solution; the pH apparatus was compared with a Beckman pH Meter.

The Secchi disc used was 20 centimeters in diameter, with alternating white and black quadrants. Turbidity was measured with a U. S. Geological Survey turbidity rod.

The top surface of the concrete supporting pillar at the south corner of the boathouse near the lake's outlet was selected as an arbitrary reference point from which water level measurements were made.

Bottom materials were collected with a standard 15.2 x 15.2 centimeter Ekman dredge (Welch, 1948:176-178). Regular procedure in quantitative sampling included the taking of three dredge hauls on each sampling day, at a given time and place from a boat at anchor. These samples were processed separately, making statistical treatment possible. Whenever the dredge failed to return with a full load of mud the sample was discarded and the procedure repeated. Exceptions to this were in areas where the bottom soils were shallow, as noted below. A careful attempt was made to obtain three comparable samples. Each dredge load was transferred in its entirety to a covered bucket, and examination was made upon return to the laboratory. Here the contents of the bucket were washed through standard #30 and #40 nested screens, with mesh sizes of 0.589 and 0.417 millimeters, respectively. No consideration was given to organisms whose size permitted them to pass through the #40 screen. The contents of each screen were transferred to a white catheter tray, and examination was made while the animals were in the living state. Organisms were counted and removed from the trays with a needle, and transferred to vials of alcohol, or to rearing dishes, in the case of certain insect larvae. Each tray was scanned first under an illuminated magnifier, and then under a dissection microscope, to insure that all organisms were found. In the case of those organisms which were sufficiently numerous to make statistical analysis feasible, volume and mass measurements were made, using techniques described by Welch (1948:304-306). In addition, dry weights were obtained on an analytical balance of organisms which had been dried in an oven overnight at 85° C. All volume and mass measurements were made on material which had been preserved in alcohol.

Organisms used for study and identification were preserved in Kahle's Fluid. Tendipedids were reared to the adult stage in covered Syracuse watch glasses containing mud and water. During the summer of 1962, a number of larvae, pupae, exuviae, and some reared adults of this family were preserved in Kahle's Fluid; some adults were preserved on pins. Insects collected during the present study have been deposited with Dr. S. E. Neff, of the Virginia Polytechnic Institute Department of Biology. In most groups, organisms were sent to specialists for identification. The names and addresses of the experts consulted, and the groups with which they worked, are shown below.

Group	Name	Address
Oligochaeta	Dr. R. O. Brinkhurst	Department of Zoology The University Liverpool 3, England
Ostracoda	Dr. G. A. Cole	Department of Biology Arizona State University Tempe, Arizona
Tendipedidae	Dr. S. E. Neff	Department of Biology Virginia Polytechnic Institute Blacksburg, Virginia

Quantitative bottom fauna sampling during the present study was of two types. First, samples were collected from a station in the profundal zone twice a month throughout the year; second, a series of samples were collected at various profundal depths during midsummer. In the seasonal sampling series, a station was established approximately one-eighth kilometer southeast of the boathouse near the lake's outlet. The depth at this station was 22 meters. This particular site was chosen for several reasons. 1) It is easily accessible from the boathouse where the boat was launched. 2) The depth here is such that a vertical series of physical and chemical observations could be made at the same spot. This was desirable, especially under adverse weather conditions. 3) The bottom sediments in this area are thick enough to allow the dredge to function properly. 4) The area within this depth zone is fairly large (figure 1), so that animals found here could be expected to form an homogeneous community, rather than a brief transition zone. 5) The size of the depth zone made the area fairly easy to locate with the boat. On each sampling day, three dredge hauls were made at this station, as described above. Twenty-two series of three samples each were collected here, between 26 January 1962 and 19 January 1963.

The depth distribution series of samples was obtained during the first week of August, 1962. A series of three samples was obtained, from each of the following depths: 10, 13, 16, 19, 21, and 24 meters. An attempt was made to establish a sampling series along a line perpendicular to the long axis of the lake, but this was abandoned because the steep bottom slope made it impossible to hold the boat in place long enough to collect three dredge hauls from the same depth. Consequently, the series was taken in the middle of the lake, at approximately the point where the depth contour in question crossed the center line of the lake. The series was begun at the southernmost extension of the 10 meter contour line (figure 1), and samples were taken at the other depths mentioned by proceeding northward along the center line of the lake until the desired depth was encountered. This method proved satisfactory, since the bottom slopes gently in this area, and slight movements of the boat at anchor did not shift it out of the desired depth zone.

K. Berg (1938:226) has remarked that a "study of the authors who have worked for a long time with bottom samplers in lakes often leaves the impression that gradually as they get more experience, they also grow more and more sceptical with regard to the reliability of the method adopted." Quantitative bottom fauna sampling is beset by difficulties of two types. The first are technical in nature, resulting from possible errors in dredge function and in screening, counting, and weighing organisms. The second type of difficulty is statistical, as Deevey and Bishop (1942:90) have observed, in that very large areas are sampled with very small apparatus. In the present study an attempt was made to reduce technical errors in several ways: 1) Non-comparable dredge hauls were discarded.

2) Screening was done in the laboratory, thereby avoiding errors which are almost certain to occur when screening is done in the field, especially under adverse weather conditions. 3) Entire dredge hauls were examined, rather than aliquot samples of them, thereby avoiding subsampling error. 4) Living material rather than preserved material was examined.

These procedures were time-consuming, however, and precluded the taking of a large number of samples in the time available. This increased the possible effect of errors of the statistical type, although it is felt that the reduction of technical errors thus achieved helps to offset the necessarily small sample size. This is supported by the findings of Deevey and Bishop (1942:90) who stated: "This [statistical] error cannot be materially reduced by taking three to five times as many samples." (Cf. Deevey, 1941:419).

An attempt was made to gain information about the inherent statistical error by separate examination of dredge hauls collected at a given time and place. In this way, the residual error found could be compared with differences between sampling series, in analyses of variance.

Qualitative samples were collected in various parts of the lake at all seasons, but especially during the summer. These samples were processed in a manner similar to the quantitative samples.

Collections of submerged plants were made during the summer of 1962, using skin diver's gear. This method permitted observations on the distribution and growth habits of the plants. These observations in the shallow water were supplemented by a number of dredge samples from the lower littoral zone. Plant identifications were checked by Dr. J. H. Hardin, or by comparison with specimens in the herbarium of the Mountain Lake Biological Station.

Gravimetric determinations were made of profundal sediments to determine loss on ignition and solubility in hydrochloric acid. These were made on mud collected from the seasonal sampling station (depth 22 meters) on 19 January 1963. Mud was placed in tared Gooch crucibles, dried overnight at 85° C., and cooled in a dessicator. After weighing on an analytical balance, the mud was ashed at 400°C. for six hours, cooled, and reweighed. Equal parts of concentrated hydrochloric acid and water were added to the contents of the crucibles and they were allowed to stand for 48 hours. The soluble contents were then washed out, and the insoluble remainder was dried overnight at 85° C., cooled, and weighed. The color of the mud after drying and after ashing was compared to the ISCC-NBS color scale (Rice, et. al., 1941).

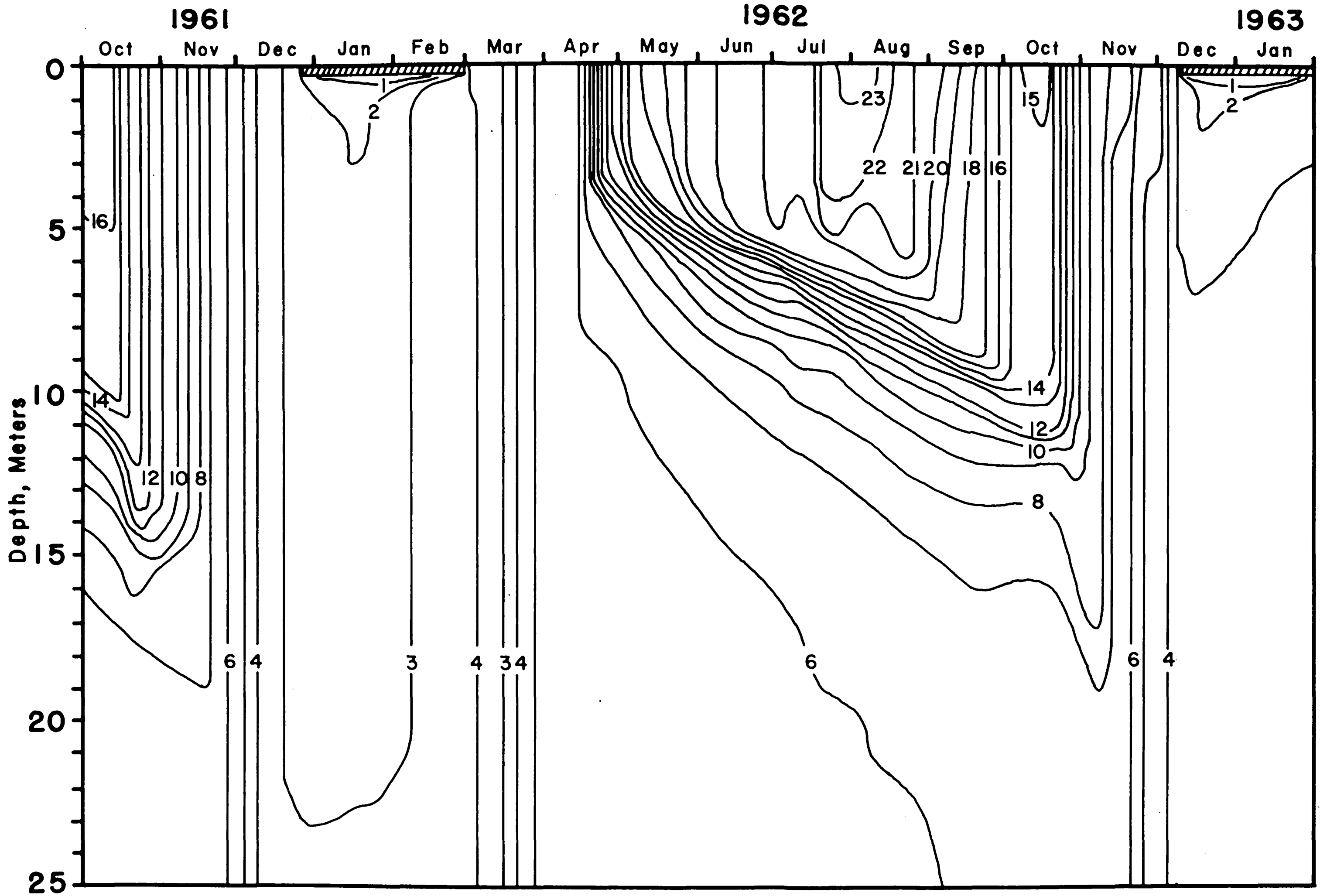
PHYSICAL AND CHEMICAL ASPECTS

TEMPERATURE

Twenty-nine vertical temperature series were obtained, between 13 October 1961 and 19 January 1963. The temperature data is presented in Appendix I. Figure 4 shows the vertical distribution of isotherms in Mountain Lake for the period under study. Selected vertical temperature series are shown in figures 5 and 6. In the following discussion, the terms epilimnion, metalimnion, thermocline, and hypolimnion are used in Hutchinson's sense (1957:427-428).

a. Autumnal Circulation. The fall overturn in Mountain Lake began about 15 November in 1962, and probably about the same time in 1961. At this time the water became isothermous at approximately 6.5^{o} C. Figures 6A and 6B illustrate the onset of circulation in 1962. The waters then cooled in an isothermous condition until the ice cover became established. Although the minimum isothermous temperature observed was 3.4^{o} C. (13 December 1961), it is likely, considering the temperature of the water under the ice immediately following the freeze (13 January 1962), that temperatures as low as 2.65^{o} C. prevail during the fall circulation period. The winter of 1962-1963 was considerably colder than the preceding year. This is reflected in the winter temperature cycle of Mountain Lake for the year: Whereas in 1961-1962 the cooling process from establishment of isothermy to the onset of inverse stratification took no less than six weeks, this was accomplished the following year in hardly more than four (figure 4). It is probable, however, judging from the data

Figure 4. Vertical distribution of isotherms in Mountain Lake, during the period 13 October 1961 through 19 January 1963.



