CHANGES IN SUBMERGED MACROPHYTES IN GREEN LAKE, WISCONSIN, FROM 1921 TO 1971

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ABSTRACT

In 1921, H. W. Rickett studied the macrophytes in this lake and his data are the basis for a 50 year comparison. The 1971 and 1921 data at the 30 selected stations showed that, overall, total biomass decreased. Five species increased in biomass while eight species decreased; four species of *Potamogeton* were not found in the 1971 quadrats, but all except one have been identified as still present elsewhere in the lake. *Myriophyllum spicatum*, *Vallisneria americana* and *Potamogeton crispus* have the largest increases, while *Chara* sp. had the largest decrease of more than 600 gm/m^2. The largest total biomass decrease occurred at the deepest area in the littoral zone 3 (3-10 m) with zone 2 (1-3 m) and zone 1 (0-1 m) also decreasing in that order. The sharp differences in biomass between the high and low stations selected from Rickett's report have diminished; all the previous high stations have declined in biomass and the low stations display no specific pattern of change. One high and one low station within the deepest zone located where effluents entered the lake, were devoid of vegetation in 1971. Over the 50 year span, the total percentage of dry weights of the comparable plant species showed an insignificant increase, but some individuals had significant variations.

No *Cladophora* problem existed in Green Lake during Rickett's observations, but, in 1971, the biomass of the filamentous algae, mainly *Cladophora* sp., formed a serious nuisance in the littoral zone and proved to be the most important autotroph by weight in zone 1 and third in both zones 2 and 3. Blue-green algae in the phytoplanktonic community in 1971 were *Microcystis aeruginosa*, *Anabaena flos-aquae*, *Aphanazomenon flos-aquae* and *Gloeotrichia echinulata*.

It appears that the littoral plant community in Green Lake has diminished in the past 50 years, especially in the deepest zone, although macrophytes of foreign origin, *Vallisneria americana* and filamentous algae are increasing in importance.

INTRODUCTION

Green Lake, located in Green Lake County (Lat. 42° 48′ N, Long. 89° 00′ W), has a narrowly oval outline oriented northeast to southwest with a length of 11.9 km and a maximum width of 3.2 km (Fig. 1). This lake, which is the deepest inland lake (72.7 m) in the

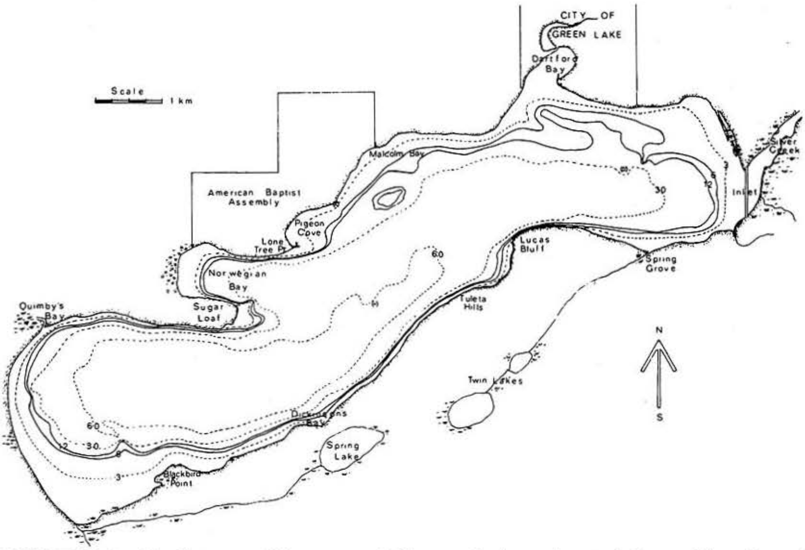

FIGURE 1. Hydrographic map of Green Lake adapted from Marsh and Chandler (1898) showing depth in meters and geographic features mentioned in text. Plankton samples were collected at Pier Station (X), Buoy Sation (#) and Deep Station (*). Some physical data were also obtained from the latter site (Bumby 1972).

state (Juday 1914), was formed by glacial action when the Green Bay lobe of the Wisconsin Stage of glaciation modified the preglacial valley formed earlier by stream erosion. The ice moved through this valley in the direction of the lake's long axis and deepened the basin which is underlain by easily worn Potsdam sandstone. Glacial drift closed the smaller tributary valleys and impounded the water into the present lake basin by depositing a moraine at the west end of the ancient valley. The water thereafter drained through a new outlet, the present day Puchyan River, which flows northeasterly to join the Fox River, finally draining into Lake Michigan.

Pietenpol (1918) noted that Green Lake is not "marsh stained". Silver Creek is the largest stream entering the lake; additional water comes from springs, either directly, or via five small streams on the SW and SE shores and one stream enters the head of Norwegian Bay, through land owned by the American Baptist Assembly (ABA). The hydrographic map of Green Lake (Fig. 1) shows the low areas which Rickett (1924) described as "extensive swamps and marshes" at the Silver Creek and other stream inlets. Other marshy areas are evident in the vicinity of Quimby's Bay and at the head of Norwegian Bay which Rickett described as a "muddy bog". The shoreline is diverse with low sandy beaches at the ends of the lake, wooded slopes of varying steepness, and perpendicular cliffs of Potsdam sandstone at Lucas Bluff, W of Lone Tree Point, S of Sugar Loaf and E of Dickenson's Bay. An unauthorized dam which raised the level of the lake 5 ft. (1.5 m) was built by the Victor Lawsons at one of the mills along the outlet; the date is unknown but probably was before the first hydrographic map (Marsh and Chandler, 1898) because the depth of the lake was reported by them as 72.2 m. Perhaps then, this change of water level, which affected the entire shoreline of the lake, occurred 23 years before Rickett's study of the macrophytes in the pristine water of Green Lake.

