# PLANKTONIC DYNAMICS AS AN INDICATOR OF WATER QUALITY IN LAKE MEAD 

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## PREFACE

This report constitutes the doctoral dissertation of the same title completed by the author in 1973.

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## ABSTRACT

The purpose of this investigation was to identify the zooplankton arc phytoplankton found in Lake Mead, to quantify their presence, to elucidate some temporal and spatial patterns, and to investigate some of the planktonic responses to physical, chemical, and biological parameters.

Phytoplankton and zooplankton population samples were collected from eight different sites at 11 depths at six times over an annual period. These samples were collected with a 6-liter Van Dorn sampler. Phytoplankton samples were preserved in Lugol's solution and the zooplankton were placed in formalin preservative. The 503 zooplankton population samples were scored in a ruled counting chamber using a stereomicroscope. Eighteen species of zooplankton were identified. The 274 phytoplankton samples were placed on Millipore filters and slides were prepared for examination with phase contrast microscopy. A total of at least 79 algae were found to comprise the phytoplankton flora.

The zooplankton for the most part were rotifers, cladocerans, and copepods. Keratella, the principal rotifer, was found to be diacmic and Bosmina, Daphnia, the calanoid, cyclopoid, and nauplii copepods were monacmic. Spatial relationships across the reservoir indicate that Bosmina and cyclopoid copepods are water quality indicators. The late summer phytoplankton were mostly Cyanophyta with populations as large as $5 \times 10^{6}$ cells/liter occurring in Boulder Basin. Winter samples contained mostly diatoms and cryptomonads, while the spring phytoplankton was mainly Chlorophyta. The early summer flora showed a mixture of Chrysophyta, Chlorophyta, and Cryptophyta.

Biomass determinations were made from average cell volumes and population counts. The blue-green alga Oscillatoria had the greatest biomass during the late summer period. Bacillariophyta reached a volumetric peak in late winter and the Chlorophyta in spring. The Cryptophyta showed a peak in winter while the Chrysophyta, represented mostly by the presence of Dinobryon, showed greatest population sizes in early summer. The Euglenophyta and Pyrrophyta were relatively unimportant groups of the biomass.

Weak nocturnal migrations were exhibited by Asplanchna sp., Keratella cochlearis, and Bosmina longirostris. This conclusion was derived from an analysis of variance of the diurnal data. The copepod groups showed no migration patterns. Since this study was performed when the lake was isothermal, it is inferred that migration is a phenomenon not influenced by temperature.

A transect study in Boulder Basin during the winter showed that Daphnia, Asplanchna, Chydorus, and Polyarthra, and possibly calanoid copepods, appear to be littoral, and are found mostly in the Las Vegas Wash area. Phytoplankton counts showed evidence for decreases in Bacillariophyta, Chlorophyta, Cyanophyta, and Cryptophyta across the basin from the wash to the dam area. Pyrrophyta, Chrysophyta, and Euglenophyta were not important in the phytoplankton flora at this season.

Nygaard's and Pearsall's ratios and Palmer's pollution-tolerant algae indices were applied to the phytoplankton data. Results of the Nygaard and Pearsall ratios, the migration study, the transect study, and the population studies indicate that Boulder Basin is eutrophic.

## INTRODUCTION

Lake Mead is the largest man-made reservoir in the western hemisphere, having an available capacity of 26.1 million acre-feet. This lake is a potential source of potable water for a growing, arid southwest. Already the cities of Las Vegas, Boulder, and Henderson, Nevada, and other residents totalling 10 million, receive most of their municipal and industrial water from the lake. The waters of Lake Mead supply much of the electrical power for the southwest, and the Hoover Powerplant generates annually about 4.5 billion kilowatt-hours of hydroelectric energy.

In a region that has a growing season of up to 353 days (Yuma, Ariz.), perhaps the most important limiting factor is water. Lake Mead represents a vast supply of water for irrigation and agricultural purposes, and the water irrigates $11 / 4 \mathrm{million}$ acres of land. The recreational value of Lake Mead is immense. During 1965 the National Park Service estimated that 1,316,000 people visited the Boulder Beach Area alone, and at least 300 boats were moored at the Las Vegas Marina (Environmental Protection Agency, 1967). In short, the Lake Mead-Colorado River System represents one of the major water arteries of the southwest.

For the reasons stated in the preceding paragraph, it is necessary that the water quality of this important reservoir be maintained. Strange indeed is the fact that a body of water of this size and stature would go practically unnoticed for 37 yr , hydrobiologically speaking. Except for the limited work by the Environmental Protection Agency (1967) and Moffett (1943), the biology of Lake Mead has not been investigated. This dissertation constitutes part of an integrated study of the chemistry, hydrobiology, and hydrodynamics of Lake Mead conducted by a team of researchers.

The hypothesis tested in the present study is that Lake Mead consists of a body of water that is eutrophic as indicated by the plankton present. The investigations designed to test this hypothesis included:
1.) quantitative and qualitative analyses of both zooplankton and phytoplankton populations over an annual cycle with collections from 11 depths of the lake at 8 sites in the reservoir. Such analyses allow one to describe certain of the temporal and spatial relationships of the plankton. This is the first serious effort to study plankton systematics in Lake Mead. Since physical and chemical data were also collected during the study, it is possible to orrelate plankton population counts with the other parameters through the use of a computer and linear regression analysis. Also, existing eutrophication indices were tested and quantified using the phytoplankton data. Among these are Pearsall's ratio, Palmer's pollution-tolerant index, and Nygaard's compunnd index.
2.) assessment of the amount of living planktonic material in this lacustrine system by determining the biomass of the dominant species of plankton. Biomass determinations can provide a better idea of plankton dynamics than simple population counts. This study therefore, represents the first major ecological study of the plankton in Lake Mead.
3.) investigation of the zooplankton migration pattern for January, 1972. Migration studies may be used as an index of the trophic level of a lake, as eutrophic lakes generally have very limited patterns of planktonic
migration. Most plankton migration studies are performed during the summer or warmer months. Temperature profiles at the Bureau Raft for January indicate isothermal conditions. If migration occurs during this period, then one could eliminate temperature gradients as a possible cuase of plankton migration.
4.) performance of a transect study across Boulder Basin analyzing water chemistry and plankton samples. This basin behaves much like a polluted lake (Everett, 1972). Data were collected from Las Vegas Wash across Boulder Basin to Hoover Dam. The samples were collected every 1/2 mile near the confluence of the Wash and Las Vegas Bay and every mile further out into the Basin. Such a study has value in indicating the spatial extent of pollution in the Las Vegas Wash.

## Geography and Physical Limnology of Lake Mead

Lake Mead, a reservoir on the Colorado River, was formed in 1935 by the construction of Hoover Dam, a concrete arch-gravity structure with a maximum structural height of 726.4 ft . The lake is located at about mile 1000 of the 1400 mile descent of the Colorado River with the lake located between latitudes $36^{\circ} 35^{\prime} \mathrm{N}$ and $36^{\circ} 00^{\prime} \mathrm{N}$ and longitudes $114^{\circ} 50^{\prime} \mathrm{W}$ and $114^{\circ} 05^{\prime} \mathrm{W}$. It is about 110 miles long and has a maximum width of about 8 miles with four major areas named: Boulder Basin, Overton Arm, Virgin Basin, and a section from Virgin Basin to Pierce's Ferry. Four rivers contribute to Lake Mead, including the Colorado River supplying 98\% of the total inflow, Virgin River producing an influx of about 1.5\%, and the Muddy River and Las Vegas Wash resulting in $0.3 \%$ and $0.2 \%$ of the total inflow, respectively. Maximum water surface elevation is 1,221.4 ft (Harbeck, 1958). The shape of the reservoir is extremely irregular with a depth of approximately 500 ft . The location of Lake Mead on the Lower Colorado River is shown in Fig. 1.

The climate at Lake Mead is xeric with an average precipitation of less than 5 inches/yr. Average annual air temperature over the lake has been recorded at about $21.4^{\circ} \mathrm{C}\left(70.6^{\circ} \mathrm{F}\right)$ during the period of the investigation. Maximum temperatures of $43.0^{\circ} \mathrm{C}\left(110^{\circ} \mathrm{F}\right)$ are not uncommon in July and August. Average minimum temperature in January is $-1.1^{\circ} \mathrm{C}\left(30^{\circ} \mathrm{F}\right)$. Winds are generally light, originating from the south in summer and from the northeast in winter. During much of the year the circulation pattern is thermally induced rather than the result of large-scale cyclonic activity (Hareeck, 1958). Possible sunshine for the area is approximately $80 \%$. Table 1 shows the monthly temperature and precipitation data for Boulder Beach and Temple Bar during the study period.

The reservoir has been described as a warm monomictic lake. Water temperature is never below $4^{\circ} \mathrm{C}$, and circulation occurs in the winter. The water temperature ranged from 10.1 to $28.4^{\circ} \mathrm{C}$ during the study. Temperature profiles during November, January and February are isothermal, and during this time density stratification is broken down with the result that nutrients from the hypolimnetic regions are circulated throughout the lake. June data indicate the formation of a thermocline with complete stratification in September. The thermocline is found between 18 and 28 m with a temperature range of 17 to $26^{\circ} \mathrm{C}$ (Everett, 1972).

The vertical distribution of dissolved oxygen in Lake Mead has been described as a negative heterograde scheme, with reduced dissolved oxygen levels in the thermocline with higher concentrations in the epilimnion and hypolimnion. Ortho-phosphate levels are in the range of an oligotrophic lake. Nitrates are highest in September and November and are excessive for algal growth at all times of the year with nitrate concentrations as high as $0.3 \mathrm{mg} / \mathrm{liter}$ (Environmental Protection Agency, 1967). The light compensation point varies from station to station throughout the year, ranging from 10 to 20 m . The $1 \%$ level seems to be consistently deeper at Bonelli Landing and Temple Bar with Bonelli Landing generally having the


Figure 1. The location of Lake Mead on the lower Colorado River.

Table 1. Monthly temperature ${ }^{\mathrm{a}}$ and precipitation ${ }^{b}$ data for two stations along Lake Mead during the study period ${ }^{\text {c }}$.

| Date | Boulder: Beach |  |  | Temple Bar |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Avg. Max. | Avg. Min. | Precip. | Avg. Max. | Avg. Min. | Precip. |
| July 70 | 105.8 | 80.2 | 0.02 | 108.8 | 79.5 | 0.37 |
| August 70 | 103.3 | 79.0 | 2.40 | 105.8 | 79.3 | 0.86 |
| Sept. 70 | 93.9 | 66.3 |  | 96.6 | 65.5 |  |
| Oct. 70 | 78.5 | 57.0 |  | 82.0 | 55.3 |  |
| Nov. 70 | 67.2 | 47.8 | 0.44 | 69.7 | 44.0 | 0.15 |
| Dec. 70 | 55.2 | 38.2 |  | 59.3 | 36.4 | trace |
| Jan. 71 | 55.9 | 37.4 | trace | 57.9 | 32.8 |  |
| Feb. 71 | 63.4 | 43.5 | 0.22 | 66.0 | 37.3 |  |
| March 71 | 71.4 | 48.5 |  | 74.1 | 43.1 | 0.04 |
| April 71 | 79.3 | 56.1 |  | 81.9 | 51.0 | trace |
| May 71 | 83,6 | 61.1 | 0.53 | 86.3 | 57.9 | 0.54 |
| June 71 | 100.8 | 70.3 |  | 101.8 | 71.0 |  |
| July 71 | 109.6 | 82.8 |  | 110.7 | 79.7 |  |
| Annual Avg. | 70.6 |  | 3.61 | 70.6 |  | 1.96 |

${ }^{\text {a }}$ Temperature data in degrees Fahrenheit.
bprecipitation data recorded in inches.
${ }^{\text {C Data supplied by U.S. Weather Bureau, Las Vegas, Nevada. }}$
clearest water in the lake. Salinity in Lake Mead varies from 0.60 ppt to 0.84 ppt (Everett, 1972). All of these physical parameters must be considered when one studies the biota of a lacustrine community. As Rawson (1939) has so appropriately stated, "while the edaphic factors determine the kinds and amounts of primary nutritive materials, the morphology of the basin and climate may be a large extent determine the utilization of these materials" (p. 46).

## Previous Studies on Lake Mead

After the completion of Hoover Dam in 1936 several investigations, most of them dealing with the physical limnology of Lake Mead, were made. Sediment dynamics were studied by the National Research Council (1949) and by Smith, Vetter, and Cummings (1948). Salinity and temperature studies were conducted by Anderson (1950) and Anderson and Pritchard (1951) Wind patterns over the reservoir were studied by the U.S. Weather Bureau (1953), while Harbeck (1958) expanded the work of Anderson and Pritchard (1951) and estimated water evaporation over Lake Mead. Moffett (1943) did a preliminary report on the plankton and fish of the lake from samples taken in November, 1941, at three locations on the lake. He found that Ceratium was the most abundant plankter and it was followed by Diaptomus, Cyclops, Microcystis, Daphnia, and Polyarthra. The volume of the net plankton averaged 0.0023 cubic inch per cubic foot of water.

In the 1960's emphasis shifted from physical limnology to water pollution, especially in Boulder Basin. An investigation of water quality during the months of April and May by the Bureau of Reclamation (1965) showed that dissolved $\mathrm{O}_{2}, \mathrm{CO}_{2}$, water pH , electrical conductivity, and temperature levels were of values which should not cause concern. In 1967, the Environmental Protection Agency published a report based upon plankton counts that showed Las Vegas Wash with the highest algal counts and decreasing numbers away from the Wash area. However, a report by Everett and Qashu (1971) using the more sensitive 14C-primary-productivity method showed a rate increase toward Hoover Dam and further showed that the problem was not unique to Las Vegas Wash. In another report published in 1970 by the Bureau of Reclamation it was shown that chlorophyll a concentrations were much higher in Las Vegas Wash than Boulder Basin during the month of May. Everett (1972) was able to show that the highest primary productivity rates occurred in Boulder Basin during the month of September.

## Definitions of Plankton, Planktonic Indices, and Some of Their Associations

The word plankton ( $\pi \lambda \alpha \gamma \kappa \tau o^{\prime} s$, Greek, Wandering) denotes several different concepts to various investigators in the field of limnology. Hensen (1887) first coined the term to include all particulate organogenic material, living or dead, passively drifting in the water. Ruttner (1963) defines plankton as "the community of the free water," while Ingram, Mackenthun and Bartsch (1966) state that plankton is "plant and animal organisms of small size, mostly microscopic, that either have relatively
small powers of locomotion or drift in water subject to the action of waves and currents" (p.7). Still another definition is offered by Pennak (1946). Plankton is "all organisms, both plant and animal, which are suspended in the water and are not independent of water movements" (p. 341). He includes three familiar groups in the plankton: (1) the zooplankton, with the Cladocera, Copepoda, Rotatoria, Protozoa, and a very few limnetic insect larvae; (2) the true photosynthetic phytoplankton, or algae, including Bacillariophyta (diatoms), Cyanophyta (blue-green algae), Chlorophyta (green algae), and a few other groups of less significance; and (3) non-photosynthetic plants, including the Schizomycetes (bacteria) and Phycomycetes (aquatic fungi).

