MACROPHYTE ECOLOGY OF MT. LAKE, VA

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THE STANDING CROP AND DISTRIBUTION OF MACROPHYTES IN MOUNTAIN LAKE, VIRGINIA, WITH PARTICULAR EMPHASIS ON THE CONTRIBUTION OF *NITELLA FLEXILIS* (L.) AG. TO THE METALIMNETIC OXYGEN MAXIMUM

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MOUNTAIN LAKE, VIRGINIA

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I. INTRODUCTION

Mountain Lake is one of two natural lakes in the state of Virginia. The lake is located at an elevation of 1180 m on top of Salt Pond Mountain near Pembroke, Virginia. This lake's small basin runs approximately north-south and measures 870 m long by 255 m wide (Roth and Neff, 1964). Other morphometric data are included in Figures 1 and 2 and on Table 1 of this thesis. At the more shallow southern end of the lake, there is a hotel and swimming/boating area used in summer months only. At the deeper, northern end of the lake, there is an old boat house surrounded by the large sandstone boulders believed to have been instrumental in forming the lake by damming the headwaters of the small mountain stream, Pond Drain (Parker, Wolfe and Howard, 1975). The lake's east and west shorelines are characterized by very steep banks forested with *Rhododendron maximum* L. and *Tsuga canadensis* (L.) Carr which extend upward 60 m - 90 m from the lake's surface. This small vegetated water shed probably does not contribute a significant input of allochthonous material. This, in addition to the cold mountain climate and sandstone basin, probably maintains the oligotrophic nature of the lake.

Mountain Lake, Virginia, exhibits two very unusual phenomena, as compared to other oligotrophic lakes, which are (1) extensive and dense beds of rooted aquatic macrophytes (mostly *Nitella flexilis* (L.) Ag., Figure 8) extending deeply into the lake's summer metalimnion, and (2) a strong, persistent oxygen maximum in the same zone. Neither of these have been adequately studied by previous researchers.

Contemporary studies have attempted to attribute the lake's unusual summer oxygen curve to phytoplankton (Obeng-Asamoa, 1971; Obeng-Asamoa and Parker, 1972; Simmons and Neff, 1973; Simmons, 1975) as has been done for other lakes with similar oxygen curves (Eberly, 1964). No one, however, has examined the potential for the extensive and deep macrophyte beds to contribute to the lake's metalimnetic oxygen maximum. The possible and often-overlooked importance of macrophytes to a lake's ecology has been alluded to by several researchers in recent times (Rich, Wetzel, and Thuy, 1971; Environmental Protection Agency, 1973).

Therefore, the objectives of this study were as follows;

1. To determine the distribution of the rooted aquatic vegetation standing crop with depth.
2. To evaluate the effect of the position of the transects around the lake's basin on the depth distribution of rooted aquatic plants.
3. To evaluate the contribution of the rooted aquatic plants to the metalimnetic oxygen maximum and to the partial alleviation of the hypolimnetic oxygen deficit.

II. REVIEW OF LITERATURE:

Mountain Lake is considered by most investigators to be an oligotrophic lake (Hutchinson & Pickford, 1932; Roth, 1963; Roth and Neff, 1964; Marland, 1967; Obeng-Asamoa, 1971; Obeng-Asamoa and Parker, 1972; Simmons and Neff, 1973; Simmons, 1975). Various investigators have found that the lake has very low nutrient levels, high transparency, a small hypolimnetic oxygen deficit, and a dense bed of rooted macrophytes which exist around the circumference of the basin to a depth of 11 m. In addition to the normal characteristics attributed to oligotrophic lakes, Mountain Lake also possesses a metalimnetic oxygen maximum which persists throughout the period of summer thermal stratification.

Two of the first investigators to study the metalimnetic oxygen maximum were Roth and Neff (1964). They concluded that the metalimnetic maximum could be produced by either biological (biogenic) or physical means. A biogenic maximum might be produced in the metalimnion where sharp viscosity changes delay the descent of sinking phytoplankton communities. The physically-produced (non-biogenic) oxygen maxima might occur at the start of the warm season when the surface heating causes reduced oxygen levels in the top few meters and benthic respiration causes a like reduction in deeper water, leaving the metalimnion with its residual of higher oxygen levels left over from spring mixing. Such physically-produced oxygen maxima are usually ephemeral as found by Cole (1954) in Kentucky or, if more persistent, they are produced by a persistent physical feature such as the rapid inflow of cold, highly-oxygenated stream water as reported by Minckley and

and Tindall (1965). Neither of these, however, explains Mountain Lake's continued strong oxygen maximum which persists late into the summer, nor the increase of at least 1 mg l^{-1} over concentrations found during spring mixing and the establishment of a supersaturated condition. Roth and Neff (1964) also note that biogenic oxygen maxima are common in lakes, such as Mountain Lake, where the water is sufficiently transparent to permit the compensation point to be in the metalimnion. Eberly (1964), who studied metalimnetic oxygen maxima throughout the world, listed four types of oxygen maxima:

1. The pseudo-metalimnetic oxygen maximum which develops temporarily in early summer. This phenomenon occurs under a high secondary thermocline in very small, well-protected lakes.

2. The temporary sub-climax oxygen maximum with highest values in early summer, and which occurs in the deep layers of the metalimnion of very clear lakes.

3. The permanent climax oxygen maximum which is characteristic of the lake throughout the summer and generally reaches its highest oxygen values just prior to the beginning of fall circulation and which may be one of two subtypes:

   A. Diatom Maximum - with diatoms as the dominant planktonic alga.

   B. Oscillatoria Maximum - with *Oscillatoria* as the dominant planktonic alga.

The phytoplankton communities in Mountain Lake have been studied by several investigators, but none has found a good correlation between phytoplankton cell densities and the metalimnetic oxygen maximum.

Hutchinson and Pickford (1932) were the first to note a low phytoplankton density in Mountain Lake. Coker and Hayes (1940), using a Forrest water bottle, found that the highest densities occurred between the surface and 4.5 m which did not coincide with the lake's oxygen maximum. Obeng-Asamoa and Parker (1972) did report phytoplankton cell densities which coincided with the lake's summer oxygen maximum from 6 m to 10 m. Their cell densities, however, (4 cells ml^{-1} to 62 cells ml^{-1}) would not seem adequate to account for such high oxygen levels. [Although it is well known that the higher turnover rate of smaller single-celled organisms often causes higher productivity rates than cell count or biomass alone might indicate (Wetzel, 1975, p. 354)]. Since the study of Obeng-Asamoa and Parker (1972) was designed primarily to determine seasonal succession of phytoplankton communities, their samples were limited to five depths, (.1 m, 1 m, 6 m, 10 m, and 17 m). It would be difficult therefore, to establish a close correlation between their cell counts and the oxygen curves in Mountain Lake. The problem is compounded by the fact that water samples for plankton counts were collected with a water bottle and concentrated by means of a Foerst electric continuous flow centrifuge (Cacchione, Parker and Tomimatsu, submitted). Additionally these investigators have determined that this older method has two drawbacks even though the 20,000 rpm speed of this continuous flow centrifuge (Welch, 1948, p. 259) meets the minimum 2000 rpm requirement for phytoplankton cell concentration as stated in the American Public Health Association, <u>et al.</u> (1971, p. 731). First, due to the extremely short time that the cells are centrifuged as the water passes through a continuous flow system, this centrifuge may not have been adequate to concentrate all cells in the sample. Second, many cells may be lost or damaged during centrifugation. Using other estimates of productivity (^{14}C, chlorophyll, and oxygen light and dark bottles), Obeng-Asamoa (1971) found that the phytoplanktonic oxygen production rate probably is not sufficiently high to account for such a consistent and strong positive heterograde oxygen curve.

Simmons and Neff (1973) used ^{14}C to estimate the primary productivity of the lake's phytoplankton community. In contrast to their initial expectation, they found no correlation between the fixation curve and the metalimnetic oxygen maximum. The ^{14}C data of Simmons and Neff (1973) indicated that the peak of phytoplankton productivity during summer stratification was between 1 m - 4 m while the oxygen peaks during the same time period were from the 10 m - 11 m depths. All of these factors indicate that it is doubtful that the planktonic algae, alone, are responsible for the lake's strong metalimnetic oxygen maximum. Based upon the carbon assimilation rates, Simons and Neff (1973) suggested that the lake is not as unproductive as other evidence might make it seem, and that the rooted aquatic macrophytes could be playing a major role in the contribution to the metalimnetic oxygen maximum of the lake.

Mountain Lake seems, therefore, to meet the criteria established by Eberly (1959, 1964) for lakes with true biogenic metalimnetic oxygen maxima because: (1) it has a summer metalimnetic oxygen level exceeding the vernal pre-stratification value; (2) the maximum persists through the summer with the highest value occurring just prior to fall overturn; (3) the water is low in color and turbidity; (4) the epilimnion is low in phytoplankton; (5) adequate light penetrates well into the metalimnion; and (6) the lake has a small water shed and stable thermal stratification protected by short fetch and sheltering mountains surrounding the lake's basin. Eberly also suggested that, for a biogenic oxygen maximum to develop, it is necessary to have an alga which finds its optimal growth range under those conditions existing in the metalimnion. Such an alga exists in Mountain Lake, although it is not a planktonic species like those referred to by Eberly (1964).

This alga, *N. flexilis*, a charophyte, has been listed as the dominant macrophyte in the lake (Forest, 1954; Roth and Neff, 1964; and Obeng-Asamoa, 1971). Mountain Lake therefore, exhibits the characteristics of Eberly's (1964) third category of oxygen maxima. However, since Eberly considered only the phytoplankton as the cause of such maxima, Mountain Lake may belong to a new subtype.

Current research indicates that phytoplankton are responsible for only part of a lake's productivity and that both allochthonous material and macrophytes must be placed in proper perspective (Wetzel, 1975, p. 355-418). Since *N. flexilis* is perennial in Mountain Lake (Forest, 1954) and covers most of the littoral zone (Roth and Neff, 1964) this alga could well be a major contributor to the lake's productivity. Due to the clarity of the water, this macrophyte probably receives adequate light into or below the metalimnion. There is also the possibility that through the use of the organic substrate as an energy source the plant might extend its range below the limit normally established by light (Obeng-Asamoa, 1971). Westlake (1965) reported that macrophytes may be more productive per unit area than phytoplankton under the same conditions.

Roth and Neff (1964) have found pronounced winter heating in Mountain Lake. This could account for the higher than expected winter phytoplankton productivity reported by Obeng-Asamoa (1971) and the maintenance of a large overwintering population of N. flexilis.

Macrophytes have been found to play a major role in the productivity of some other lakes (Rich, Wetzel and Thuy, 1971). The aquatic bryophyte, Fontinalis, (also found in Mountain Lake) has been recorded at depths of 13 m - 20 m in certain clear lakes in Wisconsin (Juday, 1934). In all cases the water was soft, clear (Secchi 13 m) and cool (8^{o} - 11^{o} C), as is the case in Mountain Lake. In certain Michigan lakes, Chara spp. and Ceratophyllum demersum L. have been found, but limited to shallow water depths, as is also the case in Mountain Lake (Rich, Wetzel and Thuy, 1971). In other cases where Chara spp. are found, increased depth seems to be limiting (0 m - 1 m) (Wilson, 1937; Frantz and Cordone, 1967; Daily, 1959). Chara spp. are probably limited to shallow water by the light requirements for germination of their oospores (Proctor, 1967). Chara spp. are especially well adapted to existence in the shallow littoral zone of lakes. This charophyte can withstand scraping by winter ice sheets (Daily, 1959), and it has spores adapted to survive the temporary periods of dehydration characteristic of shallow areas when lake levels drop (Proctor, 1967; Swindale and Curtis, 1957).

The dominant macrophyte in Mountain Lake, N. *flexilis*, however, has been shown to be tolerant of reduced light levels (Daily, 1959). This makes it especially well adapted to deeper zones in lakes as well as to heavily silted areas (Daily, 1959; Pearsall, 1920). This tolerance to lower light and heavily silted areas has been suggested as the reason for its success especially on the south-west (wind-sheltered) shores of lakes both in the Northern United States and England, (Pearsall, 1920; Daily, 1959). Both areas are characterized by prevailing winds blowing silt towards the more sheltered south-west shore. In addition to the silting factor, *Nitella* and other macrophytes often do better on the south-facing slope of the lake's basin where they receive more direct insolation (Schmid, 1965; Daily, 1959). Shen (1971) has shown that some charophytes (and perhaps the same is true of *Nitella*) may be dependent upon a high organic content of the substrate for filtering out certain toxic substances produced by the plants themselves. He found the growth of *Chara* spp. to be stimulated by the addition of charcoal and agar to the growth medium.

In general, when the primary productivity of a lake is dominated by macrophytes, rather than by phytoplankton, certain common lake characteristics have been shown to prevail. Such macrophyte-dominated lakes exhibit consistently low concentrations of dissolved nutrients. These low nutrient levels restrict phytoplankton growth, thereby allowing the rapid development of certain well-adapted macrophytes (Rich, Wetzel and Thuy, 1971). The depth and organic composition of the sediments of macrophytic lakes have been found to be of importance equal to or greater than the depth of light penetration (Pearsall, 1920). Light levels of 1% of the surface intensity have been shown in most studies to limit the depth of the littoral zone (Cole, 1975, p. 117). Therefore, most macrophyte-dominated lakes show the additional oligotrophic character of clear water.

In addition to macrophytes, epipelic algae (such as certain blue-greens) which form mats on the sediment have been shown to be fairly productive in shallow low-nutrient lakes (Gruendling, 1971). Such mats do exist in Mountain Lake (but probably not extensively). A future study of their contribution to the productivity of Mountain Lake is in order.

III. MATERIALS & METHODS

Time Period:

Data for this study were collected between the dates of September 1973 and September 1975.

Measurement of Physical Factors:

Temperature (degrees Celsius) was initially measured in Mountain Lake using a Yellow Springs Instrument (Model 33) Temperature/Conductivity meter. When this instrument became inoperative, readings were obtained using a calibrated long stem thermometer. The thermometer was placed into a 300 ml BOD bottle which was flushed approximately 2-3 times with water from each depth. The thermometer was read while it was in the bottle after allowing sufficient time for equilibration.

Incident light, at the lake's surface, was measured using a Belfort Instrument Company Model No. 5-3850A pyrheliometer placed on shore at a small weather station at the nearby Mountain Lake Biological Station. The incident radiation values recorded in Table 10 represent integrated values.

Water transparency was determined using a Whitney underwater photometer (Monte Dore Corporation, Model Number LMD 8 A). Data in 1966 were determined with a G. M. Photometer, Model Number 268 WA 300.

The material comprising the substrate along each study transect was observed by scuba divers and compared to material dredged with the plant samples.

The slope at each transect was determined from a bathymetric map of the lake from Roth and Neff (1964).

Measurement of Chemical Factors:

The Azide modification of the Winkler Technique was used to determine the dissolved oxygen (American Public Health Association, *et al.*, 1971, p. 477). Water samples for determining dissolved oxygen were collected over the deep hole in the lake on the north-east side using a Kemmerer water sampler (American Public Health Association, *et al.*, 1971, p. 477). The 300 ml BOD bottles were flushed 2-3 times. A few additional samples were collected at other locations in the lake to establish oxygen uniformity throughout the basin. All samples were acid-fixed in the field and transported to the laboratory in a dark box where they were analyzed as described in American Public Health Association, *et al.*, (1971, p. 477). All oxygen readings were converted to percent saturation adjusted for an altitude of 1200 meters using Rawson's Nomogram (Welch, 1948, p. 366).