Presently, "Big Green", as it is often called, is, and has been for some years, heavily used for recreation during all seasons of the year. It is beautifully set within a densely wooded margin which is surrounded by a large watershed area of 27,618.8 ha (Marter and Cheetham 1971). This basin can be divided into 1,537.8 ha in roads and farmsteads, 991.1 ha in urban areas (two cities) and 1, 256.6 ha in public land; the remaining 86.3% (23,832.5 ha) is mostly in agricultural use. Because of its attractive setting, large size, depth and proximity to populated areas, there are many houses of all sizes along this lake's 43.9 km of shoreline. Fortunately, extensive parts of the shore have not been subdivided. The City of Green Lake is located on the NE edge of the lake near the outlet. The Wisconsin Department of Natural Resources is authorized to determine the maximum and minimum levels of the lake but the actual control of the level is in the hands of the City of Green Lake, since it owns the dam.

Sewer lines are located within the City of Green Lake (1,033 in 1970) but the lake is not affected because the partially treated sewage is discharged into the outlet. Plans are underway to improve this plant. In 1971, treated sewage effluents did enter the lake from the ABA treatment plant, which discharges into Norwegian Bay (Fig. 1) at station 13 (Fig. 2), and also from the City of Ripon (grown from 3,929 population in 1920 to 7,053 in 1970) through its

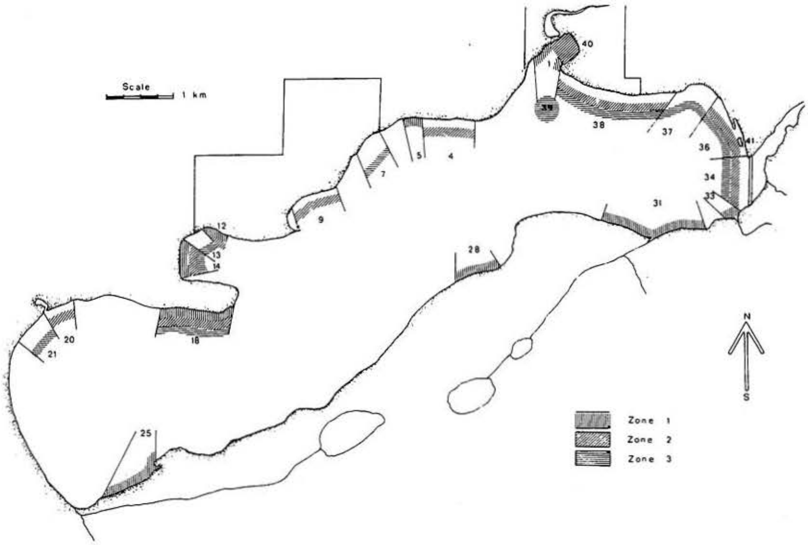

FIGURE 2. Outline map of Green Lake showing the location of the stations sampled in 1971. Depth zones at these stations are Zone 1 (0-1m), Zone 2 (1-3 m) and Zone 3 (3-10 m). Station numbers are those of Rickett (1924).

discharge into Silver Creek which enters near station 34 (Fig. 1 and 2). Septic systems are used in all other areas around the lake, regardless of steepness of slope, soil type, and height of land above the water table. Almost all of the previously described low-lying areas of the lake's shoreline have been affected by channels dredged for boat docks and by the dredge spoils used as land fill for real estate development. Perhaps because of these circumstances of population growth, large watershed area, sewage disposal methods and the change of the low-lying land from its natural state, many symptoms of deteriorating water quality have appeared in Green Lake in recent years. Colored oblique aerial photographs give evidence of some of these conditions (Bumby 1972). These photographs show opaque, discolored water entering the lake through the Silver Creek inlet which carries both Ripon's sewage effluent and runoff from a low-lying real estate development, and also at the opening of Quimby's Bay (which has been deepened and enlarged through dredging for real estate development). The obvious mixing of seston in the water in the littoral zone by heavy motorboat traffic is visible in another photo. But, the real evidence of increasing eutrophication of the lake is found in the plants including *Cladophora* sp. and other filamentous algae now growing abundantly attached to rocks and macrophytes to 1.5 m depth in spring and early summer; two introduced species, *Potamogeton crispus* and *Myriophyllum spicatum*, very prominent in the submerged community; the decreased biomass of submerged macrophytes; and the various blue-green algae floating on or near the surface of the water in summer.