Usually in a planktonic association one species will be in greater abundance with one or more obvious subdominants and several rarer species in the presence of the dominant and subdominants. Howard (1968) defines a dominant as "the taxon having the highest population in a collection" (p. 416). In regular monthly plankton samples taken at an open water station in a lake throughout the year, one can expect to identify from 40-150 species of algae and 25-100 species of zooplankton (Pennak, 1946). However, Morgan (1971) has found 199 algal species in Flathead Lake, Montana, which seems to be somewhat of a maximum number for United States lakes. If the annual plankton curve for total plankters in a deep lake is plotted, one can expect a bimodal curve. The zooplankton and phytoplankton pulses are generally coincident or immediately following one another. In general, diatoms are most abundant in spring and autumn, blue-green algae in late summer and early autumn, and green algae in midsummer. These events are well documented in research work by Brook (1957), Tucker (1957), Birge and Juday (1922), Domogalla (1926), Pennak (1949), and Lackey (1945). The total microcrustacean curve follows the typical bimodal annual curve, while the cyclic occurrence of total rotifers and Protozoa is more irregular, depending partially on the particular species present. Characteristically, these two latter groups are not abundant during the winter months. The number of planktonic organisms that occur in a given volume of a lake is of primary interest in any plankton study. Algae usually vary from the hundreds of thousands to tens of millions/liter, the Rotatoria and microcrustacea in tens of hundreds/liter, while bacteria may vary between a 100 and $2 \times 10^{9 / 1 i t e r . ~ I n ~ g e n e r a l, ~ t h e ~ p h y t o p l a n k t o n ~ b i o m a s s ~ i s ~ b e t w e e n ~}$ 2 and 10 times that of zooplankton biomass. However, Pennak (1949) concludes by saying that each lake is distinctive and should be meticulously studied as an individual case.

Eutrophication is a term that denotes a variety of meanings to different workers. Early German workers, including Thienemann (1919) used the term to describe the nutrient condition in German "Sumpfen" (bogs). Later the term was used to describe a specific stage in the life of a lake. Today the term relates nutrient flux to water quality. Lund (1967) describes eutrophication as "the process of becoming rich in dissolved nutrients" (p. 557) and points out that increasing nutrients and increasing production are paralleled by changes in the dominant organisms. Table 2 shows a comparison of lakes according to trophic state with respect to certain limnological parameters. The table is a modification of similar tables in Rawson (1956) and Everett (1972).
Table 2. A generalized classification of lakes according to trophic states.

| Characteristic | Oligotrophic | Eutrophic |
| :--- | :--- | :--- |
| Primary productivity | Low | High |
| Nutrients $\left(\mathrm{NO}_{3}, \mathrm{PO}_{4}\right)$ | Low | High |
| Depth | Deep with steep sides, <br> volume of hypolimnion <br> epilimnion | Shallow with gentle slopes, <br> volume of hypolimnion < <br> epilimnion |
| Water transparency | High | Low |
| Apparent color | Blue | Green to yellowish brown |
| Suspended matter | Low | High |
| Dissolved organics | Low | High |
| Hardness and total |  |  |
| dissolved salts (T.D.S.) | Variable but often <br> Soft with low TDS | Often high in Ca <br> and TDS |
| Bottom deposits | Poor in organic <br> deposits | High in organic deposits |

Table 2. (Continued)

| Characteristic | Oligotrophic | Eutrophic |
| :---: | :---: | :---: |
| Deep benthic fauna | Rich in species; Poor in quantity | Poor in species; rich in quantity anaerobic forms (Chironomids) dominant |
| Rooted aquatic plants | Sparse | Abundant |
| Fish fauna | Whitefishes, suckers, trout, small mouth bass | Abundant, sunfishes, carp, catfishes, large mouth bass |
| Plankton distribution | To great depths | In upper euphotic layer |
| Diurnal plankton migration | Extensive | Limited |
| Water blooms | Very rare | Frequent |
| Characteristic algal groups and genera | Chlorophyceae (desmids if Ca poor) Staurastrum or bacillariophytes: Tabellaria, Cyclotella, chrysophytes: Dinobryon | Cyanophytes: Anabaena, Aphanizomenon, Microcystis, <br> and bacillariophytes: <br> Melosira, Fragilaria, <br> Stephanodiscus, Asterionella |

Various phytoplankton indices have been suggested by different investigators to measure plankton associations. Pearsall (1921) sugge'sted the use of a basic ratio of ( $\mathrm{Na}+\mathrm{K} / \mathrm{Ca}+\mathrm{Mg}$ ) to indicate trophic levels and Munawar (1972) suggests a $\left(\mathrm{Cl}+\mathrm{NO}_{3}\right)$ percentage as an index of organic pollution. Zafar (1964) gave prime importance to Pearsall's basic ratio in the development of diatoms and many other groups of algae. In his work diatoms were in abundance when the basic ratio of water fluctuated between 0.027 and 1.2 , and they persisted in considerable number even when it was 2.0. In fact, Patrick and Reimer (1966) allude to the importance of Ca and other ions in determining diatom associations.

Thunmark (1945) has proposed the ratio of the number of species of Chlorococcales to the number of species of desmids to measure plankton associations running from those characteristic of extremely unproductive, soft, transparent waters to extremely productive, hard waters with abundant plankton. Nygaard (1949) proceeded one step further and proposed four different ratios comparing different groups of algae. A cyanophyte index was computed by figuring the ratio of the blue-green algal species to the number of desmids; a diatom index relating the number of centric diatoms to pennate diatoms; and an euglenoid index showing the number of species of euglenophytes to cyanophytes and chlorophytes. His compound index related the number of species of cyanophytes + Chlorococcales + centric diatoms is a tendency for green and blue-green algae to be summer forms, although diatoms persist throughout the year. These indices, other than the diatom quotient, should, therefore, be used only for summer collections. The diatom quotient is perhaps applicable for the entire year. Nygaard regarded lakes containing associations giving a compound index of less than 1.0 as oligotrophic and those greater than 3.0 as definitely eutrophic.

Jarnefelt (1952) in a study of some 300 lakes in Finland lists a few species of Cladocera and a number of rotifers as confined to eutrophic lakes. Bosmina obtusirostris was found only in oligotrophic lakes, while B. longirostris was found only in eutrophic lakes. Certain species of Rotatoria genera, including Polyarthra, Keratella, and Trichocerca showed distinct trophic preference. In Great STave Lake in Canada (Rawson, 1956) the oligotrophic species Bosmina obtusirostris is common, but so are two rotifers, Keratella quadrata and Asplanchna priodonta, which are considered to be European eutrophic indicators. Rawson questions the indiscriminate use of certain indices and points out that plankton ratios may not apply to the situation in the Great Slave Lake.

MATERIALS AND METHODS

## Field Sampling

Phytoplankton and zooplankton samples were collected from Lake Mead at seven different times during the study period. Eight stations were established along the lake, and the location of these stations is shown in Fig. 2. The field investigations were made from the summer of 1970 to the winter of 1972, and the sampling times are indicated in Table 3. Each of the eight stations was sampled identically. All water samples for analyses were collected using 3- and 6-liter, polyvinyl-chloride, Van Dorn samplers. The plankton population samples were taken at $0,1,3,5,7,10,15,20$, 25,30 , and 35 m . The phytoplankton samples were placed in 6-dram vials and preserved in Lugol's reagent. Each zooplankton sample was concentrated from a 6-1iter sample to 6-drams using a fine mesh of approximately $50 \mu$. This method of concentrating the samples retains all macroplankton including Rotatoria, Cladocera, and Copepoda. A 10\% formalin solution was used to preserve the zooplankton.

Field work for the migration study was conducted on January 10, 1972, and January 12, 1974. Samples were taken with a 6-1iter Van Dorn sampler for 20 of the 24 hr on the first day. A replication of the experiment occurred one day later with samples collected during 11 of the 24 hr . These samples were preserved in the same manner as the population samples.

The transect study across Boulder Basin was conducted on January 11 , 1972. Nineteen stations were established across the Basin, starting at the upper end of Las Vegas Bay and ending in the vicinity of Hoover Dam. The location of these stations is shown in Fig. 3. Water samples, including plankton samples, were collected at $0,1,3$, and 5 m . These plankton samples were again preserved in a manner similar to the population samples.

## Zooplankton Enumeration

All of the zooplankton counts, including population counts, migration study and the transect study, were made in the same way. Microscopic examination of zooplankton was made using a Bausch and Lomb Stereozoom microscope model BVB-73. For higher magnification a Zeiss compound microscope model GFL was used. The actual counting employed a technique similar to Knutson (1970) and Maloney and Tressler (1942) using a ruled counting chamber under a Bausch and Lomb dissecting scope. Population counts were made at $0,1,3,5,7,10,15,20,25,30$, and 35 m . The number of population vials scored was 503. For the migration study a total of 310 vials were counted and for the transect study across Boulder Basin the contents of 74 vials were enumerated. All counts were adjusted to the number of organisms/liter. The taxonomic keys used to identify the zooplankton include: Ahlstrom (1943), Pennak (1953), and Ward and Whipple (1959).


Figure 2. Map of Lake Mead showing the plankton sampling locations.

Boulder Basin: I. Las Vegas Wash, station 1 or LVW; II. Bureau of Reclamation Raft, station 2 or BR; III. Beacon Island, station 3 or BI. Virgin Basin: IV. Bonelli Landing, station 4 or BL. Overton Arm: V. Lower Overton Arm, station 5 or LOA; VI. Upper Overton Arm, station 6 or UOA; VII. Temple Bar, station 7 or TB. Gregg's Basin: VIII. South Cove, station 8 or SC.

Table 3. Sampling times and seasons for the study period on Lake Mead.

| Sampling Times | Season |
| :--- | :--- |
| September 6-11, 1970 | Summer |
| November 24-29, 1970 | Fall |
| January 23-27, 1970 | Winter |
| February 25-27, 1971 | Winter |
| April 3-8, 1971 | Spring |
| June 4-8, 1971 | Summer |
| January 8-13, 1972 | Winter |

a June 4-8, 1971 was a late spring sampling but for the purposes of this study is considered as a "summer" sampling time.


Figure 3. Map of Boulder Basin indicating the 19 sampling sites for the transect study and their respective water depths.

## Phytoplankton Enumeration

The phytoplankton samples were enumerated and concentrated on $0.45 \mu$ membrane filters using a technique similar to that of McNabb (1960). Contents of the phytoplankton vials were poured into a Millipore ${ }^{R}$ filtering apparatus, model XX1002500, under a very low vacuum so that about 15 min were required to aspirate a vial. The membranes were then stored overnight in a dark and dry environment. Membranes with the aspirated samples were then trimmed and dipped into Cargille immersion oil with a refractive index of 1.5150 to render the membranes transparent. Then the membranes were placed on slides and covered with number 1 cover glasses. All slides were sealed with clear nail polish to produce permanent preparations.

Microscopy of phytoplankton slides was performed with a Zeiss Compound Research microscope, model GFL, equipped with phase contrast. Vials from $0,3,5,10,20$, and 30 m were enumerated. The total number of phytoplankton from 50 randomly chosen fields of vision was counted. A Clay Adams Differential Counter, model B 4 120-4, was used to aid in counting the most numerous phytoplankton. As with the zooplankton counts, all counts were adjusted to the number of organisms/liter of water. Phytoplankton identifications were verified by observing wet mounts of live samples. A total of 274 slides was tallied for the phytoplankton population counts and 73 slides for the transect study. The taxonomic keys used to identify these organisms include the following references: Ahlstrom (1937), Allegre and Jahn (1943), Desikachary (1959), Huber-Pestalozzi (1941), HuberPestalozzi (1950), Hustedt (1930), Johnson (1944), Palmer (1962), Patrick and Reimer (1966), Prescott (1951), Smith (1920), Smith (1950), Taft and Taft (1971), Tiffany and Britton (1952), and Weber (1971).

## Phytoplankton Biomass Estimation

Biomass estimations were made using the method of Lohmann (1908) for all of the 5 m phytoplankton data of the lake. A ranking of the 10 dominant algae based upon cell counts at each sampling time was performed. Doing this for all six sampling times gave a list of 28 organisms that were dominant in cell counts throughout the l-yr study period. Next, eight approximate geometric configurations were assigned to represent the volume of the dominant 28 plankters. Table 4 lists the dominant phytoplankton and their approximate geometric configurations.

The dimensions of 50 individuals of each dominant phytoplankton were taken. Volumes of the approximate geometric figures were computed using the appropriate volume formulae listed in Table 4. Mean volumes and standard deviations were calculated with the use of a Wang Advanced Programming Calculator, Series 700. Biomass is expressed in $\mu^{3} / l i t e r$ and was obtained by multiplying the average cell number/liter by the average cell volume.

[^0]Table 4. Dominant phytoplankton and their approximate geometric configurations.

Table 4. (Continued) Microcystis incerta

Oocystis submarina
Oscillatoria brevis
Oscillatoria limnetica
Scenedesmus quadricauda Sphaerocystis schroeteri Stephanodiscus astraea Synedra delicatissima cylinder.
cylinder
cube
 cylinder
cylinder + sphere
cylinder + sphere sphere
cylinder
cylinder
cylinder cylinder
Species
Formulae


## OBSERVATIONS AND RESULTS

## Zooplankton Population Counts

Analyses were performed on the contents of the vials with zooplankton from 11 different depths. In total 503 vials were scored. Among the limnetic macroplankters of temperate lakes, the three dominant planktonic groups found are cladocerans, copepods and rotifers. All three of these were well-represented in Lake Mead. The copepods were separated at the ordinal level and counts were made of the Calanoida, Cyclopoida and the nauplii. Two genera of cladocerans were investigated: Bosmina and Daphnia. The principal rotifer found in Lake Mead was Keratella. After the counting was complete, a systematic investigation was performed and 18 zooplankters were identified. Table 5 lists the zooplankton observed from all stations.

The temporal and spatial zooplankton distribution was tabulated. Samples were added over the 35 m column and these figures appear in Appendix A. The 5 m depth was chosen for intensive analysis since water chemistry and primary productivity data at this depth were avialable from previous studies (Everett, 1972). Regression analysis of these data are now being performed.

When one examines the Lake Mead zooplankton samples, the following patterns are seen. Daphnia, a common cladoceran, reaches its maximum population size between April and June, and a minimum occurrs between September and January. The maximum number of Daphnia for the month of June occurred between 3 and 15 m across the system, indicating a somewhat euryoecious range for depth. The totals for the 5 m depth at all stations and all collecting times for Daphnia are plotted in Fig. 4.

The other cladoceran, Bosmina, behaved somewhat differently from Daphnia in that the maximum number of organisms occurred between February and April with a minimum occurring between June and September. The minimum number of organisms for the month of February occurred between 1 and 25 m , while the maximum for April was between 5 and 20 m , suggesting a euryoecious range. The data for the 5 m depth for Bosmina are expressed in Fig. 5.

The Cyclopoida showed a peak between April and June, with a minimum between November and January. The maximum for the month of April occurred between 1 and 20 m while the one for June was between 1 and 25 m . Calanoida, the other copepod order studied, had maxima for the different collecting sites over three collecting times namely, February, April, and June. Thus, one could conclude that the maximum for Calanoida occurred between February and June. The nauplii or larval copepods also showed a maximum during April. The copepod data for the 5 m depth are shown in Figs. 6-8.

Keratella is a rotifer that is sometimes very abundant in Lake Mead, especially during February, April, and September. The data suggest two maxima for this rotifer, a spring maximum occurring between February and April and a late summer maximum occurring in September. The maximum for February occurred between 0 and 30 m , for April between 1 and 15 m and

Table 5. Zooplankton observed from all stations in Lake Mead during 1970, 1971, and 1972.

| Phylum | Order | Species |
| :---: | :---: | :---: |
| Protozoa |  | lholotrichan |
| Rotatoria |  | ```Asplanchna sp. Keratella cochlearis Gosse Keratella quadrata (Muller)a Polyarthra sp.``` |
| Arthropoda | Calonoida | Diaptomus clavipes Schac. Diaptomus siciloides Lilly |
|  | Cyclopoida | ```Cyclops bicuspidatus Claus Cyclops vernalis Fisch. Mesocyclops edax Forbs. Copepod nauplii``` |
|  | Cladocera | Bosmina longirostris Mull. <br> Chydorus sp. <br> Daphnia longispina var. hyalina <br> Leydg. form galeata <br> Daphnia longispina var. hyalina <br> Leydg. form mendotae <br> Daphnia longispina var. hyalina <br> Leydg. form typica <br> Daphnia magna Strau. <br> Daphnia pulex de Greer |
|  | Ostracoda | An ostracod ${ }^{\text {a }}$ |

[^1]

Figure 4. Zooplankton analysis of Daphnia at 5 m .
X-axis = stations, y-axis = sampling times, Z-axis = number of Daphnia per liter.