Measurement of Biological Factors:

During the months of July and August, 1973, the lake's benthic macrophytes were quantitatively collected along 5 underwater transects (Figure 3) using scuba and a hand operated standard 15.2 centimeter^2 Ekman dredge (Welch, 1948). The biomass (ash-free dry weight) was subsequently determined for each sample and converted to biomass per meter^2.

Based on the plant distribution observed with scuba, the 5 transects were established at points around the lake's basin which included the north and south ends and both sides (east and west). Each transect was marked in meter depths to a depth of 11 m and placed in the positions indicated on the lake map (Figure 3). The first transect, in front of the boat house at the north end of the lake, was used for a pilot study. The other four transects were carefully positioned to include all major variations in the lake's littoral zone. Samples were then obtained by a diver who manually pushed an Eckman dredge into the substrate and closed the jaws, thus eliminating much mechanical sampling error. Five such samples were obtained at each meter depth. The samples were separated by distances of approximately one meter (except where rocky substrate dictated otherwise).

Samples were lifted to the boat and placed in labeled plastic bags. In the laboratory, the plant material was separated from the soil by washing in a 32 mesh (500 micron openings) sieve (W. S. Tyler Sieve No. 35). Once washed in this manner, samples were preserved by freezing and later further washed in accordance with the procedure described by Westlake (1969). All samples were subsequently examined under a stereomicroscope to check for extraneous material. The samples were then briefly rinsed in .12 N hydrochloric acid solution to remove any possible adhering carbonate (Dr. Bruce Parker, Dept. of Biology, VPI and SU, personal communication).

During the washing process, certain samples were randomly selected to be scanned under a microscope for the presence of epiphytic diatoms which could contribute to oxygen production. Further observations to check for possible evidence of grazing on the benthic macrophytes were made using scuba. Such grazing is unlikely since Characeae are reported to be eaten only by certain duck species which have not been reported by local observers in Mountain Lake (Martin, Zim, Nelson, 1951; Holt, 1971, p. 427-429). The lake's numerous salamanders of the genus

<u>Notophthalmus</u> (Jopson, 1936) are reported to be entirely carnivorous except for the larvae which are restricted to a diet of unicellular epipelic algae (Jopson, 1974, personal communication).

After washing, samples were blotted and weighed on a Mettler balance to obtain blotted wet weights. The samples were then dried at 105° C for 24 hours (Westlake, 1969, p. 28).

Dry weights were obtained and recorded for each sample. The dried samples were then ashed in covered crucibles for 5 hours at 500° C (American Public Health Association, <u>et al.</u>, 1971, p. 745) and again weighed on a Mettler balance. The period of 5 hours was determined to be adequate to reach a constant weight. The ash was then moistened with distilled water and redried at 105° C for 24 hours to reintroduce water of crystallization (American Public Health Association, <u>et al.</u>, 1971, p. 745). Ash-free dry weights were then calculated for each sample. It should be noted that some authors have used 550° C as the ashing temperature (Westlake, 1969). However, the lower temperature of 500° C (American Public Health Association, <u>et al.</u>, 1971, p. 745) was selected for this study to reduce the chance of carbonate decomposition reported by Westlake (1969) as a possibility at temperatures over 550° C.

Each month, during the winters of 1973-74 and 1974-75, whenever weather conditions were favorable, additional benthic macrophyte samples were collected from a boat using a surface operated standard 15.2 X 15.2 cm Ekman dredge (Welch, 1948) without scuba (along Transect 3; Figure 1) to determine the extent to which these plants overwinter. From these samples dry weights only were determined as already described.

Phytoplankton samples were collected with a Kemmerer sampler and preserved with merthiolate (American Public Health Association, _et al._, 1971, p. 729). These samples were counted by the settling technique using an inverted microscope (American Public Health Association, _et al._, 1971, p. 731; Lind, 1974, p. 97-99). The actual phytoplankton cell numbers and volumes are recorded on Table 11 but were normalized by dividing each number by the smallest number prior to graphing on Figures 19 and 20.

Phytoplankton productivity was estimated using the carbon -14 technique (American Public Health Association, _et al._, 1971; Lind, 1974). A four hour incubation period from 10:00 a.m. to 2:00 p.m. was used (Lind, 1974).

Algal macrophyte species were identified where possible using the Mountain Lake Biological Station's herbarium and the key to the _Charophytes of North America_ (Wood, 1967). Identification was verified by Drs. Bernice M. Speese and Joseph L. Scott at the Department of Biology, College of William and Mary. Identification of bryophytes was verified by Dr. Susan Moyle of Centre College, Kentucky and Dr. David A. Breil of Longwood College. Vascular plant identifications were confirmed by Dr. Warren H. Wagner, University of Michigan; Dr. Carl S. Keener, the Pennsylvania State University; and Joseph Lankalis of the Mountain Lake Biological Station. Generic names were subsequently checked in Gleason and Cronquist (1963). Voucher specimens of the lake's 5 dominant plants have been placed in the herbarium of the Mountain Lake Biological Station.

IV. RESULTS AND DISCUSSION

Species Composition

During the course of this study 39 species of macrophytes (2 charophytes, 14 bryophytes, and 23 vascular plants) representing 22 families were found to occur in the littoral zone of Mountain Lake. These are listed in Appendix B of this thesis. This is a greater diversity of species and families than is usually found in an oligotrophic lake and even exceeds the 27 species from 18 families (all vascular plants) found by Wilson (1937) in a much more eutrophic Wisconsin lake.

In a similarly oligotrophic Michigan lake, Rich, Wetzel and Thuy (1971) found only 23 species (3 charophytes, no bryophytes, and 20 vascular plants) representing 9 families. Frantz and Cordone (1967) found 19 species (2 charophytes, 4 filamentous algae, 13 bryophytes, and no vascular plants) representing 8 families in the ultra-oligotrophic Lake Tahoe. They, however, were studying only the deepwater macrophytes, thus eliminating from their count all of the shallow littoral species which may have been present.

In this study most of the 39 macrophyte species found in Mountain Lake were represented by very low numbers and were restricted to only a few locations at the very shallow edge of the lake. Thus, only 5 species were collected by dredge along the randomly placed transects. These are: (1) _Fontinalis novae-angliae_ Sull., (2) _Chara braunii_ Gm., (3) _Anacharis canadensis_ (Michx.) Rich., (4) _Ceratophyllum demersum_ L., and (5) _Nitella flexilis_ (L.) Ag. Color photos of these 5 dominants are included in this thesis (Figures 4-8).

Small numbers and low diversity are not unexpected in an oligotrophic lake where nutrients could be limiting (Rich, Wetzel and Thuy, 1971). Often all but attached macrophytes are eliminated by the nutrient-deficient waters of oligotrophic lakes (Pearsall, 1920). The attached plants (including charophytes), however, have been shown capable of obtaining necessary nutrients from the sediment (Pearsall, 1920; Wetzel, 1975, p. 372).

Another possible cause of low species diversity, low temperature (characteristic of this high mountain lake), is probably offset by the increased solubility of gases (characteristic of cold waters) which are essential in respiration and photosynthesis (Pearsall, 1920). In addition to this, Mountain Lake's steep basin creates a situation where water pressure increases rapidly in most of the littoral zone. Pressure is often limiting for higher plant species, which possess gas-filled lacunae, but not for lower macrophytes such as bryophytes or charophytes (Hutchinson, 1975, p. 423). A couple of additional factors are evidently precluding some plant growth from the very shallow edges (nearly free of vegetation) of Mountain Lake. Daily (1959) has shown that shading by overhanging trees and shrubs as well as scouring by waves and ice (in winter) severely limits macrophyte growth.

Of the 5 dominant macrophytes in Mountain Lake, *N. flexilis* was found to be the major contributor to the littoral standing crop. This charophyte was determined in this study to comprise 90% of the total macrophyte biomass. Its greatest contribution is at depths of 6 meters (Tables 2 and 3).

Locally there has been a controversy over which charophyte, N. flexilis or C. braunii, is dominant in Mountain Lake. Dr. L. Whitford of North Carolina State University in a letter to Dr. G. M. Simmons, Jr. of VPI and SU (1971) identified C. braunii as the species of Chara in Mountain Lake. C. braunii was present in the lake but limited to the very shallow sandy area just to the west of the boat house at the lake's south end. The easy access to this site for collecting may explain why some investigators have thought C. braunii rather than N. flexilis to be this lake's dominant littoral species. C. braunii, however, is not as well adapted to Mountain Lake as is N. flexilis. N. flexilis, which has been shown by Hutchinson (1975, p. 16) to favor a pH range of 5.5-7.1 and soft water is probably better adapted to Mountain Lake's soft water and low pH ($\bar{x}$=6.8) than C. braunii, which favors harder water and a pH range from 6.5-8.0 In addition to this, C. braunii has been shown to grow better on quartz sand than on the fine silt preferred by N. flexilis (Shen, 1971). The only place in this lake having sandy sediment is the site of the lake's Chara bed, the south end by the boat house where sand has been applied to the swimming area.

Factors Influencing Distribution

During this study observations were made on the distribution of the 5 dominant species of macrophytes as well as on the distribution of their biomass.

(1) Species Distribution:

Of the 5 dominant macrophytes in Mountain Lake, only two seem to be substantially restricted to certain areas in the lake's basin. C. braunii and C. demersum, both relatively sparsely represented, are shown on Tables 6 and 8 to be restricted to the shallow southern end of the lake (Transect 3). The remaining 3 macrophytes appear to be uniformly distributed around the lake's basin. This limited distribution, in the case of C. braunii (Table 6), may be due to the requirement of this species for a substrate composed mainly of quartz sand (Shen, 1971) as already discussed. Another factor which may be limiting the distribution of this species is the preference of C. braunii for the lower organic content characteristic of this sandy substrate (Proctor, 1967).

Ceratophyllum demersum was found in this study to be highly restricted to the 4 m depth along Transect 3 (Table 8) in the lake's south end. The author's inability to relocate the population of C. demersum two years after the initial study may indicate that these plants are mostly unattached and drifting near the substrate as reported by Hutchinson (1975, p. 82 and 83). If this is the case, this species would probably exhibit the greatest growth rate in the lake's south end where the slope is gentle enough to prevent its movement to areas below its compensation level and where shading from large boulders and the larger macrophyte, N. flexilis, is absent.

Fontinalis novae-angliae in Mountain Lake is predominantly confined to the very shallow shoreline and often grows exposed (Table 5). This species is found attached to logs and rocks along the shore where the most rapid input of allochthonous organic material (twigs and leaves) occurs. This is consistent with similar observations on this genus by Hutchinson (1975, p. 63).

Anacharis canadensis (like *C. demersum*) exhibits its greatest contribution to the lake's macrophyte standing crop at a depth of 4 m (Table 7). This macrophyte was found during this study to be fairly uniformly distributed around the lake's basin to a maximum depth of 6 m. This is not surprising since Hutchinson (1975, p. 423) reports that such higher macrophytes with lacunae are often depth limited by pressure, as previously discussed. It is, however, interesting to note that the south-facing slope did not show the greatest *Anacharis* growth as is reported by other investigators (Schmid, 1965; Daily, 1959).

Nitella flexilis is the most uniformly distributed and abundantly represented of the macrophytes in Mountain Lake. This species comprises almost 90% of Mountain Lake's macrophyte standing crop (Table 3). This figure would be much higher if it were not for the heavy growth of *Fontinalis* in the top meter (Table 3). On Table 2 it is evident that the greatest *Nitella* standing crop occurs at depths below 4 m. This table also shows the presence of *N. flexilis* at all depths in this lake's littoral zone from the surface to 11 meters. As with other lake plants, the *N. flexilis* sample weights for Transect 3 at the shallow south end of Mountain Lake are greater than those of the other 4 transects. This increase probably reflects the increased area of the euphotic zone along this very gradually sloping transect (Figure 13) as well as the associated greater thickness of fine sediment.

Pearsall (1920) noted that *N. flexilis* exhibits its best growth when a heavy layer of fine silt covers the bottom. Mountain Lake's deepwater sediment was found by Roth and Neff (1964) and by Marland (1967, p. 63) to be composed of sand, clay and sandstone rocks overlain by 8 cm of gyttja (decomposing animal and plant parts usually derived from animal excrement) with an 18.6% organic content. The organic content of this sediment is relatively low compared to that of more eutrophic lakes in which the organic content may approach 60% (Marland, 1967, p. 62). It may, however, be sufficient to stimulate the growth of *Nitella,* both by forming a suitable, soft, nutrient-rich substrate, and by filtering from this substrate any autotoxins which these charophytes may be producing (Shen, 1971).

This observation is substantiated by the almost total absence of this species from shallow zones of all 5 transects (Table 9), where coarser sediment (quartz sand) of very low organic content predominates. Since *Nitella* is reported to be tolerant to low light levels (0.3% of surface light by Frantz and Cordone, 1967) and shading (Daily, 1959), it seems unlikely that it would be excluded so completely from the lake's shore zone by shading from overhanging vegetation. Daily (1959), however, found that wave action and winter ice may also serve to remove some macrophytes from the very shallow zones of temperate lakes, and this may be an additional factor in limiting the distribution of *N. flexilis* in Mountain Lake, Virginia.

As discussed above, the greatest standing crop weights for *N. flexilis* in Mountain Lake are found in the lower littoral zone. While this may in part be due to the improved sediment conditions in that zone, the increase in biomass is probably largely the result of the perennial nature of Mountain Lake's *Nitella.* This was first reported by Forest (1954) and is confirmed in this present study (Figure 21). It can be seen on Figure 21 that while Mountain Lake's rooted macrophyte standing crop (90% Nitella) does decline in the winter, a significant biomass survives winter conditions. This surviving population is located primarily at depths of 6 to 10 m. Because of this, plants in the deeper littoral zone have a head start when summer growth begins anew.

(2) Effect of position and depth on the combined standing crop:

It is evident from Tables 4-9 that significant differences in macrophyte biomass do exist among the 5 transects. These differences can probably be attributed to one or more of the following differences between the transects: substrate, direction of slope, and angle of slope. Figures 11-15 show the wide range in slope among the transects. There is an inverse relationship between standing crop and angle of slope (Table 4). The same table shows that the south-facing slope (more direct sun) does not show increased plant growth as reported by Schmid (1965) and Daily (1959). This is probably due to the overriding effect of steepness as discussed above. The very gentle south slope may be responsible for the accumulation of a thicker layer of silt and organic sediment (already discussed) while providing a large well lighted area for many macrophytes to develop. Thus macrophytes would more easily become established in this soft well-lighted sediment than in the lower light levels, sand, and large sandstone boulders found at the other transect locations. Finally, with these improved growth conditions for plants at the south end (Transect 3), one would expect both the increase in total biomass as well as the increased species diversity reflected on Tables 5-9.

Differences in mean sample weights from the same depths along each of the 5 transects were tested using a Model I Analysis of Variance (ANOVA). The analysis shows the effect of transect position (due to variations in substrate and slope) to be highly significant (α =.0001).

Table 2 shows that there was significant variation in the standing crop weights of Mountain Lake's macrophytes with depth. Since at lower levels *N. flexilis* contributed $>$99% of the biomass, the distribution of this species alone is primarily responsible for these differences. These have already been discussed in the previous section (p. 30). Table 2 also shows that 11 m was the lower limit of macrophytes in Mountain Lake. Figure 10 illustrates how this corresponds closely to the level of 1% light transmittance, which is considered to be the compensation level for most aquatic plant growth (Lind, 1974, p. 18; Cole, 1975, p. 68 & 117; Odum, 1971, p. 301). Since pressure is considered to have no limiting effect on charophytes (Wetzel, 1975, p. 376), light seems to be the most likely factor limiting the lower level of Mountain Lake's littoral zone.