Mountain Lake, Virginia—1961-1963 Figure 4 for 5 December 1962, that the temperature of the water at the time of the ice formation was slightly higher in the second season studied.

b. Winter Stratification. Inverse stratification began with the establishment of ice cover. This took place, in the winter of 1961-1962, around 1 January. During that winter the thickness of the ice never exceeded 15 centimeters, and the duration of ice cover was approximately 8 weeks. The lake froze three weeks earlier and attained a thickness of at least 28 centimeters the following year. Observed ice thicknesses at the sampling site are shown in Appendix IV. The duration of the ice cover in the winter of 1962-1963 is not known, since sampling of the lake was discontinued on 19 January 1963. It is possible that in less severe winters than those observed, Mountain Lake does not freeze at all; or that it freezes, thaws, and refreezes during one winter. In such a season, the lake would appear to be influenced more by its latitude than by its elevation. Its temperature cycle would, in that event, be comparable to that described by Cole (1954) and Krumholz and Cole (1959) for Tom Wallace Lake, Kentucky. Hutchinson (1957: 440-443) has discussed the effects of latitude and altitude on temperature regimes in lakes. It would appear from his statements that Mountain Lake is within the latitude for warm monomixis. Probably the lake would be monomictic if its elevation were lower.

It is evident from Appendix I and figure 4 that the waters of Mountain Lake warm considerably during the period of ice cover. This phenomenon has been discussed for other lakes by Hutchinson (1957:454-456), who attributed it to solar radiation and warming from the bottom mud. In addition to these factors, it is likely that winter heat is also contributed in Mountain Lake by underwater springs, which are stated by Hutchinson and Pickford (1932: 253-254) to be around 5° C. Figures 6C and 6D illustrate this heating process, which is apparent from the data of both years studied. For example, the mean temperature of the water on 13 January 1962 was 2.21° C., and by 11 February, less than a month later, the mean temperature was 3.31° C.

c. <u>Vernal Circulation</u>. The ice cover on Mountain Lake was partially destroyed in 1962 on 2 March. On that date about one-third of the water was open, and the remaining ice sheet occupied the southern end of the lake. This ice was weak and "honey-combed." The temperature series taken from a boat near the edge of the ice sheet showed an unstable inversion of 0.2° C. (Appendix I). The warm surface temperatures may have been caused by warm melt water flowing in from the top of the ice. Two weeks later ice was completely absent, and the water entered into circulation at an isothermous temperature of about 4° C. (figure 5A, 18 March 1962), and then began isothermous warming. Since data from this season were collected only for a single year, it is impossible to say whether this period of vernal cooling generally occurs, or whether the 1962 instance constitutes an anomaly. By 1 April, the mean water temperature was 5.38° C. On 15 April the first signs of resistance to mixing appeared, the water below the 15 meter contour being at approximately 5.5° C. The spring overturn thus occupied six weeks in 1962.

d. Summer Stratification. Summer stratification is the longest thermal season in Mountain Lake. In 1962, this condition prevailed for seven months, from the middle of April until the third week of November. Thermal resistance to mixing was well established by the end of April (figure 5B), at which time the thermocline lay at 4.5 meters. The temperature of the hypolimnion at this time was approximately 5.5° C., and that of the epilimnion about 13° C. After the formation of a well-defined thermal gradient, the surface waters warmed rapidly (figure 4). As summer progressed, the epilimnion continued to warm, and the level of the thermocline gradually dropped. At the same time, the hypolimnion steadily gained small amounts of heat. Figure 5C illustrates the temperature conditions on 31 May 1962. At this time the thermocline had dropped to 5 meters, and the metalimnion was found between 4.5 to 8.5 meters in depth. The maximum surface temperature, 23.1° C., was observed on 6 August 1962 (figure 5D), although the highest mean temperature (13.04° C.) was recorded two weeks later. On the former date, a small secondary thermocline appeared at 4 meters. The primary one on that date was found at 9 meters. The temperature of the hypolimnion at the height of thermal stratification was 6° C.

After 20 August, the lake began to lose heat in the upper strata, while slight increases in hypolimnetic temperature continued. The thermocline continued to move downward. This process was interrupted by a short period of high temperatures in October, which warmed the surface waters enough to raise the mean temperature slightly (figure 4). This was not of long duration, however, and the cooling soon resumed. By early November (figure 6A) the upper circulating layer had penetrated to a depth of 18 meters. A small thermal gradient (about 2^{o} C.) still separated it from the remainder of the lake. The lake had entered into autumnal circulation by the time the next observation was made, two weeks later.

Temperature Summary. In the classification scheme proposed by Hutchinson (1957:437-440), Mountain Lake is a second class temperate dimictic lake. Data collected during the present study indicated that the annual range of surface, bottom and mean temperatures, respectively, were 0-23.1, 2.65-6.6, and 2.21-13.04, all in degrees Celsius. Mountain Lake has four thermal seasons, autumnal circulation, winter stratification, vernal circulation, and summer stratification. The respective duration of each in the 1961-1962 year were approximately 6, 8, 6 and 28 weeks.

CONDUCTIVITY

Conductivity readings were made in situ and later corrected to a reference temperature (18^{o} C.), using the methods and correction coefficients provided by Smith (1962). It was found that the conductivity meter employed was not sufficiently accurate for use in water which has the extremely low electrolyte concentrations found in Mountain Lake. The data obtained did, however, indicate that there is no appreciable vertical gradient of electrolytes in Mountain Lake at any season. The actual conductivity of the water probably averages between 9 and 18 micromhos (reciprocal megohms), since those values were the lowest and highest obtained. There is little doubt that the electrolyte contents of the water are very slight, since the instrument when tested with ion-exchanged water recorded approximately 6 micromhos. Hutchinson and Pickford (1932:257-258) made gravimetric determinations of the water of Mountain Lake, and found 10.4 milligrams per liter of inorganic material. Those authors commented on the oligotrophic nature of the water, pointing out that no North American water then known contained as little inorganic material.

TRANSPARENCY AND TURBIDITY

Observed Secchi disc limits of visibility are shown in Appendix IV . Transparencies varied considerably between sampling days, and could not be correlated with other characteristics of the lake. The highest reading obtained was 8.5 meters on 19 October 1962. Lowest was 4.8 meters, recorded on 1 April 1962. Mean value was 6.15 meters. Secchi levels are shown for certain sampling days in figures 5 and 6. As Hutchinson and Pickford (1932:256) have observed, the disc at half of the limit of visibility appeared light yellowish green in color.

Turbidity values, when measured with the USGS turbidity rod, did not fall within the range of that instrument. Seven milligrams per liter (parts per million) silica is the smallest concentration which can be measured with the rod; all observations in Mountain Lake were considerably lower than this.

DISSOLVED OXYGEN

Appendix II contains the dissolved oxygen values determined for Mountain Lake, as well as the approximate percent saturation for each observation. The latter figures were extracted from Mortimer's revised nomogram, as found in Hutchinson (1957:582), and corrected for an altitude of 1200 meters. Dissolved oxygen concentrations are also shown for selected days on the composite diagrams (figures 5 and 6). Saturation values shown in these figures were taken from the tables of Truesdale, Downing, and Louden, as given by Hutchinson (1957:580), and similarly corrected.

a. <u>Annual Cycle</u>. During the spring overturn, dissolved oxygen became uniformly distributed with respect to depth, as the lake "took a deep breath." By 18 March 1962 (figure 5A) the water was 91-95% saturated with the gas, the concentration being about 10.5 milligrams per liter. Similar saturation values were found throughout the vernal circulation period, and no supersaturation was observed while the lake was in isothermy.

As the upper waters began to warm, their ability to retain oxygen in solution was reduced, and the warming layer lost oxygen

Figure 5. Composite diagrams illustrating the vertical distribution of physical and chemical factors in Mountain Lake.

Figure 5A. Early spring warming, 18 March 1962.

Figure 5B. Early summer stratification, 29 April 1962.

Figure 5C. Summer stagnation, 31 May 1962.

Figure 5D. The height of summer stagnation, 6 August 1962. Stippled area denotes water supersaturated with oxygen.

Symbols used:

 secchi disc; length of vertical line represents limit of visibility.

θ temperature, ^{o}C.

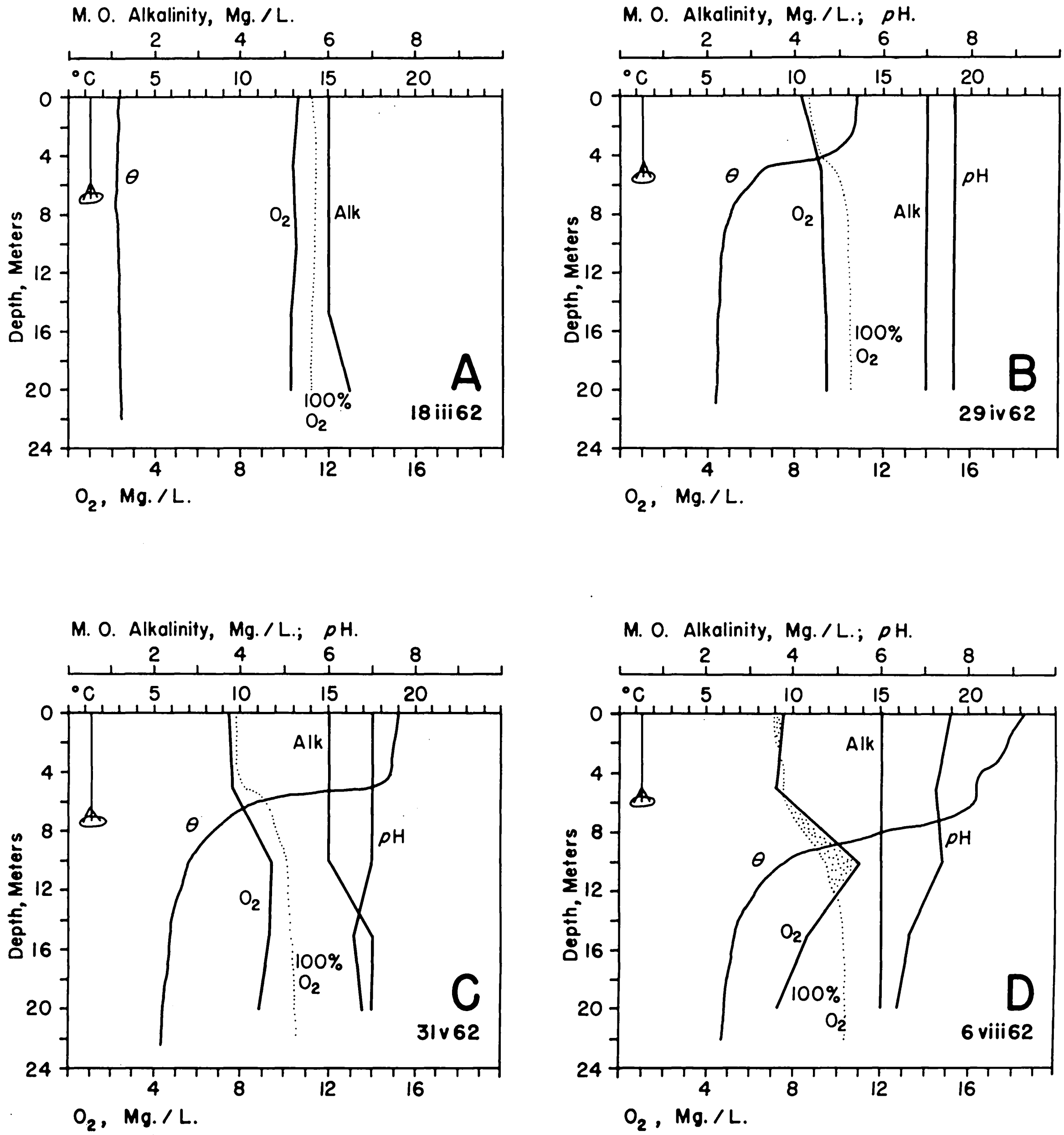

M. O. Alkalinity, Mg. / L.
°C
Depth, Meters
θ
O2
Alk
100% O2
A
18 iii 62
O2, Mg. / L.
M. O. Alkalinity, Mg. / L.; pH.
θ
O2
Alk
pH
100% O2
B
29 iv 62
M. O. Alkalinity, Mg. / L.; pH.
Alk
θ
pH
O2
100% O2
C
31 v 62
M. O. Alkalinity, Mg. / L.; pH.
Alk
θ
pH
O2
100% O2
D
6 viii 62

Figure 5

to the atmosphere. This is illustrated by figure 5B, showing conditions on 29 April 1962. In this figure, it is apparent that the metalimnetic and hypolimnetic oxygen concentrations have not yet been affected by the lack of circulation which is to prevail throughout the summer. On 31 May, however (figure 5C), while the circulating epilimnion remained in contact with the atmosphere, and 96-98% saturated, the metalimnion showed a slight development of a maximum concentration, a condition which became more pronounced as warming of the water continued. On that date the hypolimnion began to reflect a small saturation deficit. This is a common occurrence in lakes in general, and is usually considered to be caused by oxidation of falling seston into the lower depths, and, to a lesser extent, the respiration of profundal bottom animals. Quantitative aspects of the oxygen deficit are discussed below.