Figure 5. Zooplankton analysis of Bosmina at 5 m .
X-axis = stations, $Y$-axis = sampling times, and Z-axis = number of Bosmina per liter.


Figure 6. Zooplankton analysis of Cyclopoida at 5 m .
$X$-axis = stations, $Y$-axis = sampling times, and $Z$-axis $=$ number of Cyclopoida per liter.


Figure 7. Zooplankton analysis of Calanoida at 5 m . X-axis $=$ stations, $Y$-axis $=$ sampling times, Z-axis $=$ number of Calanoida per liter.


Figure 8. Zooplankton analysis of nauplii at 5 m .
$X$-axis $=$ stations, $Y$-axis $=$ sampling times, and Z-axis $=$ number of nauplii per liter.


Figure 9. Zooplankton analysis of Keratella at 5 m .
X-axis = stations, $Y$-axis = sampling times, and Z-axis = number of Keratella per liter.


IIDeuglenophyta


SEPTEMBER 6-11, 1970
Figure 10. Phytoplankton distributions for the late summer sampling period.


Figure 11. Phytoplankton distributions for the fall sampling period.


Figure 12. Phytoplankton distributions for the early winter sampling period.


Figure 13. Phytoplankton distributions for the late winter sampling period.

##  CHLOROPHYTA <br> E=ت CRYPTOPHYTA CHRYSOPHYTA



Figure 14. Phytoplankton distributions for the spring sampling period.


Figure 15. Phytoplankton distributions for the early summer period.
for September between 0 and 10 m , suggesting a trend toward a sternoecious range with respect to depth. The minimum counts for this rotifer occurred during the November sampling, but the rotifer appears to be present throughout the year. The data for Keratella are shown in Fig. 9.

## Phytoplankton Population Counts

A total of 503 phytoplankton population samples were collected, representing collections from 11 different depths at eight different stations on the lake at six different sampling times. Not all of these phytoplankton samples were analyzed. Samples collected at 0, 3, 5, 10, 20, and 30 m depths were made into slides and all of the phytoplankton from 50 randomly chosen fields of vision were counted. On these 274 slides, 79 different phytoplankton were identified and most of these were identified to the species level. Table 6 lists these algae and their respective divisions. The Bacillariophyta represent the most diverse group since 42 different forms of diatoms were found. The Chlorophyta represent the second most diverse group with 18 algal species and the Cyanophyta had 9 . There were three species found in both the Chrysophyta and the Cryptophyta with the Pyrrophyta and Euglenophyta both having two species.

Counts of each species were made at each station and at each sampling time for all six depths. Then a total number of cells/liter was calculated for each station at each depth for each sampling time. Next, the percentages of the seven divisions of algae were computed from the population counts and these numbers appear in Appendix B. The 5 m data for each sampling time were plotted showing the percentages of each algal group at each of the eight sampling sites for the six sampling times (Figs. 10-15).

The bacillariophyta are present during most of the year with maxima occurring during the winter and early spring months. The maximum percentage of diatoms found was about $75 \%$ of all cells counted and this occurred during January at 70 m at the Las Vegas Wash site. Here the population size was about $1.5 \times 10^{6}$ cells/liter, and the principal diatom was Mastogloia smithii. The Chlorophyta or green algae are also present during the entire year at all but the 30 m depth at selected sites (see Appendix B). There appears to be a spring percentage maximum for this group with the April counts showing the highest percentages. In total, 18 different green algae were found, only three of these were desmids and these were found only on occasion. The major order of green algae was the Chlorococcales with a few Tetrasporales and two Volvocales. The annual distribution percentages of the green algae are shown in Figs. 10-15.

The Cyanophyta or blue-green algae include nine species in the Lake Mead samples, and this was the major phytoplankton group during September and November. Up to $83 \%$ of the population counts were comprised of bluegreen algae. The most common blue-green alga was Oscillatoria limnetica, a filamentous form. Population sizes up to $5 \times 10^{6}$ cells/liter of gluegreen algae were found in Boulder Basin at the surface during September. The largest cyanophyte populations, in general, were found at the Boulder Basin sites. During the four other sampling times the blue-green populations were reduced but never were truly lacking in Boulder Basin. The Cryptophyta

Table 6. Phytoplankton observed from the eight stations in Lake Mead during 1970, 1971, and 1972.

| Division | Species |
| :---: | :---: |
| Chlorophyta | Ankistrodesmus falcatus (Corda) Ralfs |
|  | Chlorella vulgaris Beij. |
|  | Cladophora sp. |
|  | Closterium sp. |
|  | Cosmarium sp. |
|  | Crucigenia quadrata Morrn. |
|  | Gonium sp. |
|  | Oocystis submarina Lag. |
|  | Pandorina morum Bory |
|  | Pediastrum simplex Meyen |
|  | Pediastrum simplex var. duodenarium (Baily.) Rabnh. |
|  | Scenedesmus dimorphus (Turpin) Kutz. |
|  | $\frac{\text { Scenedesmus }}{\text { (Chod.) }} \frac{\text { quadricauda }}{\text { Smith }}$ var. quadrispina |
|  | Selenastrum gracile Reins. |
|  | Sphaerocystis schroeteri Chod. |
|  | Spirogyra sp. |
|  | Staurastrum sp. |
|  | Tetraedron minimum (A. Braun) Hansg. |
| Euglenophyta | Euglena deses Ehr. |
|  | Phacus acuminata Stoks. |
| Bacillariophyta | Achnanthes exigua Grun. |
|  | Achnanthes lanceolata (Breb) Grun. |
|  | Achnanthes minutissima (Kutz.) Cleve |
|  | Asterionella formosa Hass. |
|  | Cocconeis pediculus Ehr. |
|  | Cocconeis placentula Ehr. |
|  | Cyclotella glomerata Bachm. |
|  | Cyclotella kuetzingiana Thwtz. |
|  | Cyclotella meneghiniana Kutz. |
|  | Cymbella amphicephala Naeg. |
|  | Cymbella lacustris (Agrdh.) Cleve |
|  | Cymbella ventricosa Kutz. |
|  | Denticula elegans Kutz. |
|  | Diatoma hiemale var. mesodon (Ehr.) Grun. |
|  | Diatoma vulgare Bory |
|  | Diploneis smithii (Breb. ex W. Sm.) Cleve |
|  | Epithemia turgida (Ehr.) Kutz. |
|  | Fragilaria brevistriata Grun. |

Table 6. (Continued)


Table 6. (Continued)
Division Species

Cyanophyta (Cont'd.)
Merismopedia glauca (Ehr.) Nag. Microcystis incerta Lemm. Oscillatoria brevis (Kutz.) Gom. Oscillatoria limnetica Lemm.
Raphidiopsis Curvata Frits et Rich Spirulina meneghiniana Zan. ex Gomnt.
is another perennial group with three main plankters, Cryptomonas, Chroomonas, and Rhodomonas. This group shows a winter percentage maximum with up to $50 \%$ of the population counts.

The Pyrrophyta are represented by two species, Peridinium sp., and and Ceratium hirundinella. Of the two, Ceratium is the more abundant. Ceratium is one organism that was counted in both the zooplankton and the phytoplankton samples, as it is visible under a stereomicroscope. The zooplankton data show that Ceratium is sternoecious with respect to depth, showing maximum numbers, during the daylight sampling times, between 3 and 7 m . Also it appears that Ceratium has its greatest development at Bonelli Landing and South Cove during June and consistently showed lowest counts in the Boulder Basin. The phytoplankton population data substantiate the zooplankton counts. The largest counts again were at the June sampling time at the 5 m depth. However, in terms of cell counts, the pyrrophyta are a very insignificant group since their counts always composed less than $5 \%$ of the total phytoplankton even during peak times.

The Chrysophyta was usually an unimportant group in the phytoplankton of Lake Mead in terms of cell counts. Their occurrence was seasonal with populations of Dinobryon occurring only in the June samples and this plankton comprising the majority of the Chrysophytes. In fact, at some sampling sites Dinobryon was the subdominant organism. This pattern held for the $0,3,5,10$, and 20 m June samples. Other Chrysophyta present were Mallomonas and Chrysidalis. These two genera were present usually at times other than June, and usually constituted less than 10\% of the population. The Euglenophyta was another insignificant group in the overall flora of Lake Mead. Population counts never exceeded $3 \%$ with highest counts occurring in the warmer months. Euglenophyta were found in the $0,3,5,10$, and 20 m samples with no preference to sampling sites. Becuase of their scarcity and sporadic occurrence, few, if any, generalities can be made about their planktonic distributions.

## Trends in Phytoplankton Dominance and Biomass

During the study period various phytoplankton became dominant and subdominant in the flora of Lake Mead. The biomass calculations that are summarized in Tables $7,8,9$, and 10 represent only the most common organisms in terms of average cell number/liter of water at each sampling time for the Bureau Raft station. Calculations of biomasses were subsequent to this ranking of most common species. This station was chosen becuase it lies in Boulder Basin, which is thought to be the most productive basin in the lake (Everett, 1972). The 5 m depth was chosen because primary productivity and water chemistry data were available for this depth. A composite listing of the dominant algae across the lake was arranged and biomasses were computed. The purpose of the listing was to compare the Bureau Raft with the entire system. These data are summarized in Table 11.

In all of the sampling periods at the Raft, two perennials were found. They were the cryptomonads, Chroomonas nordstedtii, and Rhodomonas lacustris. These species were consistently in the top ranking and their biomasses were high at all times of the year. At no time during the study period were
Table 7. Summer phytoplankton biomass for 5 m data at Bureau Raft.

| Species | $\begin{aligned} & \text { Cell no./ } \\ & \text { liter } \\ & \times 10 \end{aligned}$ | Avg. <br> cell <br> volume $\left(\mu^{3}\right)$ | S.D. ${ }^{\text {a }}$ | $\begin{aligned} & \text { Biomass } \\ & \left(\mu^{3} / 1 \text { iter }\right) \\ & \times 10^{6} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| September 6-11, 1970 |  |  |  |  |
| Oscillatoria limnetica | 3,100 | 46.6 | 30.8 | 144 |
| Chroomonas nordstedtii | 214 | 25.0 | 15.3 | 5.35 |
| Chlorella vulgaris | 149 | 51.9 | 24.3 | 7.73 |
| Oscillatoria brevis | 79.3 | 79.0 | 18.5 | 6.26 |
| Cyclotella glomerata | 37.1 | 112 | 44.3 | 4.16 |
| Sphaerocystis schroeteri | 31.7 | 128 | 42.4 | 4.06 |
| Synedra nana | 17.3 | 237 | 187 | 4.10 |
| Microcystis incerta | 14.2 | 1 |  | 0.0142 |
| Rhodomonas lacustris | 11.7 | 1260 | 728 | 14.7 |
| Tetraedron minimum | 7.90 | 368 | 310 | 29.1 |
| Totals | 3,660 |  |  | 219 |

Table 7. (Continued)

| Species | $\begin{aligned} & \text { Cell no./ } \\ & \text { liter } \\ & \mathrm{x} 10^{3} \end{aligned}$ | Avg. cell volume ( $\mu^{3}$ ) | S.D. ${ }^{\text {a }}$ | $\begin{aligned} & \text { Biomass } \\ & \left(\mu^{3} / 1 \text { iter }\right) \\ & \times 10^{6} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| June 4-8, 1971 |  |  |  |  |
| Sphaerocystis schroeteri | 26.8 | 128 | 42.4 | 3.43 |
| Rhodomonas lacustris | 17.4 | 1260 | 728 | 21.9 |
| Microcystis incerta | 16.2 | 1 |  | 0.0162 |
| Chroomonas nordstedtii | 13.8 | 25.0 | 15.3 | 0.345 |
| Dinobryon divergens | 8.60 | 118 | 12.0 | 1.01 |
| Oocystis submarina | 8.40 | 491 | 360 | 4.12 |
| Fragilaria capucina | 4.60 | 1340 | 267 | 6.16 |
| Ankistrodesmus falcatus | 4.20 | 60.0 | 55.5 | 0.252 |
| Stephanodiscus astraea | 2.20 | 1170 | 369 | 2.57 |
| Fragilaria crotonensis | 2.00 | 2140 | 601 | 4.28 |
| Totals | 104 |  |  | 44.1 |

Table 8. Fall phytoplankton biomass for 5 m data at Bureau Raft.

| Species | $\begin{aligned} & \text { Cell no./ } \\ & \text { liter } \\ & \times \quad 10^{3} \end{aligned}$ | $\begin{aligned} & \text { Avg. cell }{ }^{3} \text {, } \\ & \text { volume }\left(\mu^{3}\right) \end{aligned}$ | S.D. ${ }^{\text {a }}$ | $\begin{aligned} & \text { Biomass } \\ & (\mu 3 / 1 \text { iter }) \\ & \times 10^{6} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| November 24-29, 1970 |  |  |  |  |
| Oscillatoria limnetica | 516 | 46.6 | 30.8 | 24.0 |
| Chroomonas nordstedtii | 104 | 25.0 | 15.3 | 2.60 |
| Chlorella vulgaris | 54.8 | 51.9 | 24.3 | 2.84 |
| Scenedesmus quadricauda | 43.2 | 37.9 | 30.7 | 1.64 |
| Tetraedron minimum | 16.1 | 368 | 310 | 5.92 |
| Sphaerocystis schroeteri | 13.7 | 128 | 42.4 | 1.75 |
| Rhodomonas lacustris | 13.2 | 1260 | 728 | 16.6 |
| Oscillatoria brevis | 11.3 | 79.0 | 18.5 | 0.893 |
| Cyclotella meneghiniana | 7.75 | 682 | 228 | 5.28 |
| Synedra nana | 6.55 | 237 | 187 | 1.55 |
| Totals | 787 |  |  | 63.1 |

${ }^{\text {a }}$ S.D. refers to standard deviation.
Table 9. Winter phytoplankton biomass for 5 m data at Bureau Raft.

| Species | $\begin{aligned} & \text { Cell no./ } \\ & \text { liter } \\ & \mathrm{x} 10^{3} \end{aligned}$ | $\begin{aligned} & \text { Avg. cell }{ }_{3} \\ & \text { volume }\left(\mu^{2}\right) \end{aligned}$ | S.D. ${ }^{\text {a }}$ | $\begin{aligned} & \text { Biomass } \\ & \left(\mu^{3} / 1 \text { iter }\right) \\ & \times 10^{6} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| January 23-27, 1971 |  |  |  |  |
| Chlorella vulgaria | 490 | 51.9 | 24.3 | 25.4 |
| Oscillatoria limnetica | 442 | 46.6 | 30.8 | 20.6 |
| Chroomonas nordstedtii | 269 | 25.0 | 15.3 | 6.72 |
| Sphaerocystis schroeteri | 221 | 128 | 42.4 | 28.3 |
| Rhodomonas lacustris | 142 | 1260 | 728 | 179 |
| Cyclotella glomerata | 111 | 112 | 44.3 | 12.4 |
| Scenedesmus quadricauda | 47.4 | 37.9 | 30.7 | 1.80 |
| Stephanodiscus astraea | 23.7 | 1170 | 369 | 27.7 |
| Synedra ulna | 15.8 | 1750 | 624 | 27.6 |
| Synedra nana | 7.90 | 237 | 187 | 1.87 |
| Totals | 1,770 |  |  | 331 |