In the six years since the summer of 1971 several changes have occurred. The *Potamogeton* species which were reported in 1921 but not collected in 1971, have been identified (except for one) along with previously unreported species in Green Lake. Concern for water quality has risen over the effect of the body wastes of the Canada geese which linger at Green Lake until late freeze-up date in mid-January. This problem has been aggravated by the new DNR policies enacted to make Horicon Marsh inhospitable to the migrating geese. But perhaps recent changes to liberalize hunting regulations will help. The three collective sewage systems in the watershed area have made improvements. The ABA put into operation a primary facility with an absorption pond for land disposal of effluent to avoid discharge into Norwegian Bay. The Green Lake City sewage system has been extended to some lakeshore residents and a hotel, and is now planning the necessary enlargement and modernization of its sewage plant. The City of Ripon has in almost full operation its new modern activated sludge, tertiary treatment system which will significantly change Silver Creek and its environs. Fifteen Ripon College students completed studies of the physical, chemical and biological parameters from June 1972 to August 1974 paid by the federal government and by the Green Lake Association. This latter organization of interested volunteers pursues many issues and problems concerning the lake. The Green Lake Sanitary District (established in 1964) is financing a study which will produce a feasibility report on control of the input of nutrients into the lake. The conversion of the sanitary district into a lake district is an important issue before the Green Lake County Board. Mechanical harvesting of nuisance weeds had been studied and considered too expensive but some owners have sprayed herbicides on the aquatic weeds and algae. This approach is not inexpensive either and may have more detrimental effects than now known, besides causing toxic reactions in unknowing swimmers who enter these areas too soon after spraying. The problems of the changes in water quality of Green Lake are profoundly interwoven with human activity.

METHODS

The sampling method used in this study was based as nearly as possible on Rickett's method so that data from the two studies could be validly compared. Rickett (1924) chose 41 stations of which 38 were determined by shore characteristics and the three others were marshy bays. At each station, aquatic plants were taken from three depth zones: zone 1 (0-1 m), zone 2 (1-3 m), and zone 3 (3-10 m or where plants cease to grow) and collections were taken in the shallow zone first. A square frame of thin, heavy metal, 50 x 50 x 7 cm, was used to delineate a 0.25 m^2 area of the bottom, and all large algae and macrophytes (including roots) within the frame were collected.

Actually, the pattern Rickett used for the collection of samples is not clear. He stated that multiple samples were taken at stations in zones 1 and 2, whereas, because the plants in zone 3 were more homogeneous where bottom type and slope were similar, one collection was often applied to several of these similar stations in that zone. The number of 0.25 m^2 samples collected averaged less than three per station for all depth zones. Whatever the pattern of sample collection used by Rickett, the weights were computed in g per m^2 for each species at the stations; see Tables 3, 4 and 5 of Rickett (1924). I used the totals of these 1921 wet weights in choosing the stations to be studied in 1971. No dates of collection of samples were furnished in the 1921 study.

For this 1971 study, ten of Rickett's 41 stations were selected in each zone (depth) to include the five highest and the five lowest in wet weight total values. Because of these criteria, it can be noted in Fig. 2 that the ten stations compared over the 50 years for zone 1 are not necessarily the same stations used for zones 2 or 3. The pattern for the collection of the samples consisted of the following: in both zones 1 and 2, samples were taken at three different anchorages randomly located within the limits of each station, whereas in zone 3, one sample was randomly collected at each station. Wet weights were tabulated, averaged (for zones 1 and 2) and then computed into g/m^2 for all species collected within each of the 10 stations at each of the three zones. Thus, data of 1971 and 1921 can be satisfactorily compared for the majority of the species; the problems involving the species will be revealed below.

The 1971 collections in zone 1 were completed July 7-9; all 30 samples were taken within 0.5-1.0 m depth, average 0.8 m. In zone 2, the 30 samples were collected between 1.4-2.6 m, average 2.1 m and were taken from July 16-30. The 10 samples in zone 3 were collected on August 7-8 in depths ranging from 3.7-5.2 m, average 4.4 m. Sometimes a clear line was observed at about 4.6 m beyond which little or nothing grew on the bottom; Rickett reported no plants after 8 m.

Labeled plastic bags separated each sample collected within a quadrat and kept the plants fresh. Collected material was examined and sorted the same day by placing the contents into a large, white enamel pan filled with water. As much of the filamentous algae as practicable was separated from the *Chara* sp. and other macrophytes. After sorting and identifying the species of macrophytes and filamentous algae (under 20 to 140x magnification), they were wrapped in absorbent, dry cloths to remove the excess water, then unwrapped and weighed with a Dial-O-Gram scale accurate to 0.1 g. The weighed samples were separately placed in labeled paper bags and dried at 70 C for 4-6 days. Rickett estimated dry weights from the wet weights with a factor for wet:dry for each species.

Data for biomass of the filamentous algae over the 50 year period are not comparable because in 1921 algal biomass was not determined for each quadrat. Rickett wrote of the lack of *Cladophora* sp. in Green Lake, contrasting this with the serious algal problems in Lake Mendota at that time. He reported that in Green Lake *Cladophora* sp. grew only as a fringe on a few of the rocks at the edge of the water or a few inches below the surface in some areas. Estimations of the biomass of the very few large patches of *Cladophora* sp. then growing in Green Lake in zone 1 were obtained with a different technique from the collection of plants in quadrats; the perimeter of a patch was estimated by Rickett after rowing a boat around it and, from the wet and dry weights directly obtained from the algae collected in one of these patches, the biomass of the other patches was approximated. Therefore, it was not possible to satisfactorily compare these different areas and weight measurements for *Cladophora* over this 50 year interval.