The data for 6 August (figure 5D) are typical for the lake at the height of summer stratification. A slight supersaturation of the surface water was noted, which probably resulted from the inability of the water to lose oxygen rapidly enough to keep pace with the warming at the surface. The metalimnetic maximum was well developed on that date, the water at 10 meters being 115% saturated. Hutchinson (1957:620-621) discussed this type of oxygen distribution for other lakes, and attributed it to photosynthesis by phytoplankton in the metalimnion, where sharp viscosity changes in the water delay their descent. This positive heterograde type of oxygen curve is a normal occurrence in lakes where the compensation point lies within the metalimnion, allowing oxygen production to continue at that depth. If the compensation point is taken as 1.2 times the Secchi disc limit of visibility (Hutchinson, 1957:620), this condition would have been satisfied in Mountain Lake on 6 August 1962. The hypolimnetic oxygen concentration on that date had dropped to 70% of saturation (7.3 milligrams per liter). Hutchinson and Pickford (1932:256) sampled the lake on 1 August 1931 and found a positive heterograde oxygen distribution and a similar saturation value in the hypolimnion (70%).

During the cooling phase of the lake cycle in late summer, oxygen became renewed at successively lower depths, as the circulating epilimnion expanded downward. Figure 6A shows the conditions in Mountain Lake on 5 November, shortly before the beginning of autunmal circulation. Here the circulating water shows high oxygen concentrations (88-92% of saturation), while the remaining non-circulating bottom layer shows the maximum oxygen deficit observed (5.5 milligrams per liter, or 57% of saturation). Profundal bottom organisms can withstand much lower oxygen concentrations than this (Welch, 1952:181). It is certain, especially considering the temperatures of the hypolimnion, that oxygen is not a limiting factor to benthos in Mountain Lake.

Two weeks later, on 17 November (figure 6B), the fall overturn was in progress, and oxygen was once more uniformly distributed with respect to depth (9.4-9.6 milligrams per liter, or 91-98% of saturation). As isothermal cooling progressed, oxygen concentrations increased slightly, so that at the beginning of inverse stratification, the water contained 9.8-10.6 milligrams per liter of the gas.

Figure 6. Composite diagrams illustrating the vertical distribution of physical and chemical factors in Mountain Lake.

Figure 6A. Shortly before the beginning of autumnal circulation, 5 November 1962.

Figure 6B. During early autumnal circulation, 17 November 1962.

Figure 6C. During early winter stratification, 17 December 1962.

Figure 6D. During late winter stratification, 19 January 1963. Stippled area denotes water supersaturated with oxygen.

Symbols used as in figure 5.

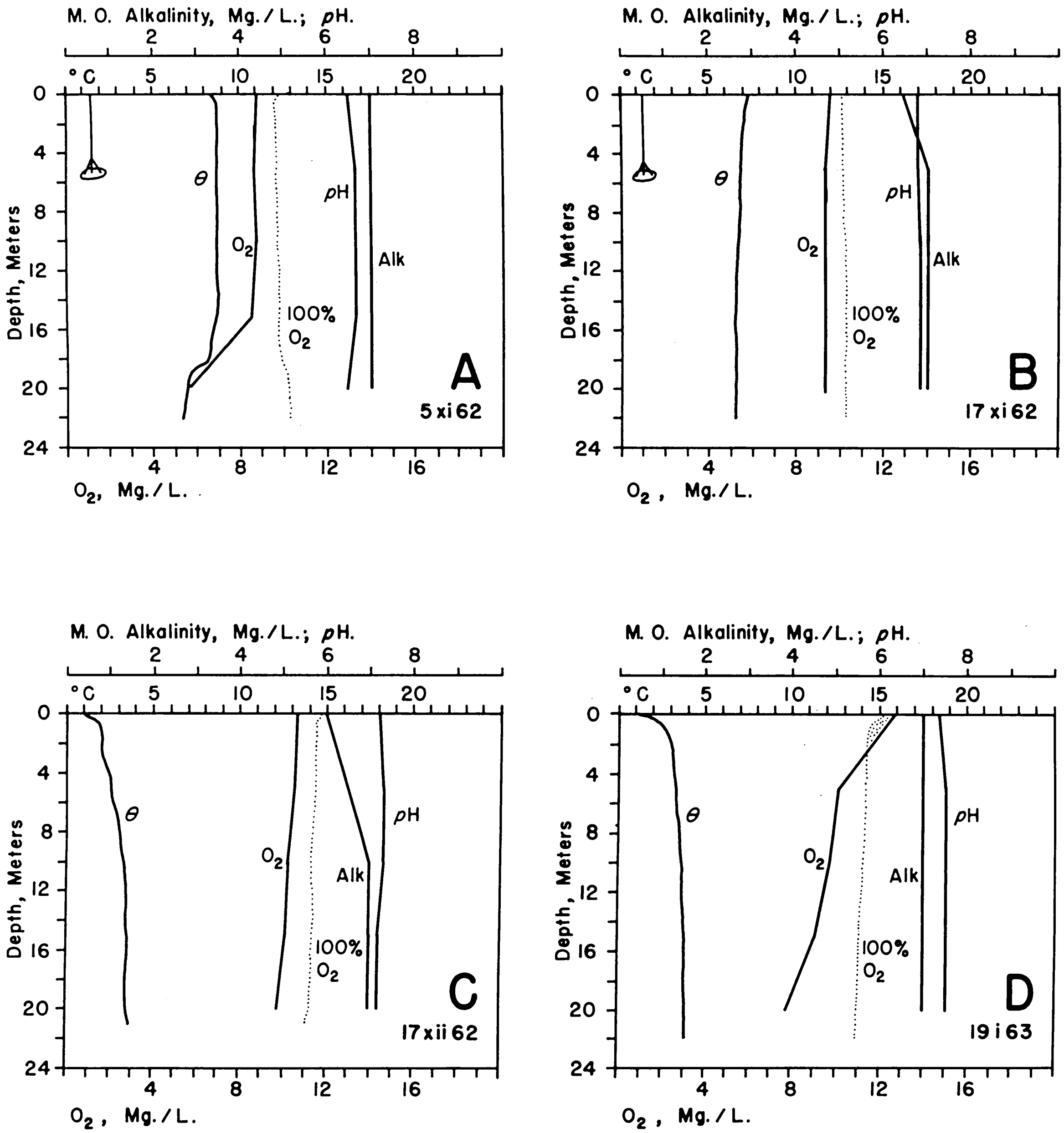

M. O. Alkalinity, Mg./L.; pH.
°C
Depth, Meters
O2, Mg./L.
θ
O2
100% O2
pH
Alk
A
5 xi 62
B
17 xi 62
C
17 xii 62
D
19 i 63

Figure 6

The oxygen distribution during inverse stratification was similar to that during direct stratification, except that no metalimnetic maximum developed in winter. In early winter, as in early summer, oxygen was uniformly distributed, near saturation (figure 6C). After five weeks of winter stagnation (figure 6D) a definite oxygen deficit near the bottom could be detected. The supersaturation of the water immediately under the ice shown in figure 6D could have been caused when the presence of the ice prevented the loss of oxygen in response to winter warming; it may also have been in part an artifact resulting from inadvertent agitation of the water with the ice spud, as the samples were being collected.

b. The Areal Oxygen Deficit. The quantitative aspects of the oxygen deficit, and its use in analysis of the productivity and typology of lakes has been discussed by Hutchinson (1938; 1957: 639-649). He pointed out that mere visual inspection of an oxygen curve can be misleading, due to the effect of the morphometry of the lake in question on the hypolimnetic deficit, and suggested the areal deficit as a means of eliminating this error. Arbitrary values were set, to distinguish lake types on this basis.

Using data from Appendix II and table 2, the actual hypolimnetic areal deficit (*sensu* Hutchinson, 1957:642) can be calculated for Mountain Lake. If the upper limit of the hypolimnion on 6 August 1962 is taken as 14 meters (figure 5D), it is seen from table 2 that this stratum has an area of 60,000 square meters. Since the volume of water below that contour, as given in the same table, is 134,400 cubic meters, the average depth of the hypolimnion on that date was $\frac{134,400 \text{ m}^3}{60,000 \text{ m}^2} = 2.24$ meters. Each square centimeter of the hypolimnion surface, therefore, covers a volume of 1 cm^2 x 224 cm = 224 cm^3. The average hypolimnetic oxygen concentration on 6 August was 7.9 milligrams per liter; this corresponds to $\frac{7.9 \text{ Mg}}{1000 \text{ cm}^3}$ x 224 cm^3 = 1.778 milligrams per square centimeter of hypolimnetic surface. In a similar manner the oxygen concentration per square centimeter of hypolimnetic surface on 15 April is calculated $\frac{9.75 \text{ Mg}}{1000 \text{ cm}^3}$ x 224 cm^3 = 2.182 milligrams per square centimeter. In 113 days stagnation, 2.182 – 1.778 = 0.404 milligrams per square centimenter were consumed. This corresponds to $\frac{0.404}{113} = 0.0035$ milligrams per square centimeter per day. This value of the areal oxygen deficit is well within the range denoting oligotrophy. The oxygen deficits observed in the hypolimnion of Mountain Lake are thus influenced by the lake's small mean depth (9.75 meters). It is seen that the lake basin is more or less of a eutrophic type, while other estimates of productivity, such as the areal oxygen deficit, water quality, and bottom type and fauna (discussed below) would indicate oligotrophy.

ALKALINITY

Alkalinities are reported in Appendix III and figures 5 and 6. The highest methyl orange (bicarbonate) alkalinity observation made was 8.0 milligrams per liter, although on most days 6 or 7 milligrams per liter was found. The extreme softness of Mountain Lake water is probably a consequence of the insoluble rocks in the drainage basin. No important vertical concentration gradient was found at any season. When depth differences appeared, they were never more than one milligram per liter. No phenolphthalein alkalinity was present at any depth or at any season.

HYDROGEN ION CONCENTRATION

Appendix III and figures 5 and 6 contain the pH data collected. The total range of hydrogen ion concentration found was pH 6.4-7.6. During most seasons the surface water of Mountain Lake was slightly alkaline, pH 7.2-7.6. Acid water (pH 6.6-6.8) was found at the surface in October and November, 1962 (figures 6A and 6B), probably as a result of allochthonous materials in the drainage basin and in the lake itself.

During summer stagnation the pH curve strongly paralleled the oxygen curve (figures 5C and 5D). The metalimnetic maximum is probably, as in the case of the oxygen distribution, related to phytoplankton concentration. Partial hypolimnetic oxygen depletion in summer was accompanied by acid pH values, as low as 6.4. This condition was not apparent during winter stagnation, however (figure 6D).