Table 9. (Continued)

| Species | $\begin{aligned} & \text { Cell no./ } \\ & \text { liter } \\ & \mathrm{x} 10^{3} \end{aligned}$ | $\begin{aligned} & \text { Avg. cell } \\ & \text { volume }\left(\mu^{3}\right) \end{aligned}$ | S.D. ${ }^{\text {a }}$ | $\begin{aligned} & \text { Biomass } \\ & \left(\mu^{3} / 1 \text { iter }\right) \\ & \times 10^{6} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| February 25-27, 1971 |  |  |  |  |
| Cyclotella glomerata | 106 | 112 | 44.3 | 11.9 |
| Chroomonas nordstedtii | 75.4 | 25.0 | 15.3 | 1.88 |
| Chlorella vulgaris | 59.8 | 51.9 | 30.8 | 3.10 |
| Rhodomonas lacustris | 54.8 | 1260 | 728 | 69.0 |
| Stephanodiscus astraea | 19.6 | 1170 | 369 | 22.9 |
| Scenedesmus quadricauda | 13.4 | 37.9 | 30.7 | 0.508 |
| Oscillatoria limnetica | 12.1 | 46.6 | 30.8 | 0.564 |
| Cyclotella meneghiniana | 0.200 | 682 | 228 | 0.136 |
| Synedra ulna | 0.200 | 1750 | 624 | 0.350 |
| Totals | 342 |  |  | 110 |

${ }^{\text {a }}$ S.D. refers to standard deviation.
Table 10. Spring phytoplankton biomass for 5 m data at Bureau Raft.

| Species | $\begin{aligned} & \text { Cell no./ } \\ & \text { liter } 3 \\ & \mathrm{x} \quad 10^{3} \end{aligned}$ | $\begin{aligned} & \text { Avg. cell } \\ & \text { volume }\left(\mu^{3}\right) \end{aligned}$ | S.D. ${ }^{\text {a }}$ | $\begin{aligned} & \text { Biomass } \\ & \left(\mu^{3} / 1 \text { iter }\right) \\ & \times 10^{6} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| April 3-8, 1971 |  |  |  |  |
| Chlorella vulgaris | 148 | 51.9 | 24.3 | 7.68 |
| Chroomonas nordstedtii | 50.2 | 25.0 | 15.3 | 1.26 |
| Stephanodiscus astraea | 27.4 | 1170 | 369 | 32.1 |
| Mallomonas sp. | 14.6 | 298 | 192 | 4.35 |
| Scenedesmus quadricauda | 7.60 | 37.9 | 30.7 | 0.288 |
| Sphaerocystis schroeteri | 4.40 | 128 | 42.4 | 0.563 |
| Oscillatoria limnetica | 4.40 | 46.6 | 30.8 | 0.205 |
| Rhodomonas lacustris | 4.20 | 1260 | 728 | 5.29 |
| Synedra delicatissima | 0.200 | 993 | 405 | 1.98 |
| Totals | 261 |  |  | 53.7 |

${ }^{\text {a }}$ S.D. refers to standard deviation.
Table 11. Phytoplankton biomass for 5 m data at all stations.

| Sampling Times | $\begin{aligned} & \text { Avg. cell } \\ & \text { no./liter } \times 10^{3} \end{aligned}$ | $\begin{aligned} & \text { Biomass } \\ & \left(\mu^{3} / \text { liter } \times 10^{6}\right) \end{aligned}$ | Dominant organism (based on cell counts) |
| :---: | :---: | :---: | :---: |
| Sept. 1970 | 3,017 | 300 | Oscillatoria limnetica |
| Nov. 1970 | 399 | 37.7 | Oscillatoria limnetica |
| Jan. 1971 | 668 | 189 | Chroomonas nordstedtii |
| Feb. 1971 | 571 | 78.5 | Chlorella vulgaris |
| April, 1971 | 307 | 37.8 | Chlorella vulgaris |
| June, 1971 | 283 | 114 | Chlorella vulgaris |

euglenoids important in terms of population counts or biomass. Dinoflagellates were present at this station but numerically were unimportant.

The trends in the phytoplankton composition were seasonal. In the early summer, cell counts showed that the largest percentage of organisms were Chlorophyta, followed closely by the Cryptophyta. Cyanophyta, Bacillariophyta, and Chrysophyta all showed minor contributions to the flora in terms of numbers. The Chrysophyta showed a peak during early summer, because of the presence of Dinobryon divergens. The Cryptophyta were present in greatest volume with Bacilloriophyta, and Chlorophyta having a considerable biomass. The Chrysophyta represent about $2 \%$ of the biomass and the Cyanophyta less than $1 \%$. In late summer the trend is different. The shift is toward the Cyanophyta and this is expressed both in cell counts and biomass calculations. The other groups of algae are unimportant in terms of biomass. Besides the large populations of blue-greens, Pediastrum spp. were present.at this time. According to Dr. C. E. Taft of Ohio State University (personal communication) Pediastrum may be an indicator of eutrophy in Lake Erie.

The fall sampling indicated that blue-green algae are still high in cell counts while their biomsss had decreased from September. The cryptomonads showed an increasing trend, both numerically and volumetrically during the late summer situation. Green algae and diatoms constituted only a minor proportion of the flora. During early winter Bacillariophyta increased in biomass as well as in cell count. The green algae reached one of their percentage peaks. The Blue-greens continue to decrease in importance. Cryptophyta continued to increase and reached a maximum in late winter. By late winter diatoms appeared to increase to a high point in their cycle. Stephanodiscus astraea and Cyclotella glomerata were the major centric diatoms, while Rhodomonas lacustris was the dominant cryptomonad.

In the April samples, both cell counts and cell volume are at a low point. Blue-green algae were not important in the flora. Diatoms reached a volumetric peak at this time. The green algae reached another numerical peak during this time and seemed to be dicyclic in their seasonal pattern, with maxima in January and April. The cryptomonads decreased significantly from the late winter siutation, while the chrysophytes, becuase of a Mallomonas sp., appear to contribute a minimal amount of volume and number. These general trends are shown in Figs. 16-20.

When the data from Table 11 for the entire system are compared to the data from the Bureau Raft several observations can be made. One obvious relationship is that the total number of organisms at Bureau Raft and their biomasses seem to agree with the general trend across the lake, if they differ, usually the Bureau Raft data are higher. This suggests the important influence of this station when compared to the entire system. Especially is this true of the Cyanophyta, as the percentage of the blue-greens is higher at Bureau Raft than the general trend across the lake. Another interesting trend at the Raft is the lack of Ceratium hirundinella, a dinoflagellate, in the early summer flora. This observation was made by Everett (1972) when he stated that Ceratium was found at numerically lower levels in Boulder Basin than at other locations in the lake. Another general observation is that the trends at the Raft seem to occur later and for a longer


Figure 16. Percentage composition of dominant Bacillariophyta at 5 m for Bureau Raft station.


Figure 17. Percentage composition of dominant chlorophyta at 5 m for Bureau Raft station.


Figure 18. Percentage composition of dominant Cyanophyta at 5 m for Bureau Raft Station.


Figure 19. Percentage composition of dominant Cryptophyta at 5 m for Bureau Raft station.


Figure 20. Percentage composition of dominant C̄hrysophyta at 5 m for Bureau Raft station.
length of time than the trends across the system. Thus, the interpretation of trends seems to be difficult at this station.

## Pollution-Tolerant Algae Index

Palmer (1969) published a composite rating of algae in terms of their ability to tolerate organic pollution. The listings were compiled from the reports of 165 authors. In this paper he has several lists, one of which is a list of the 60 most pollution-tolerant genera of algae. Of these 60 genera, 37 occur in Lake Mead. These organisms are listed in Table 12. With this list is a ranking of the 80 most tolerant algal species; of these 19 are found in Lake Mead. Palmer also published five tables which indicate the species most tolerant to pollution for the genera Euglena, Oscillatoria, Nitzschia, Scenedesmus, and Navicula. These five genera represent five of Palmer's seven most pollution-tolerant genera. The flora of Lake Mead contains at least one of each of these most troublesome algae.

In the same paper, Palmer has algal pollution indices which were developed for use in rating water samples for high or low organic pollution. Two indices are presented, one for algal genera and another for algal species. For each, a pollution-index factor was assigned and this factor was determined by the relative number of total points credited to the listed algae. A score of 20 or more for a sample is taken as evidence of high organic pollution, while a score of 15 to 19 is taken as probable evidence of high organic pollution. The results of this analysis for Lake Mead are tabulated in Table 13. The data for all depths and all stations were used. The genus pollution index indicates high organic pollution during September at Bureau Raft, Beacon Island, Lower Overton Arm, Temple Bar, and South Cove.

## Nygaard's Phytoplankton Indices

Nygaard (1949) attempted to classify the phytoplankton associations of a number of Danish lakes based upon five ratios or quotients. These quotients are:

The myxophycean index = number of species of Myxophyceae/ number of species of Desmideae;

The chlorophycean index = number of species of Chlorococcales/ number of species of Desmideae;

The diatom index = number of species of centric diatoms/ number of species of pennate diatoms;

The euglenophyte index = number of species of Euglenophyta/ number of species of Myxophyceae and Chlorophyceae;

The compound index = number of species of Myxophyceae, Chlorococcales, centric diatoms, and Euglenophytoa/ number of species of Desmideae.
Table 12. Pollution-tolerant genera of algae as described by Palmer (1969) and their occurrence in

| No. | Genus | Occurrence in Lake Mead | No. | Genus | Occurrence in Lake Mead |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1. | Euglena | + | 19. | Anacystis | + |
| 2. | Oscillatoria | + | 20. | Lepocinclis | - |
| 3. | Chamydomonas | - | 21. | Spirogyra | + |
| 4. | Scenedesmus | + | 22. | Anabaena | + |
| 5. | Chlorella | + | 23. | Cryptomonas | + |
| 6. | Nitzschia | + | 24. | Pediastrum | + |
| 7. | Navicula | + | 25. | Arthrospira | - |
| 8 | Stigeoclonium | - | 26. | Trachelomonas | - |
| 9. | Synedra | + | 27. | Carteria | - |
| 10. | Ankistrodesmus | + | 28. | Chlorogonium | - |
| 11. | Phacus | + | 29. | Fragilaria | + |
| 12. | Phormidium | - | 30. | Ulothrix | - |
| 13. | Melosira | + | 31. | Surirella | - |
| 14. | Gomphonema | + | 32. | Stephanodiscus | + |
| 15. | Cyclotella | + | 33. | Eudorina | + |
| 16. | Closterium | + | 34. | Lyngbya | - |
| 17. | Micractinium | - | 35. | Oocystis | + |
| 18. | Pandorina | + | 36. | Agmenellum | - |

Table 12. (Continued)

| No. Genus | Occurrence in Lake Mead | No. | Genus | Occurrence in Lake Mead |
| :---: | :---: | :---: | :---: | :---: |
| 37. Spirulina | + | 49. | Pinnularia | + |
| 38. Pyrobotrys | - | 50. | Chlorococcum | - |
| 39. Cymbella | + | 51. | Asterionella | + |
| 40. Actinastrum | - | 52. | Cocconeis | + |
| 41. Coelastrum | - | 53. | Cosmarium | + |
| 42. Cladophora | + | 54. | Gonium | + |
| 43. Hantzschia | + | 55. | Tribonema | - |
| 44. Diatoma | + | 56. | Stauroneis | + |
| 45. Spondylomorum | - | 57. | Selenastrum | + |
| 46. Golenkinia | - | 58. | Dictyosphaerium | - |
| 47. Achnanthes | + | 59. | Cymatopleura | - |
| 48. Synura | - | 60. | Crucigenia | + |

Table 13. Palmer's pollution-tolerant algae index applied to the algae of Lake Mead.

| Station | $\begin{gathered} \text { Sept. } \\ \frac{1970}{G^{\frac{1}{2}} \quad S^{b}} \end{gathered}$ |  | $\begin{aligned} & \text { Nov. } \\ & 1970 \end{aligned}$ |  | $\begin{aligned} & \text { Jan } \\ & 1971 \\ & \hline \end{aligned}$ |  | $\begin{aligned} & \text { Feb } \\ & 1971 \\ & \hline \end{aligned}$ |  | Apr. <br> 1971 |  | June <br> 1971 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | G | S | G | S | G | S | G | S | $\overline{\mathbf{G}}$ | S |
| $\mathrm{BR}^{\text {c }}$ | 24 | 11 | 23 | 11 | 22 | 14 | 18 | 8 | 15 | 11 | 13 | 9 |
| LVW | -- | -- | 20. | 11 | 21 | 14 | 18 | 8 | 17 | 6 | 23 | 12 |
| BI | 23 | 11 | 18 | 18 | 15 | 11 | 11 | 14 | 13 | 6 | 15 | 11 |
| BL | 14 | 7 | 22 | 8 | 22 | 17 | 15 | 11 | 10 | 9 | 1.6 | 6 |
| LOA | 21 | 9 | 26 | 15 | 14 | 11 | 15 | 11 | 14 | 11 | 6 | 7 |
| UOA | -- | -- | 18 | 8 | 9 | 6 | 13 | 8 | 12 | 6 | 6 | 5 |
| TB | 24 | 4 | 21 | 11 | 21 | 11 | 11 | 7 | 18 | 9 | 11 | 5 |
| SC | 26 | 11 | 21 | 11 | 15 | 14 | 15 | 11 | 17 | 14 | 9 | 5 |

${ }^{\mathrm{a}} \mathrm{G}$ Refers to Palmer's genus pollutionindex.
${ }^{\mathrm{b}}$ S Refers to Palmer's species pollution index.
${ }^{C}$ BR Refers to the Bureau Raft, LVW is Las Vegas Wash, BI denotes Beacon Island, Station BL is Bonelli Landing, LOA refers to Lower Overton Arm, and UOA is Upper Overton Arm, TB designates Temple Bar and SC is the South Cove Station.

Since there was abundance of green and blue-green algae in the summer flora while diatoms persisted at any time of the year, these indices, except for the diatom index, are applicable only to summer collections. In general, Nygaard regarded lakes containing associations giving a compound index of less than 1.0 as unproductive and those of 3.0 or more as definitely eutrophic. Diatom index values greater than 0.4 are considered as indicators of more productive waters.

These ratios for the summer phytoplankton collections are shown in Table 14. In compiling these ratios the data for all depths at each sample site were used. It appears that Nygaard's ratios, except for the diatom quotient, are not a good test for the flora of Lake Mead probably because of the lack of desmids in the plankton. These data suggest that the number of species of Chlorococcales exceeds the number of species of Desmidiaceae. This general fact is considered by Rawson (1956) as a eutrophic situation. Where it was possible to calculate ratios, most were well above the oligotrophic values. The average diatom value for September is 0.608 and for June is 0.599. Table 15 shows the diatom ratios for seasons other than summer. These values are reflected in the graph for the percent distribution of diatoms, since the values are highest during the winter months.

## Diurnal Zooplankton Migration Study

The contents of 310 zooplankton samples were analyzed for calanoid and cyclopoid copepods, as well as copepod nauplii, Bosmina, Keratella, and Polyarthra. The study was done on two days to test the reproducibility of the patterns. After the counts were made, a statistical analysis was undertaken and the means, variances and standard errors were computed. The results of the counts for the first day are plotted in Figs. 21-23. The dashed lines on each graph represent the depth of the average individual. The sunset time was about 5:40 PM and the sunrise time was approximately 7:40 AM. An analysis of variance on the data comparing the variation in the mean depth during the daylight hour to the night hour was performed in order to test whether the variations were due to chance alone. Both $F$ and $t$ values were calculated and the significance was at the 0.01 level. The results of the analysis of variance are shown in Table 16. These results indicate that Keratella cochlearis, Bosmina longirostris, and Polyarthra sp. were migrating. The difference in mean depth between day and night for Keratella was 4.78 m , for Bosmina the value was 4.70 m and Polyarthra showed a difference of 2.58 m . The analysis indicates that chance variation alone explain the differences for Calanoida, Cyclopoida, and the nauplii.