The depth variations in the weights of the standing crop of macrophytes were attributed to winter ice action, wave action, changes in substrate, pressure, and light. This effect due to depth was also tested using a Model I Analysis of Variance. The depth effect was highly significant (α =.0001).

The Metalimnetic Oxygen Maximum

(1) *Duration of the Maximum*

A metalimnetic oxygen maximum in Mountain Lake, Virginia, between the depths of 7 m and 12 m is characteristic of the lake during summer stratification (Figure 16). This maximum has been observed by numerous investigators.

Simmons and Neff (1973) have shown that this oxygen maximum forms in May and persists through September. This coincides with the lake's usual period of summer thermal stratification (Roth and Neff, 1964; Marland, 1967; Obeng-Asamoa and Parker, 1972). Data obtained during this study, for the years 1973-1974 showed that the metalimnetic oxygen maximum existed from late June (rather than from May) through September (Table 3 of Appendix A and Figure 19). The one month discrepancy in the development of this oxygen maximum may be explained by delayed spring warming which could delay the development of the lake's producers. All investigators of Mountain Lake have found a similar period of thermal stratification, while this study has shown that the time of establishment of the metalimnetic oxygen maximum is a month later.

(2) Persistence of the Oxygen Maximum

Numerous investigators have speculated about the persistence of the metalimnetic oxygen maximum in Mountain Lake, Virginia. Accordingly, an 18-day study was conducted as part of this investigation in which the lake's oxygen curve was compared to insolation (Figures 17 and 18). This study showed that the oxygen maximum in Mountain Lake's metalimnion did not vary significantly between cloudy and bright days. The metalimnetic oxygen maximum persisted even after several days of cloudy weather. Data gathered at 2 a.m. and 6 a.m. revealed that this maximum is still present through the hours of darkness (Table 2, Appendix A).

(3) Origin of the Oxygen Maximum

One of the basic questions of this study was whether or not a correlation existed between this lake's unusual oxygen curve and the obvious dense stand of rooted macrophytes reported by divers (Figure 9).

Eberly (1964) showed that the usual cause of metalimnetic oxygen maxima in lakes is either the physically induced oxygen saturation through warming or the biologically produced oxygen from phytoplankton. Data found during this present study and by Obeng-Asamoa and Parker (1972) indicate that neither of these two conditions are likely in Mountain Lake. Data on oxygen and temperature for June 2, 1974 (Appendix A, Table 3) show that thermal stratification precedes the development of the oxygen maximum. This delay as well as the persistence of high metalimnetic oxygen levels over those found during spring mixing suggest that the metalimnetic oxygen maximum in Mountain Lake is not produced by physical means alone (Eberly, 1964; Cole, 1954). Eberly's (1964) two types of phytoplankton maxima are also unlikely explanations for Mountain Lake's high summer metalimnetic oxygen levels. Diatoms have been reported by Obeng-Asamoa and Parker (1972) to be the dominant phytoplankton species in Mountain Lake during winter months only. This, however, would not produce high summer oxygen levels. During the present study no significant diatom count was observed during summer months. Eberly's (1964) second cause of such maxima, *Oscillatoria,* was found in Mountain Lake during periods of summer stratification during this study and that of Obeng-Asamoa and Parker (1972).

However, both investigations found it in very low numbers and *Oscillatoria* was not the dominant planktonic species as described by Eberly (1964).

Summer limnetic cell densities ranging from 41 to 15,338 cells per ml were found during this study (Table 11). These densities were significantly higher than the 4-62 cells per ml reported by Obeng-Asamoa (1971). However, neither the phytoplankton cell densities or volumes (Figure 19 and 20) nor the limnetic ^{14}C assimilation curve (Figure 19) show good correlation with the lake's metalimnetic oxygen maximum. The ^{14}C assimilation curve together with the poor condition of many of these cells observed during counting, may indicate that many cells were in a moribund state and had settled in or on the higher density water of the metalimnion. The generally low phytoplankton cell numbers found in Mountain Lake are in keeping with the low nutrient levels reported for this oligotrophic body of water (Roth and Neff, 1964; Marland, 1967; Obeng-Asamoa and Parker, 1972; and others). Under these conditions it does not seem likely that the phytoplankton of Mountain Lake could be productive enough to account for such a strong persistent oxygen maximum.

This hypothesis was substantiated by two studies of Mountain Lake's phytoplankton conducted as part of the present investigation. Both studies compared cell densities, volumes and limnetic productivity (^{14}C) with the lake's oxygen maximum in the metalimnion. The data show that the oxygen maximum does not seem to be correlated with phytoplankton cell densities or volumes (Table 11) nor with their photosynthetic rates shown on Table 12. These three indices of limnetic productivity are shown on Figures 19 and 20 to be highest in the top 6 m while the metalimnion and its associated oxygen maximum are confined to lower levels between 7 m and 12 m. These findings are consistent with those of an earlier study by Simmons and Neff (1973) who concluded that factors other than (or at least in addition to) limnetic fixation appear to influence this lake's metalimnetic oxygen maximum.

Rich, Wetzel and Thuy (1971) reported that oligotrophic lakes such as Mountain Lake are often characterized by high macrophyte productivity and low diversity. They suggest that low nutrient levels in the water column may eliminate some macrophytes and severely limit phytoplankton growth. Low phytoplankton densities permit deep light penetration, thereby enhancing the growth of suitable macrophytes in the lower littoral zone. Lake macrophytes have been discussed by Wetzel (1975, p. 131) as the cause of high oxygen levels in the metalimnion of lakes. Wetzel reported that in Lawrence Lake, Michigan, the oxygen maximum is correlated with both the phytoplankton and macrophyte densities simultaneously. Wetzel (1975, p. 415) listed other examples of lakes in which benthic macrophytes have dominated the production of oxygen and established a maximum in the metalimnion. For one alpine oligotrophic lake in the Pyrenees, he described a case where _Nitella_ sp. was shown to be the major contributor to that lake's oxygen maximum. The same genus dominates the macrophyte beds of Mountain Lake.

The rooted macrophytes in Mountain Lake ($>$ 90% _N. flexilis_) have been shown during this study to persist year round with their greatest biomass between 6 m and 10 m (Table 13 and Figure 21), although some decrease in biomass did occur during the winter months. When data on the summer standing crop of these macrophytes are compared to the mean metalimnion during the same season (Figure 23) it is interesting to note that the two maxima do coincide. Thus there is a strong correlation that was not found between the lake's phytoplankton and summer oxygen levels.

Wetzel (1975, p. 371) noted that caution should be used when attributing oxygen production to macrophytes, since epiphytic algae (usually diatoms) often cover the macrophytes and are themselves responsible for higher productivity than their macrophyte hosts. This does not appear to be the case, however, in Mountain Lake. Several of the macrophytes were examined by Dr. Joseph Scott of the College of William and Mary. Dr. Scott found that epiphytes, although present, are in much lower numbers than would be expected. He felt that these were probably not present in great enough numbers to produce a significant contribution to lake oxygen levels.

It should also be noted that a single set of standing crop data is usually considered to be, in itself, a poor indication of productivity (Wetzel, 1975, p. 377). However, since there is a striking correlation of Mountain Lake's macrophytes with the mean location of the lake's metalimnion, the possibility of a macrophyte generated oxygen maximum cannot be dismissed. Other researchers have found that deep-water species, such as _N. flexilis,_ are quite productive at low light levels (Daily, 1959; Hutchinson, 1975, p. 39). Wetzel (1975, p. 377) reported that _Chara_ may have an annual net production of 50-80% of the standing crop. If the rate for Nitella is similar, a high macrophyte productivity rate is indicated (Table 2).

It is quite possible then, that these macrophytes, which can obtain nutrients from the sediment (Rich, Wetzel and Thuy, 1971; Pearsall, 1920) and are not limited by limnetic nutrient deficiencies, could be contributing significantly to lake oxygen levels.

In addition it is interesting to note that, while the macrophytes persist throughout the year, the lake's metalimnion and associated oxygen maximum are not equally as stable. As can be seen (Figure 22), of the 5 months out of the year during which the lake's oxygen maximum has been shown to exist (May-September) the macrophyte standing crop maximum coincides exactly with the metalimnion during four of the months. Only during August is the correlation not precise. During the six months of non-stratification the total water column is exposed to the oxygen released through macrophyte productivity. Since the data of Simmons and Neff (1973) and of this study indicate that the oxygen maximum is not as pronounced at the onset of stratification, it seems reasonable to conclude that the increase in macrophyte growth during the summer months (Figure 21) may well be a major source of metalimnetic oxygen. This could explain the gradual increase in metalimnetic oxygen levels as the stratification period progresses and oxygen is accumulated (and trapped) in the cold non-circulating water of the metalimnion where temperatures are sufficiently low to reduce its loss through respiration.

The data of this study, therefore, indicate a third sub-type of biogenic metalimnetic oxygen maximum in addition to the two proposed by

Eberly (1964) (p. 17 of this thesis). A "macrophyte maximum" appears to occur in Mountain Lake. Obeng-Asamoa (1971) and Obeng-Asamoa and Parker (1972) reported that, during the time of their study, hypolimnetic oxygen levels in Mountain Lake never fell below 8 ppm. With the exception of one low reading (317 ppm at 14 meters on August 1, 1974), the data of this study are in agreement with this finding. It is evident, therefore, that some factor is helping to balance oxygen demand in Mountain Lake's hypolimnion.

The data of Figure 22 indicate that the macrophytes may be responsible for this oxygenation of the lake's hypolimnetic waters during all but the months of July, August and September. This, however, is not to say that the deepest plants, probably growing near their compensation level, are themselves responsible for much excess oxygen production. Macrophytic oxygenation of the hypolimnion is more probably indirect through water circulation during periods of non-stratification, as well as possibly by eddy currents during the stratified period.

V. SUMMARY

Mountain Lake, the only remaining unaltered natural lake in the state of Virginia, exhibits two very unusual phenomena. These are (1) extensive and dense beds of rooted aquatic macrophytes which extend across the lake's summer metalimnion and (2) a strong, persistent oxygen maximum in the same zone. Neither of these have been adequately studied by previous researchers. In this study the following results were obtained:

1. The species composition of Mountain Lake's littoral macrophyte community was determined.

2. The distribution of the rooted aquatic vegetation standing crop with depth was determined.

3. The effect of the position of the transects around the lake's basin on the depth distribution of rooted aquatic plants was evaluated.

4. The contribution of the rooted aquatic plants to the metalimnetic oxygen maximum and to the partial alleviation of the hypolimnetic oxygen deficit was evaluated.

The rooted macrophyte community of Mountain Lake's littoral zone was found to be composed of 39 species from 22 families. This is higher than has usually been reported for similar oligotrophic lakes. The absence of floating macrophytes and the low population sizes for most of the species have been attributed to low dissolved nutrient levels and low water temperatures.

Only 5 macrophytes were found to occur in significant numbers, with the charophyte, *N. flexilis,* contributing 90% of the total standing crop weight. This species has been reported to be well adapted to the conditions found in Mountain Lake especially in the lower littoral zone.

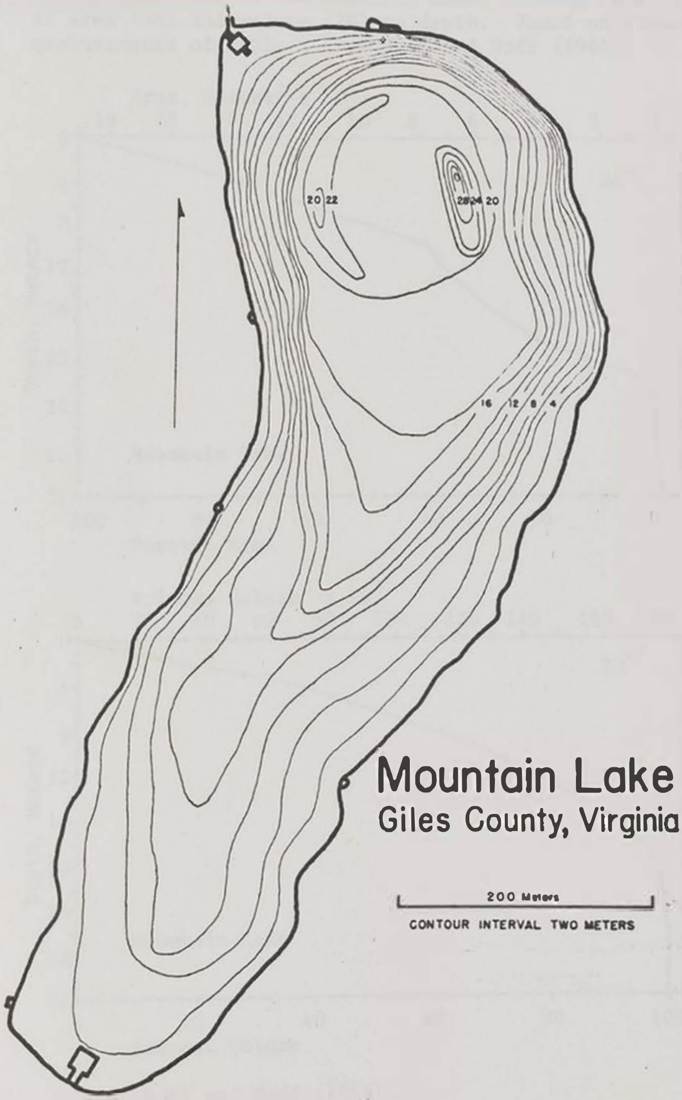
Variations, both in species composition and in weight were found between samples from different depths along the same transect and between samples from the same depths along transects located at different positions around the lake's basin. The effect of depth was attributed to ice action, wave action, substrate differences, pressure and light. Light is considered to be the most important factor limiting Mountain Lake's littoral zone at 11 m. The effect of transect position was attributed to the variations in substrate and in slope. It was found during this study that the south facing slope in Mountain Lake does not show the greater biomass or species diversity reported for other similar lakes. This may be due to the greater steepness of the south facing slope of Mountain Lake's basin. An analysis of variance showed that the effect of depth and transect position on the sample weights was highly significant ($\alpha = .0001$).

A strong metalimnetic oxygen maximum has been reported by several investigators to occur in Mountain Lake, Virginia. In this study, these unusually high oxygen levels in the metalimnion were found to persist day and night and even after several days of cloudy weather. Data indicate that this positive heterograde oxygen curve is caused by the lake's rooted macrophytes, and in particular the charophyte, *N. flexilis.* This finding is at variance with that of other researchers who have attributed such oxygen maxima to the phytoplankton communities. It is proposed therefore, that a third sub-type of oxygen maximum, that of "macrophyte maximum", be added to Eberly's (1964) list of biogenic oxygen maxima caused by phytoplankton.

Data from this study also indicate a possible contribution of the macrophyte beds to maintaining higher than expected hypolimnetic oxygen levels by offsetting benthic respiration. This conclusion is supported by the presence of these macrophytes in the zone of the lake's summer hypolimnion nine months out of the year. Oxygen may be contributed to lower levels by eddy currents during periods of stratification.