WATER LEVEL

Water level observations are presented in Appendix IV. The total range observed in 1962 was 66 centimeters. Mountain Lake levels respond rather quickly to rainfall increases within the drainage basin. For example, frequent rains during the first week of August raised the lake's level 19 centimeters. Highest water levels were noted in winter and spring. The water gradually dropped as summer progressed, to an autumn minimum on 5 November. After that date, the water rose rather quickly, achieving approximately its spring level by 17 November.

BENTHOS

BOTTOM MATERIALS

The littoral zone in Mountain Lake is not extensive. Except for a small area near the boathouse at the north end of the lake, and the area surrounding its southern tip, the lake bottom drops off sharply from the shore (figure 1). Thick growths of Rhododendron and Kalmia extend to the water's edge, and in many areas overhang the water. Emergent vegetation is virtually absent in Mountain Lake, except for the areas mentioned, where the water is sufficiently shallow to allow a sparse growth of a few emergent species. The ecological influence of these plants on the lake in general is probably slight. The list compiled by Thorne and Cooperrider (1960) includes plants along the shore. Appendix V is an annotated list of submerged plants found in Mountain Lake during the summer of 1962. The lower littoral zone in the lake is covered by a fairly continuous *Nitella* bed. The maximum downward extension of living *Nitella* was found to be about 10 meters, which depth may be taken as the downward limit of the littoral zone. Only six other plant species were found. They included *Elodea* and two species of *Potamogeton*. Although only desultory collections were made of littoral animals in Mountain Lake, the fauna in this zone appears to be a poor one. Papers by Beyers (1951), Carter (1944), and Ferguson, *et. al.* (1939) include local records and notes on the Odonata, Harpacticoida and Turbellaria, respectively.

Typically, the bottom of Mountain Lake is rocky near the shore, with soft bottom materials increasing in thickness as the depth increases. Observations made in conjunction with the depth distribution samples yielded the following information about the bottom types in the lake. The Ekman dredge was practically useless at depths less than ten meters. Here the bottom soil must be very thin, since the sounding lead can be heard "clicking" against the bottom, as on bare rock. At 10 and 13 meters the bottom still "feels" rocky to the sounding lead, but some mud was brought up with the dredge. It is estimated that the thickness of the mud at the former depth is 6-8 centimeters. At that depth the wet mud appeared chocolate brown. Small chunks of sandstone, grading into sand, were collected there. Materials collected at 13 meters were similar to those from ten meters, except that living plants were absent, and the stones in the washed sediments were more numerous and slightly larger. At 16 meters, the mud was thick enough to allow the dredge to penetrate about 10 centimeters. Here the mud was of a similar color when wet, but contained more sand. No sandstone chunks larger than one centimeter were collected at this depth.

Soft bottom materials at 19, 21, and 24 meters were thick enough to allow the dredge to obtain a full sample. At these depths stones were not collected, fine sand being the largest particle size in the washed sediments (apart from decaying leaves, etc.). A marked vertical stratification was observed in the mud at 19 meters. The superficial, dark chocolate brown layer of watery consistency appeared to be about 7-8 centimeters thick. Under this superficial ooze, a claylike layer was found. The mud at 21 and 24 meters showed a similar two-layered stratification, the only important difference being that the underlying clay layer appeared to become more viscous with increasing depth. The bottom at the seasonal sampling station was of this layered type. It was possible, as was noted by Eggleton (1931:249) of Third Sister Lake, Michigan, to separate these layers and obtain nearly pure samples of each. This was done, and gravimetric determinations were made on each layer separately. To make statistical comparison possible, three samples were determined from each layer. It is seen from table 3 and the analysis of variance table below that the superficial ooze had a significantly higher organic content(as estimated by loss on ignition) than did the underlying clay. Abbreviations used in the tables below are explained in Appendix VI.

Analysis of Variance--Percent Loss On Ignition

Source of Variation	df	SS	MS	F
Between Levels	1	169.0598	169.0598	3,321.41**
Within Levels	4	0.2035	0.0509	--------
Total	5	169.2633	--------	--------

Materials insoluble in hydrochloric acid appeared to be mainly fine white sand, so a rough estimate of the silica content of the mud is obtained by solubility tests. It was found that the two layers were not significantly different with respect to the silica content of the

** significant at 1% level.

insoluble residue:

Analysis of Variance--Percent Soluble of Inorganic Residue

Source of variation	df	SS	MS	F
Between Levels	1	0.3078	0.3078	0.101
Within Levels	4	12.1903	3.0476	----
Total	5	12.4981	----	----

The following table summarizes the information obtained on the quality of the profundal mud.

Table 3. Gravimetric data on Profundal Mud

	ooze	clay
Ignitable Matter (organic)	18.76%	8.14%
Insoluble in Acid (silica)	71.49%	81.25%
Soluble in HCl	9.75%	10.61%
Total	100.00%	100.00%
ISCC-NBS Color, After drying	brownish gray	light brownish gray
ISCC-NBS Color, After Ashing	weak orange	weak orange

Hutchinson and Pickford (1932:258) found similarly low organic and high silica content in mud collected from Mountain Lake at 20 meters. Those authors commented that the mud "reflects the oligotrophic condition of the water," a statement verified by the present data.

PROFUNDAL BOTTOM FAUNA

a. Qualitative. Following the usual practice, benthic habitats in Mountain Lake can be divided into littoral, sublittoral, and profundal zones. If the downward limit of the littoral zone is taken as the lakeward limit of rooted plants (Eggleton, 1931:245), this zone would extend to a depth of about 10 meters in Mountain

Lake. The sublittoral, in Eggleton's sense, extends to the upper limit of the hypolimnion, and thus increases in area with the falling thermocline which marks the advance of summer stratification. The profundal zone lies below this, and reaches to the bottom. The depth distribution data reveal that during the first week of August, 1962, a transitional, sublittoral fauna was found at 10 and 13 meters. At these depths, in addition to the profundal species, several other kinds of organisms were found, although each was present only in small numbers (less than 30 per square meter of bottom surface). These constitute the sublittoral fauna. This fauna in Mountain Lake included water mites (Hydracarina), free-living nematodes, bottom-dwelling copepods, heleid larvae, Calopsectra (=Tanytarsus) larvae (Tendipedidae), finger-nail clams (Sphaeriidae), and the gastropod, Helisoma. Undoubtedly other animals are found here as well, but escaped collection in the small number of samples taken in this zone. These animals were rarely collected at profundal depths, and when they were found, without exception, only a single individual was obtained from the three dredge hauls.

It is characteristic of a truly profundal fauna that it is qualitatively poor but quantitatively rich (Eggleton, 1931:253). Such a fauna was found in Mountain Lake below 16 meters. The typical profundal fauna consisted in most cases of familiar lacustrine species known from other localities. These included tubificid oligochaetes, Chaoborus larvae, tendipedid larvae, and ostracods. The most striking feature of the profundal bottom fauna of Mountain Lake is that the most numerous organisms found were tubificids, whereas in many lakes tendipedid and _Chaoborus_ larvae constitute the dominant profundal populations. The following species were found during the present study to form the typical profundal bottom fauna.

ANNOTATED LIST OF PROFUNDAL BOTTOM FAUNA

OLIGOCHAETA

Limnodrilus hoffmeisteri Clap. This species was found to constitute about 10-15% of the oligochaete fauna at 16 meters. It occurred less frequently in samples from lower depths. _L. hoffmeisteri_ may have been commoner in the littoral zone, although no data are available to demonstrate this.

Tubifex templetoni Southern. _T. templetoni_ populations were found to contain larger numbers per unit area of bottom, at all profundal depths, than any other organism collected. Except for depths where the larger _L. hoffmeisteri_ is common, _Tubifex_ also accounted for most of the volume and mass of animals per unit of bottom area. Brinkhurst (personal communication) commented that the association of _L. hoffmeisteri_ and _T. templetoni_ also occurs, at 30 meters, in Lake Windemere, in the English Lake District.

Lumbriculidae. A few immature lumbriculids were found at 16 meters and shallower. These are possible littoral and sublittoral forms.

OSTRACODA

Candona sp. Mature males and females of *Candona* collected in August, 1962 showed morphological characteristics intermediate between those of *C. caudata* and *C. intermedia*. They could not be assigned to either of these species, however. *Candona* was found at all profundal depths. Ostracods showed both an autumn population maximum and a smaller vernal one, at 22 meters (see below). It is impossible from the present data to tell whether a single species with two generations per year is involved, or whether the spring form is another species.

DIPTERA

Chaoborus (*Sayomyia*) *punctipennis* Say. Phantom midge larvae were collected at all profundal depths.

Microtendipes sp. This species was identified from a larva collected at 13 meters in summer. It is probably found under deeper water as well.

Tendipes (*Tendipes*) *attenuatus* (Walk.) (valid name for *T. decorus* (Joh.)--see Townes, 1959:135). *T. attenuatus* was the largest and most common tendipedid found. Adults of this species were reared from larvae collected at various profundal depths, and from the littoral zone. Mature larvae and pupae were collected at 22 meters during July and August. Immature larvae were most numerous in February and March.

Tendipes (_Limnochironomus_) _modestus_ (Say). This is a small species which is apparently present throughout the profundal zone. Reared adults of _T. modestus_ were difficult to obtain, however. Adults of this species are presumed to have emerged in August and September, since mature larvae and pupae were collected then, and only at that season could successful rearings be accomplished.

Procladius culiciformis (L.). _P. culiciformis_ was present at all profundal depths, and apparently in the littoral zone as well. Like those of _T. modestus_, the larvae of this species are very active swimmers, and also proved difficult to rear in the laboratory. The predatory habit of this species, referred to by Neff (1955:5) accounts for the difficulty in rearing the adults. Emergence time was late summer, as in _T. modestus_.

No qualitative nor quantitative statement concerning Turbellaria is possible, beyond the fact that these animals seem to have been present at all depths. It was found that the screening technique used allowed flatworms to pass through the #40 screen during the washing process, either by fragmenting them or distorting their bodies enough so that they could pass through the screens. When qualitative samples were allowed to stand overnight in buckets, a few flatworms could often be observed on the sides of the bucket. These were never found in the screens after washing, however.

Ferguson, _et. al_. (1939) studied the Turbellarian fauna of Mountain Lake during the summer of 1938. These authors sampled mainly in shallower water, but made some collections at 9.1 meters, where two species, Euplanaria trigrina (Muller) and Rynchomesostroma rostratum (Girard) were found.

b. Quantitative. Data collected during the seasonal study are shown in Appendix VII. Appendix VIII contains the depth distribution data. Each table includes counts from each dredge haul, totals, and the approximate number of organisms per square meter of bottom surface. The oligochaete data also includes volume and dry weight per square meter estimates. These values for insects and ostracods were not measured for two reasons. First, the numbers of these animals were not large enough to provide sufficient mass or volume to be accurately detected by the methods used. This was especially true for ostracods. Second, in the case of insects, since these organisms were only collected in small numbers, it was felt that they would be of more value when used for qualitative purposes. In most cases, oligochaetes made up at least 95% of the total volume and mass of animals.

Count data for statistical analysis was transformed by adding 0.50 to each observation and extracting the square root. This is a regular procedure used to equalize the high variances characteristic of count data. It is also useful in that it provides a test of the assumption of Poisson variation in the raw data. This transformation is not valid for counts lower than 3, which made the technique inapplicable to the insect counts. Transformed data were placed in analyses of variance, and the differences between dates were compared for significance against the within-sample variation. These analyses are presented as Appendix VI. The conclusions that can be drawn from all four of these analyses are similar. In each case, it was found that there was a significant difference, at the 1% level, between means of samples collected at different seasons (and at different depths). Each analysis further indicates that the assumption of Poisson type variation in the raw data is not satisfied. Had the raw data been subject to this kind of variation, the error mean square of the transformed data would not have differed significantly from 0.250, which is the expected variance after this transformation. With both the seasonal and depth studies, it is concluded that the animals found were not randomly distributed over the bottom surface within a given depth zone. The above statement assumes that technical errors in collection and examination of material were not of significant magnitude. A more rigorous statistical treatment is not warranted with the amount of data available.