The total biomass collected in 1971 at each station and zone is presented in two ways in this report; the biomass is given both with and without the weights of the filamentous algae, mainly *Cladophora* sp. Without the algae, the values are the basis for comparison with Rickett's data, while the inclusion of the algae gives a clearer portrayal of the plant community in Green Lake during the growing season of 1971.

In 1971, the samples in zone 1 and 2 were taken by a diver using snorkel, face mask and flippers. A SCUBA diver collected the plants in zone 3, using a pressure sensor to determine the exact depth at which the samples were taken. A "diver with a helmet" was used by Rickett in the deepest zone.

Rickett wrote of the lumping of rare species with similar macrophyte species because his study was a quantitive one. Certainly, it is unfortunate that no voucher specimens from his study could be located because verification of their identifications would help answer several questions. Voucher specimens from the 1971 study are deposited in the University of Wisconsin-Milwaukee herbarium. The nomenclature for various plant species is that of Fassett (1960) as revised by Ogden (except for the species of *Myriophyllum* and *Ranunculus);* algae were identified according to Smith (1920), and the revised edition of Ward and Whipple (Edmondson 1963) was used for the zooplankton.

RESULTS

The biomass of the individual species of submerged macrophytes in 1921 and 1971 are discussed in sequence from the largest over-all increase in wet weight to the largest decrease, followed by comment on those plants which seemingly disappeared. References are made to minor aquatic plants, to attached filamentous algae (according to biomass), to plankton (according to presence), and to some physical data.

This report gives the macrophytes found in Green Lake in 1971 and also in 1921, the macrophytes reported only in 1921, and the macrophytes not found in 1971 but identified later from 1971 to 1974; 6 taxa of macrophytes are noted which either were not present in 1921 or were possibly missidentified at that time. The basic data for these comparisons of changes in biomass and species are tabulated in the thesis (Bumby 1972) in Appendices A, B and C and are summarized in its Tables 3, 4 and 5. Each species collected in 1971 is compared to the 1921 data according to their biomass (total g/30 m^2 for total zones or total g/10 m^2 for any one zone) numerically and in percentage (Bumby 1972), and here graphically (Figs. 3, 4, 5, and 6).

The biomass of the algae is often indicated in the above data for each macrophyte species at the zones as it is also for the changes in the selected stations in each zone (Figs. 7A, 7B, 8A, 8B, 9A, 9B).

BIOMASS CHANGES IN SUBMERGED MACROPHYTES

Increases

The following taxa increased in wet weight biomass over the 50 year period in the selected stations. Approximations of biomass compared are in total g/30 m^2 with or without the inclusion of the filamentous algal biomass. As the result of this study, the most abundant species and the one with the largest increase in biomass is *Myriophyllum spicatum* L. The species identified as *M. verticillatum* L. var. *pectinatum* Wallbr. by Rickett is no longer present in the lake in any of the stations checked in 1971 (where it had been abundant in 1921). Its place has been completely taken over by the Eurasian invader, *M. spicatum*, with more than one-third increase in biomass (Fig. 3). As mentioned before, no voucher specimens from the 1921 study have been located so the specimens concerned cannot be verified. Thus, it is possible that the species of the 1921 study may have been either incorrectly identified or may have changed from a minor species (the same or a different minor species) to a dominant one in the plant community today. In my thesis, I designated this taxon as *M. exalbescens* Fernald, but it was identified from voucher specimens as *M. spicatum* in November 1972 by F. M. Uhler of the Patuxent Wildlife Research Center, Laurel, Maryland.

Myriophyllum spicatum is the most important plant in Green Lake today and this is not unusual for a hard water lake of 163 to 183 ppm $CaCO_3$ (Hasler 1967). Over the 50 year period, total wet weight of the *Myriophyllum* taxon increased by 2,232 g. Its 1971 total wet weight of 8,265 g represented 46% (56% dry weight) of the total biomass in this comparative study (Bumby 1972). In 1921, Rickett reported *M. verticillatum* L. var. *pectinatum* Wallbr. present in Green Lake with a total wet weight of 6,033 g which was only 11.6% (10% dry weight) of the total biomass at the selected stations. Flowers and fruits were found on floating *Myriophyllum* on July 2, 1971 and, in September, more flowers and fruits were seen on both floating and rooted plants in a sheltered area. During the summer and fall of 1972 and 1973, no fertile plants were observed, but 1974 produced profuse growths of fertile plants.

The species showing the second largest increase in biomass is *Vallisneria americana* Michx. whose wet weight was 1,785 g in 1971 in contrast to 214 g in 1921. In 1971, this wet weight was about 10% of the total biomass whereas 50 years ago, it was only 0.4%.