## Transect Study Across Boulder Basin

A transect study across Boulder Basin, the most productive basin in the reservoir, was undertaken on the afternoon of January 11, 1972. A total of 19 stations was established starting at the confluence of Las Vegas Wash with Lake Mead and stopping near Hoover Dam. Phytoplankton and zooplankton samples from $0,1,3$, and 5 m were taken. A total of 73 samples of phytoplankton was examined. Membranes for the phytoplankton samples at station 1 did not clear, probably because of the tremendous number of diatom frustules
Table 14. Nygaard's ratios for Lake Mead.

| Station | Index |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Myxophycean |  | Chlorophycean |  | Diatom |  | Euglenophyte |  | Compound |  |
| September, 1970 |  |  |  |  |  |  |  |  |  |  |
| BR | -- | (4/0) | -- | (3/0) | 2.000 | (4/2) | 0.000 | (0/8) | -- | (11/0) |
| $L V W^{\text {a }}$ |  |  |  | ---- | ----- | ---- |  | --- |  |  |
| BI | -- | (4/0) | -- | (4/0) | 0.333 | (2/6) | 0.111 | (1/9) |  | (11/0) |
| BL | -- | (4/0) | -- | (2/0) | 0.233 | (3/7) | -- | (0/7) |  | (9/0) |
| LOA | -- | (5/0) | -- | (6/0) | 0.429 | $(3 / 7)$ | 0.083 | (1/12) |  | (12/0) |
| UOA ${ }^{\text {a }}$ | -- | ---- |  | --- | ---- | ---- |  | ---- |  |  |
| TB | -- | (3/0) | -- | (2/0) | 0.400 | (2/5) | 0.400 | (2/5) |  | (9/0) |
| SC | -- | (6/0) | -- | $(6 / 0)$ | 0.255 | (2/9) | 0.077 | (1/13) | -- | (15/0) |
| June, 1971 |  |  |  |  |  |  |  |  |  |  |
| BR | -- | (1/0) | -- | (3/0) | 0.400 | (2/5) | 0.00 | (0/5) | -- | (6/0) |
| LVW | 3.00 | (3/1) | 3.00 | (3/1) | 0.225 | (2/9) | 0.16 | (1/6) | 9.0 | (9/1) |
| BI | -- | (1/0) | -- | (3/0) | 0.000 | $(0 / 3)$ | -- | (0.6) | -- | (4/0) |

Table 14. (Continued)

| Station | Index |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Myхоphycean | Chlorophycean |  | Diatom |  | Euglenophyte |  | Compound |  |
| June, 197 | (Continued) |  |  |  |  |  |  |  |  |
| BL | (1/0) | -- | (3/0) | 0.333 | (2/6) | 0.20 | (1/5) | -- | (7/0) |
| LOA | 0.00 (0/0) | -- | (2/0) | 0.667 | (2/3) | 0.00 | (0/3) | -- | (4/0) |
| UOA | (1/0) | -- | (3/0) | 2.000 | (2/1) | 0.00 | (0/5) | -- | (6/0) |
| TB | -- (1/0) | -- | (2/0) | 0.167 | (1/6) | 0.00 | (0/4) | -- | (3/0) |
| SC | 0.00 (0/0) | -- | (2/0) | 1.000 | (4/4) | 0.00 | (0/3) |  | (6/0) |

Table 15. Nygaard's diatom ratios for the sampling stations during fall, winter, and spring.
Station $\quad$ Diatom Index (Centric/Pennate)

November, 1970

| BR | 0.363 | $(4 / 11)$ |
| :--- | :--- | :--- |
| LVW | 0.500 | $(4 / 8)$ |
| BI | 0.800 | $(4 / 5)$ |
| BL | 2.000 | $(2 / 1)$ |
| LOA | 1.000 | $(4 / 4)$ |
| UOA | 1.333 | $(4 / 3)$ |
| TB | 1.000 | $(4 / 4)$ |
| SC | 0.833 | $(5 / 6)$ |

January, 1971

| BR | 0.600 | $(3 / 5)$ |
| :--- | :--- | :--- |
| LVW | 0.400 | $(4 / 10)$ |
| BI | 0.600 | $(3 / 5)$ |
| BL | 0.750 | $(3 / 4)$ |
| LOA | 0.750 | $(3 / 4)$ |
| UOA | 1.000 |  |
| TB | $0.3714)$ |  |
| SC | 0.667 | $(4 / 11)$ |

February, 1971

| BR | 0.600 | $(3 / 5)$ |
| :--- | :--- | :--- |
| LVW | 1.500 | $(3 / 2)$ |
| BI | 1.000 | $(3 / 3)$ |
| BL | 1.500 | $(3 / 2)$ |
| LOA | $1.000(3 / 3)$ |  |
| UOA | $0.750(3 / 4)$ |  |
| TB | $1.000(2 / 2)$ |  |
| SC | $5.000(5 / 1)$ | avg. 1.544 |

April, 1971

| BR | 1.000 | $(2 / 2)$ |
| :--- | :--- | :--- |
| LVW | 0.400 | $(2 / 5)$ |
| BI | 0.333 | $(1 / 3)$ |
| BL | 0.750 | $(3 / 4)$ |
| LOA | 4.000 | $(4 / 1)$ |
| UOA | 0.667 | $(2 / 3)$ |
| TB | 0.400 | $(2 / 5)$ |
| SC | 0.800 | $(4 / 5)$ |




Figure 22. Diurnal patterns for nauplii (a) and Bosmina (b). -- The dashed line represents the depth of the average individual.


Table 16. Analysis of variance designed to test whether migratory patterns were due to chance alone. -- The level of significance level was the 0.01 .

| Organism | $d f^{\text {a }}$ | $t$ values | Mean difference in depth (m) | Migrating |
| :---: | :---: | :---: | :---: | :---: |
| Keratella | 1852 | 11.90 | 4.78 | yes |
| Bosmina | 1301 | 7.91 | 4.70 | yes |
| Cyclopoida | 272 | 2.40 | 3.19 | no |
| Calanoida | 115 | 1.85 | 2.99 | no |
| Polyarthra | 1905 | 6.12 | 2.58 | yes |
| Nauplii | 373 | 1.39 | 1.34 | no |

[^2]and other seston present in the water. The results of these analyses are illustrated in Fig. 24-29. Also some of the chemical and physical parameters of the water were measured at this time. All chemical samples were taken at the surface except at Bureau Raft where 5 m and 30 m depths were sampled. These data are shown in Table 17.

Upon examining these data the following trends and observations can be made. Station 1 shows significantly higher soluble salt values than the other stations, with station 2 through the raft having remarkably close values for each parameter measured. The cation sequence for the transect study is $\mathrm{Na}>\mathrm{Ca}>\mathrm{Mg}>\mathrm{K}$, and the anion sequence is $\mathrm{SO}_{4}>\mathrm{HCO}_{3}>\mathrm{Cl}$.
Pearsall's basic ratio changes only slightly from station 1 to the Bureau Raft ( 0.94 to 0.85 ). These ratios are, in Pearsall's spectrum, characteristic of waters having mostly diatoms and Myxophyceae. Numerically these two groups were found to be most important in the phytoplankton flora at this sampling time.

The Bacillariophyta in this study consisted of four centric and 11 pennate diatoms. The centric diatoms include Cyclotella glomerata, C . kuetzingiana, C. meneghiniana, and Stephanodiscus astraea, while the pennate diatoms found were: Asterionella formosa, Cymbel $\bar{a}$ lacustris, C. ventricosa, Fragilaria brevistriata, Navicula sp., Nitzschia linearis, Pleurosigma delicatum, Rhoicosphenia curvata, Synedra acus, $\frac{S}{}$. nana, and S. ulna. Diatoms appear to be more abundant at lower depths than at the surface and there appears to be a general decrease in the total number of diatoms across the basin. Fig. $24 a$ shows that the number of diatoms peaks at about 500 cells/ml at lower depths near the wash and reaches a lower limit of about 30 cells/ml near the dam. The membranes for station 1 , which did not completely clear, contain high numbers of diatoms including species of Mastogloia, Pinnularia, Navicula, Epithemia, Gyrosigma, Pleurosigma, Nitzschia, Stephanodiscus, Cyclotella, Melosira, Rhopalodia, Surirella, Synedra, and Cocconeis. These results are not surprising since diatoms are often found in waters having low Pearsall ratios and high silicate concentrations.

The Chlorophyta show a trend similar to the Cryptophyta in terms of total population numbers, but differ from this group in diversity. The green algae here include 1 volvocalean alga, Pandorina morum; 5 chlorococcalean algae, Ankistrodesmus falcatus, Chlorella vulgaris, Scenedesmus polymorphus, $\underline{S}$. quadricauda, and Tetraedron minimum; 1 tetrasporalean alga, Sphaerocystis schroeteri and 1 desmid Cosmarium sp. The lack of desmids in the flora is expected since they are characteristic of water with low T.D.S., high basic ratios, and a Ca deficient lake (Pearsall, 1932). The presence of more chlorococcalean algae than desmids is considered by Rawson (1956) as a eutrophic situation and Pandorina morum is the ninth species listed on Palmer's (1969) 80 most pollution-tolerant algae. Fíg. 24b shows the Chlorophyta distribution across the basin. The maximum counts were found at station 6 at 3 m and the counts were about $900 \mathrm{cells} / \mathrm{ml}$ and showed a minimum of about $60 \mathrm{cell} \mathrm{s} / \mathrm{ml}$ near the dam.

The Cyanophyta have the largest population counts of any of the algal groups. The principal blue-green algae present were: Merismopedia glauca,





Figure 26. Distribution patterns for Chrysophyta (a) and Euglenophyta (b).



Figure 28. Distribution patterns for


Figure 29. Distribution patterns for cyclopoid copepods (a) and nauplii (b).
Table 17. Chemical ${ }^{\text {a }}$ and physical data for the transect study across Boulder Basin.

| Parameter | Station |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 | 7 | BR ( 5 m ) | BR(30 m) |
| Soluble |  |  |  |  |  |  |  |  |
| Salts | 2411 | 805 | 791 | 785 | 797 | 799 | 805 | 804 |
| $E C^{\text {b }} \times 10^{3}$ | 3.42 | 1.19 | 1.17 | 1.17 | 1.17 | 1.17 | 1.14 | 1.14 |
| Ca | 300 | 94 | 92 | 94 | 94 | 94 | 94 | 94 |
| Mg | 86 | 38 | 36 | 36 | 34 | 35 | 36 | 35 |
| Na | 330 | 109 | 104 | 105 | 106 | 107 | 104 | 104 |
| Cl | 506 | 104 | 98 | 98 | 96 | 96 | 96 | 96 |
| $\mathrm{SO}_{4}$ | 900 | 295 | 295 | 290 | 300 | 300 | 300 | 300 |
| $\mathrm{CO}_{3}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $\mathrm{HCO}_{3}$ | 210 | 156 | 156 | 156 | 159 | 159 | 159 | 159 |
| $\mathrm{NO}_{3}$ | 42.7 | 1.6 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.9 |
| $\mathrm{PO}_{4}$ | 2.336 | . 030 | . 030 | . 020 | . 020 | . 020 | . 020 | . 020 |
| K | 34.4 | 6.6 | 6.2 | 6.2 | 6.2 | 6.2 | 6.1 | 6.1 |
| $\mathrm{SiO}_{3}$ | -- | -- | - | -- | -- | -- | 8.4 | 8.4 |


| Table 17. (Continued) |  |  |  |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  |  |  |  |  |  |  |  |  |

$$
\begin{aligned}
& a_{\text {All }} \text { water chemistries expressed in ppm. } \\
& b_{\text {EC refers to electrical conductivity and is expressed in micromhos. }}
\end{aligned}
$$

Microcystis incerta, Anabaena sp., Anabaenopsis arnoldii, and Oscillatoria limnetica, with the latter comprising the majority of the cyanophytes. The first two are members of the Chroococcales or coccoid group, while the next three are members of the Oscillatoriales, a filamentous group. Microcystis incerta, although at low concentrations during this study, is one of the organisms listed by Kingsbury (1964) as a toxic plant. Analysis of the data shows that the blue-green algae are more numerous at the surface and decrease in numbers with depth. The abundant blue-green algal populations, even in the winter, are expected from the low Pearsall's ratios. The maximum number of cyanophytes were found at station 2 at the surface with counts of about 1175 cells $/ \mathrm{ml}$. Minimum blue-green populations were found near the dam with approximately 50 cells/ml. These results are shown in Fig. 24c.

The Cryptophyta is another important group in terms of phytoplankton counts with two flagellates dominating the flora, Chroomonas nordstedtii and Rhodomonas lacustris. There is a decreasing trend across the basin with the wash area having more organisms than the dam area. Maximum numbers of Cryptophyta were about $850 \mathrm{cell} \mathrm{s} / \mathrm{ml}$ at station 8 and minimum counts of about 50 cells/m1 were recorded at station 19. The Pyrrophyta were found across the basin in low numbers at all sampled depths with more organisms found near the first sampling sites. The maximum number of dinoflagellates found was about $135 \mathrm{cells} / \mathrm{ml}$ and the main dinoflagellate was Peridinium sp. The Chrysophyta are not a very important group in the overall flora of the basin, but they occur mostly near the Las Vegas Bay area where approximately $24 \mathrm{cells} / \mathrm{ml}$ were recorded. Mallomonas sp. is the only Crysophyte that was found. The Euglenophyta were almost non-existent in the phytoplankton observed during this study.

The zooplankton trends are shown in Figs. 27-29. Three rotifers were found during this study: Asplanchna sp., Keratella cochlearis, and Polyarthra sp. Asplanchna populations show maximum counts at station 1 near the surface where there were 225 organisms/liter. After station 6, which roughly corresponds to the Las Vegas Wash site for the 1970-71 population counts (see map, p. 23), the number of organisms is less than l/liter at all four depths. It appears that this species of rotifer thrives in littoral situations and may explain why it was not found in the population counts of 1970-71. The increase in Asplanchna populations at stations 4 and 5 may be accounted for by the increase in populations of Keratella at these stations, for Asplanchna is known to feed upon Keratella. The rotifer Keratella does not appear to be littoral in its distribution since it was found at about a density of 2 organisms/liter across the basin except at stations 4, 5, 6, and 7 where it reached counts of 9 organisms/liter. Also Keratella was found in the euplankton in the population counts of 1970-71 at all stations, which suggests its true planktonic behavior. Polyarthra showed population peaks at stations 4 and 5 with counts of 35 organisms/ liter, and since Keratella peaked at stations 4, 5, and 6. Population profiles for Polyarthra Show that it is also abundant in shallow waters and the counts decrease rapidly past station 5, where counts were 2-3 organisms/ liter through station 19.

The copepods examined in this study were divided into two main groups, calanoid and cyclopoid, and copepod counts were made for these two groups. The principal calanoid copepod was Diaptomus silicoides and the most common cyclopoid copepod was Cyclops vernalis. Also, counts of nauplii were made.

All three graphs for copepods show similar trends, with higher numbers at the dam. The calanoid copepods showed a maximum of 3.5 organisms/liter at the wash and about 0.5 organisms/liter at the dam while cyclopoid copepods were generally higher with a maximum of $16 / 1$ iter at station 2 and a number of about 1 or $2 / l i t e r$ for most of the remaining stations. Also nauplii were low across the basin with about l organism/liter occurring everywhere except at station 1 where they had a 27.5 organisms/liter density (Figs. 28b and 29).

The status of cladocerans for winter in the basin was very uniform and Bosmina longirostris is the principal microcrustacean. With perhaps the exception of the second station at the 3 m depth, most samples showed less than 25 organisms/liter. However, this species represents the most common zooplankton across the basin. Maximum counts of 120 organisms/liter occurred at station 2. Another cladoceran found in limited numbers was Daphnia longispina var. hyalina form typica. The density of this cladoceran was very limited ( $<1$ organism/liter) in the open waters but was found at a concentration of nearly 2 organisms/liter at station 1. Chydorus sp., another cladoceran, was found only at stations 1 and 2, perhaps indicating its littoral nature. Besides the rotifers, copepods, and cladocerans mentioned, two other organisms were found at station 1 . These were an ostracod and a segmented worm which were found in very low numbers.