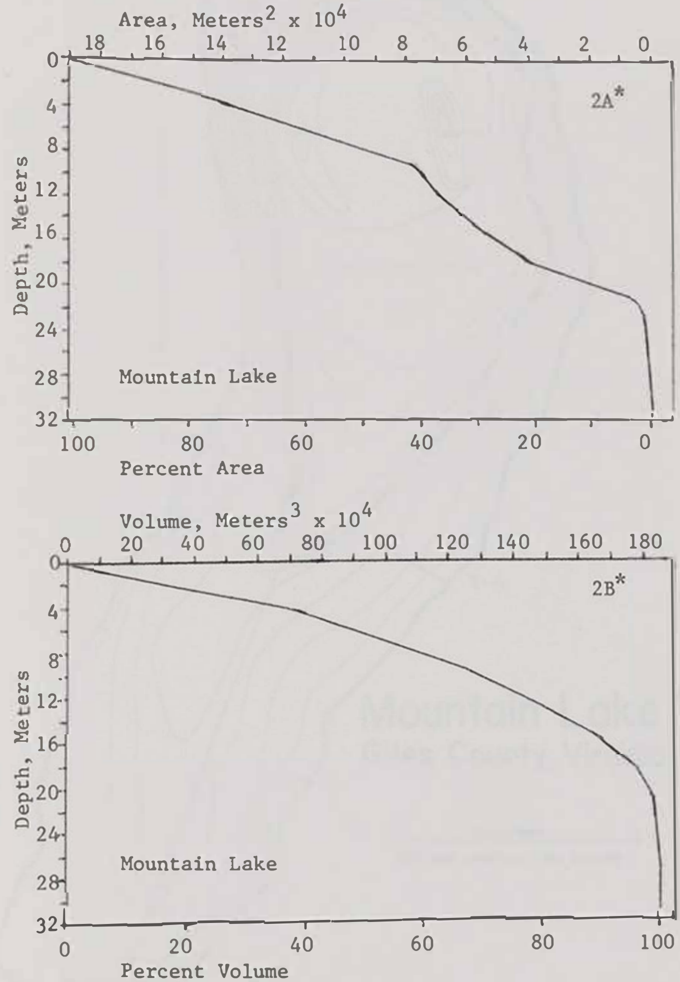
The need for development of a workable technique for estimation *in situ* of the productivity of fresh water macrophytes plus further studies on physical properties that may be contributing to the establishment of the oxygen maximum are indicated.

Figure 1. Bathymetric Chart of Mountain Lake, Va.*



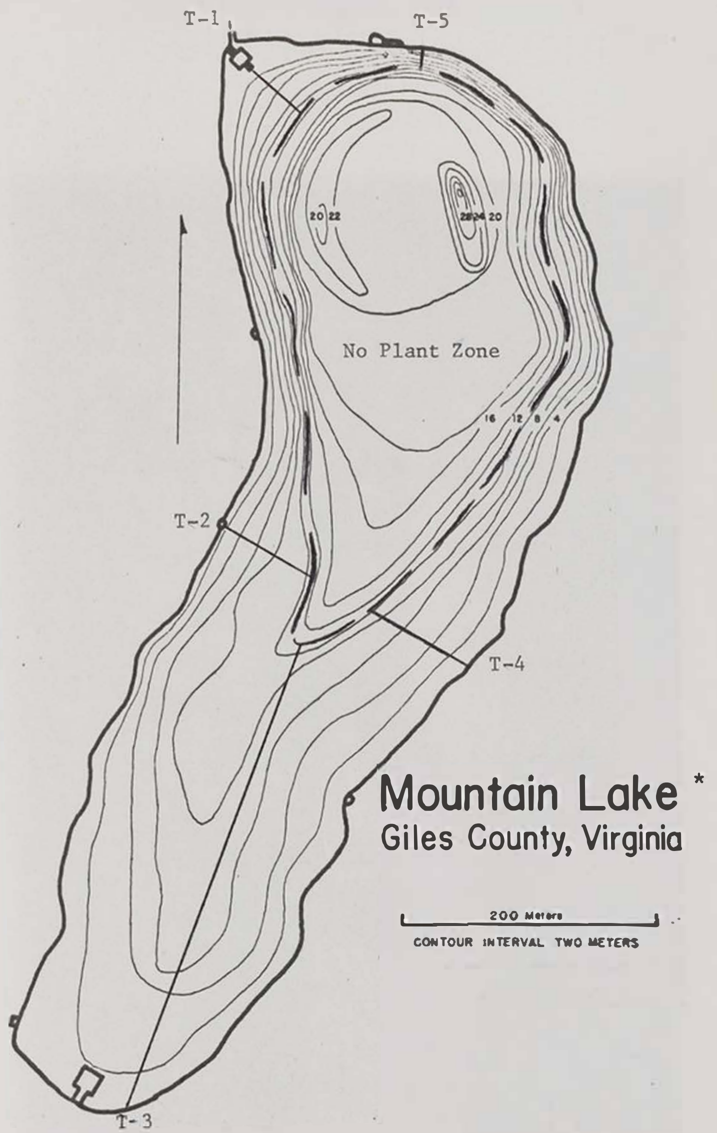
*From Roth and Neff (1964).

Figure 2. Hypsographic curves for Mountain Lake, showing relationship of area (2A) and volume (2B) to depth. Based on planimetric measurements of Table 1 from Roth and Neff (1964).



*From Roth and Neff (1964).

Figure 3. Location of the 5 transect lines for the standing crop study in Mountain Lake, Virginia--July, 1973



*Bathymetric Chart from Roth and Neff (1964).

Figure 4. *Fontinalis novae-angliae* Sull. from Mountain Lake, Virginia--August, 1974.

Figure 5. Chara braunii Gm. from Mountain Lake, Virginia--August, 1974.

Figure 6. Anacharis canadensis (Michx.) Rich. from Mountain Lake, Virginia--August, 1974.

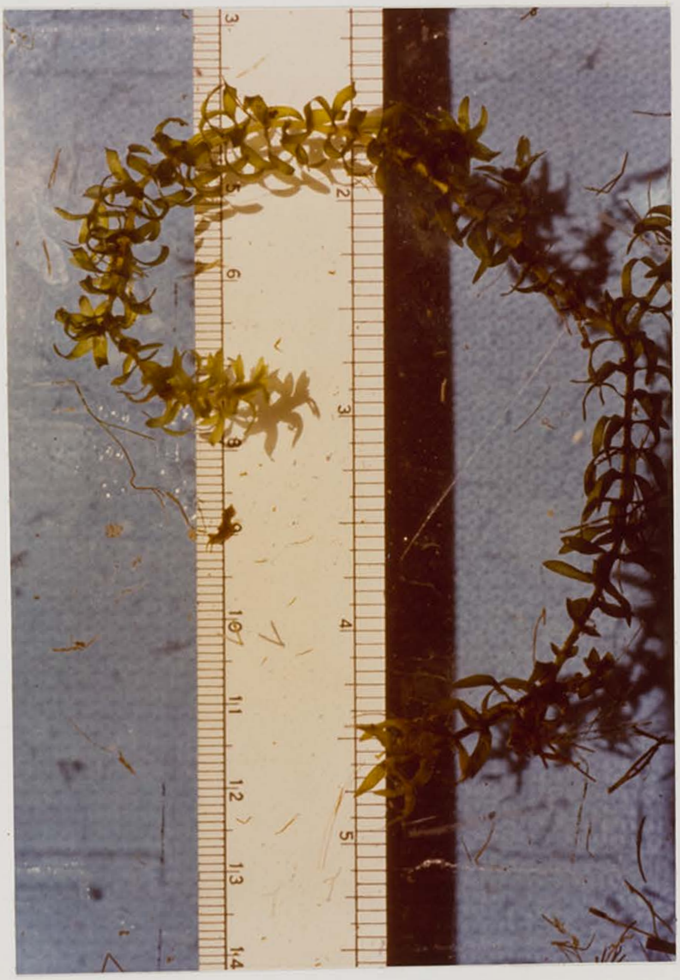


Figure 7. Ceratophyllum demersum L. from Mountain Lake, Virginia--August, 1974.

Figure 8. Nitella flexilis (L.) Ag. from Mountain Lake, Virginia--August, 1974.

Figure 9. Scuba Diver's View of Rooted Macrophytes in Mountain Lake, Virginia

(based upon observations by scuba divers and upon dry weights ($gms\ m^{-2}$) collected along Transect 3 by a rope-operated 15.2 cm^2 Ekman dredge without scuba)

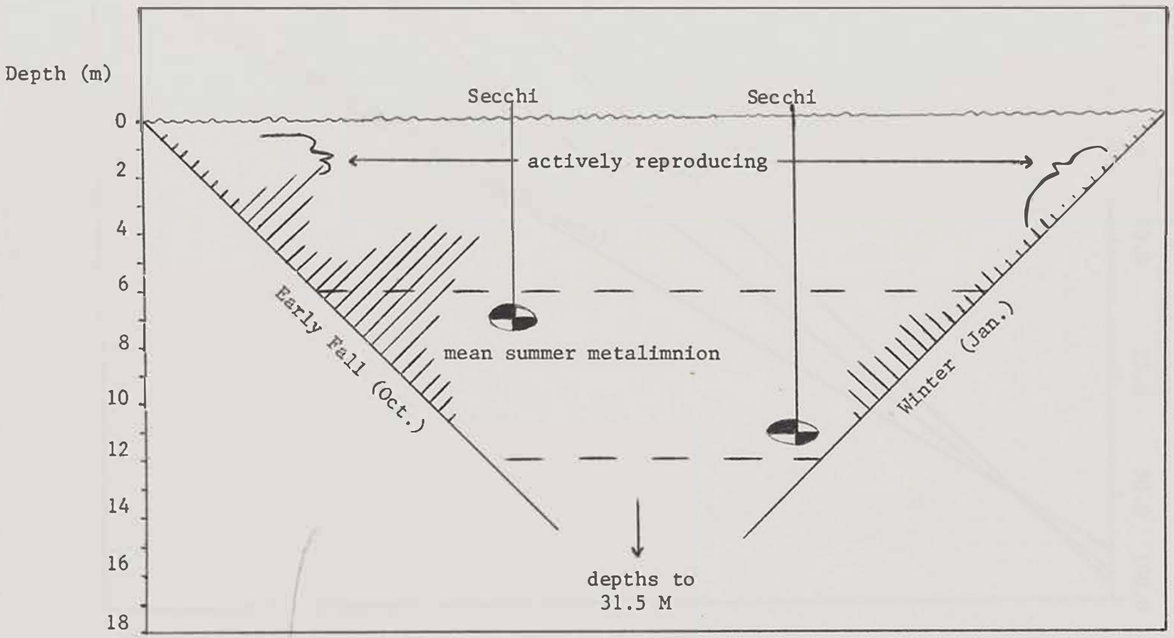


Figure 10. Transmittance of unfiltered light at noon on three sunny dates in Mountain Lake, Virginia.

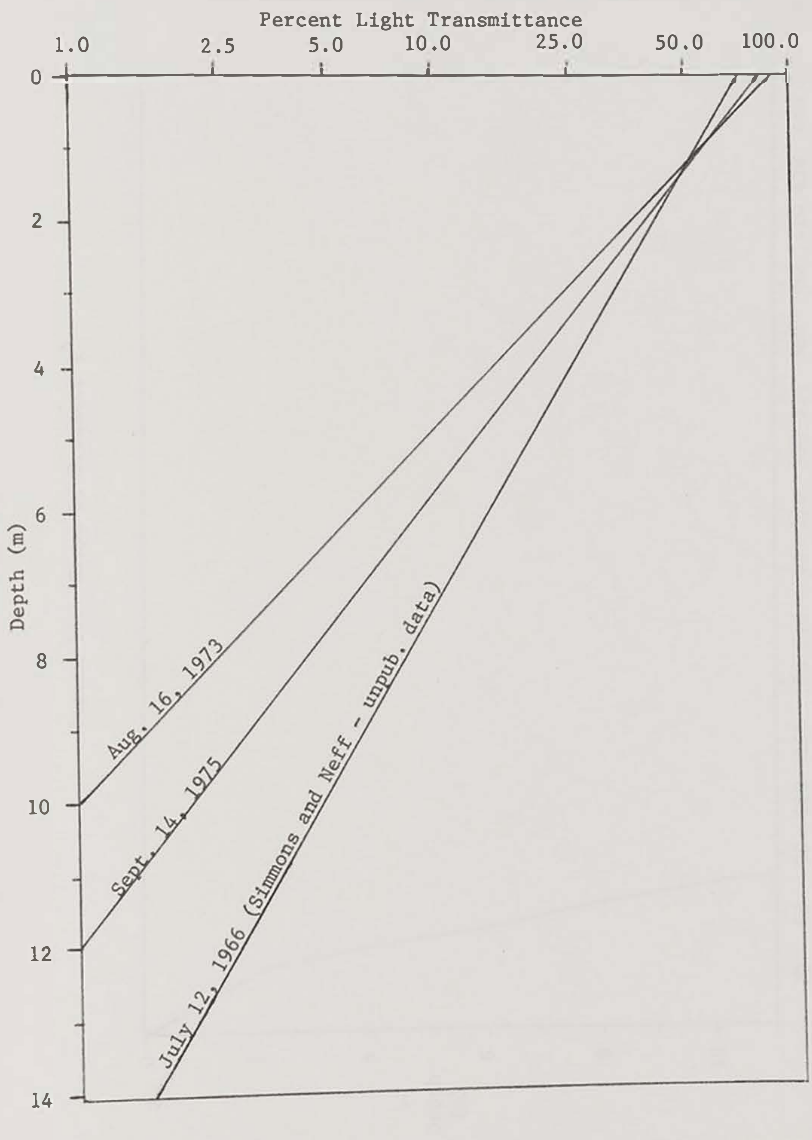
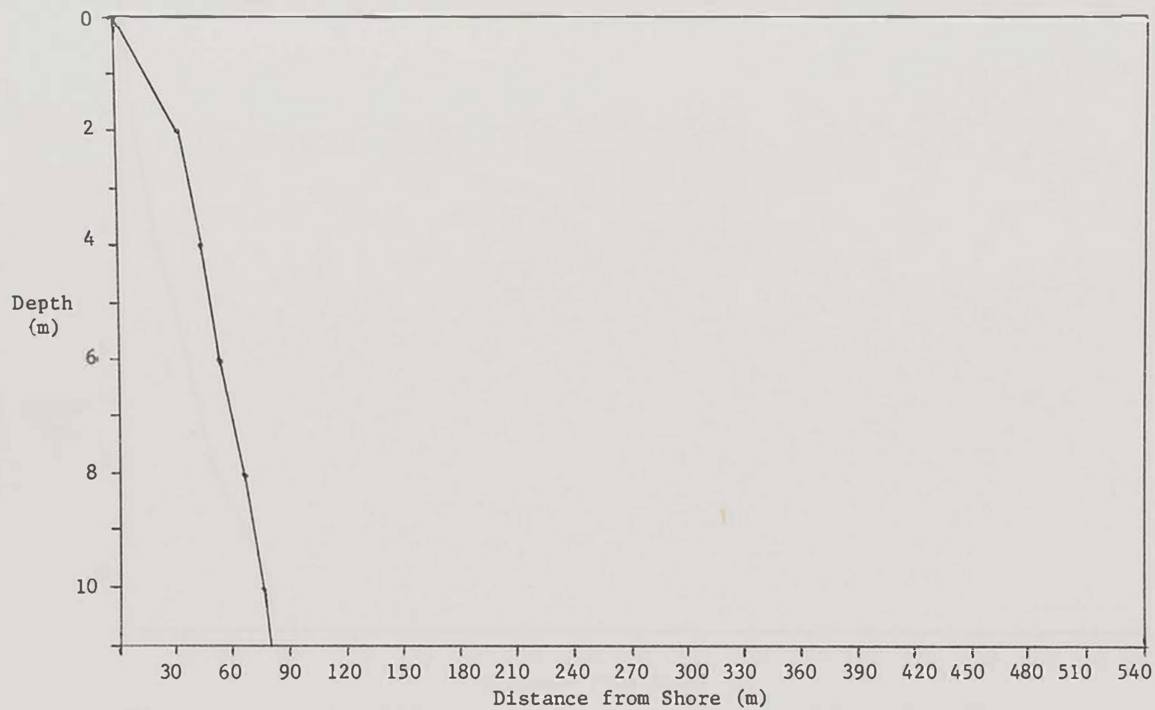
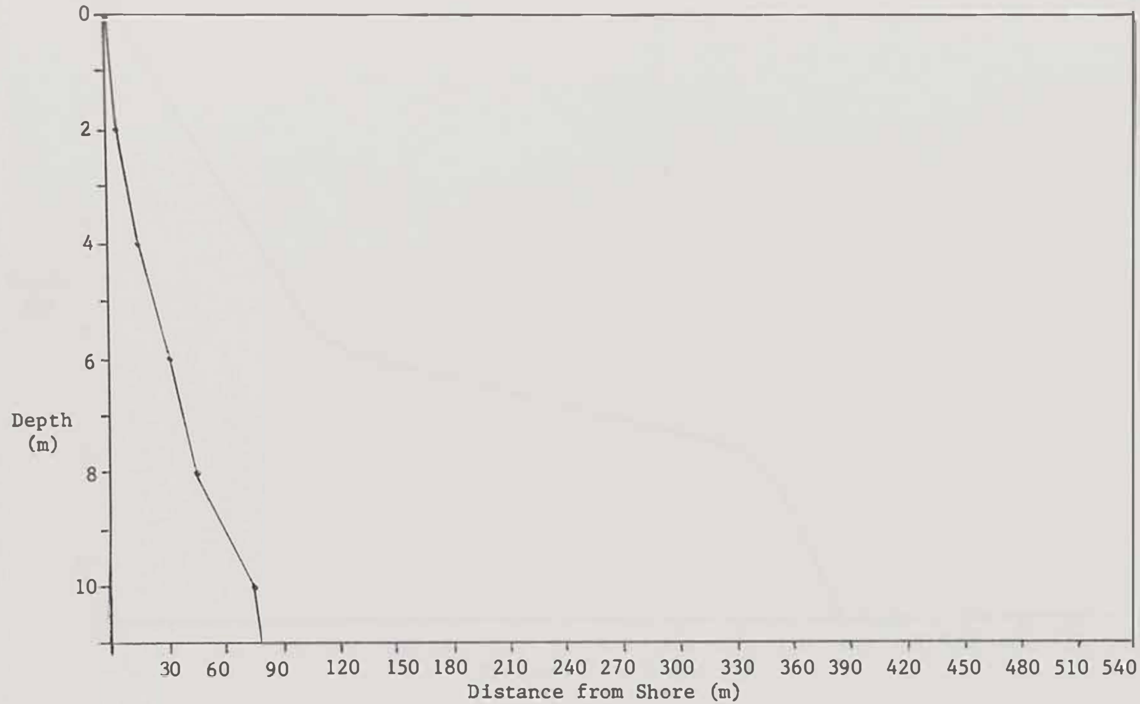