Rickett listed *V. spiralis* L. as being present in Green Lake, but this seems to be an error in identification; Fassett (1960) comments that the latter species is European and the only species recorded in North America is *V. americana*. Also, only *V. americana* has been

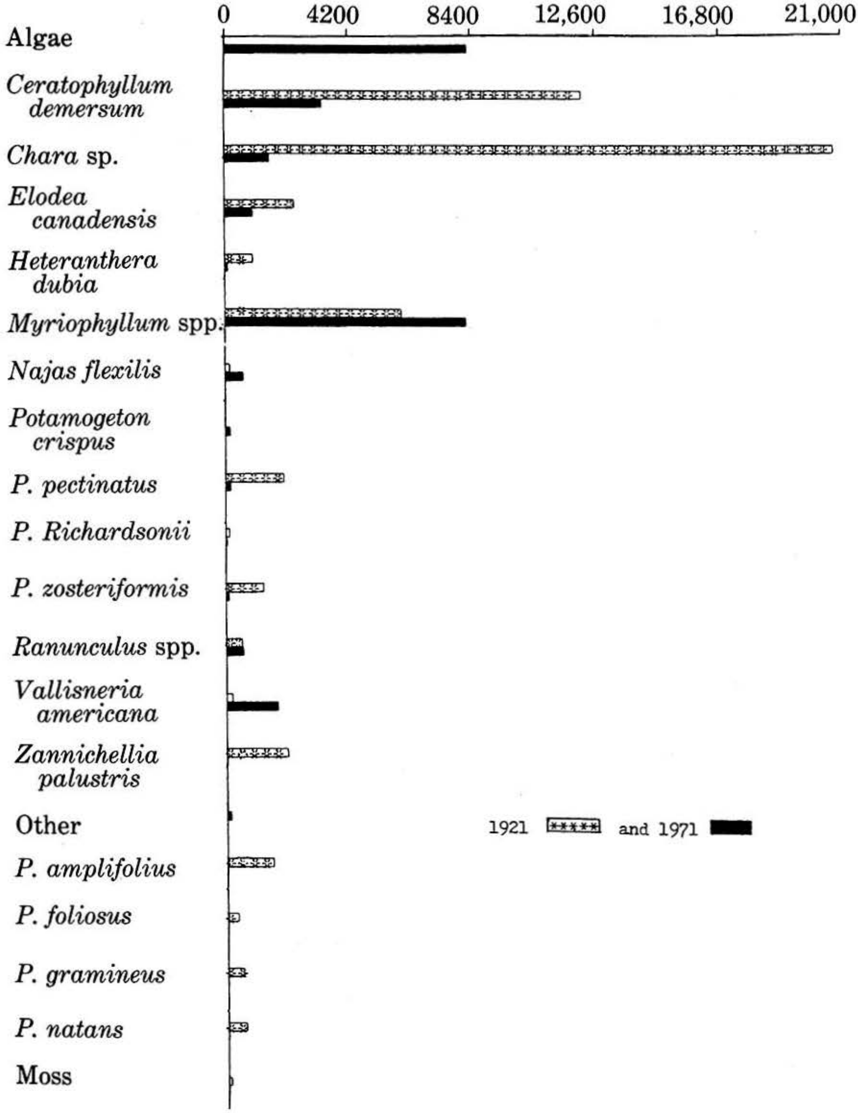

FIGURE 3. The total changes in wet weight biomass g/30m² of each species collected in the three zones in 1921 and 1971.

reported by Nichols and Mori (1971), Modlin (1970) and Belonger (1969) whereas Rickett (1922) reported that it had the greatest biomass in Lake Mendota in 1920.

Third in the series of those macrophytes showing increases is *Najas flexilis* (Willd.) Rostk. and Schmidt, one of the three taxa in Green Lake with true hydrophily. It increased in wet weight from 186 g (0.4% of total biomass) to 647 g in 1971 (3.6% of total biomass).

Ranking fourth in weight among taxa with increasing total biomass was an early summer macrophyte which was not reported in the 1921 study. *Potamogeton crispus* L. has a total wet weight of 180.4 g which was 1% of the total biomass in this study. Since it disintegrates in early summer, its weight is probably undervalued. The appearance of *P. crispus*, an important European invader, may be of particular significance in judging the quality of lake waters because it often appears in polluted water (Fassett 1960) and in waters which have been enriched with city wastes (McCombie and Wile 1971). On the other hand, Sculthorpe (1967) includes *P. crispus* with the "almost truly cosmopolitan" submerged hydrophytes which become easily established in the areas where native plants are not well adapted. Its turion is the most highly specialized of all the aquatic plants and these winter buds were often seen floating in Green Lake during this study and have become increasingly evident in the summers since 1971. Fertile plants were not noticed until 1974, when they were profuse. Since its introduction from Europe, it has spread to the West Coast (Ogden 1943), and Moyle (1945) reported this species in Minnesota about 1910; perhaps this plant was in the lake in 1921 and was lumped in with another *Potamogeton* species. Unfortunately, this taxon will probably become extremely important in the plant community because of its abundant vegetative reproduction.