## DISCUSSION AND CONCLUSIONS

The study of planktonic populations in a large reservoir the size of Lake Mead presents a vast number of problems. If one is able to elucidate only a few general patterns, then the effort is justifiable. The zoolimnoplankton consist principally of three groups of organisms, the rotifers, cladocerans, and copepods and these are present extensively in the Lake Mead fauna. The rotifer population consists of at least four species and Keratella cochlearis is the dominant taxon. Based upon the sampling in this study, it appears that $K$. cochlearis is diacmic, having two maxima/yr. These maxima occur in early spring and 7 ate summer and the counts reach 32 organisms/liter during early April in Boulder Basin. This figure compares to $129 \times 10^{3}$ rotifers $/ \mathrm{m}^{3}$ during October in western Lake Erie (Davis, 1969) (1000 liter $=1 \mathrm{~m}^{3}$ ). Boulder Basin is the area with the highest Keratella densities and this species has been considered by Hutchinson (1967) to generally inhabit eutrophic waters.

The cladoceran population in Lake Mead consists of at least seven species in two major genera. These are Bosmina and Daphnia, which appear to be monacmic, having but one maximum during the year. Bosmina shows a high population between late February and early April. The work of Kuntza (1938) and Wesenberg-Lund (1904) in Danish lakes also indicates a prevernal maximum for this cladoceran. Maximum populations of Bosmina occurred in Boulder Basin with a count of 74 organisms/liter during April. Hasler (1969) has stated that $B$. longirostris is one of the organisms indicating eutrophy. Daphnia spp. behave like Bosmina in that they show spring maxima. In the Lake Mead samples a maximum number of organisms occurs between April and June. The minimum populations occurred in September. Hazelwood and Parker (1961) found a positive correlation between Daphnia densities and dissolved oxygen. It is interesting to note that the lowest oxygen levels occur during September (Everett, 1972) in Lake Mead when the Daphnia populations are at a low level. The dissolved oxygen level at this time is below the Arizona and Nevada levels of $5-8 \mathrm{mg} / 1 \mathrm{l}$ ter suggested by the Water Quality Standard Criteria Digest. The highest counts of Daphnia were about 74 organisms/liter during the month of April. This agrees with the findings of Kuntze (1938) in the Schleinsee, Germany.

The cyclopoid copepods showed a peak between April and June with a minimum between November and January. The order Calanoida had maxima for the different collecting sites over three collecting times, namely February, April, and January. In other investigations, Wesenberg-Lund (1904) and Elster (1954), using the calanoid Eudiaptomus gracilis from Danish lakes and the Obersee found peaks in late winter and early spring (January-March). Davis (1954) found maximum populations of copepods in Lake Erie, a very productive lake, during late May with counts of 23,400 copepods $/ \mathrm{m}^{3}$. Maximum counts in Lake Mead were about 82,000 copepods $/ \mathrm{m}^{3}$. A total of five different copepods was found in Lake Mead.

The spatial relationships of the zooplankton are somewhat difficult to interpret because of the lack of obvious trends across the reservoir. This is especially true with Daphnia, Calanoida and nauplii copepods and Keratella. However, Bosmina and Cyclopoida copepods (Figs. 5-6) are more abundant in the Boulder Basin area. If this area is truely a more productive area of Lake Mead as stated by Everett (1972), then perhaps Bosmina and Cyclopoida are indicators of eutrophic water quality.

The phytoplankton flora of Lake Mead is comprised of at least 79 different algae. This is a relatively small number of organisms when one compares this figure to the 199 algal species found in Flathead Lake, Montana (Morgan, 1971). Flathead Lake is considered by Morgan to be an oligotrophic lake. Another striking aspect of the flora is the rare occurrence of desmids in the population studies. Rawson (1956) has indicated that oligotrophic lakes are usually rich in Chlorophyceae, including the desmids and that the plankton is usually poor in numbers of individuals with a high diversity of species (see Table 2). This is in opposition to the Lake Mead situation which appears to have an abundance of Cyanophyta, especially in the late summer when population counts of $5 \times 10^{6}$ cellis/liter were recorded. Usually the number of species found at a site for a particular period was less than 20. Among the Cyanophyta of this reservoir are Anabaena and Anabaenopsis, which are known to contain nitrogen-fixing species. Also included in the blue-green flora is Microcystis, and, although this organism is found in small quantities, its presence represents a potential problem. Kingsbury (1964) lists Microcystis as having a fastdeath factor which has been identified as a cyclic polypeptide. He states further that the poisoning does not occur unless dense blooms are formed.

These large populations of blue-greens persist into November and start to decrease in the winter, although blue-greens have been found at all of the sampling times. In the winter, the dominant species change from bluegreens to diatoms and cryptomonads. A large population of diatoms having a population size of about $1.5 \times 10^{6}$ cells/liter was found in January at the Las Vegas Wash site. The principal diatom here was Mastogloia smithii. Also large populations of Cyclotella and Stephanodiscus develop at this time. Hutchinson (1944) noted that lakes which contain large populations of blue-green algae in the summer generally have Melosira granulate at other seasons. Melosira granulata is found in Lake Mead, but never abundantly. The main cryptomonads were Chroomonas and Rhodomonas which are perennials in the flora.

The chlorophyta show population peaks in the spring but their densities are never as large as the cyanophytes and the greens share the dominant position with the diatoms at this season. The major group of green algae is the chlorococcales with Ankistrodesmus, Chlorella, and Scenedesmus the major taxa present. Two other groups of algae show some degree of development in the spring and persist to at least early June. These groups are the Pyrrophyta and Chrysophyta. Ceratium is the main dinoflagellate and its highest counts are found in June at the 5 m depth at Bonelli Landing, a relatively unproductive site. Smallest counts for this organism are found in Boulder Basin and this may indicate that Ceratium is sensitive to productive waters and is not pollution-tolerant. Since Ceratium was visible under a stereomicroscope it was counted with the zooplankton as well as with the phytoplankton. Counts from Boulder Basin are drastically lower than the rest of the lake, sometimes as great as one third of that of the other stations in the reservoir.

The volumes of the 28 most common phytoplankters were determined and the biomasses of these organisms were obtained by the Lohmann method (1908) which is still considered to be one of the best quantitative procedures for
estimating biomass. These calculations were performed on the 5 m data at the Bureau Raft, one of the sites in the Boulder Basin. Good correlation between population counts and biomasses seem to hold for the Bacillariophyta, Cyanophyta, Cryptophyta, and Chrysophyta. Each of these groups show biomass and population count maxima at about the same time. By far the dominant summer form is Oscillatoria, a filamentous cyanophyte. The 10 most abundant phytoplankton species at Bureau Raft for the late summer data have a combined biomass of $219 \times 10^{6}{ }^{4} 3 / 1$ iter. This quantity compares to early summer lows of $44.1 \times 10^{6} \mu^{3} / 7$ iter and at this time Rhodomonas has the greatest biomass. Since only the values for one depth and for the 10 most common phytoplankton were determined, it is difficult to compare these biomass figures to other investigations such as those of Willen (1966) and Goldman, Gerletti, Javornicky, Melchiorri-Santolini, and Amezaga (1968).

Most zooplankton migration studies are conducted in the warmer months when lakes are thermally stratified. In the present investigation the lake temperature was isothermal with a water temperature of about $11^{\circ} \mathrm{C}$. Reports of isothermal migrations are cited for Daphnia carinata (Bayly, 1962). Migration distances of over 400 m have been reported in marine environments (Waterman and Berry, 1967) and at the other extreme Birge (1895) found little evidence of the Phenomenon at all in Lake Mendota, Wisconsin. Rawson (1956) indicated that oligotrophic lakes generally have extensive migrations whereas eutrophic lakes have limited patterns.

Keratella cochlearis is a species that is known to undergo diurnal migration patterns (Kikuchi, 1930). It is reported that this species rises at night from deeper waters into the more superficial layers of the lake. Such a pattern is known as a nocturnal migration (Hutchinson, 1967). In this study, Keratella coclearis, Polyarthra sp., and Bosmina longirostris were found to exhibit nocturnal migration patterns. The migration distances, which were not extensive, were under 5 m for the three species. Evidence for migration patterns in the other three zooplankton was not found. Pennak (1944) has indicated that migrations are a function of light. If this is true, then perhaps stronger migration patterns could be seen in a summer migration study.

The general pattern that developed in the transect study across the Boulder Basin is one of decreasing numbers. The Bacillariophyta, Chlorophyta, Cyanophyta, and the Cryptophyta all showed marked decreases in population sizes from the Las Vegas Wash area to Hoover Dam. The group having the highest cell counts was the Cyanophyta. Even though this study was performed in January, counts as high as $1.0 \times 10^{6}$ blue-greens/liter were found near the wash area. Perhaps the increase in tourists using the city of Las Vegas during the winter is part of the reason for high counts in January. The Pyrrophyta, Chrysophyta, and Euglenophyta were not too abundant in the algal population at this time although highest values were found in the wash area. Besides the decrease in algal concentrations across the basin, there were decreases in the concentrations of the anions and cations in the water. This probably explains partially the phytoplankton trends. The phytoplankton study seems to indicate that one of the main sources of pollution is from the Las Vegas Wash.

The pattern in the zooplankton transect study also indicates general
drops in the counts, with highest counts in the wash area. One notable exception is the trend for the rotifers with highs recorded at stations $2,3,4,5$, and 6. These differences may be explained by predator-prey relationships. Several organisms appear to be littoral during this season and these include: Daphnia, Chydorus, Asplanchna, Polyarthra, and perhaps calanoid copepods. This is especially true in Asplanchna where counts of 224 organisms/liter were recorded at station 1 , and few if any, organisms were found near the dam. Perhaps, this explains why no Asplanchna, Polyarthra, and Chydorus were found in the zooplankton counts which were made in waters that are euplanktonic.

Several phytoplankton indices were applied to some of the Lake Mead samples in an attempt to classify the reservoir. Nygaard's rations were computed whenever possible. One of the problems with Nygaard's myxophycean, chlorophycean, and compound ratios is that the denominator is the number of species of desmids. In lakes where few if any desmids occur, as in Lake Mead, this would make the ratio undefined. Strom (1924) attributes the paucity of desmids to water contamination with their absence an indicator of eutrophication. Pearsall (1932) says that desmids occur in calcium deficient lakes. The calcium level in Lake Mead is above 80 ppm at most times of the year so this could account for the small number of desmids. Whenever myxophycean, chlorophycean, or compound indices were obtained, the ratios were all in the more productive range. The diatom ratio shows the relationship between centric and pennate forms. Values above 0.3 are considered to be characteristics of more productive lakes. Many of the diatom quotients are above 0.3.

Pearsall's ratio is the quotient of the alkali metals and the alkalineearth metals. Pearsall (1921) holds that lakes having basic ratios below 1.5 contain mostly diatoms and blue-green algae. Only a few Pearsall ratios were calculated for Lake Mead since K analyses were not performed for each sampling time. The ratios that were calculated are in the 0.94 to 0.85 range and since the Cyanophyta and Bacillariophyta are the principal groups of algae found at this time, it is believed that Pearsall's ratio is a good index for Lake Mead.

Palmer's pollution-tolerant algae index (1969) was applied to all of the phytoplankton population data. In general, little correlation seemed to exist between the genus and species pollution indices. Based upon the present study, this author questions the validity of Palmer's pollution index since often the genus index would indicate highly polluted conditions while the species index would indicate relatively clean conditions.

Eutrophication, as defined by the author, is the result or effect of an increase of nutrients, particularly those likely to be limiting for the growth of algae (e.g., orthophosphate). This result will be manifested in the kinds of organisms present and the way they behave. These organisms will be indicators of the quality of the water present. The organisms that will be primary reflectors of this condition are the phytoplankton and secondarly those zooplankton that graze upon phytoplankton or other seston suspended in the water. The planktonic organisms in this study found to indicate eutrophic conditions are largely the Cyanophyta, especially

Oscillatoria. There is little doubt that dense populations of blue-green algae are indicators of eutrophy. At stations in Boulder Basin during the late summer period, up to $83 \%$ ( $5 \times 10^{6}$ cells/liter) of the cells counted were found to be blue-green algae (Fig. 10). Even during the winter at stations in Boulder Basin blue-greens still remained a problem (Fig. 23c). Biomass calculations at Bureau Raft for late summer show that Oscillatoria occupies the dominant position and that no other organisms are even close (Table 7). Besides the blue-green algal flora, the green algal flora indicates something about the trophic level of a lake. It has been suggested that the absence of desmids in a lake is an indicator of eutrophication (Strom, 1924). Truly in Lake Mead there is a lack of desmids, with only 7 or the 274 slides examined containing desmids and these were found in very low concentrations. The data from this study show that the number of species of Chlorococcales exceeds the number of species of Desmidiaceae. This general condition is considered by Rawson (1956) as a eutrophic situation. Planktonic floras containing Pediastrum spp. are considered by Taft (personal communication) to be indicators of more productive waters as in Lake Erie. At least two species of Pediastrum are found in Lake Mead and these are found during the more productive periods. The dinoflagellate Ceratium appears to be sensitive to more productive waters and is found at lower concentrations in Boulder Basin than at other stations in the reservoir.

Besides the phytoplankton, some of the zooplankton appears to thrive in the more productive waters. Bosmina and Cyclopoida copepods are more abundant in Boulder Basin waters than at other sites (Figs. 5-6). This observation agrees with the work of Hasler (1969). Limited diurnal migration patterns have been considered to be an index of eutrophic conditions (Rawson, 1956). In Lake Mead during a migration study performed in January, migration patterns of less than 5 m , a very limited pattern, have been recorded (Figs. 20-22).

The composition of the planktonic flora, the Nygaard ratios computed from the phytoplankton, the planktonic fauna present, the Pearsall ratios calculated from the ionic constituents of the water, the behavior of the zooplankton during a diurnal migration study, the results of a transect study across Boulder Basin and the biomass calculations all suggest that Lake Mead is eutrophic. The results of the present investigation support the hypothesis of the author that Lake Mead, especially Boulder Basin, is eutrophic.

1. Eighteen different zooplankton were found to occur in Lake Mead. Sixteen of these are either rotifers, copepods or cladocerans. Keratella, the principal rotifer, was found to be diacmic, whereas Bosmina, Daphnia, calanoid, cyclopoid, and nauplii copepods were found to be monacmic. Maximum copepod densities were found to be greater than those reported in Lake Erie.
2. The phytoplankton flora of Lake Mead is comprised of at least 79 algae. The late summer and fall phytoplankton were found to be mostly blue-green algae. Populations as large as $5 \times 10^{6}$ cells/liter of bluegreen algae were found in Boulder Basin. Winter sampling showed that diatoms and cryptomonads dominated, while spring phytoplankton counts revealed mostly green algae. The flora can be characterized by its lack of desmids and a dominance of blue-green and diatoms.
3. Biomass calculations indicate that the late summer period produces the greatest biomass. Oscillatoria, a filamentous cyanophyte, is the dominant late summer algae. Early summer calculations indicate that this time represents a low period in terms of biomass production.
4. Migration studies showed that euplanktonic Keratella cochlearis, Polyarthra sp., and Bosmina longirostris were able to undergo nocturnal migrations. The depth of the average individual in these three species was found to change less than 5 m between day and night populations, suggesting limited migration patterns. Evidence indicates that calanoid, cyclopoind, and nauplii copepods do not migrate. Since this study was performed under isothermal conditions of winter, it is believed that migration is not a function of temperature.
5. Results of a transect study showed a decreasing trend across Boulder Basin with more species occurring in the Las Vegas Wash area than at the dam. The principal phytoplankter was Oscillatoria, a blue-green alga. The ionic composition of the water across the Basin was found to decrease, perhaps explaining the decreasing trend in cell counts. Several zooplankton appear to be littoral during this season, and these include Daphnia, Chydorus, Asplanchna, Polyarthra, and possibly calanoid copepods. Temperature may be a limiting factor to their population densities as the shallower waters have warmer temperatures than the euplanktonic waters.
6. Nygaard's diatom ratio and Pearsall's basic ratio were successfully applied to the phytoplankton flora in an effort to characterize Lake Mead. These indices and the results of the migration studies, the population studies, and the biomass calculations indicate that Boulder Basin is eutrophic. Palmer's pollution-tolerant algae indices were found unsatisfactory for use in this study.