Although the data collected must be examined with caution, a number of interesting trends can be seen by inspection of the mean counts. Figure 7A illustrates the approximate number of organisms per square meter of bottom surface. These are based on mean counts of oligochaetes, ostracods, and total insects, as well as dry weight of oligochaetes, in milligrams per square meter, obtained in the seasonal study. Mean counts for the depth distribution study are shown in figure 7B. In figure 7B, the cube roots of the numbers per square meter are plotted as abscissae, in the usual way.

Figure 7. Seasonal and depth distribution of common profundal animals.

Figure 7A. Seasonal distribution at 22 meter depth in Mountain Lake, 1962. Numbers per square meter were calculated from the total counts of organisms in three dredge hauls.

Figure 7B. Depth distribution in Mountain Lake during the first week of August, 1962. The abscissae are the cube roots of the numbers of organisms per square meter of bottom surface.

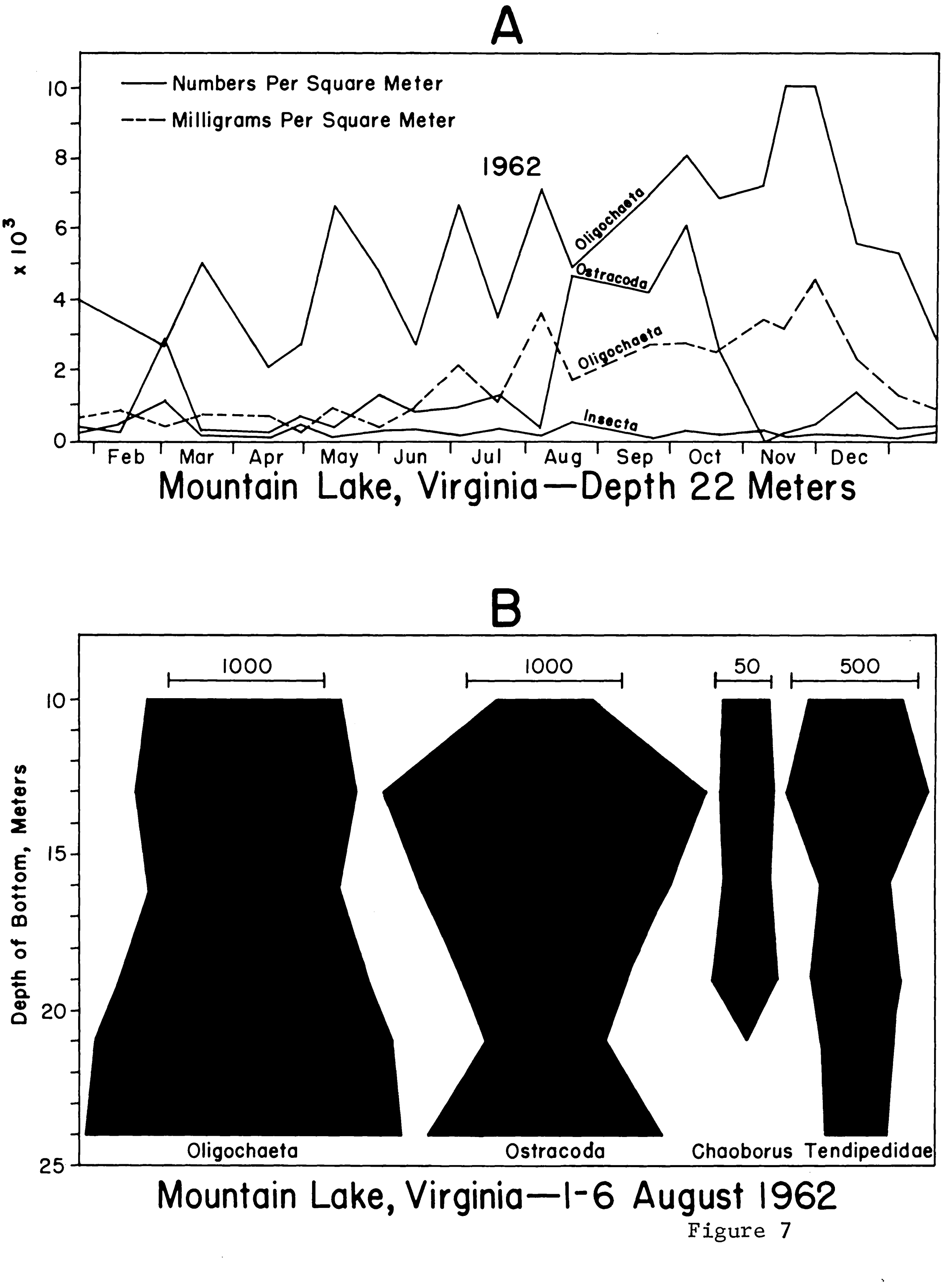

A
Numbers Per Square Meter
Milligrams Per Square Meter
1962
x 10^3
Oligochaeta
Ostracoda
Oligochaeta
Insecta
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Mountain Lake, Virginia—Depth 22 Meters
B
1000
1000
50
500
Depth of Bottom, Meters
Oligochaeta
Ostracoda
Chaoborus
Tendipedidae
Mountain Lake, Virginia—1-6 August 1962

Figure 7

Oligochaetes showed great variation which obscured seasonal trends. These animals at 22 meters numbered about 4000 per square meter in winter, and gradually increased to a peak of over 10,000 per square meter in late autumn. This trend is also shown by increases in dry weight (broken line in figure 7A). Total range of dry weight was from about 250 to over 4500 milligrams per square meter. These figures can be taken as approximately the total weight of animals found, since oligochaetes were by far the most important animal numerically. Eggleton (1931:278-279) found that tubificids in Third Sister Lake, Michigan showed no important seasonal variation.

In the depth distribution study, these forms were most numerous at lower depths. A poorly developed concentration zone (Eggleton, 1931:271) was noted at 13 meters (figure 7B). Numbers of tubificids varied from less than 2000 per square meter (at 10 meters) to over 8000 per square meter (at 24 meters). As mentioned above, it is somewhat enigmatic that tubificids, which are often characteristic forms of very productive or polluted waters, should be the dominant profundal animal in Mountain Lake. The lake appears to be an extremely unproductive one, by all criteria save its morphometry. The quantitative poverty of other profundal animals, especially insects, would also be suggestive of an oligotrophic situation.

Ostracods at the seasonal sampling station numbered between 200 and 1000 individuals per square meter at most seasons. A well marked population peak of around 5000 per square meter was observed on 20 August (figure 7B). This maximum dropped off rapidly in early October.

Ostracods were entirely absent in the sample series taken on 5 November. A smaller peak of about 3500 per square meter was observed in the 2 March series. It also was followed by minimal counts immediately following the peak. Three possible explanations can be offered for the vernal maximum: 1) It is an artifact, resulting from technical errors. 2) Ostracods in the lake are of one species, which has two generations and two maxima per year. 3) Two profundal species are found in the lake, and these achieve population maxima at different seasons.

The depth distribution study suggests that in August, ostracods were most numerous at 13 meters, where a definite concentration zone is apparent in figure 7B. At this depth, almost 9000 individuals per square meter were found. From this depth downward numbers dropped to a minimum of about 400 per square meter, at a depth of 21 meters. Below the latter depth, numbers again increased, to about 2000 per square meter at 24 meters.

The insect fauna of Mountain Lake is a poor one. Only five profundal species were found, and the average number of insect larvae per square meter at 22 meters over all seasons was about 300. Figure 7A shows that the insect populations remained fairly constant throughout the year. One exception was the data for 2 March, when a maximum of over 1100 per square meter occurred. The numerous tendipedid larvae collected at this time were small. Neff (1955:5) has discussed the phenomenon of half-grown larvae of Procladius culiciformis "hibernating" in lumps of ooze during winter. It is possible that tendipedids in Mountain Lake follow a similar pattern, the small larvae burrowing out of range of the dredge during the winter and emerging into the upper strata in spring. Whether the population dropped after that date due to mortality of larvae or from their horizontal migration is not known.

Table 3 shows that Chaoborus larvae were absent from the deeper waters during midsummer. At other seasons, however, Chaoborus commonly frequented the seasonal sampling station (Appendix VIII). The depth distribution data (figure 7B, Appendix VIII) show that in August Chaoborus was found from 10 to 19 meters, but absent below the latter depth. It is not known why these larvae did not occur in deeper waters during June, July and early August. Maximum number found at any season was about 100 per square meter. No data collected in the present study indicated when the adults of this species hatch from Mountain Lake.

Figure 7B shows that tendipedids also were concentrated at 13 meters in August. Over 700 larvae per square meter were found there, while at lower depths only between 50 and 175 per square meter were collected.

Many more dredge samples would be needed to satisfactorily study a population as sparse as the profundal insect fauna of Mountain Lake.

c. Typology. European limnologists e. g., Thienemann, (1922) Lundbeck, (1926) have classified lakes on the basis of bottom animals. An historical review of the European literature on this subject was given by Brundin (1949:616-639). Most systems proposed have been based on the oxygen requirements of the dominant type of tendipedid found in the profundal zone. Thus, Chironomus (= Tendipes sensu str.)

Lakes were supposed to be eutrophic, and Tanytarsus (auct.) Lakes of the oligotrophic type, since the former can withstand lower oxygen tensions than the latter. More elaborate systems have been proposed, incorporating other animals, as advancements in knowledge of lacustrine ecology were made.

Although American workers have generally neglected this approach to lake typology, Deevey (1941) has applied a faunistic classification system to Connecticut lakes, and more recently Stahl (1959) discussed the possibilities of application of such a system to the developmental history of an Indiana lake, through a study of benthic microfossils. These authors have raised some serious objections to faunistic typology.

Since the profundal tendipedid species used in characterizing lake types are influenced by oxygen conditions prevailing in the hypolimnion, confusion between primary (edaphic) and secondary (morphometric) typology can arise. Factors other than oxygen may be important as well. Tendipedids may form only an unimportant part of the total bottom fauna in some lakes. The taxonomy of Nearctic tendipedids is not well enough known to apply such a system on this continent with a validity equal to that which the system enjoys in Europe.

In the light of what was learned from the physical and chemical data about the productive typology of Mountain Lake, the bottom fauna data provide a number of intriguing paradoxes. Why, for example, should tubificids ("eutrophic" animals) be the dominant profundal animals in Mountain Lake, rather than insects? If some other factor than those studied were limiting the benthos, would sphaeriids, a hardy group, according to Berg (1938:144) and other authors, be limited to littoral and sublittoral depths? (Low alkalinities probably limit calcium carbonate available to molluscs, but this is true at all depths.) Why should a "eutrophic" tendipedid (*T. attenuatus*) be common in Mountain Lake? And why should *Calopsectra* (an "oligotrophic" form) be restricted to the littoral and sublittoral zones? Why, in the absence of oxygen depletion, do *Chaoborus* larvae desert the hypolimnion and remain in the sublittoral in midsummer?

Satisfactory answers to these questions cannot be made at this time. Perhaps further study of Mountain Lake, and benthic ecology in general will provide explanations in the future.

SUMMARY

The physical limnology and profundal bottom fauna of Mountain Lake, Virginia were studied during 1961, 1962, and 1963. The lake has a maximum length of 870 meters, a maximum depth of 31.5 meters, and a mean depth of 9.75 meters. It has a mountaintop location in western Virginia 1180 meters above sea level, and is fed by seepage and by underwater springs. The lake was formed by a natural rockslide dam of a mountain stream valley.

Mountain Lake was sampled twice a month from 13 January 1962 to 19 January 1963, and on each day data were collected on temperature, conductivity, pH, dissolved oxygen, alkalinity, transparency, turbidity, water level, and bottom fauna. Bottom fauna sampling included both a seasonal series at 22 meters and a depth distribution series taken in August, 1962.

Mountain Lake is shown to be a second class temperate dimictic lake, although it is possible that it is monomictic in some years. Thermal stratification prevailed for 28 weeks in summer and for 8 weeks in winter. Winter heating was pronounced, and was probably contributed to by underwater springs. A vernal cooling period was noted in 1962. The annual ranges of surface, bottom and mean temperatures in 1962 were 0-23.1, 2.65-6.6, and 2.21-13.04, all in degrees Celsius.

Conductivity of Mountain Lake water ranged between 9 and 18 micromhos, and was not stratified. Secchi disc limits of visibility averaged 6.15 meters. Turbidity values were less than 7 milligrams per liter silica.