Comparison of weights of *Ranunculus longirostris* Godron [= *R. circinatus* Sibth. (Fassett 1960)] with weights of the *Ranunculus* sp. reported in 1921, indicated the least gain in biomass, only 19 g. The 1921 *Ranunculus* sp. with 553 g wet weight, was 1.1% of the biomass; the 1971 species, with 572 g wet weight, was 3.2% of the biomass. On July 2, 1971, flowering specimens of the former species were identified in the floral key of Muenscher (1944). Rickett had reported the presence of *R. aquatilis* L. var. *capillaceus* D.C. (now called *R. trichophyllus* Chaix., according to Fassett, 1960). The species Rickett found was not collected in the present study. However, both of these species have been reported in water bodies in this area by Belonger (1969), Modlin (1970) and Nichols and Mori

(1971) who cite *R. longirostris*, while *R. trichophyllus*, reported by Rickett, was listed by Lind and Cottam (1969). Interestingly, Hotchkiss (1967) considers *R. aquatilis* and *R. longirostris* as the "same". As in the *Myriophyllum* situation, a complete replacement by another species of the same genus over the 50 year period may have occurred or there may have been an error in identification, which cannot be resolved because no herbarium specimens of the earlier collection are available.

Decreases

The following taxa showed declines in wet weight biomass at the 30 stations compared in 1921 and 1971. Often an increase in percentage of the total biomass in 1971 will be evident which reflects the decline in total biomass of that year, especially for those species in the lower range of decreases. See Fig. 3.

Potamogeton Richardsonii (Benn.) Rybd. changed from 119 g in 1921 to 53 g in 1971. This taxon had the least decline in wet weight biomass, although it constituted only 0.2% of the total biomass 50 years ago and 0.3% in 1971. This minor increase may reflect the different total biomass values in these studies.

Second in the group of species with decreases is *Heteranthera dubia* (Jacq.) MacM. which declined a total of 867 g and changed from 1.8% of the 1921 total biomass to 0.5% in 1971.

Potamogeton zosteriformis Fernald decreased 1,234 g in wet weight and changed from 2.5% of the total biomass in 1921 to only 0.4% in 1971. Perhaps indicative of its low status in eutrophic lakes is its relative frequency of 0.12% in University Bay (Lind and Cottam 1969) and 0.4% in Lake Wingra (Nichols and Mori 1971).

Elodea canadensis (Michx.) Planchon [= *Anacharis canadensis* (Michx.) Planchon] changed from 2,380 g wet weight in 1921 when it was 4.6% of the total biomass, to 952 g of wet weight and 5.3% of the total biomass at the present time. McCombie and Wile (1971) found that *Elodea* sp. was either absent or abundant, but always associated with abundant *Chara* sp., in the clearer impoundments with specific conductivities between 224 and 330 micromhos/cm^2 at 18 C. Because *Chara* sp. also declined in the 1971 study (see below), this study seems to support their observations of a relationship between these two taxa.

Potamogeton pectinatus L. diminished 1,858 g in wet weight since 1921. Its biomass changed from 4% of the total biomass in 1921 to 1% of the total biomass in 1971. The date of collection is important as this is a late-maturing plant (Belonger 1969). Fertile plants were common every year 1971-74 in Green Lake. Sculthorpe (1967) wrote that *P. pectinatus* may grow in very polluted areas and is among the "silt-loving species". This seems contradictory in this study, since silted and polluted conditions are a recent occurrence in this lake; perhaps this plant is responding to other physical or chemical environmental factors.

Zannichellia palustris L., one of the few macrophytes with true hydrophily, was identified by its seeds on frail, otherwise barren stems, collected in July and early August 1971. The biomass of this early-summer plant would have been greater, if its leaves had been present at the time of collections. During the time of the study, this plant showed a decrease of 2,072 g in wet weight with a change from 2,083 g in 1921 (4% of the total biomass) to 11.4 g (0.06% of the total biomass) in 1971. It was not reported by Modlin (1970), Belonger (1969), Nichols and Mori (1971), Livingston and Bentley (1964) or McCombie and Wile (1971). Lind and Cottam (1969) reported it in University Bay in Lake Mendota with a relative frequency of 0.03% and noted that it had not been reported previously in that area. It is a very small plant which matures in early June and could be easily overlooked if broken into small pieces.

Ceratophyllum demersum L., another common plant with submerged hydrophilous flowers, diminished 8,834 g in wet weight from 12,190 g (23% of the total biomass) in 1921 to 3,356 g (19% of the total biomass) in 1971.

Chara sp. showed the most dramatic decline from its peak biomass 19,194 g (40% wet and 54% dry of the total biomass) in 1921 to 1,553 g (9% wet and 13% dry of the total biomass) in 1971. In 1971, *Nitella* sp. was observed in Green Lake in very small quantities and was not separated from *Chara* sp. Rickett reported the abundance of *Chara* sp. in Green Lake; he found that it grew " . . . almost everywhere . . . sometimes mixed with other plants, often forming great masses in which no other form can get a foothold." He contrasted its abundance in Green Lake with its paucity in Lake Mendota which he had studied the summer before. The difference he attributed to Lake Mendota's muddier bottom and its warmer, more turbid water. Recent documentation of the abundance of *Chara* sp. has been reported by Modlin (1970) and Belonger (1969) and the tolerance of it for wide ranges of $CaCO_3$ (4.2-118 ppm) can be found in the work of Livingston and Bentley (1964). However, environmental situations exist where no *Chara* sp. can be found, as in Lake Wingra (Nichols and Mori 1971), and where it is the taxon with the lowest relative frequency of 0.01%, as in University Bay in Lake Mendota (Lind and Cottam 1969). Thus, *Chara* sp., although still present in Lake Mendota, is very limited (at least in University Bay). It has declined in Green Lake, according to this study, from about 50% to 10% of the total biomass over these 50 years and yet it is still very successful in other lakes mentioned above. Can there be chemical and/or physical parameters causing these two opposite trends? Perhaps the increased erosion of the rich farmland in the watershed area is changing Green Lake's bottom and its water clarity to be more like Lake Mendota's of 1920.