# APPENDIX A <br> PRINCIPAL ZOOPLANKTON DISTRIBUTIONS ${ }^{\text {a }}$ 

${ }^{\mathrm{a}}$ The numbers represent the totals of the 35 m water column.

| Organism | Bureau <br> Raft | Las Vegas Wash | Beacon Island | Miner's Cove | Echo Bay | Bonelli <br> Landing | $\begin{aligned} & \text { Temple } \\ & \text { Bar } \end{aligned}$ | South Cove | Month |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Keratella | 426 | 277 | 397 | 143 | 69 | 79 | 23 | 27 | Jan |
|  | 970 | 1274 | 656 | 55 | 85 | 52 | 25 | 70 | Feb |
|  | 564 | 750 | 623 | 39 | 32 | 118 | 143 | 128 | Apr |
|  | 75 | 991 | 40 | 9 | 43 | 17 | 0 | 29 | Jun |
|  | 470 |  | 842 | 1342 | 14 | 342 | 320 | 216 | Sep |
|  | 84 | 47 | 88 | 8 | 0 | 31 | 1 | 0 | Nov |
| Daphnia | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 4 | Jan |
|  | 5 | 16 | 4 | 19 | 191 | 9 | 28 | 19 | Feb |
|  | 255 | 858 | 507 | 436 | 572 | 647 | 228 | 187 | Apr |
|  | 1475 | 674 | 315 | 361 | 384 | 191 | 321 | 235 | Jun |
|  | 0 |  | 0 | 0 | 2 | 0 | 0 | 0 | Sep |
|  | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 2 | Nov |
| Bosmina | 70 | 332 | 50 | 17 | 21 | 4 | 74 | 133 | Jan |
|  | 726 | 1835 | 343 | 293 | 319 | 226 | 184 | 123 | Feb |
|  | 153 | 1749 | 1338 | 248 | 152 | 406 | 185 | 185 | Apr |
|  | 8 | 60 | 4 | 4 | 8 | 4 | 9 | 22 | Jun |
|  | 4 |  | 8 | 34 | 2 | 2 | 4 | 6 | Sep |
|  | 15 | 25 | 19 | 23 | 133 | 77 | 28 | 29 | Nov |
| Calanoida | 0 | 8 | 8 | . 0 | 17 | 9 | 6 | 21 | Jan |
|  | 162 | 54 | 51 | 385 | 285 | 32 | 25 | 15 | Feb |
|  | 152 | 104 | 71 | 261 | 310 | 253 | 137 | 129 | Apr |
|  | 215 | 86 | 209 | 264 | 386 | 72 | 272 | 219 | Jun |
|  | 0 |  | 0 | 8 | 0 | 0 | 2 | 0 | Sep |
|  | 0 | 0 | 11 | 12 | 31 | 10 | 14 | 5 | Nov |

## APPENDIX B

## DISTRIBUTION OF ALGAL DIVISION IN PERCENTAGES ${ }^{\text {a }}$

$a_{\text {Where }} 1$ is Bacillariophyta, 2 is Chlorophyta, 3 is Cyanophyta, 4 is Cryptophyta, 5 is Pyrrophyta, 6 is Chrysophyta, 7 is Euglenophyta.

| Stations | Algal Divisions in Percentages |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| September | 0 meter | data |  |  |  |  |  |
| BR | 30.9 | 9.8 | 48.6 | 9.6 | 0 | 0 | 1.1 |
| LVW | - | - | - | - | - | - | - |
| BI | 5.0 | 10.8 | 83.7 | 0.1 | 0 | 0.4 | 0 |
| BL | 16.2 | 30.3 | 45.3 | 7.2 | 0 | 1.0 | 0 |
| LOA | 23.8 | 33.7 | 37.9 | 4.6 | 0 | 0 | 0 |
| UOA | - | - | - | - | - | - | - |
| TB | 14.6 | 64.0 | 20.5 | 0.4 | 0 | 0 | 0,5 |
| SC | 0 | 48.8 | 0 | 48.8 | 0 | 2.4 | 0 |

November 0 meter data

|  | 9.7 | 13.6 | 58.3 | 18.4 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| BR | 10.8 | 12.7 | 44.9 | 31.6 | 0 | 0 | 0 |
| LVW | 5.3 | 26.2 | 54.8 | 11.4 | 0 | 2.3 | 0 |
| BI | 6.0 | 21.0 | 64.5 | 6.5 | 0 | 1.5 | 0.5 |
| BL | 3.0 | 26.0 | 55.0 | 14.3 | 0 | 0.2 | 1.5 |
| LOA | 8.4 | 27.6 | 38.4 | 24.9 | 0 | 0.7 | 0 |
| UOA | 6.0 | 21.8 | 41.6 | 29.8 | 0 | 0.8 | 0 |
| TB | 5.3 | 31.1 | 20.0 | 43.6 | 0 | 0 | 0 |
| SC |  |  |  |  |  |  |  |

January 0 meter data

| BR | 26.6 | 23.5 | 21.0 | 18.0 | 0 | 10.5 | 0.4 |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LVW | 13.5 | 43.0 | 21.2 | 22.3 | 0 | 0 | 0 |
| BI | 19.8 | 15.6 | 31.4 | 26.7 | 0 | 6.5 | 0 |
| BL | 35.5 | 57.1 | 0 | 1.8 | 0 | 5.6 | 0 |
| LOA | 13.0 | 36.2 | 0 | 50.8 | 0 | 0 | 0 |
| UOA | 18.8 | 27.7 | 0 | 48.7 | 4.8 | 0 | 0 |
| TB | 18.8 | 46.2 | 10.0 | 16.2 | 0 | 8.8 | 0 |
| SC | 64.0 | 15.3 | 0 | 19.4 | 0 | 1.3 | 0 |

February 0 meter data

|  | 18.8 | 40.1 | 35.7 | 5.4 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| BR | 47.3 | 32.9 | 0 | 19.8 | 0 | 0 | 0 |
| LVW | 13.6 | 68.2 | 0 | 18.2 | 0 | 0 | 0 |
| BI | 2.3 | 70.6 | 0 | 23.5 | 0 | 3.6 | 0 |
| BL | 34.3 | 42.0 | 0 | 7.9 | 0 | 15.8 | 0 |
| LOA | 5.3 | 70.2 | 0 | 24.5 | 0 | 0 | 0 |
| UOA | 1.9 | 76.6 | 0 | 20.7 | 0 | 0.8 | 0 |
| TB | - | - | - | - | - | - | - |


|  | Algal |  |  |  |  | Divisions |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  | in | Percentages |  |  |  |  |
|  | 1 | 2 | 3 | 5 | 6 | 7 |

April 0 meter data

| BR | 6.6 | 73.3 | 7.5 | 12.6 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| LVW | 5.7 | 79.4 | 0 | 5.3 | 0 | 9.6 | 0 |
| BI | 5.6 | 64.3 | 0 | 23.3 | 0 | 6.8 | 0 |
| BL | 0 | 54.6 | 0 | 33.8 | 0 | 11.6 | 0 |
| LOA | 2.1 | 50.0 | 0 | 45.7 | 0 | 2.2 | 0 |
| UOA | 0.8 | 51.5 | 0 | 45.3 | 0 | 2.4 | 0 |
| TB | 0 | 70.6 | 0 | 20.7 | 0 | 8.7 | 0 |
| SC | - | - | - | - | - | - | - |

June 0 meter data

| BR | 0 | 79.0 | 0 | 21.0 | 0 | 0 | 0 |
| :--- | :---: | ---: | :---: | ---: | :---: | ---: | :--- |
| LVW | 19.5 | 65.8 | 2.3 | 11.7 | 0 | 0.4 | 0.2 |
| BI | 0 | 57.4 | 10.7 | 2.1 | 0 | 29.8 | 0 |
| BL | 0 | 85.4 | 0 | 8.8 | 0 | 5.8 | 0 |
| LOA | 1.0 | 70.2 | 0 | 6.8 | 0 | 22.0 | 0 |
| TB | - | - | - | - | - | - | - |
| SC | 0 | 44.6 | 0 | 30.8 | 0 | 24.6 | 0 |

September 3 meter data

| BR | 6.8 | 5.8 | 68.5 | 17.9 | 0 | 1.0 | 0 |
| :--- | ---: | ---: | ---: | ---: | ---: | :--- | :--- |
| LVW | - | - | - |  | - | - | - |
| BI | 4.8 | 2.0 | 83.7 | 9.5 | 0 | 0 | 0 |
| BL | 28.5 | 3.7 | 21.0 | 46.8 | 0 | 0 | 0 |
| LOA | 38.6 | 12.4 | 39.7 | 12.8 | 0 | 0 | 0.5 |
| UOA | 41.2 | 14.0 | 32.3 | 12.5 | 0 | 0 | 0 |
| TB | 15.0 | 9.8 | 35.0 | 40.2 | 0 | 0 | 0 |
| SC | 51.3 | 4.0 | 19.8 | 24.9 | 0 | 0 | 0 |

November 3 meter data

| BR | 4.6 | 8.8 | 59.8 | 26.5 | 0 | 0.3 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| LVW | 9.8 | 17.2 | 28.9 | 43.7 | 0 | 0.4 | 0 |
| BI | 5.5 | 26.4 | 49.8 | 18.3 | 0 | 0 | 0 |
| BL | 4.8 | 13.7 | 79.3 | 2.2 | 0 | 0 | 0 |
| LOA | 3.8 | 19.6 | 64.9 | 11.7 | 0 | 0 | 0 |
| UOA | 11.0 | 16.0 | 46.0 | 27.0 | 0 | 0 | 0 |
| TB | 6.8 | 11.1 | 57.8 | 24.3 | 0 | 0 | 0 |
| SC | 0.3 | 10.8 | 35.7 | 53.2 | 0 | 0 | 0 |


|  | Algal |  |  |  |  |  | Divisions |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  | Stations | 2 | 3 | 4 | 5 | 6 | 7 |

January 3 meter data

| BR | 6.4 | 37.6 | 11.5 | 44.5 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| LVW | 20.9 | 15.2 | 7.3 | 56.6 | 0 | 0 | 0 |
| BI | 4.3 | 32.6 | 21.8 | 41.3 | 0 | 0 | 0 |
| BL | 12.0 | 42.3 | 0 | 44.7 | 0 | 0 | 0 |
| LOA | 9.9 | 31.1 | 0 | 59.0 | 0 | 0 | 0 |
| UOA | 12.2 | 14.9 | 0 | 70.8 | 0 | 2.1 | 0 |
| TB | 25.8 | 6.9 | 0 | 67.3 | 0 | 0 | 0 |
| SC | 22.2 | 26.3 | 0 | 51.5 | 0 | 0 | 0 |

February 3 meter data

| BR | 26.5 | 25.7 | 0 | 47.8 | 0 | 0 | 0 |
| :--- | ---: | :--- | :--- | :--- | :--- | :--- | :--- |
| LVW | 39.0 | 20.3 | 5.0 | 35.7 | 0 | 0 | 0 |
| BI | - | - | - | - | - | - | - |
| BL | 6.2 | 51.5 | 7.1 | 35.2 | 0 | 0 | 0 |
| LOA | 2.5 | 46.9 | 22.9 | 27.7 | 0 | 0 | 0 |
| UOA | 4.9 | 46.6 | 0 | 48.5 | 0 | 0 | 0 |
| TB | 3.5 | 53.3 | 0 | 39.7 | 0 | 3.5 | 0 |
| SC | 8.0 | 57.0 | 0 | 35.0 | 0 | 0 | 0 |

April 3 meter data

| BR | 8.6 | 55.2 | 0 | 36.2 | 0 | 0 | 0 |
| :--- | ---: | :--- | :--- | :--- | :--- | :--- | :--- |
| LVW | 3.4 | 50.3 | 0 | 46.3 | 0 | 0 | 0 |
| BI | 1.5 | 63.8 | 0 | 34.7 | 0 | 0 | 0 |
| BL | 1.0 | 41.2 | 0 | 57.8 | 0 | 0 | 0 |
| LOA | 1.8 | 34.6 | 0 | 63.6 | 0 | 0 | 0 |
| UOA | 2.5 | 39.5 | 0 | 58.0 | 0 | 0 | 0 |
| TB | 0.8 | 35.3 | 42.0 | 21.9 | 0 | 0 | 0 |
| SC | 5.2 | 42.5 | 16.0 | 36.3 | 0 | 0 | 0 |

June 3 meter data

| BR | 0 | 53.4 | 0 | 43.8 | 0 | 2.8 | 0 |
| :--- | :--- | :--- | :--- | :--- | :--- | ---: | :--- |
| LVW | 6.6 | 54.6 | 7.4 | 30.4 | 0 | 1.0 | 0 |
| BI | 1.0 | 52.6 | 0 | 32.8 | 1.0 | 12.6 | 0 |
| BL | 3.8 | 32.4 | 32.4 | 18.8 | 0 | 12.6 | 0 |
| LOA | 0 | 27.9 | 0 | 57.4 | 0 | 14.7 | 0 |
| UOA | 0 | 46.8 | 0 | 44.4 | 0 | 8.8 | 0 |
| TB | 0 | 37.3 | 0 | 38.5 | 0 | 24.2 | 0 |
| SC | 0 | 39.0 | 0 | 50.4 | 0 | 10.6 | 0 |


|  | Algal |  |  |  |  | Divisions | in |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  | Stations | 1 | 2 | 3 | 4 | 5 | 6 |

September 5 meter data

| BR | 7.0 | 22.0 | 46.0 | 25.0 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| LVW | - | - | - | - | - | - | - |
| BI | 3.9 | 5.8 | 82.7 | 7.6 | 0 | 0 | 0 |
| BL | 1.9 | 3.4 | 73.4 | 21.3 | 0 | 0 | 0 |
| LOA | 42.9 | 4.5 | 45.8 | 7.8 | 0 | 0 | 0 |
| UOA | - | - | - | - | - | - |  |
| TB | 12.6 | 29.2 | 34.1 | 24.1 | 0 | 0 | 0 |
| SC | 51.9 | 7.6 | 23.9 | 16.6 | 0 | 0 | 0 |

Noyember 5 meter data

|  | 3.0 | 15.8 | 66.4 | 14.8 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| BR | 7.1 | 23.6 | 60.0 | 9.3 | 0 | 0 | 0 |
| LVW | 1.8 | 11.2 | 59.0 | 28.0 | 0 | 0 | 0 |
| BI | 0.2 | 20.0 | 73.9 | 5.9 | 0 | 0 | 0 |
| BL | 12.9 | 20.0 | 26.4 | 40.7 | 0 | 0 | 0 |
| LOA | 13.2 | 35.2 | 50.0 | 1.2 | 0.4 | 0 | 0 |
| UOA | 2.8 | 34.5 | 38.9 | 23.8 | 0 | 0 | 0 |
| TB | 0.6 | 44.7 | 16.1 | 38.2 | 0 | 0.4 | 0 |
| SC |  |  |  |  |  |  |  |