The dissolved oxygen cycle in Mountain Lake included a positive heterograde summer distribution, and a minimum hypolimnetic concentration of 57% of saturation at the end of stagnation. The areal oxygen deficit, calculated after 113 days.stagnation, was 0.0035 milligrams per square centimeter per day, which would indicate that Mountain Lake is primarily oligotrophic. The shape of the oxygen curve suggested secondary (morphometric) eutrophy.

Mountain Lake water is very soft. Bicarbonate alkalinities ranged between 6 and 8 milligrams per liter, and were not stratified. Total pH range was 6.4-7.6. At most seasons, the surface water was slightly alkaline, but in fall, acid values were found. The pH curve in summer paralleled the oxygen curve.

The level of Mountain Lake water fluctuated 66 centimeters in 1962.

Rhododendron and Kalmia overhang the rocky shore of the lake, and there are few emergent plants. The littoral zone is small, and covered by a Nitella bed. Soft bottom mud is found only below 10 meters, and is thickest under deeper water. At 22 meters, the superficial ooze had a significantly higher organic content (19%) than the underlying clay (8%), although the inorganic remainder of both layers was about 11% soluble in HCl.

The littoral zone in Mountain Lake extends to 10 meters. In August, 1962, a sublittoral fauna was found at 10 and 13 meters. Typical profundal fauna included tubificids (2 species), ostracods (1 or 2 species), tendipedids (at least 4 species), and Chaoborus

(1 species). Statistical data showed that differences between depths and between seasons existed, and that the animals showed a contagious (non-random) distribution over the bottom.

Tubificids were the dominant animals, both in numbers and in mass. Total dry mass of profundal organisms was never more than 5 grams per square meter, and was usually much less. Tubificids were most numerous in autumn, least numerous in spring. During August they were most common in deep water.

Ostracods showed two population maxima, one in spring and one in fall, and it is not known whether 1 or 2 species are responsible. Average populations were between 200 and 1000 per square meter at 22 meters depth. Ostracods in August showed a concentration zone at 13 meters, as did tendipedids.

Insect populations were small. *Chaoborus* was absent from the deep water during midsummer, and at most other seasons had less than 100 individuals per square meter. Tendipedids numbered about 300 per square meter at most seasons. A small vernal maximum was noted.

The bottom fauna of Mountain Lake presents a number of interesting paradoxes, and it does not fit any typological scheme which has been proposed.

ACKNOWLEDGEMENTS

Gratitude is expressed to Dr. Stuart E. Neff, who, as the author's major professor and mentor, freely gave time, advice, and encouragement throughout the course of the study.

Dr. James L. Riopel, Director of the Mountain Lake Biological Station of the University of Virginia, and the National Science Foundation, made it possible for the author to continue the present study during the summer of 1962. Their aid is appreciated.

Organisms collected from Mountain Lake were examined by experts who willingly gave of their time and talents. To Drs. Ralph O. Brinkhurst, Gerald A. Cole, and Stuart E. Neff, credit must be given for helping to make the present study a success.

Dr. John G. Saw, Department of Statistics, VPI, read and criticized the statistical parts of the manuscript.

More persons than can be named here, fellow graduate students and others, helped the author to collect data when the weather made it impossible for him to do the task alone. To these foul-weather friends who willingly suffered discomfort, and who maintained a sense of humor long after his was exhausted, the author is indebted.

REFERENCES CITED

Berg, K. 1938. Studies on the bottom animals of Estrom Lake. Mem. Acad. Royale Sci. Lett. Danemark Copenhague, Sec. Sci. Ser. 9, t. 8:1-255.

Brundin, L. 1949. Chironomiden und andere Bodentiere der sudschwedischen Urgebirgssen. Inst. Freshwater Research Drottningholm. Rept. 30:1-915. (with a summary in English).

Byers, C. F. 1951. Some notes on the Odonata fauna of Mountain Lake,Virginia. Entomol. News. 62:164-167.

Campell, M. R. 1898. Earthquake shocks in Giles County, Virginia. Science. 7:233-235.

Carter, M. E. 1944. Harpacticoid copepods of the region of Mountain Lake, Virginia. J. Elisha Mitchell Sci. Soc. 60: 158-166.

Castor, A. S. 1958. Map of Mountain Lake Biological Station and vicinity. Scale: 1/15,625.

Chapman, H. H. 1949. Yale professor discusses Mountain Lake enigma. Va. and the Va. County. 3(2):27.

Coker, R. E., and W. J. Hayes, Jr. 1940. Biological observations on Mountain Lake, Virginia. Ecology. 21:192-198.

Cole, G. A. 1954. Studies on a Kentucky knobs lake. I. Some environmental factors. Trans. Kentucky Acad. Sci. 15(3):31-47.

Deevey, E. S. 1941. Limnological studies in Connecticut. VI. The quantity and composition of the bottom fauna of 36 Connecticut and New York lakes. Ecol. Monograph. 11:413-455.

Deevey, E. S., and J. S. Bishop. 1942. Limnology. p. 69-121, 296-298. <u>In</u> A fishery survey of important Connecticut lakes. Conn. Geol. Nat. Hist. Survey Bull. 63.

Deevey, E. S., Jones, J. A., and E. F. Daly. 1957. Bathymetric chart of Mountain Lake, Virginia. Unpublished; stored in the library of the Mountain Lake Biological Station of The University of Virginia.

[Dietrich, R. V.] 1957. Mountain Lake. Mineral Industries J. 4(2):7-8.

Eggleton, F. E. 1931. A limnological study of the profundal bottom fauna of certain fresh-water lakes. Ecol. Monograph. 1:231-332.

Ferguson. F. F., Stirewalt, M. A., Brown, T. D., and W. J. Hayes, Jr. 1939. Studies on the turbellarian fauna of the Mountain Lake Biological Station. J. Elisha Mitchell Sci. Soc. 55:274-288.

Forest, H. S. 1954. Checklist of algae in the vicinity of Mountain Lake Biological Station--Virginia. Castanea. 19:88-104.

Grover, W. W., and R. E. Coker. 1940. A study of depth distribution of certain net plankters in Mountain Lake, Virginia. Ecology. 21:199-205.

Holden, R. J. 1938. Geology of Mountain Lake, Virginia. (Abst.) Va. Acad. Sci. Proc. 1937-1938:73.

Hubbard, G. D., and C. G. Croneis. 1924. Notes on the geology of Giles County, Virginia. J. Sci. Lab. Denison. Univ. 20: 307-377.

Hutchinson, G. E. 1938. On the relation between the oxygen deficit and the productivity and typology of lakes. Intern. Rev. ges. Hydrobiol. u. Hydrogr. 36: 336-355.

Hutchinson, G. E. 1957. A Treatise on Limnology. New York: John Wiley & Sons. 1015 p.

Hutchinson, G. E., and G. E. Pickford. 1932. Limnological observations on Mountain Lake, Virginia. Intern. Rev. ges. Hydrobiol. u. Hydrogr. 27:252-264.

Johnston, D. E. 1906. A history of middle New River settlements and contiguous territory. Huntington, W. Va.: By the Author. 500 p.

Kercheval, S. 1925. A history of the valley of Virginia. ed. 4. Strasburg, Va.: Shenandoah. 391 p.

Krumholz, L. A., and G. A. Cole. 1959. Studies on a Kentucky knobs lake. IV. Some limnological conditions during an unusually cold winter. Limnol. Oceanog. 4: 367-385.

Lundbeck, J. 1926. Die Bodentierwelt norddeutscher Seen. Arch. f. Hydrobiol. Suppl. 7:1-473. (not seen).

Neff, S. E. 1955. Studies on a Kentucky knobs lake. II. Some aquatic Nematocera (Diptera) from Tom Wallace Lake. Trans. Kentucky Acad. Sci. 16(1):1-13.

[Nicklin, P. H.] . "Peregrine Prolix," pseud. 1837. Letters discriptive of Virginia springs. Philadelphia: H. S. Tanner. 248 p.

Pendleton, W. C. 1920. History of Tazewell County and southwest Virginia, 1748-1920. Richmond: W. C. Hill. 684 p.

Platt, R. B., and C. S. Shoup. 1950. The use of a thermistor in a study of summer temperature conditions of Mountain Lake, Virginia. Ecology. 31:484-488.

Pollard, E. A. 1870. The Virginia tourist. Philadelphia: Lippincot. 277 p.

Rice, T. D., Nickerson, D., O'Neal, A. M., and J. Thorp. 1941. Preliminary color standards and color names for soils. U. S. Dept. Agr. Misc. Publ. 425.

Rogers, W. B. 1835. Geology of the Virginias. (Reprinted 1884). New York: Appleton-Century.

Sharp, H. S. 1933. The origin of Mountain Lake, Virginia. J. Geol. 41:636-641. Also pub. 1936. Va. Geol. Survey Bull. 46-H.

Smith, S. H. 1962. Temperature correction in conductivity measurements. Limnol. Oceanog. 7:331-334.

Stahl, J. B. 1959. The developmental history of the chironomid and Chaoborus faunas of Meyers Lake. Invest. Indiana Lakes & Streams. 5(2):47-102.

Summers, L. P. 1903. History of southwest Virginia. 1746-1786. Richmond: By the Author. 921 p.

Summers, L. P. 1929. Annals of southwest Virginia. 1769-1800. Abingdon, Va.: By the Author. 1757 p.

Thienemann, A. 1922. Die beiden Chironomus-Arten Tiefenfauna der norddeutschen Seen. Ein hydrobiologisches Problem. Arch. f. Hydrobiol. 13:609-646. (not seen).

Thorne, R. F., and T. S. Cooperrider. 1960. The flora of Giles County, Virginia. Castanea. 25:1-53.

Townes, H. K. 1959. Notes on types of Nearctic Tendipedini in London and Copenhagen. Proc. Entomol. Soc. Wash. 61: 135-136.

Welch, P. S. 1948. Limnological methods. New York: McGraw-Hill. 381 p.

Welch, P. S. 1952. Limnology. ed. 2. New York: McGraw -Hill. 538 p.

The vita has been removed from
the scanned document

APPENDIX I. Temperatures, in degrees Celsius, observed in Mountain Lake between 13 October 1961 and 19 January 1963.

Depth in Meters	13 x 61	20 x 61	27 x 61	13 xii 62	13 i 62	26 i 62	11 ii 62	2 iii 62	18 iii 62
0	16.20	13.50	11.30	3.40	0.50	1.30	0.40	4.00	2.95
1	16.15	13.50	11.40	3.40	1.90	2.50	3.30	4.00	2.90
2	16.10	13.50	11.40	3.40	2.00	2.50	3.30	3.95	2.80
3	16.10	13.50	11.40	3.40	2.00	2.50	3.30	3.95	2.80
4	16.10	13.55	11.40	3.40	2.50	2.50	3.30	3.95	2.75
5	16.05	13.60	11.40	3.40	2.10	2.50	3.30	3.95	2.75
6	15.90	13.60	11.40	3.40	2.10	2.50	3.30	3.90	2.70
7	15.75	13.60	11.40	3.40	2.20	2.50	3.30	3.90	2.70
8	15.65	13.50	11.40	3.40	2.25	2.50	3.40	3.90	2.80
9	15.60	13.50	11.40	3.40	2.30	2.50	3.40	3.85	2.85
10	15.15	13.50	11.40	3.40	2.35	2.50	3.40	3.85	2.90
11	13.30	13.40	11.40	3.40	2.45	2.50	3.50	3.80	2.90
12	10.85	13.10	11.40	3.40	2.50	2.50	3.50	3.80	2.90
13	9.60	11.50	11.35	3.40	2.60	2.60	3.50	3.80	2.90
14	8.85	11.40	10.80	3.40	2.60	2.65	3.50	3.80	2.95
15	8.00	8.20	9.40	3.40	2.65	2.70	3.50	3.80	3.00
16	7.25	8.20	7.60	3.40	2.65	2.75	3.50	3.80	3.00
17	7.00		7.30	3.40		2.80	3.50	3.80	3.00
18	6.95		7.00			2.80	3.50	3.85	3.00
19	6.75		6.70			2.85	3.60	3.85	3.00
20	6.70		6.80			2.90	3.60	3.90	3.05
21	6.60					2.90	3.90	3.90	3.05
22	6.40					2.95			3.05
23						3.25			
24									
25									
Mean	11.87		10.24	3.40	2.21	2.64	3.31	3.88	2.90

APPENDIX I. Continued.