Aquatic Plants Reported in 1921 But Not Collected in 1971

Four species of *Potamogeton* which occurred in Green Lake in 1921 were not found in the 1971 quadrat samples: *P. amplifolius* Teckerm., *P. foliosus* Raf., *P. gramineus* L. and *P. natans* L. However, *P. natans* and *P. gramineus* were found in other areas of the lake during the 1971 study. *P. amplifolius* and *P. foliosus* were not collected in quadrats nor observed elsewhere in the lake in 1971. In Rickett's study, these four species collectively represented a small percentage (6.4%) of the total biomass. Further investigation during 1972 through 1974 led to the verification of the presence of *P. amplifolius, P. nodosus* Poir., and *P. friessi* Rupr. The narrow-leaved *Potamogeton* species (which resembles *P. foliosus)* was determined by R. R. Haynes. No flowers were observed in 1971, but, except for *P. natans,* fertile plants were found during succeeding summers.

In 1921, *P. amplifolius* was relatively abundant at 3% of the total biomass. Besides its apparent absence in 1971 in Green Lake, it also was not reported in Lake Wingra (Nichols and Mori 1971) or University Bay of Lake Mendota, although it had been a common species in 1922 (Lind and Cottam 1969). Documentation of its abundance in other areas are given by Modlin (1970) and Belonger (1969). In 19 impoundments in Ontario, this aquatic plant was found only in the least fertile impoundment with the lowest conductivity and with Secchi disc reading of 2.2 m (McCombie and Wile 1971). Presently in Green Lake, it does grow in beds between stations 28 and 25 (Fig. 2).

Although present in Green Lake in 1971, *P. gramineus* was not recorded in any of the quadrats; its special floating leaves and flowers were not observed in 1971 nor during the years since. This species comprised 1.1% of the total biomass in 1921.

P. natans made up 1.2% of the total biomass in 1921. Although seen in the lake in 1971, it was not collected in any of the quadrats. No flowers were seen in the years since, but its floating leaves have been observed.

P. foliosus had a wet weight of 363 g or 0.7% of the biomass in the collections of 1921. In 1971, this species was not found in the quadrats nor through casual sampling in the years since but a similar plant *(P. friessi)* was verified in 1972 and 1973.

Minor Aquatic Plants

Several aquatics such as a moss and species of *Lemna* were observed in 1971 but not in sufficient quantities for adequate comparisons (Table 3 of Bumby 1972).

In 1921, these plants comprised 0.4% of the total biomass. Rickett stated that a diver could sink up to his knees into beds of the moss *Drepanocladus* sp., quite abundant in zones 2 and 3. Only one of the selected stations sampled in 1971 had mosses in 1921; thus, these plants occur but in sparse distribution.

Lemna minor L. and *L. trisulca* L. were found in the lake, the latter only in very small numbers in Dartford Bay quadrats (station 40) where this tiny flowering plant was entangled with algae and macrophytes growing on the bottom.

Neither the aquatic moss nor *Lemna* sp. was present in sufficient numbers to be compared with Rickett's results or listed except as minute amounts or traces (X) in the figures and tables (Bumby 1972).

The Algae

Attached algae collected in Green Lake in 1921 and collected in 1971 were: *Cladophora* sp., *Nostoc* sp., *Rhizoclonium* sp., *Rivularia* sp., *Spirogyra* sp., *Tolypothrix* sp., *Ulothrix* sp., *Zygnema* sp. *Vaucheria tuberosa (?) was not collected in 1971.*

Although this study is mainly concerned with macrophytes, some observations of the algae were made in 1971 because they are significant in interpreting the changes in biomass in Green Lake. Massive nuisance blooms of *Cladophora* sp. have appeared in Green Lake in recent years; these growths often extend from the waterline down to a depth of 1.5 m in rocky areas. No *Cladophora* problem existed in 1921 and Rickett used a different technique for estimation of the algal biomass. Rickett noted that sometimes

Oedogonium sp. replaced *Cladophora* sp. in the muddier stations and *Spirogyra* sp. also grew on the plants and rocks.

In 1971, most of the algae were of the filamentous type and only a cursory microscope examination of each sample collected in a quadrat was made to identify the conspicuous genera. The weights of the algae which were collected in the quadrats in each zone are on record in Table 3 (Bumby 1972) and the weights at each station are in Appendices A, B and C (Bumby 1972); weights of non-filamentous algae (as *Rivularia* sp. and *Nostoc* sp.) are not included, unless found attached to the macrophytic plants in all zones, and not separated from these plants when they were weighed.