Figure 11. Slope of Transect 1*



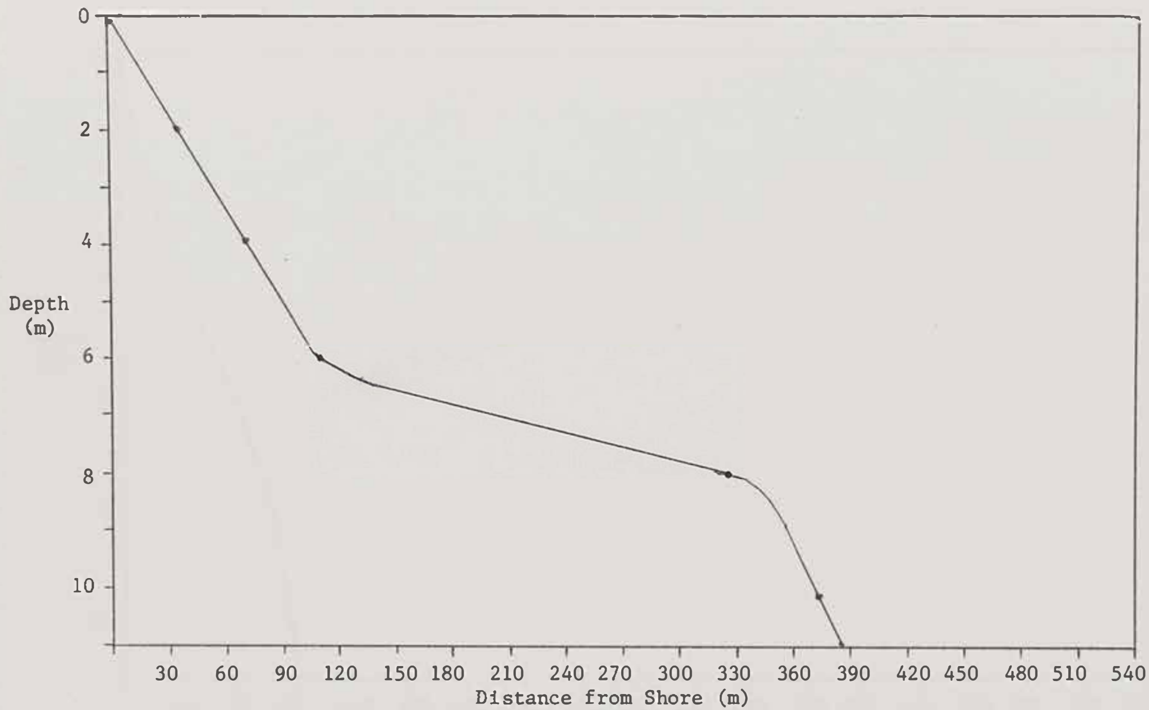
*From Mountain Lake bathymetric chart in Roth and Neff (1964).

Figure 12. Slope of Transect 2*



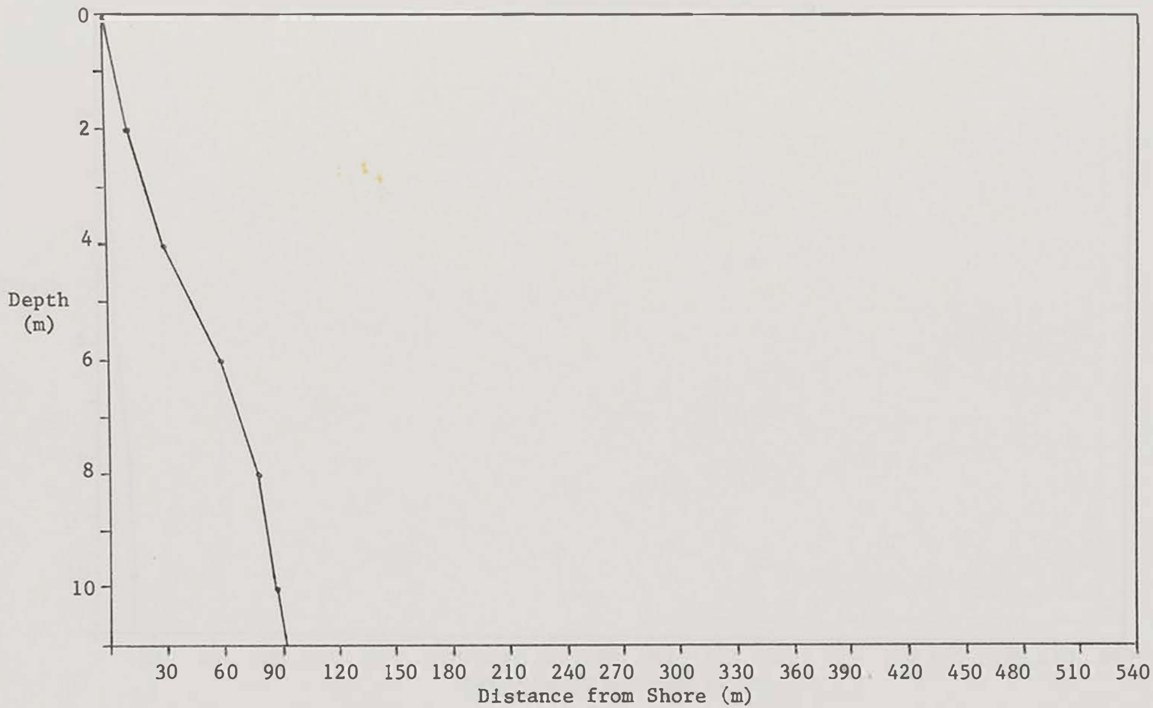
*From Mountain Lake bathymetric chart in Roth and Neff (1964)

Figure 13. Slope of Transect 3*



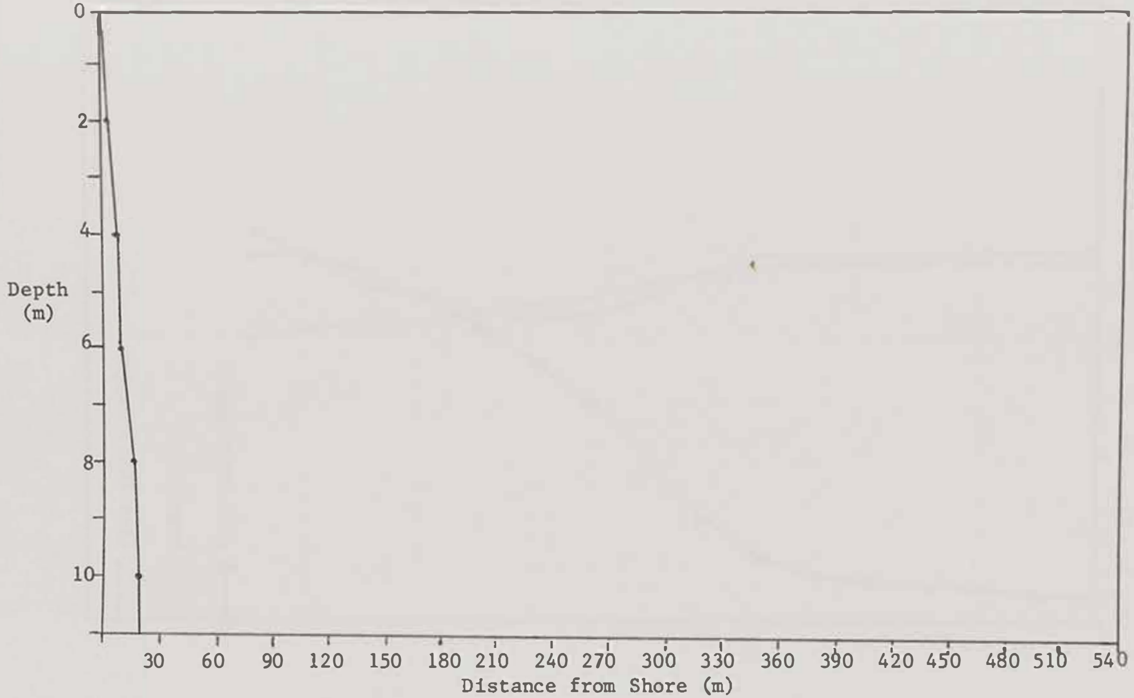
*From Mountain Lake bathymetric chart in Roth and Neff (1964)

Figure 14. Slope of Transect 4*



*From Mountain Lake bathymetric chart in Roth and Neff (1964)

Figure 15. Slope of Transect 5*



*From Mountain Lake bathymetric chart in Roth and Neff (1964)

Figure 16. Mean temperature-oxygen profile for Mountain Lake, Virginia--(July-Aug., 1974).

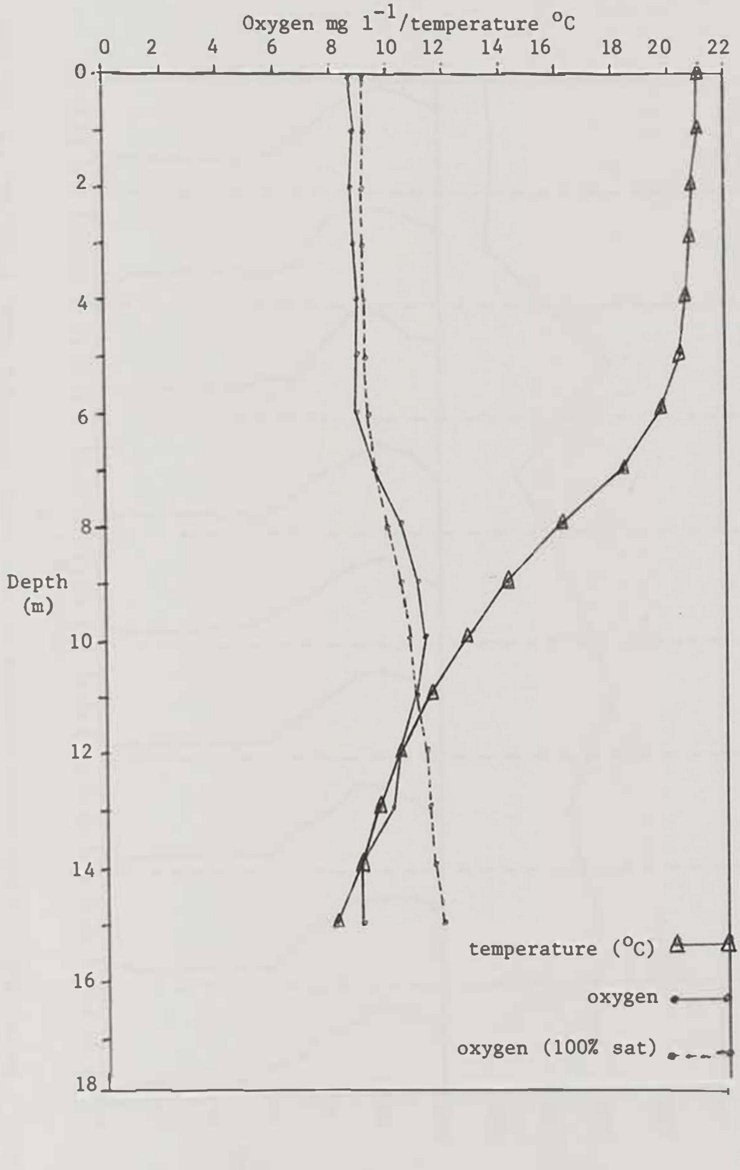


Figure 17. Summer daily oxygen curves compared to insolation, Mountain Lake, Virginia, for July-Aug., 1974.