Depth in Meters	1 iv 62	15 iv 62	29 iv 62	13 v 62	31 v 62	16 vi 62	3 vii 62	10 vii 62	20 vii 62
0	5.60	6.00	13.40	16.50	18.90	19.30	20.40	20.60	22.60
1	5.50	6.00	13.35	16.50	18.80	19.30	20.30	20.50	22.60
2	5.45	6.00	13.25	16.00	18.70	19.20	20.25	20.40	22.55
3	5.40	6.00	12.65	15.90	18.60	19.20	20.25	20.30	22.50
4	5.40	6.00	11.60	15.70	18.45	19.10	20.25	20.10	22.50
5	5.40	6.00	7.90	10.25	16.00	19.10	20.20	19.90	21.40
6	5.40	6.00	7.10	8.80	11.00	14.40	16.50	19.40	19.35
7	5.40	6.00	6.55	7.80	9.30	11.20	12.80	12.50	15.05
8	5.40	6.00	6.20	6.95	8.20	9.15	10.30	10.60	11.60
9	5.40	5.95	6.00	6.50	7.50	8.00	8.80	9.60	9.65
10	5.35	5.90	5.90	6.30	6.80	7.15	7.80	8.50	8.50
11	5.35	5.90	5.85	6.10	6.50	6.80	7.30	7.80	7.90
12	5.35	5.90	5.75	5.95	6.30	6.50	6.90	7.00	7.25
13	5.35	5.85	5.70	5.90	6.10	6.30	6.60	6.60	6.80
14	5.35	5.80	5.65	5.80	5.95	6.10	6.30	6.40	6.60
15	5.35	5.80	5.60	5.70	5.90	6.00	6.15	6.20	6.40
16	5.35	5.75	5.60	5.70	5.80	5.90	6.05	6.10	6.30
17	5.35	5.70	5.55	5.65	5.75	5.85	5.95	6.00	6.15
18	5.35	5.60	5.55	5.60	5.70	5.75	5.90	6.00	6.05
19	5.35	5.55	5.50		5.60	5.70	5.80	5.90	6.00
20	5.35	5.50	5.50		5.60	5.70	5.80	5.80	5.95
21	5.35	5.50	5.40		5.55	5.60	5.80	5.80	5.90
22	5.30	5.40			5.55		5.75	5.70	5.95
23	5.30				5.50		5.70		
24					5.50		5.70		
25					5.50				
Mean	5.38	5.83	7.52	9.14	9.19	10.51	10.54	11.20	11.98

APPENDIX I. Continued.

Depth in Meters	6 viii 62	20 viii 62	21 ix 62	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62
0	23.10	22.55	18.10	14.90	15.50	8.40	7.25	5.45	1.10
1	22.70	22.35	18.10	14.60	15.40	8.50	7.10	5.30	2.00
2	22.40	21.85	18.15	14.50	15.10	8.50	7.00	5.25	2.00
3	22.00	21.75	18.15	14.45	14.60	8.50	6.85	5.20	2.05
4	20.80	21.65	18.15	14.35	14.60	8.50	6.80	4.85	2.30
5	20.50	21.20	17.95	14.30	14.50	8.50	6.80	4.85	2.55
6	20.35	21.00	17.70	14.30	14.50	8.50	6.70	4.75	2.80
7	18.80	19.40	17.60	14.25	14.35	8.50	6.70	4.70	3.00
8	14.70	15.60	17.45	14.25	14.20	8.50	6.65	4.70	3.10
9	11.50	12.60	17.00	14.20	14.15	8.50	6.65	4.70	3.20
10	9.65	10.55	12.20	14.00	13.90	8.50	6.65	4.70	3.30
11	8.60	9.00	10.40	12.00	12.55	8.50	6.60	4.70	3.35
12	7.80	8.20	9.30	9.25	10.20	8.50	6.60	4.70	3.40
13	7.20	7.70	8.40	8.40	8.60	8.50	6.55	4.70	3.45
14	6.80	7.10	7.70	7.85	7.80	8.50	6.55	4.70	3.50
15	6.60	6.80	7.25	7.30	7.30	8.50	6.55	4.65	3.50
16	6.50	6.60	7.00	6.90	7.05	8.25	6.50	4.65	3.55
17	6.30	6.40	6.75	6.70	6.90	8.10	6.50	4.65	3.60
18	6.20	6.30	6.60	6.60	6.75	7.95	6.50	4.65	3.60
19	6.10	6.20	6.50	6.50	6.60	7.00	6.50	4.65	3.60
20	6.00	6.10	6.40	6.45	6.50	6.85	6.50	4.65	3.65
21	6.00	6.05	6.35	6.40	6.50	6.75	6.50	4.65	3.70
22	5.95		6.35	6.30	6.30	6.60	6.50	4.65	
23			6.30						
24									
25									
Mean	12.46	13.04	11.91	10.81	11.03	8.15	6.67	4.80	3.01

APPENDIX I. Concluded.

Depth in Meters	5 i 63	19 i 63
0	0.30	0.50
1	1.95	2.40
2	2.50	2.90
3	2.65	2.95
4	2.75	3.05
5	2.90	3.15
6	3.05	3.20
7	3.10	3.30
8	3.25	3.30
9	3.25	3.40
10	3.30	3.45
11	3.40	3.50
12	3.50	3.60
13	3.55	3.65
14	3.60	3.70
15	3.65	3.75
16	3.75	3.80
17	3.70	3.80
18	3.75	3.85
19	3.80	3.85
20	3.80	3.90
21	3.80	3.90
22	3.85	3.95
23		
24		
25		
Mean	3.18	3.34

APPENDIX II. Dissolved Oxygen, milligrams per liter, and approximate Percent Saturation of Oxygen, observed in Mountain Lake between 13 January 1962 and 19 January 1963.

	Depth Meters	13 i 62	26 i 62	11 ii 62	2 iii 62	18 iii 62	1 iv 62	15 iv 62	29 iv 62
	0	11.4	11.5	11.6	10.5	10.8	10.0	9.7	8.3
	5	10.85	10.9	10.35	10.5	10.5	10.0	9.6	9.2
OXYGEN	10	10.6	10.1	9.2	10.0	10.6	9.4	9.8	9.3
	15	10.8	10.2	9.9	9.6	10.25	9.75	9.7	9.55
	20	----	9.75	8.8	9.8	10.35	9.9	9.8	9.5
	0	95	98	97	96	95	95	94	96
	5	94	96	93	97	92	96	89	92
% SAT.	10	93	88	91	91	92	89	94	89
	15	95	90	89	87	91	92	93	91
	20	----	86	79	89	92	94	92	90

APPENDIX II. Continued.

	Depth Meters	13 v 62	31 v 62	16 vi 62	3 vii 62	20 vii 62	6 viii 62	20 viii 62	21 ix 62
	0	7.6	7.4	7.15	7.15	7.1	7.6	7.4	7.6
	5	9.2	7.7	7.6	8.45	7.3	7.2	7.5	7.5
OXYGEN	10	9.2	9.45	9.4	9.15	10.2	11.0	10.8	7.5
	15	8.7	9.4	9.4	8.4	8.0	8.5	8.5	7.9
	20	----	8.9	8.6	8.4	7.4	7.3	6.6	6.1
	0	93	96	93	96	97	105	102	93
	5	97	98	97	112	118	97	102	107
% SAT.	10	89	93	94	93	98	115	115	85
	15	83	91	91	81	77	83	84	78
	20	----	84	82	80	72	70	64	60

APPENDIX II. Concluded.

	Depth Meters	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62	5 i 63	19 i 63
OXYGEN	0	8.0	8.0	8.9	9.6	10.1	10.6	12.0	12.7
	5	7.9	8.1	8.7	9.4	10.1	10.5	10.35	10.15
	10	8.1	8.85	8.8	9.4	10.0	10.3	10.1	9.8
	15	8.1	6.85	8.6	9.4	10.0	10.1	9.55	9.05
	20	6.2	6.22	5.5	9.4	10.0	9.8	8.7	7.85
% SAT.	0	96	97	92	98	95	90	99	105
	5	93	96	89	93	94	92	92	91
	10	95	103	90	92	93	93	90	88
	15	81	68	88	92	93	91	87	83
	20	62	62	57	91	91	88	78	72

APPENDIX III. Total Alkalinity, milligrams per liter, and pH, observed in Mountain Lake between 13 January 1962 and 19 January 1963.

	Depth Meters	13 i 62	26 i 62	11 ii 62	2 iii 62	18 iii 62	1 iv 62	15 iv 62	29 iv 62
pH	0	7.6	7.6	7.4	7.4	---	---	7.6	7.6
	5	---	7.4	7.4	7.4	---	---	7.6	7.6
	10	---	7.2	7.4	7.5	---	---	7.6	7.6
	15	7.6	6.8	7.4	7.3	---	---	7.6	7.6
	20	---	6.6	6.8	7.5	---	---	7.6	7.6
ALKALINITY	0	7.0	7.0	6.0	7.0	6.0	6.0	7.0	7.0
	5	---	7.0	6.0	6.0	6.0	7.0	7.0	7.0
	10	---	6.0	7.0	6.0	6.0	---	---	---
	15	7.0	7.0	7.0	6.0	6.0	6.0	---	---
	20	---	6.0	6.0	7.0	6.5	6.0	7.0	7.0

APPENDIX III. Continued.

	Depth Meters	13 v 62	31 v 62	16 vi 62	3 vii 62	20 vii 62	6 viii 62	20 viii 62	21 ix 62
pH	0	7.0	7.0	7.2	7.4	7.2	7.6	7.2	7.4
	5	7.2	7.0	7.4	7.2	7.4	7.2	7.4	7.4
	10	7.0	7.0	7.4	7.2	7.4	7.4	7.4	7.2
	15	7.4	6.6	7.0	6.8	6.6	6.6	7.0	7.0
	20	---	6.8	6.8	6.4	6.6	6.4	6.4	6.6
ALKALINITY	0	6.0	6.0	7.0	6.0	6.0	6.0	6.0	7.0
	5	6.0	6.0	7.0	6.0	6.0	6.0	6.0	7.0
	10	6.0	6.0	7.0	6.0	6.0	6.0	6.0	7.0
	15	6.0	7.0	6.0	6.0	6.0	6.0	6.0	7.0
	20	---	7.0	6.5	6.0	6.0	6.0	6.0	7.0

APPENDIX III.   Concluded.

	Depth Meter	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62	5 i 63	19 i 63
	0	7.0	6.8	6.6	6.8	7.1	7.2	7.6	7.4
	5	7.0	6.8	6.7	6.8	7.1	7.3	7.4	7.5
pH	10	7.0	6.8	6.7	6.9	7.1	7.3	7.3	7.5
	15	6.6	6.6	6.7	6.9	7.2	7.2	7.3	7.5
	20	6.6	6.4	6.5	6.9	7.2	7.2	7.2	7.5
	0	6.0	7.5	7.0	6.5	7.0	6.0	7.0	7.0
	5	6.0	7.5	7.0	7.0	7.0	6.0	6.0	7.0
ALKALINITY	10	6.0	7.5	7.0	7.0	7.0	7.0	6.0	7.0
	15	6.0	8.0	7.0	7.0	7.0	7.0	7.0	7.0
	20	6.0	7.5	7.0	7.0	7.0	7.0	6.0	7.0

APPENDIX IV. Secchi Disc limits of visibility, ice thickness and water level, observed in Mountain Lake between 13 January 1962 and 19 January 1963.