January 5 meter data

| BR | 9.5 | 42.8 | 24.6 | 23.1 | 0 | 0 | 0 |
| :--- | ---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LVW | 22.3 | 44.0 | 4.3 | 29.4 | 0 | 0 | 0 |
| BI | 14.7 | 62.7 | 0 | 22.6 | 0 | 0 | 0 |
| BL | 13.6 | 46.6 | 0 | 39.8 | 0 | 0 | 0 |
| LOA | - | - | - | - | - | - | - |
| UOA | - | - | - | - | - | - | - |
| TB | 3.9 | 64.5 | 0 | 31.6 | 0 | 0 | 0 |
| SC | 28.5 | 41.6 | 0 | 29.9 | 0 | 0 | 0 |

February 5 meter data

| BR | 37.0 | 21.1 | 3.4 | 38.5 | 0 | 0 | 0 |
| :--- | ---: | ---: | :--- | :--- | :--- | :--- | :--- |
| LVW | - | - | - | - | - | - | - |
| BI | 39.6 | 42.7 | 0 | 15.5 | 0 | 2.2 | 0 |
| BL | 8.8 | 63.1 | 0 | 28.1 | 0 | 0 | 0 |
| LOA | 3.4 | 44.8 | 0 | 51.8 | 0 | 0 | 0 |
| UOA | 4.5 | 74.0 | 0 | 21.5 | 0 | 0 | 0 |
| TB | - | - | - | - | - | - |  |
| SC | 33.2 | 41.9 | 0 | 24.9 | 0 | 0 | 0 |


| Stations | Algal Divisions in Percentages |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| April | 5 meter data |  |  |  |  |  |  |
| BR | 10.6 | 61.5 | 1.6 | 20.7 | 0 | 5.6 | 0 |
| LVW | 5.2 | 71.0 | 0 | 23.7 | 0 | 0.1 | 0 |
| BI | 12.0 | 54.2 | 0.8 | 33.0 | 0 | 0 | 0 |
| BL | 11.8 | 65.3 | 0 | 22.9 | 0 | 0 | 0 |
| LOA | 2.0 | 61.6 | 0 | 36.4 | 0 | 0 | 0 |
| UOA | 1.1 | 63.7 | 0 | 32.2 | 0 | 3.0 | 0 |
| TB | 0.7 | 78.8 | 0 | 20.0 | 0 | 0 | 0.5 |
| SC | 2.3 | 73.0 | 0 | 24.7 | 0 | 0 | 0 |

June 5 meter data

| BR | 10.8 | 36.5 | 15.1 | 28.8 | 0.8 | 8.0 | 0 |
| :--- | ---: | :---: | ---: | ---: | ---: | ---: | ---: |
| LVW | 9.6 | 78.7 | 4.7 | 7.0 | 0 | 0 | 0 |
| BI | 0.9 | 29.0 | 0 | 66.9 | 0 | 3.2 | 0 |
| BL | 3.2 | 23.5 | 30.2 | 29.1 | 0.8 | 13.2 | 0 |
| LOA | 3.3 | 27.7 | 0 | 37.2 | 1.8 | 30.0 | 0 |
| UOA | 6.3 | 43.5 | 30.7 | 11.0 | 0.1 | 8.4 | 0 |
| TB | 3.4 | 17.4 | 16.2 | 40.0 | 0.9 | 22.1 | 0 |
| SC | 4.8 | 71.0 | 0 | 8.5 | 0.2 | 15.5 | 0 |

September 10 meter data

| BR | 3.0 | 8.2 | 78.4 | 10.4 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| LVW | - | - | - | - | - | - | - |
| BI | 4.0 | 10.7 | 55.3 | 30.0 | 0 | 0 | 0 |
| BL | 28.8 | 12.4 | 36.0 | 22.4 | 0 | 0.4 | 0 |
| LOA | 28.9 | 12.5 | 36.0 | 22.8 | 0 | 0 | 0 |
| UOA | - | - | - | - | - | - | - |
| TB | 20.0 | 29.8 | 22.4 | 22.0 | 0 | 5.5 | 0.3 |
| SC | 45.2 | 19.4 | 8.7 | 26.7 | 0 | 0 | 0 |

November 10 meter data

| BR | 7.8 | 8.6 | 76.9 | 5.8 | 0 | 0.9 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| LVW | 13.4 | 15.1 | 54.8 | 16.7 | 0 | 0 | 0 |
| BI | 2.0 | 16.6 | 70.1 | 11.3 | 0 | 0 | 0 |
| BL | 7.9 | 17.3 | 59.8 | 14.2 | 0 | 0.8 | 0 |
| LOA | 12.5 | 27.3 | 19.4 | 40.8 | 0 | 0 | 0 |
| UOA | 4.0 | 24.0 | 47.1 | 24.9 | 0 | 0 | 0 |
| TB | 5.2 | 14.4 | 25.9 | 53.2 | 0 | 0.6 | 0.6 |
| SC | 1.5 | 19.0 | 22.5 | 56.0 | 0 | 1.0 | 0 |


| Stations | Algal Divisions in Percentages |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| January | 10 meter | data |  |  |  |  |  |
| BR | 11.6 | 21.9 | 31.9 | 34.6 | 0 | 0 | 0 |
| LVW | 74.0 | 1.1 | 7.5 | 15.8 | 0 | 1.5 | 0 |
| BI | 10.8 | 21.7 | 27.7 | 38.7 | 0 | 1.1 | 0 |
| BL | 41.1 | 30.6 | 0 | 28.3 | 0 | 0 | 0 |
| LOA | 76.7 | 0 | 0 | 23.3 | 0 | 0 | 0 |
| UOA | 34.8 | 18.2 | 0 | 46.8 | 0 | 0 | 0 |
| TB | 12.4 | 11.8 | 6.9 | 68.2 | 0 | 0.8 | 0 |
| S ${ }_{\text {C }}$ | 29.2 | 12.5 | 0 | 58.2 | 0 | 0 | 0 |

February 10 meter data

| BR | 60.3 | 9.0 | 0 | 30.7 | 0 | 0 | 0 |
| :--- | ---: | ---: | :--- | :--- | :--- | :--- | :--- |
| LVW | 59.7 | 11.1 | 0 | 29.2 | 0 | 0 | 0 |
| BI | 23.9 | 39.7 | 0 | 36.3 | 0 | 0 | 0 |
| BL | 4.4 | 11.8 | 0 | 83.8 | 0 | 0 | 0 |
| LOA | 15.5 | 34.5 | 0 | 50.0 | 0 | 0 | 0 |
| UOA | 5.4 | 22.8 | 0 | 69.0 | 0 | 2.7 | 0 |
| TB | 13.5 | 39.3 | 0 | 47.2 | 0 | 0 | 0 |
| SC | 10.8 | 37.2 | 0 | 51.9 | 0 | 0 | 0 |

April 10 meter data

| BR | 3.4 | 45.1 | 8.5 | 41.8 | 0 | 0 | 1.2 |
| :--- | ---: | :--- | :--- | :--- | :--- | :--- | :--- |
| LVW | 1.3 | 68.7 | 0 | 30.0 | 0 | 0 | 0 |
| BI | 10.0 | 57.9 | 0 | 31.9 | 0 | 0 | 0 |
| BL | 1.2 | 60.6 | 0 | 36.9 | 1.2 | 0 | 0 |
| LOA | 0 | 45.0 | 0 | 55.0 | 0 | 0 | 0 |
| UOA | 0 | 48.4 | 0 | 50.0 | 1.5 | 0 | 0 |
| TB | 0 | 61.6 | 0 | 38.4 | 0 | 0 | 0 |
| SC | 10.5 | 62.7 | 0 | 26.7 | 0 | 0 | 0 |

June 10 meter datta

| BR | 0 | 29.4 | 0 | 70.6 | 0 | 0 | 0 |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LVW | 20.4 | 36.5 | 2.4 | 38.2 | 0 | 2.5 | 0 |
| BI | 1.9 | 40.7 | 28.4 | 28.7 | 0 | 0 | 0 |
| BL | 0 | 35.2 | 0 | 57.4 | 1.4 | 5.7 | 0 |
| LOA | 0 | 51.2 | 0 | 43.0 | 0 | 5.8 | 0 |
| UOA | 0 | 87.8 | 0 | 10.8 | 1.3 | 0 | 0 |
| TB | 0 | 45.2 | 0 | 41.7 | 0 | 12.4 | 0 |
| SC | 0 | 36.8 | 0 | 53.6 | 0 | 9.6 | 0 |



February 20 meter data

|  | 47.9 | 19.9 | 0 | 31.5 | 0 | 0.2 | 0 |
| :--- | ---: | :--- | :---: | :--- | :--- | :--- | :--- |
| BR | 57.3 | 17.3 | 10.0 | 15.4 | 0 | 0 | 0 |
| LVW | 46.0 | 38.0 | 0 | 16.0 | 0 | 0 | 0 |
| BI | 5.6 | 53.8 | 0 | 37.9 | 0 | 2.8 | 0 |
| BL | 0 | 77.5 | 0 | 23.4 | 0 | 0 | 0 |
| LOA | 4.7 | 71.5 | 0 | 23.8 | 0 | 0 | 0 |
| UOA | - | - | - | - | - | - | - |
| TB | 2.3 | 57.9 | 0 | 39.6 | 0 | 0 | 0 |


|  | Algal |  |  |  |  |  |  |  |  | Divisions | in | Percentages |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :---: | :---: | :---: | :---: | :---: |
| Stations | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |  |  |  |  |

April 20 meter data

| BR | 27.4 | 36.4 | 0 | 32.2 | 0 | 4.0 | 0 |
| :--- | ---: | ---: | :--- | :--- | :--- | :--- | :--- |
| LVW | 22.6 | 30.4 | 8.7 | 38.2 | 0 | 0 | 0 |
| BI | 24.7 | 41.5 | 0 | 33.0 | 0 | 0.7 | 0 |
| BL | 46.8 | 2.4 | 0 | 50.8 | 0 | 0 | 0 |
| LOA | 4.2 | 30.9 | 0 | 64.8 | 0 | 0 | 0 |
| UOA | 2.0 | 32.1 | 0 | 66.2 | 0 | 0 | 0 |
| TB | 9.0 | 63.1 | 0 | 28.0 | 0 | 0 | 0 |
| SC | 34.6 | 42.4 | 0 | 23.0 | 0 | 0 | 0 |

June 20 meter data

| BR | 0 | 10.2 | 81.0 | 8.8 | 0 | 0 | 0 |
| :--- | :---: | ---: | :---: | ---: | :--- | :--- | :--- |
| LVW | 17.6 | 29.4 | 0 | 52.8 | 0 | 0 | 0 |
| BI | 0 | 39.4 | 0 | 57.8 | 0 | 2.6 | 0 |
| BL | 0 | 82.8 | 0 | 14.2 | 0 | 0 | 2.9 |
| LOA | 2.4 | 24.9 | 0 | 39.4 | 0 | 33.3 | 0 |
| UOA | 0 | 35.2 | 0 | 64.8 | 0 | 0 | 0 |
| TB | 2.1 | 10.8 | 0 | 87.1 | 0 | 0 | 0 |
| SC | 0 | 4.7 | 0 | 85.6 | 0 | 9.7 | 0 |

September 30 meter data

| BR | 10.2 | 2.5 | 0 | 87.3 | 0 | 0 | 0 |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LVW | - | - | - | - | - | - | - |
| BI | 6.5 | 3.2 | 0 | 90.3 | 0 | 0 | 0 |
| BL | - | - | - | - | - | - | - |
| LOA | 0 | 0 | 0 | 100.0 | 0 | 0 | 0 |
| UOA | - | - | - | - | - | - | - |
| TB | 17.7 | 0 | 0 | 82.3 | 0 | 0 | 0 |
| SC | 38.7 | 0 | 0 | 61.3 | 0 | 0 | 0 |

November 30 meter data

| BR | 7.5 | 12.2 | 74.1 | 6.2 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| LVW | 4.0 | 26.3 | 30.7 | 39.0 | 0 | 0 | 0 |
| BI | 2.2 | 24.6 | 35.9 | 37.3 | 0 | 0 | 0 |
| BL | 14.3 | 12.7 | 58.0 | 15.0 | 0 | 0 | 0 |
| LOA | 10.0 | 21.5 | 51.3 | 17.2 | 0 | 0 | 0 |
| UOA | 11.0 | 38.2 | 20.1 | 30.7 | 0 | 0 | 0 |
| TB | 1.0 | 13.7 | 50.6 | 34.7 | 0 | 0 | 0 |
| SC | 0 | 31.2 | 13.1 | 55.7 | 0 | 0 | 0 |


| Stations | Algal Divisions in Percentages |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| January | 30 meter | data |  |  |  |  |  |
| BR | 18.6 | 65.5 | 0 | 15.9 | 0 | 0 | 0 |
| LVW | 1.7 | 27.7 | 8.9 | 61.7 | 0 | 0 | 0 |
| BI | 0 | 84.2 | 0 | 15.8 | 0 | 0 | 0 |
| BL | 0 | 5.7 | 65.9 | 28.4 | 0 | 0 | 0 |
| LOA | 7.7 | 0 | 0 | 92.3 | 0 | 0 | 0 |
| UOA | 9.1 | 18.2 | 0 | 72.7 | 0 | 0 | 0 |
| TB | 10.5 | 10.5 | 0 | 78.9 | 0 | 0 | 0 |
| SC | 56.8 | 11.1 | 0 | 32.1 | 0 | 0 | 0 |

February 30 meter data

| BR | 53.0 | 8.2 | 0 | 38.8 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | :--- | :--- | :--- |
| LVW | 45.2 | 14.8 | 0 | 40.0 | 0 | 0 | 0 |
| BI | 43.2 | 13.3 | 0 | 43.5 | 0 | 0 | 0 |
| BL | 10.8 | 18.6 | 0 | 7.0 .6 | 0 | 0 | 0 |
| LOA | 0 | 16.6 | 0 | 83.4 | 0 | 0 | 0 |
| UOA | 3.3 | 6.7 | 0 | 90.0 | 0 | 0 | 0 |
| TB | 0 | 16.7 | 0 | 83.3 | 0 | 0 | 0 |
| SC | 10.0 | 5.0 | 0 | 85.0 | 0 | 0 | 0 |

April 30 meter data

|  | 24.3 | 22.1 | 0 | 53.6 | 0 | 0 | 0 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | :--- |
| BR | 50.0 | 15.7 | 0 | 34.3 | 0 | 0 | 0 |
| LVW | 0 | 0 | 0 | 100.0 | 0 | 0 | 0 |
| BI | 5.1 | 18.6 | 0 | 76.3 | 0 | 0 | 0 |
| BL | 13.4 | 34.6 | 0 | 52.0 | 0 | 0 | 0 |
| LOA | 4.0 | 8.0 | 0 | 88.0 | 0 | 0 | 0 |
| UOA | 0 | 33.5 | 0 | 66.5 | 0 | 0 | 0 |
| TB | 6.7 | 13.3 | 0 | 80.0 | 0 | 0 | 0 |
| SC |  |  |  |  |  |  |  |

June 30 meter data

| BR | 0 | 0 | 0 | 100.0 | 0 | 0 | 0 |
| :--- | ---: | :---: | ---: | ---: | ---: | ---: | ---: |
| LVW | 14.3 | 71.4 | 0 | 14.3 | 0 | 0 | 0 |
| BI | 7.8 | 0 | 0 | 38.4 | 0 | 53.8 | 0 |
| BL | 4.5 | 0 | 0 | 95.5 | 0 | 0 | 0 |
| LOA | 0 | 0 | 0 | 100.0 | 0 | 0 | 0 |
| UOA | 8.3 | 8.3 | 0 | 83.4 | 0 | 0 | 0 |
| TB | 0 | 0 | 0 | 100.0 | 0 | 0 | 0 |
| SC | 66.7 | 0 | 0 | 33.3 | 0 | 0 | 0 |

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[^0]:    RMillipore Filter Corporation, Bedford, Mass.

[^1]:    ${ }^{\mathrm{a}}$ Extremely rare.

[^2]:    ${ }^{\text {a }}$ df is degrees of freedom.