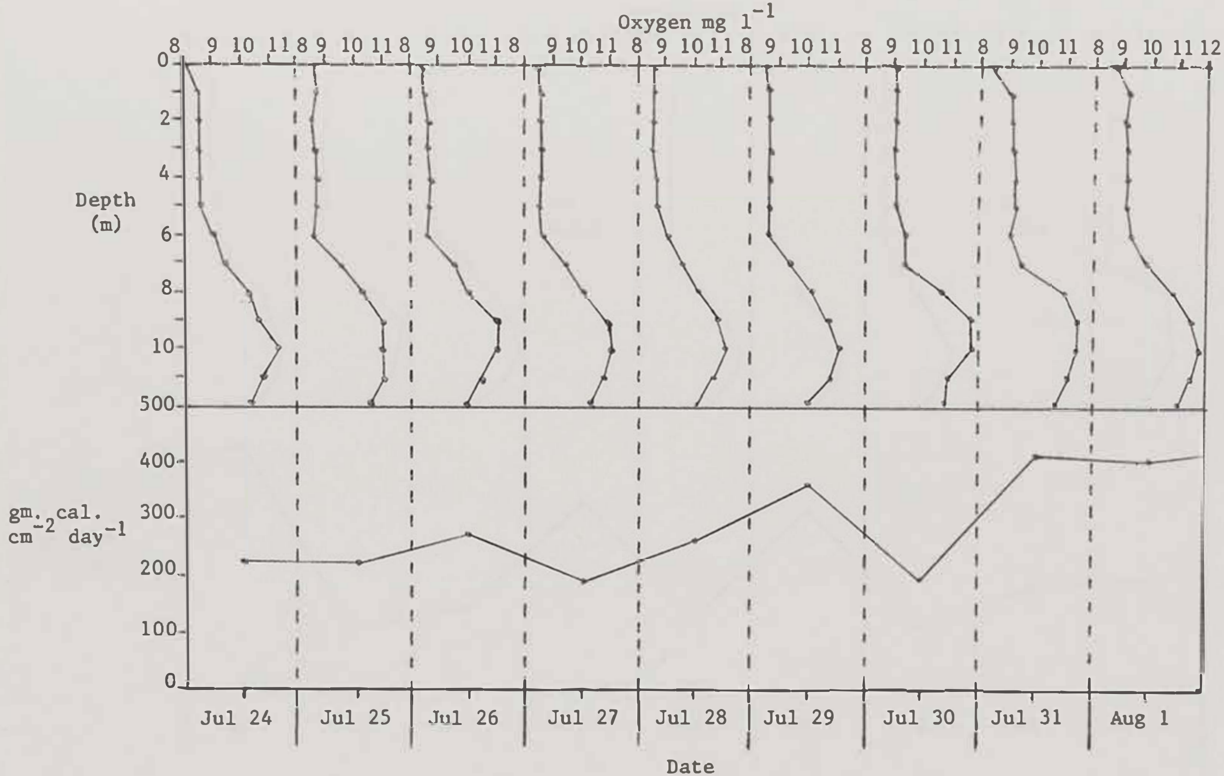


Figure 18. Summer daily oxygen curves compared to insolation, Mountain Lake, Virginia, for July-Aug., 1974.

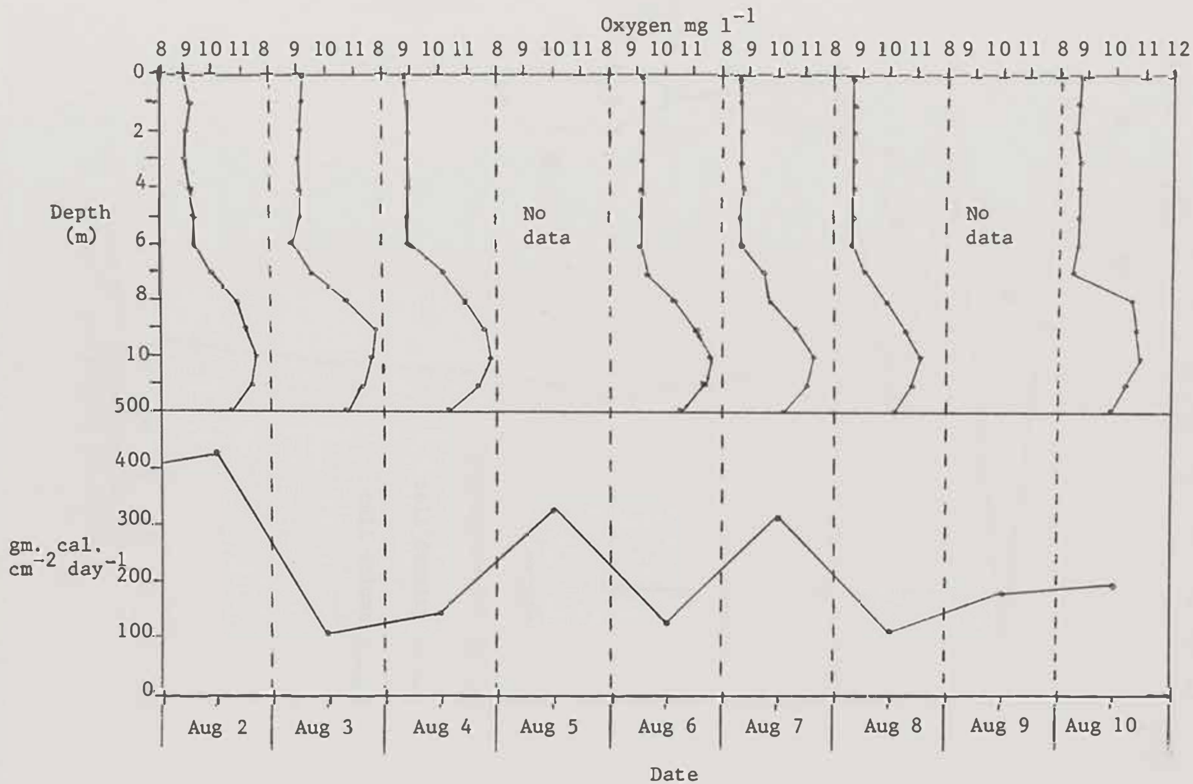


Figure 19. Phytoplankton cell densities and volumes for June 24, 1974 in Mountain Lake, Va.

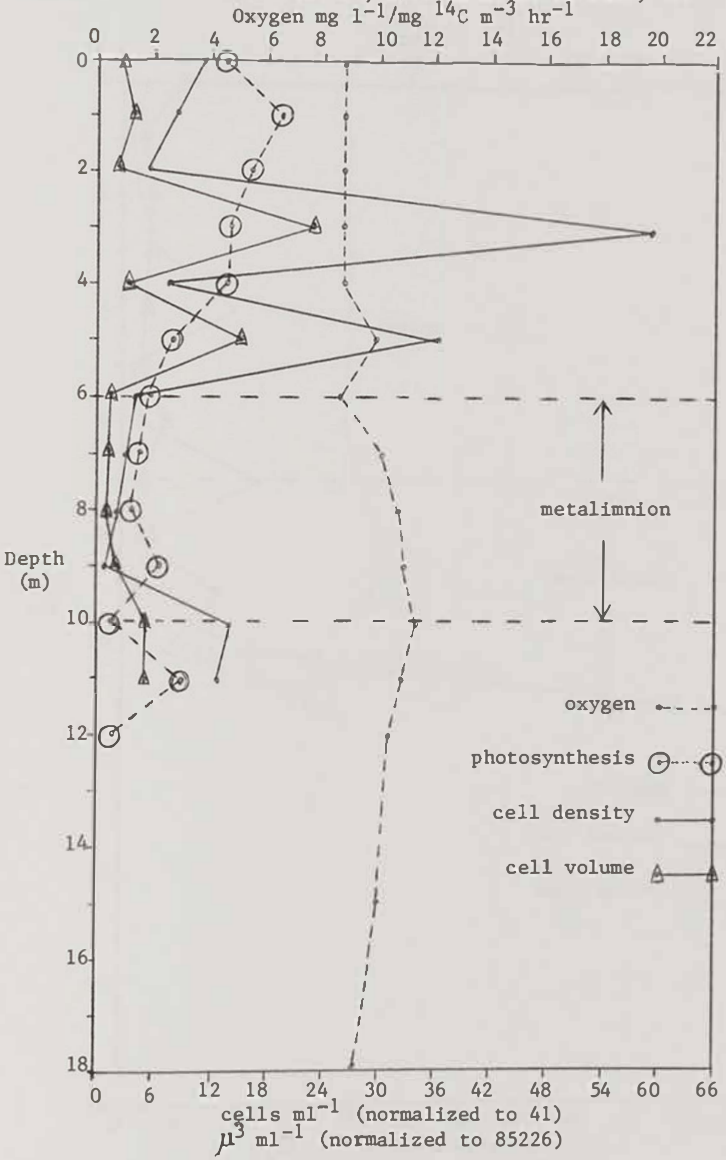


Figure 20. Phytoplankton cell densities and volumes for Sept. 22, 1974 in Mountain Lake, Va.

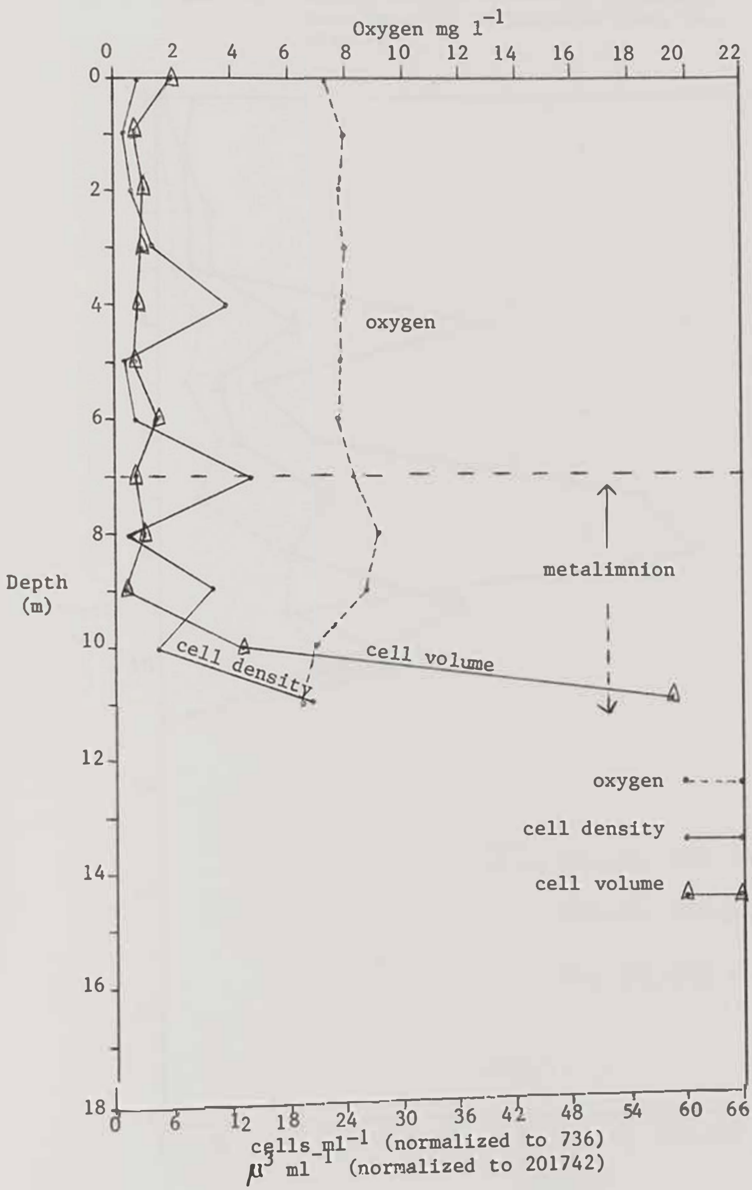


Figure 21. Winter changes in rooted macrophyte standing crop in Mountain Lake, Va., 1974-75.

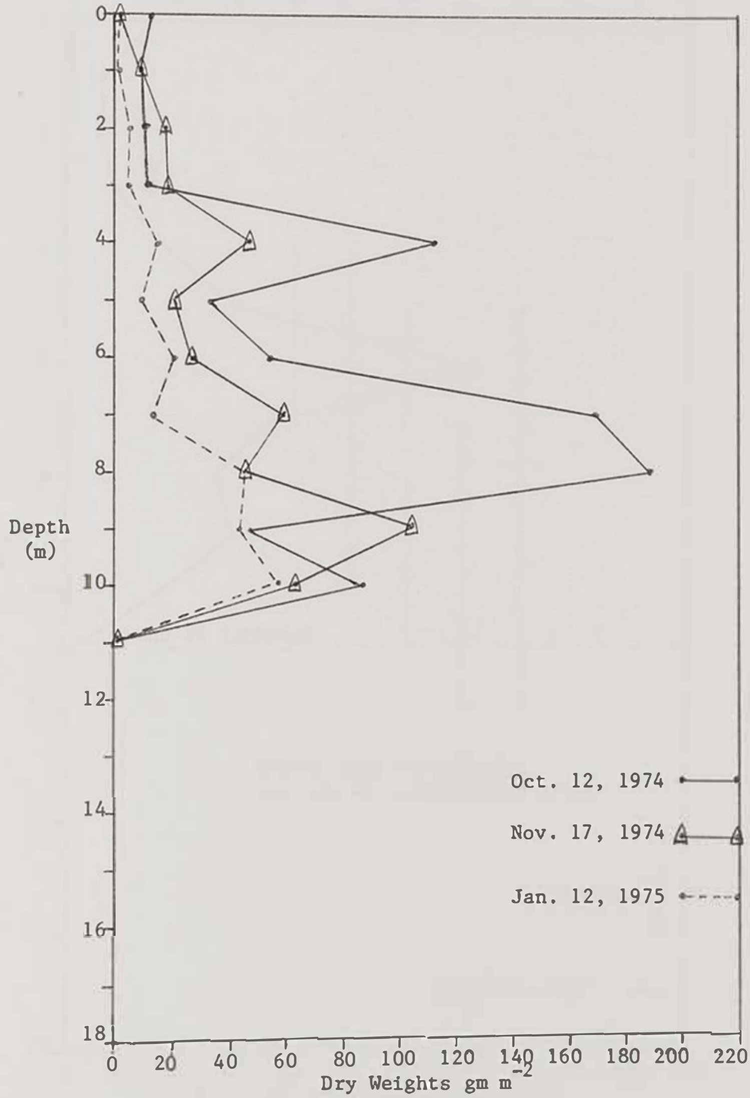


Figure 22. Seasonal penetration of the littoral zone into and below the metalimnion in Mountain Lake, Virginia.

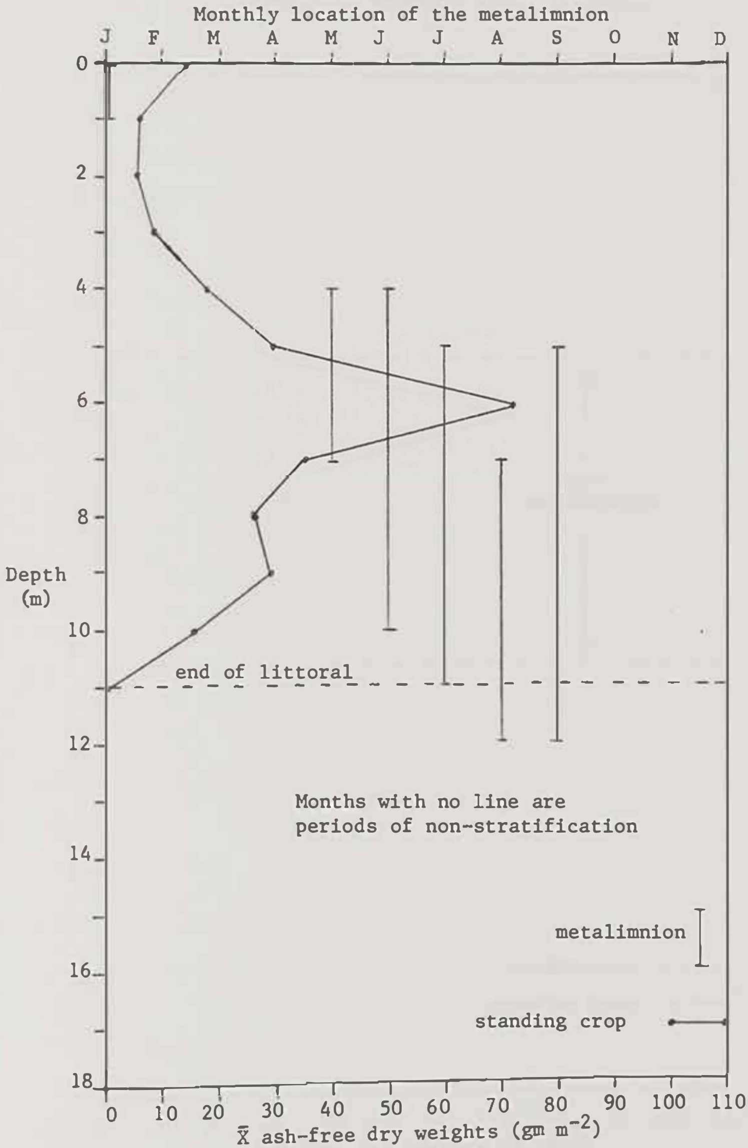


Figure 23. Mean summer rooted macrophyte standing crop compared to the mean summer metalimnion in Mountain Lake, Virginia.