	13 i 62	26 i 62	11 ii 62	2 iii 62	18 iii 62	1 iv 62	15 iv 62	29 iv 62	13 v 62	31 v 62	16 vi 62	3 vii 62
SECCHI, METERS				6.5	7.0	4.8	6.0	5.5	5.5	7.3	6.7	5.5
ICE, CENTIMETERS	15	15	see text									
WATER LEVEL, CENTIMETERS	--	--	--	--	--	--	3	10	-18	-16	-16	-30

	20 vii 62	6 viii 62	20 viii 62	21 ix 62	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xi 62	5 i 63	19 i 63
SECCHI, METERS	5.5	6.0	6.7	5.5	7.3	8.5	5.5	5.5	5.5			
ICE, CENTIMETERS										16.3	26	28
WATER LEVEL, CENTIMETERS	-37	-18	-25	-52	-56	-55	-63	-36	-26	0	3	3

APPENDIX V

ANNOTATED LIST OF SUBMERGED PLANTS

THALLOPHYTA

Characeae

Nitella flexilis Ag. Muskgrass. Recorded by Forest (1954). This species is very common in Mountain Lake, and forms an essentially continuous bed, which extends from a depth of about two meters to ten meters.

BRYOPHYTA

Fontinalaceae

Fontinalis antipyretica L. Water Moss. Commonly found on all sides of the lake, from the shore to a depth of about two meters; rarely found as deep as ten meters.

TRACHEOPHYTA

Isoetaceae

Isoetes Engelmanni A. Br. Quillwort. Recorded by Thorne and Cooperrider (1960). Found in shallow water (up to 25 centimeters); most common near the lake's outlet and at the southern tip. Occasionally found along the remainder of the shore.

Najadaceae

Potamogeton natans L. Floating-leaf Pondweed. Occasionally collected near the shore on all sides of the lake, although this species is not common.

P. pectinatus L. Sago Pondweed. More common in Mountain Lake than *P. natans*; forms submerged clumps in water 1.5 to 3 meters deep. In midsummer this species sometimes becomes so covered with attached *Hydra* sp. as to cause the plants to appear red in color. The red pigment of the animals presumably results from their ingestion of planktonic copepods.

APPENDIX V. Concluded.

Hydrocharitaceae

Elodea _Nuttallii_ (Planch.) Waterweed. Recorded by Thorne and Cooperrider (1960). A common species ranging from a few centimeters to three meters in depth. In addition to flatworms and tendipedid larvae, common animal associates include the immature stages of the hydroptilid caddis fly, _Oxyethira_ sp., which attaches its flask-shaped pupal case to the _Elodea_ leaves. The larvae and pupae of this species were seldom found on any other plant in Mountain Lake.

Ceratophyllaceae

Ceratophyllum _demersum_ L. Coontail. Recorded by Thorne and Cooperrider (1960). This species occurs throughout the littoral zone, although it is never numerous at any depth.

APPENDIX VI

ANALYSES OF VARIANCE--PROFUNDAL BOTTOM FAUNA*

1. Seasonal Distribution--Oligochaetes

Source of Variation	df	SS	MS	F
Between Dates	21	381.2375	18.1542	3.66 **
Within Dates	44	218.3543	4.9626	----
Total	65	599.5918	-----	----

2. Seasonal Distribution--Ostracods

Source of Variation	df	SS	MS	F
Between Dates	20	520.3409	26.0170	16.69 **
Within Dates	42	65.4753	1.5589	----
Total	62	585.8162	------	----

3. Depth Distribution--Oligochaetes

Source of Variation	df	SS	MS	F
Between Depths	5	143.8996	28.7799	16.55**
Within Depths	12	20.8712	1.7393	----
Total	17	164.7708	------	----

4. Depth Distribution--Ostracods

Source of Variation	df	SS	MS	F
Between Depths	5	303.9710	60.7942	27.31**
Within Depths	12	26.7127	2.2260	-----
Total	17	330.6837	------	-----

* df = degrees of freedom
SS = sums of squares
MS = mean square
F = F-ratio

** significant at 1% level

APPENDIX VII. Counts of profundal bottom fauna collected in Mountain Lake at a depth of 22 meters, between 26 January 1962 and 19 January 1963.

Oligochaeta

	26 i 62	11 ii 62	2 iii 62	18 iii 62	5 iv 62	29 iv 62	13 v 62	31 v 62	16 vi 62	3 vii 62	20 vii 62
Dredge 1	100	81	54	61	85	77	166	106	49	221	118
Dredge 2	122	101	96	101	27	42	142	98	93	71	56
Dredge 3	57	53	39	187	29	73	157	130	47	175	56
Total	279	235	189	349	141	192	465	334	189	467	230
#/m^2	4026	3391	2727	5036	2035	2771	6710	4820	2727	6739	3319
Mg dry/m^2	693	753	443	729	750	339	991	397	864	2120	1056
Ml Vol/m^2	8.7	7.2	2.9	8.7	13.0	1.4	10.1	1.4	5.8	18.8	8.7

APPENDIX VII. Continued.

	Oligochaeta										
	6 viii 62	20 viii 62	21 ix 62	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62	5 i 63	19 i 63
Dredge 1	139	148	149	262	69	298	179	106	158	80	63
Dredge 2	233	51	145	195	226	112	210	381	76	163	41
Dredge 3	118	146	193	106	188	91	339	220	161	130	101
Total	490	345	487	563	483	501	728	707	395	373	205
#/m^2	7071	4978	7027	8124	6970	7229	10505	10202	5700	5382	2958
Mg dry/m^2	3570	1693	2795	2788	2583	3492	3245	4508	2388	1775	905
Ml Vol/m^2	20.2	8.7	23.1	18.8	21.6	23.8	23.1	23.8	15.9	13.7	8.7

APPENDIX VII. Continued.

Ostracoda

	26 i 62	11 ii 62	2 iii 62	18 iii 62	5 iv 62	29 iv 62	13 v 62	31 v 62	16 vi 62	3 vii 62	20 vii 62
Dredge 1	5	6	67	4	7	27	9	8	20	17	28
Dredge 2	20	10	117	5	2	8	5	34	36	9	23
Dredge 3	8	4	55	13	3	10	7	50	3	36	35
Total	33	20	239	22	12	45	21	92	59	62	86
#/m ^{2}	476	289	3449	317	173	649	303	1328	851	895	1241

	6 viii 62	20 viii 62	21 ix 62	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62	5 i 63	19 i 63
Dredge 1	5	87	77	145	25	0	2	8	35	4	18
Dredge 2	14	140	70	140	75	0	3	9	38	10	9
Dredge 3	10	92	145	140	80	0	12	11	24	6	6
Total	29	319	292	425	180	0	17	28	97	20	33
#/m^2	418	4603	4214	6132	2597	0	245	404	1400	289	476

APPENDIX VII. Continued.

Tendipedidae

	26 i 62	11 ii 62	2 iii 62	18 iii 62	5 iv 62	29 iv 62	13 v 62	31 v 62	16 vi 62	3 vii 62	20 vii 62
Dredge 1	7	10	19	5	6	14	5	2	11	3	4
Dredge 2	6	15	46	0	1	1	1	5	14	1	1
Dredge 3	6	2	16	6	1	12	0	6	1	4	11
Total	19	27	81	11	8	27	6	13	26	8	16
#/m^2	274	390	1169	159	115	390	87	188	375	115	231

	6 viii 62	20 viii 62	21 ix 62	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62	5 i 63	19 i 63
Dredge 1	2	15	2	5	2	4	0	3	3	0	5
Dredge 2	3	12	2	3	0	2	4	1	2	1	1
Dredge 3	1	4	1	1	1	1	4	1	0	1	3
Total	6	31	5	9	3	7	8	5	5	2	9
#/m^2	87	447	72	130	43	101	115	72	72	29	130

APPENDIX VII. Continued.

Chaoborus

	26 i 62	11 ii 62	2 iii 62	18 iii 62	5 iv 62	29 iv 62	13 v 62	31 v 62	16 vi 62	3 vii 62	20 vii 62
Dredge 1	1	0	1	0	0	5	1	0	0	0	0
Dredge 2	0	3	0	0	0	0	0	1	0	0	0
Dredge 3	0	0	0	0	0	0	0	0	0	0	0
Total	1	3	1	0	0	5	1	1	0	0	0
#/m^2	14	43	14	0	0	72	14	14	0	0	0

	6 viii 62	20 viii 62	21 ix 62	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62	5 i 63	19 i 63
Dredge 1	0	0	1	3	0	3	0	1	2	2	3
Dredge 2	0	0	2	2	0	1	1	4	1	0	0
Dredge 3	0	1	2	2	1	3	3	2	1	0	3
Total	0	1	5	7	1	7	4	7	4	2	6
#/m^2	0	14	72	101	14	101	58	101	58	28	87

APPENDIX VII. Concluded.

Total Insects

	26 i 62	11 ii 62	2 iii 62	18 iii 62	5 iv 62	29 iv 62	13 v 62	31 v 62	16 vi 626	3 vii 62	20 vii 62
#/m ^{2}	288	423	1173	159	115	462	101	202	375	115	231

	6 viii 62	20 viii 62	21 ix 62	6 x 62	19 x 62	5 xi 62	17 xi 62	1 xii 62	17 xii 62	5 i 63	19 i 63
#/m^2	87	461	144	231	57	202	173	173	130	57	217

APPENDIX VIII. Counts of profundal bottom fauna collected in Mountain Lake at various depths in August, 1962.

	Oligochaeta						Ostracoda					
	Depth in Meters						Depth in Meters					
	10	13	16	19	21	24	10	13	16	19	21	24
Dredge 1	48	54	55	97	139	235	2	225	140	35	5	30
Dredge 2	32	93	34	92	233	168	9	185	75	30	14	110
Dredge 3	55	49	42	94	118	181	4	197	65	17	10	86
Total	135	196	131	283	490	584	15	607	280	82	29	226
#/m^2	1948	2828	1890	4084	7011	8427	216	8759	4040	1183	418	3261
Mg Dry/m^2	970	384	1276	3104	3570	3556						
Ml Vol/m^2	11.5	9.4	13.7	14.4	40.2	17.3						

APPENDIX VIII. Concluded.

	Chaoborus Depth in Meters						Tendipedidae Depth in Meters					
	10	13	16	19	21	24	10	13	16	19	21	24
Dredge 1	0	0	0	3	0	0	8	16	4	5	2	1
Dredge 2	2	2	1	2	0	0	2	19	1	4	3	3
Dredge 3	0	1	1	0	0	0	3	14	0	3	1	0
Total	2	3	2	5	0	0	13	49	5	12	6	4
#/m^2	29	43	29	72	0	0	188	707	72	173	87	58

STUDIES OF MOUNTAIN LAKE, VIRGINIA
WITH PARTICULAR REFERENCE TO
PHYSICAL LIMNOLOGY AND PROFUNDAL BOTTOM FAUNA

by

James C. Roth

ABSTRACT

Mountain Lake, Giles County, Virginia was sampled twice a month between 13 October 1961 and 19 January 1963, and observations were made on the temperature, dissolved oxygen, pH, alkalinity, transparency, conductivity, turbidity, and water level.

Mountain Lake is situated in the latitude for warm monomixis, but being 1180 meters above sea level, it was dimictic in both years studied. The lake is basically an oligotrophic water in a more or less eutrophic basin. The value of the actual areal hypolimnetic oxygen deficit, calculated after 113 days stagnation (0.0035 milligrams per square centimeter per day) indicates oligotrophy. Due to the lake's shallowness (mean depth = 9.75 meters) the maximum observed oxygen depletion in the hypolimnion at the end of summer stratification was 43% of saturation. Total alkalinity observations (around 7 milligrams per liter), Secchi disc limits of visibility (around 6 meters), and conductivity values (9-18 micromhos), also suggest low production.

Profundal bottom animals were collected with an Ekman dredge. Sampling included a seasonal series at 22 meters and a depth series during midsummer. Technical errors were minimized by a refined technique, and separate examination of each dredge haul made statistical test possible. Analyses of variance showed that differences existed between seasons and between depths, and that animals were non-randomly distributed.

Tubificids were the most common animals, although tendipedids, *Chaoborus*, and ostracods were also found. Oligochaetes comprised over 90% of the total dry weight, and averaged about 1.8 grams per square meter. Paradoxes between the Mountain Lake fauna and proposed faunistic lake typology systems were noted.