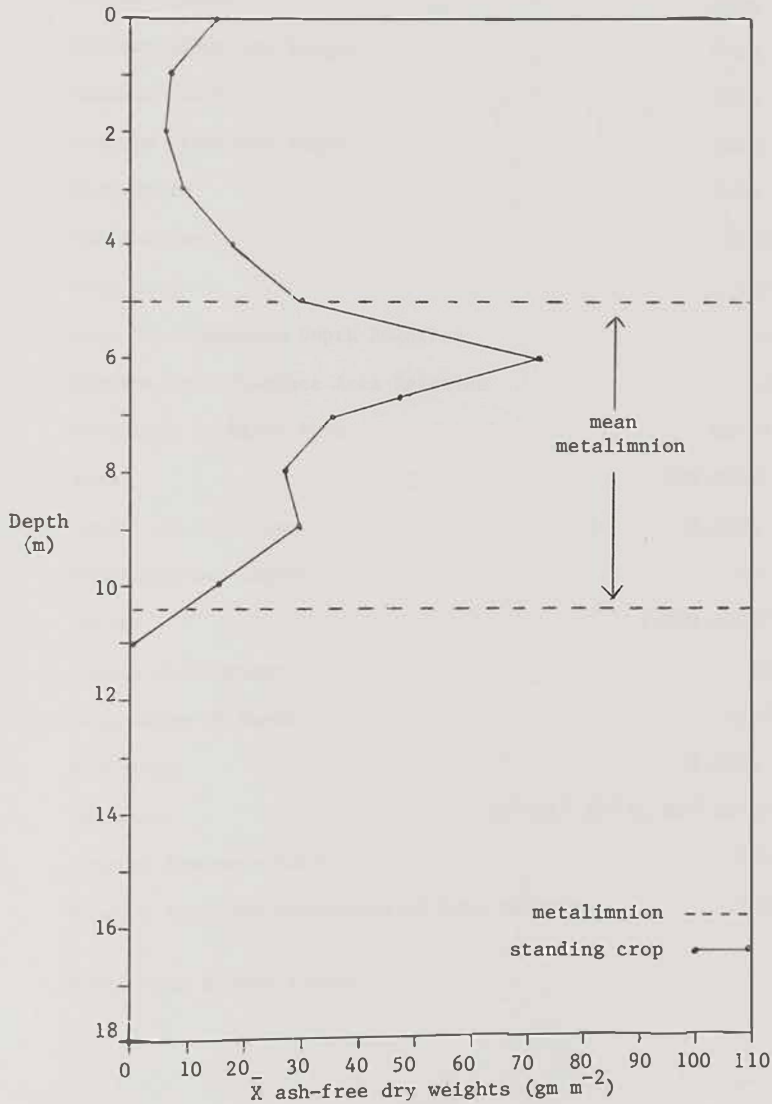


Table 1. - Morphometric and hydrographic statistics for Mountain Lake.*

Maximum Length	870m
Maximum Effective Length	845m
Maximum Width	266m
Maximum Effective Width	344m
Mean Width	218m
Maximum Depth	31.5m
Mean Depth	9.75m
Mean Depth/Maximum Depth Relation	.310
Maximum Depth/Surface Area Relation	.073
Direction of Major Axis	NE-SW
Area	189,000m^2
Length of Shoreline	2,160m
Shoreline Development	1.37
Volume	1,850,000m^3
Volume Development	.93
Mean Slope of Basin	15.0%
Elevation	1,180m
Location	37° 21' 56" N, 80° 31' 39" W
Area of Drainage Basin	0.95km^2
Area of Drainage Basin/Area of Lake Relation	5.02

*From Roth & Neff (1964)

Table 2. - Mean ash-free dry weights (gms m^{-2}) for the dominant summer macrophyte species at each meter depth on all transects of the littoral zone and the total sample weight of each macrophyte in Mountain Lake, Virginia--July, 1973.

Depth (m)	*Fontinalis novae-angliae* Sull.	*Chara braunii* Gm.	*Anacharis canadensis* (Michx.) Rich.	*Ceratophyllum demersum* L.	*Nitella flexilis* (L.) Ag.	$\bar{X}$ combined macrophyte weight (gm m^{-2})
0	73.83	.66	.03	0	.02	14.91
1	15.37	.94	.04	0	17.95	6.86
2	.17	0	.44	0	30.66	6.25
3	0	0	3.10	0	40.15	8.64
4	0	0	9.57	21.55	54.61	17.15
5	0	0	3.21	0	145.02	29.65
6	0	0	2.30	0	356.20	71.70
7	0	0	0	0	177.67	35.54
8	0	0	0	0	130.87	26.17
9	0	0	0	0	148.04	29.61
10	.01	0	0	0	76.07	15.22
11	0	0	0	0	.14	.03
Total*	89.38	1.60	18.74	21.55	1177.40	

*Total reflects the total sample weight of each macrophyte species.

Table 3. - Percent of sample ash-free dry weight occupied by each of the 5 rooted macrophytes collected from 5 transects combined in Mountain Lake, Virginia--July, 1973.

Depth (m)	*Fontinalis novae-angliae* Sull.	*Chara braunii* Gm.	*Anacharis canadensis* (Michx.) Rich.	*Ceratophyllum demersum* L.	*Nitella flexilis* (L.) Ag.
0	99.05	.89	.03	0	.03
1	44.82	2.47	.12	0	52.32
2	.54	0	1.42	0	98.04
3	0	0	7.15	0	92.85
4	0	0	11.16	25.14	63.70
5	0	0	2.16	0	97.84
6	0	0	.64	0	99.36
7	0	0	0	0	100.00
8	0	0	0	0	100.00
9	0	0	0	0	100.00
10	.02	0	0	0	99.98
11	0	0	0	0	100.00
Total	6.83	.12	1.43	1.65	89.97

Table 4. - Combined standing crop ash-free dry weights (gms m^{-2}) and total ash-free dry weight of the rooted macrophytes on each of 5 transects in Mountain Lake, Virginia--July, 1973.

Depth (m)	Transect 1 (East-facing)	Transect 2 (East-facing)	Transect 3 (North-facing)	Transect 4 (West-facing)	Transect 5 (South-facing)	$\bar{X}$ combined macrophyte weight (gm m^{-2})
0	.01	27.75	45.90	.81	.07	14.91
1	3.50	14.95	15.86	0	0	6.86
2	.14	6.43	20.69	1.29	2.73	6.25
3	6.96	9.16	14.41	10.73	1.93	8.64
4	15.14	15.81	46.51	6.96	1.30	17.15
5	22.36	39.63	22.57	47.96	15.71	29.65
6	44.23	73.66	183.70	42.91	14.00	71.70
7	25.58	33.20	27.29	32.48	59.12	35.54
8	47.70	27.10	18.58	30.29	7.20	26.17
9	25.17	65.85	13.37	18.79	24.86	29.61
10	21.29	46.32	3.55	2.56	2.36	15.22
11	0	.002	0	0	.13	.03
Total*	212.08	359.86	412.43	194.78	129.41	
% Grade	13.8	13.8	2.9	12.4	61.0	

*Total reflects the total plant weight for each transect.

Table 5. - Percent of sample ash-free dry weight occupied by *Fontinalis novae-angliae* Sull. along each of 5 transects in Mountain Lake, Virginia--July, 1973.

Depth (m)	Transect 1 (East-facing)	Transect 2 (East-facing)	Transect 3 (North-facing)	Transect 4 (West-facing)	Transect 5 (South-facing)
0	100.00	99.82	98.56	100.00	100.00
1	13.06	0	94.08	0	0
2	0	0	.83	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	.55
11	0	0	0	0	0
Total*	.22	7.70	14.63	.42	.07

*Total reflects the percent *Fontinalis novae-angliae* Sull. out of the total plant weight collected at all depths along the transect.

Table 6. - Percent of sample ash-free dry weight occupied by Chara braunii Gm. along each of 5 transects in Mountain Lake, Virginia--July, 1973.

Depth (m)	Transect 1 (East-facing)	Transect 2 (East-facing)	Transect 3 (North-facing)	Transect 4 (West-facing)	Transect 5 (South-facing)
0	0	0	1.44	0	0
1	0	0	5.92	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
Total*	0	0	.38	0	0

*Total reflects the percent Chara braunii Gm. out of the total plant weight collected at all depths along the transect.

Table 7. - Percent of sample ash-free dry weight occupied by Anacharis canadensis (Michx.) Rich. along each of 5 transects in Mountain Lake, Virginia--July, 1973.

Depth (m)	Transect 1 (East-facing)	Transect 2 (East-facing)	Transect 3 (North-facing)	Transect 4 (West-facing)	Transect 5 (South-facing)
0	0	.11	0	0	0
1	.81	.08	0	0	11.14
2	89.87	0	.08	0	14.72
3	31.14	6.37	.36	0	5.59
4	15.59	20.04	8.52	0	1.92
5	.08	0	12.78	0	0
6	5.20	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
Total*	3.30	1.05	1.68	0	.74

*Total reflects the percent Anacharis canadensis (Michx.) Rich. out of the total plant weight collected at all depths along the transect.

Table 8. - Percent of sample ash-free dry weight occupied by *Ceratophyllum demersum* L. along each of 5 transects in Mountain Lake, Virginia--July, 1973.

Depth (m)	Transect 1 (East-facing)	Transect 2 (East-facing)	Transect 3 (North-facing)	Transect 4 (West-facing)	Transect 5 (South-facing)
0	0	0	0	0	0
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	46.34	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
Total*	0	0	5.23	0	0

*Total reflects the percent *Ceratophyllum demersum* L. out of the total plant weight collected at all depths along the transect.

Table 9. - Percent of sample ash-free dry weight occupied by Nitella flexilis (L.) Ag. along each of 5 transects in Mountain Lake, Virginia--July, 1973.

Depth (m)	Transect 1 (East-facing)	Transect 2 (East-facing)	Transect 3 (North-facing)	Transect 4 (West-facing)	Transect 5 (South-facing)
0	0	.07	0	0	0
1	86.13	99.92	0	0	0
2	10.13	100.00	99.09	100.00	88.86
3	68.86	93.63	99.64	100.00	85.28
4	84.41	79.96	45.14	100.00	94.41
5	99.92	100.00	87.22	100.00	98.08
6	94.80	100.00	100.00	100.00	100.00
7	100.00	100.00	100.00	100.00	100.00
8	100.00	100.00	100.00	100.00	100.00
9	100.00	100.00	100.00	100.00	100.00
10	100.00	100.00	100.00	100.00	99.45
11	0	100.00	0	0	100.00
Total*	96.5	91.25	78.08	99.58	99.19

*Total reflects the percent Nitella flexilis (L.) Ag. out of the total plant weight collected at all depths along the transect.

Table 10. - Insolation in the vicinity of Mountain Lake, Virginia during the summer of 1974.

Date	Gram Calories cm^{-2} Day^{-1}
July 24, 1974	226.93
July 25, 1974	226.93
July 26, 1974	272.22
July 27, 1974	191.02
July 28, 1974	262.72
July 29, 1974	363.78
July 30, 1974	191.02
July 31, 1974	410.79
August 1, 1974	403.64
August 2, 1974	421.90
August 3, 1974	107.48
August 4, 1974	148.82
August 5, 1974	326.39
August 6, 1974	130.56
August 7, 1974	313.68
August 8, 1974	109.08
August 9, 1974	182.26
August 10, 1974	191.02
August 11, 1974	99.58
August 12, 1974	148.94

Table 11. - Phytoplankton cell densities (cells ml^{-1}) and cell volumes (μ^3 ml^{-1}) on two dates in 1974 in Mountain Lake, Virginia.

	June 24, 1974		September 22, 1974	
Depth (m)	cells ml^{-1}	μ^3 ml^{-1}	cells ml^{-1}	μ^3 ml^{-1}
0	459	218146	1869	1199762
1	359	306406	736	398864
2	228	204373	1307	609564
3	2396	1968436	2755	581796
4	309	273527	8583	495688
5	1466	1304032	761	403786
6	169	135489	1724	915222
7	128	112947	10405	420819
8	100	85226	852	621254
9	41	136360	7728	201742
10	568	461819	3326	2705574
11	505	454032	15338	11787806

Table 12. - ^{14}C fixation by phytoplankton in Mountain Lake, Virginia--June 24, 1974.

Depth (m)	$\frac{mg\ ^{14}C}{m^3\ hr^{-1}}$
0	4.5
1	6.5
2	5.4
3	4.7
4	4.5
5	2.7
6	1.8
7	1.5
8	1.2
9	2.2
10	0.5
11	3.0
12	0.5

Table 13. - Winter changes in rooted macrophyte standing crop in Mountain Lake, Virginia* 1974-75

Depth (m)	Oct. 12, 1974	Nov. 17, 1974	Jan. 12, 1975
0	12.4	1.7	0
1	8.5	8.6	.8
2	10.5	18.2	4.5
3	11.7	18.1	4.5
4	112.1	46.4	15.7
5	32.6	20.7	9.5
6	54.2	26.5	21.3
7	168.9	59.6	12.7
8	189.9	45.4	47.2
9	47.1	105.6	42.8
10	87.4	62.6	56.4
11	0	0	.01

*Collected by remote operated standard 15.2 cm^2 Ekman dredge (not with scuba) and recorded as an average of 3 dry weights (gm m^{-2}).

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Appendix A

Table 1. - Summer noon temperature*-oxygen* data for Mountain Lake, Virginia--1973 and 1974.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	Aug. 8, 1973		July 24, 1974		July 25, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	21.5	9.1	19.8	8.2	20.3	8.6
1	21.0	9.1	19.8	8.6	20.3	8.7
2	21.0	9.1	19.8	8.6	20.3	8.5
3	20.8	9.1	19.8	8.6	20.3	8.7
4	20.7	9.1	19.8	8.6	20.3	8.7
5	20.7	9.1	19.8	8.6	20.2	8.7
6	20.0	8.9	18.8	9.1	19.2	8.6
7	19.5	9.9	16.5	9.5	17.2	9.5
8	17.0	10.1	14.4	10.3	15.3	10.4
9	15.5	11.0	12.5	10.6	13.5	11.0
10	13.5	11.7	11.4	11.3	11.9	11.0
11	12.5	11.4	10.0	10.8	10.0	11.0
12	11.5	10.7	9.2	10.4	9.6	10.6
13	11.0	10.4	8.4	10.4	8.9	10.2
14	10.5	9.9	8.0	9.6	8.3	9.9
15	10.0	9.3	7.5	8.9	8.0	9.5

Appendix A

Table 1. - Summer noon temperature*-oxygen* data for Mountain Lake, Virginia--1973 and 1974.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	July 26, 1974		July 27, 1974		July 28, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	20.8	8.5	21.2	8.5	21.0	8.6
1	20.8	8.5	21.0	8.6	21.0	8.5
2	20.8	8.6	20.8	8.6	21.0	8.5
3	20.2	8.6	20.6	8.6	21.0	8.5
4	20.1	8.7	20.2	8.6	21.0	8.6
5	19.9	8.6	20.1	8.5	21.0	8.6
6	18.8	8.6	19.9	8.6	20.1	9.0
7	16.4	9.5	17.5	9.5	19.0	9.5
8	14.2	10.0	15.8	10.1	16.5	10.1
9	11.8	11.0	14.1	10.9	14.5	10.8
10	10.8	11.0	11.9	11.0	13.1	11.0
11	9.8	10.4	10.9	10.7	12.0	10.6
12	9.0	10.0	10.1	10.3	11.2	10.1
13	8.2	9.6	9.7	10.2	10.2	10.1
14	7.8	9.2	9.2	9.6	9.9	9.5
15	7.6	8.6	8.4	8.8	9.3	8.8

Appendix A

Table 1. - Summer noon temperature*-oxygen* data for Mountain Lake, Virginia--1973 and 1974.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	July 29, 1974		July 30, 1974		July 31, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	21.8	8.5	20.8	9.0	20.8	8.4
1	21.8	8.6	20.2	9.0	20.8	9.1
2	21.2	8.6	20.1	9.0	20.8	9.1
3	21.1	8.6	19.9	9.2	20.8	9.1
4	20.8	8.6	19.3	9.2	20.7	9.2
5	20.2	8.6	19.1	9.2	20.2	9.2
6	19.5	8.6	17.1	9.4	19.7	9.1
7	17.8	9.3	15.2	9.4	17.5	9.4
8	15.2	10.1	13.5	10.7	15.3	11.0
9	13.3	10.7	12.2	11.7	13.9	11.4
10	11.8	11.1	10.9	11.7	12.3	11.4
11	10.1	10.8	9.8	10.9	10.5	11.1
12	9.3	10.0	9.0	10.8	9.2	10.7
13	8.8	9.7	8.7	10.1	8.2	10.4
14	8.3	9.4	7.9	9.9	8.0	10.2
15	7.9	9.2	7.4	9.9	7.7	9.3

Appendix A

Table 1. - Summer noon temperature*-oxygen* data for Mountain Lake, Virginia--1973 and 1974.

*(All temperatures in ^{o}Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	Aug. 1, 1974		Aug. 2, 1974		Aug. 3, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	22.4	8.7	22.0	9.0	21.5	9.1
1	22.3	9.2	22.5	9.2	21.5	9.1
2	22.3	9.1	22.5	9.0	21.5	9.1
3	22.2	9.2	22.5	9.0	21.5	9.1
4	22.0	9.2	22.0	9.2	21.5	9.1
5	21.5	9.1	22.0	9.3	21.0	9.1
6	20.1	9.3	20.0	9.3	20.2	8.9
7	18.4	9.9	19.0	9.9	19.0	9.5
8	15.6	10.8	16.5	10.8	16.5	10.7
9	13.2	11.5	14.6	11.1	15.5	11.7
10	12.1	11.7	12.0	11.4	15.0	11.6
11	10.5	11.4	11.0	11.3	14.0	11.3
12	9.3	11.1	10.0	10.6	13.0	10.7
13	8.3	10.3	10.0	10.1	11.0	10.6
14	7.5	3.7	9.2	9.9	10.0	10.0
15	7.5	9.1	8.8	9.3	9.5	9.3

Appendix A

Table 1. - Summer noon temperature*-oxygen* data for Mountain Lake, Virginia--1973 and 1974.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	Aug. 4, 1974		Aug. 6, 1974		Aug. 7, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	19.0	8.8	20.5	9.2	21.2	8.7
1	20.0	8.9	20.5	9.2	21.1	8.7
2	20.0	8.9	20.5	9.2	21.1	8.7
3	20.0	8.9	20.5	9.2	21.0	8.7
4	20.0	8.9	20.5	9.2	21.0	8.7
5	20.0	8.9	20.5	9.1	20.8	8.7
6	20.0	8.9	20.3	9.1	20.3	8.7
7	18.5	10.1	19.5	9.3	18.8	9.5
8	16.0	10.9	17.4	10.4	18.0	9.7
9	13.5	11.5	15.0	11.1	15.8	10.6
10	13.0	11.7	13.0	11.7	14.7	11.3
11	11.0	11.3	12.0	11.4	13.2	11.0
12	10.0	10.3	11.0	10.6	12.0	10.2
13	9.0	10.2	11.0	10.4	11.3	10.0
14	8.0	9.7	10.0	10.2	9.8	9.7
15	8.0	9.3	9.4	9.6	9.8	9.1

Appendix A

Table 1. - Summer noon temperature*-oxygen* data for Mountain Lake, Virginia--1973 and 1974.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	Aug. 8, 1974		Aug. 10, 1974		Aug. 11, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	20.8	8.7	20.8	8.8	20.2	8.8
1	20.9	8.7	20.8	8.7	20.2	8.8
2	20.8	8.7	20.8	8.6	20.2	8.8
3	20.7	8.7	20.8	8.7	20.2	8.8
4	20.5	8.7	20.8	8.7	20.2	8.8
5	20.3	8.7	20.6	8.7	20.1	8.8
6	20.0	8.7	20.5	8.7	20.1	8.8
7	19.5	9.1	19.5	8.5	19.5	10.4
8	18.0	9.9	15.1	10.6	17.5	10.7
9	15.5	10.6	16.2	10.8	14.5	10.8
10	13.0	11.1	14.3	10.9	13.5	10.9
11	12.0	10.8	13.5	10.4	12.5	11.5
12	10.8	10.2	11.8	9.9	11.5	10.2
13	9.0	9.9	11.2	9.2	10.0	9.7
14	8.0	9.5	10.0	8.9	9.7	9.5
15	7.8	8.9	10.0	8.8	9.5	8.9

Appendix A

Table 1. - Summer noon temperature*-oxygen* data for Mountain Lake, Virginia--1973 and 1974.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	Aug. 13, 1974		$\bar{X}$ Summer Value	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen
0	20.5	8.9	20.9	8.7
1	20.5	9.1	20.9	8.9
2	20.5	9.1	20.8	8.8
3	20.4	9.1	20.8	8.9
4	20.3	9.1	20.6	8.9
5	20.2	9.1	20.4	8.9
6	20.2	9.1	19.7	8.9
7	19.5	9.1	18.3	9.5
8	17.2	10.1	16.1	10.4
9	15.5	10.9	14.2	11.0
10	13.5	11.0	12.7	11.3
11	12.5	10.8	11.5	11.0
12	11.5	10.4	10.5	10.4
13	11.0	9.9	9.7	10.1
14	10.5	9.5	9.0	9.4
15	10.0	8.8	8.1	9.1

Appendix A

Table 2. - Summer nocturnal temperature*-oxygen* data for Mountain Lake, Virginia--1974.

*(All temperatures in ^{o}Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948).

	2 AM		6 AM		6 AM	
	Aug. 1, 1974		Aug. 5, 1974		Aug. 9, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	21.0	9.2	22.5	9.1	20.3	8.7
1	21.0	9.3	21.0	9.1	20.3	8.7
2	21.0	9.1	20.5	9.1	20.2	8.7
3	20.7	9.2	20.2	9.1	20.2	8.7
4	20.2	9.2	20.0	9.1	20.1	8.7
5	20.8	9.2	20.0	9.1	20.1	8.7
6	18.8	9.3	20.0	9.1	20.1	8.7
7	16.2	9.3	18.5	9.1	19.5	9.1
8	14.2	9.7	16.0	10.4	17.5	9.9
9	12.1	10.9	15.0	11.4	14.8	11.0
10	11.0	11.8	11.5	11.7	12.2	11.3
11	10.2	11.4	10.5	11.4	11.8	11.0
12	9.5	11.7	9.5	10.7	11.0	10.4
13	9.8	11.0	9.0	10.3	10.0	10.2
14	8.2	10.2	8.5	10.1	9.6	9.9
15	8.0	9.3	8.0	9.2	9.5	9.2

Appendix A

Table 3. - Temperature*-oxygen* data for Mountain Lake, Virginia prior to and following its maximum summer stratification period.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948; all data collected at noon on the dates indicated).

	Sept. 3, 1973		Oct. 12, 1974		Nov. 16, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	24.0	8.9	14.5	10.0	7.0	10.2
1	23.5	8.7	14.5	10.0	7.0	10.1
2	23.0	8.9	14.5	10.0	7.0	9.5
3	22.5	9.1	14.5	10.0	7.0	10.6
4	21.5	9.5	14.5	8.2	7.0	9.9
5	20.5	9.6	14.5	10.0	7.0	10.2
6	19.0	8.9	14.5	10.0	7.0	10.0
7	17.0	9.2	14.5	9.9	7.0	10.3
8	14.0	9.1	14.5	9.9	7.0	10.3
9	12.0	8.5	14.5	9.7	7.0	10.2
10	10.0	8.6	14.5	9.7	7.0	10.6
11	9.0	7.9	14.0	9.7	7.0	10.0
12	8.0	8.2	----	----	7.0	10.2
13	7.5	----	----	----	----	----
14	7.0	8.1	----	----	----	----
15	7.0	----	12.0	7.7	7.0	10.3

Appendix A

Table 3. - Temperature*-oxygen* data for Mountain Lake, Virginia prior to and following its maximum summer stratification period.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948; all data collected at noon on the dates indicated).

	Dec. 8, 1973		Jan. 19, 1963**		Feb. 10, 1974	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	----	10.2	0.5	12.7	----	11.4
1	6.2	10.2	2.4	----	2.7	11.4
2	6.4	10.0	2.9	----	2.8	11.4
3	6.4	10.2	3.0	----	2.9	11.5
4	6.4	10.1	3.1	----	3.2	11.5
5	6.4	10.2	3.2	10.2	3.2	11.5
6	6.4	10.3	3.2	----	3.2	11.3
7	6.4	10.4	3.3	----	3.2	11.0
8	6.4	10.2	3.3	----	3.2	11.4
9	6.1	10.2	3.4	----	3.2	11.1
10	6.1	10.2	3.5	9.8	3.5	11.3
11	----	----	3.5	----	3.7	11.8
12	----	----	3.6	----	----	11.3
13	----	----	3.7	----	----	11.2
14	----	----	3.7	----	----	----
15	----	----	3.8	9.1	----	----

**After Roth and Neff (1964).

Appendix A

Table 3. - Temperature*-oxygen* data for Mountain Lake, Virginia prior to and following its maximum summer stratification period.

*(All temperatures in ^{o}Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948; all data collected at noon on the dates indicated).

	March 16, 1974		April 15, 1962**		May 13, 1962**	
Depth (m)	Temp.	Oxygen	Temp.	Oxygen	Temp.	Oxygen
0	3.8	11.4	6.0	9.7	16.5	7.6
1	3.8	11.4	6.0	----	16.5	----
2	3.6	11.4	6.0	----	16.0	----
3	3.6	11.5	6.0	----	15.9	----
4	3.6	11.5	6.0	----	15.7	----
5	3.6	11.5	6.0	9.6	10.3	9.2
6	3.7	11.3	6.0	----	8.8	----
7	3.8	11.0	6.0	----	7.8	----
8	3.5	11.4	6.0	----	7.0	----
9	3.5	11.1	6.0	----	6.5	----
10	3.7	11.3	5.9	9.8	6.3	9.2
11	3.6	11.8	5.9	----	6.1	----
12	3.6	11.3	5.9	----	6.0	----
13	3.6	11.2	5.9	----	5.9	----
14	3.7	----	5.8	----	5.8	----
15	3.6	----	5.8	9.7	5.7	8.7

**After Roth and Neff (1964)

Appendix A

Table 3. - Temperature*-oxygen* data for Mountain Lake, Virginia prior to and following its maximum summer stratification period.

*(All temperatures in °Celcius; all oxygen values in mg l^{-1} corrected to an elevation of 1200 meters according to Welch, 1948; all data collected at noon on the dates indicated).

June 2, 1974

Depth (m)	Temp.	Oxygen
0	17.0	11.3
1	17.0	10.7
2	17.0	11.3
3	17.0	11.4
4	17.0	11.7
5	16.0	10.9
6	15.0	10.2
7	14.0	10.1
8	12.0	10.0
9	10.0	9.6
10	9.0	9.3
11	9.0	9.5
12	8.0	9.5
13	8.0	9.5
14	7.0	----
15	5.0	----

Appendix B

List of macrophytes growing in Mountain Lake, Giles County, Virginia, 1973-1975

I. ALGAE: (Nomenclature according to Wood, 1967)

CHARACEAE

Chara braunii Gm.

Nitella flexilis (L.) Ag.

II. BRYOPHYTES: (Nomenclature according to Conard, 1956)

A. Mosses (Musci):

FISSIDENTACEAE

Fissidens bryoides Hedw.

Fissidens hallianus (Sull. and Lesq.) Mitt.

MNIACEAE

Mnium punctatum Hedw.

HYPNACEAE

Brachythecium rivulare B. S. G.

Climacium americanum Brid.

C. kindbergii (Ren. & Card.) Grout

Hygrohypnum eugyrium (B. S. G.) Loeske

Leptodictyum riparium (Hedw.) Warnst

FONTINALACEAE

Fontinalis novae-angliae Sull.

B. Liverworts (Hepaticae):

HARPANTHACEAE

Chiloscyphus pallescens (Ehrh.) Dum.

PLAGIOCHILACEAE

Plagiochila asplenioides (L.) Dum.

SCAPANIACEAE

Scapania undulata (L.) Dum.

PORELLACEAE

Porella pinnata L.

RICCARDIACEAE

Riccardia latifrons Lindb.

III. VASCULAR PLANTS: (Nomenclature according to Gleason and Cronquist, 1963)

EQUISETACEAE

Equisetum arvense L.

ISOETACEAE

Isoetes engelmannii A. Br.

POTOMOGETONACEAE

Potomogeton spirillus Tuckerm.

ALISMATACEAE

Alisma plantago-aquatica L.

HYDROCHARITACEAE

Anacharis canadensis Michx.

A. nuttallii (Planeh.) St. John

CYPERACEAE

Carex baileyi Britt.

C. crinita Lam.

C. frankii Kunth

C. scoparia Schk.

Eleocharis obtusa (Willd.) Schultes

E. palustris (L.) R. & S.

JUNCACEAE

Juncus acuminatus Michx.

J. brevicaudatus (Engelm.) Fern.

J. bufonius L.

J. effusus L.

J. marginatus Rostk.

J. tenuis Willd.

SALICACEAE

Salix sericea Marsh.

POLYGONACEAE

Polygonum scandens L.

CERATOPHYLLACEAE

Ceratophyllum demersum L.

CALLITRICHACEAE

Callitriche heterophylla Pursh.

HYPERICACEAE

Hypericum mutilum L.

VITA

Charles Irving Dubay was born in Boston, Massachusetts on October 11, 1942. He lived with his parents, Mr. and Mrs. Jesse King Dubay and two brothers, Frederick King Dubay and Robert Carr Dubay in Waltham, Massachusetts. He began elementary school in Waltham but finished the first level of formal education in Falls Church, Virginia when his father moved to enter government service. He began high school in Falls Church, continued his formal secondary education in Hong Kong, B.C.C. while his father was stationed there with the United States Consulate, and graduated from Fairfax High School in Fairfax, Virginia upon return to the United States.

In 1962 he entered the College of William and Mary in Williamsburg, Virginia from where he received a B. S. degree in biology in 1967. At the time of graduation from college he received a commission as a Second Lieutenant in the United States Army Signal Corps through the ROTC program. Following graduation from college, he spent two years active duty with the army, one of which was spent at Fort Gordon, Georgia and the other in Thailand as a communications officer.

After this period of active duty he obtained a job as a high school biology teacher in Williamsburg, Virginia (which he presently holds) while serving first in the active and later the inactive army reserve. During this same period he worked as a part-time instructor of scuba diving at the College of William and Mary.

In 1973 Charles Dubay entered graduate school at the University of Virginia and began work toward the Master of Science degree in biology.