Algae listed above were attached either to the macrophytes or to the rocks under shallow water. In zone 1, 24 of the 60 samples contained filamentous algae; in zone 2, 33 of the 60 samples; while in zone 3, only 2 out of 10 samples (actually 2 in 8, as two samples were devoid of plants) contained weighable quantities of filamentous algae. Their occurrence in zone 1 (from the highest to the lowest frequency) are *Cladophora* sp., *Rhizoclonium* sp., and *Spirogyra* sp., whereas in zone 2, *Cladophora* sp. was most abundant followed by *Rhizoclonium* sp., *Zygnema* sp., *Rivularia* sp. and *Tolypothrix* sp. In zone 3, *Rhizoclonium* sp. and *Rivularia* sp. were present but sparse.

In recent years, a massive floating bloom of *Spirogyra* sp. has been an unsightly covering of the lake along the shore but only on calm days in the very early spring. *Vaucheria tuberosa (?)* was listed at one station in 1921, but was not observed in the present study. The attached filamentous algae were extremely important among the autotrophs in Green Lake in 1971 and will be discussed further with the macrophytic biomass changes within the zones and stations.

CHANGES IN THE PERCENTAGE OF WATER TO DRY CONTENT FOR EACH SPECIES

The dry weight comparison for each species found in 1921 and 1971 are listed in Table 1 as percentages of wet weights. Eight of the 12 macrophytes with comparable data were almost at the same level of water content in both studies. For that reason I have used wet weights in most of these comparisons but dry weights are shown in the graphs (Figs. 7, 8 and 9) and data are in the thesis (Bumby 1972). Comparing dry weights of the taxa eliminates the weight variability accumulated because of the differences in both water adhering to the outside of freshly sampled plants (due to the

TABLE 1. PERCENTAGE DRY WEIGHT IN EACH SPECIES FOR ALL ZONES IN 1921 AND 1971

Species Found in 1921 & 1971	% Dry Wt. 1921	% Dry Wt. 1971
Algae		18.22
Ceratophyllum demersum	7.02	8.50
Chara sp.	15.08	20.12
Elodea canadensis	4.4	13.07
Heteranthera dubia	10.56	9.28
Myriophyllum spicatum		16.44
M. verticillatum var. *pectinatum*	9.63	
Najas flexilis	9.93	10.05
Potamogeton crispus		7.97
P. pectinatus	12.21	12.50
P. Richardsonii	14.64	19.35
P. zosteriformis	12.41	14.10
Ranunculus longirostris		13.35
R. aquatilis var. *Capillaceus*	11.69	
Vallisneria americana	7.71	6.49
Zannichellia palustris	6.96	7.10
Other		14.35
P. amplifolius	11.9	
P. foliosus	10.55	
P. gramineus	11.5	
P. natans	11.43	
Moss	19.49	
Lemna Sp.		5.71
With Algae:		15.06 ± 4.65 S. D.
Without Algae	11.19	13.58 ± 4.52 S. D.

differences in leaf forms, etc.) and in the water content within the structurally different cells of the plants (Sculthorpe 1967).

Every species in each sample collected in 1971 was weighed both wet and dry. In contrast, Rickett dried about 12 samples of a species, averaged the dry weights as a percentage of the wet weights and then used these averages for estimating dry weights of these samples. The macrophytes in 1921 had an average dry weight percentage of 11.2; the 1971 average dry weight was 13.6% ± 4.52% S.D. The minor differences in the 1971 and 1921 dry weights may be due to an increase in epiphytic algae and other organisms clinging to the macrophytes, to an increase in the settling out of particulate matter from the water, to an increase in the accuracy of the equipment and to the differences in the technique for determining dry weights in the two studies. The latter does not permit a comparison of the significance of the changes in dry weights because there is no way of estimating the within-sample variance of Rickett's data.

Although no great change in the total percentage of dry weight of the aquatic plants in Green Lake occurred over this 50 year period, some significant variations appeared among the individual species. *Elodea canadensis* indicates a three fold increase over the 1921 percentage dry weight; however, its 1921 percentage of 4.4 seems unusually low. What may be two *Myriophyllum* species (as identified in 1921 vs. 1971) have a substantial difference almost twice what was reported in the earlier survey and *Chara* sp. showed a 25% increase in 1971 weight data. Macrophytes with almost the same dry content in both studies are as follows: *C. demersum*, *H. dubia*, *N. flexilis*, *P. pectinatus*, *P. zosteriformis*, *Ranunculus* spp., *V. americana* and *Z. palustris*.

BIOMASS CHANGES IN THE ZONES

Previously, I discussed changes of the individual taxa in total biomass (Fig. 3); next the changes in the individual macrophyte species collected in each zone in 1921 and 1971 as wet weights in grams are shown graphically in Figs. 4, 5 and 6. These are based on the numerical total wet weights (g/10 m^2) which are listed for each zone in Table 3 (Bumby 1972).

In zone 1 (Fig. 4), a shift of dominance occurred from *Chara* sp. and *Ceratophyllum demersum* to *Chara* sp. and *V. americana*. Altogether, 14 species were found in zone 1 in 1921 with wet weights ranging from 2,520 to 44 g, whereas 13 species were present in 1971 with wet weight ranging only 614 to 3.3 g. The total biomass of macrophytes of this shallow zone in 1971 was only about one-third that in 1921. The filamentous algae were the most important autotrophs in this zone in 1971.

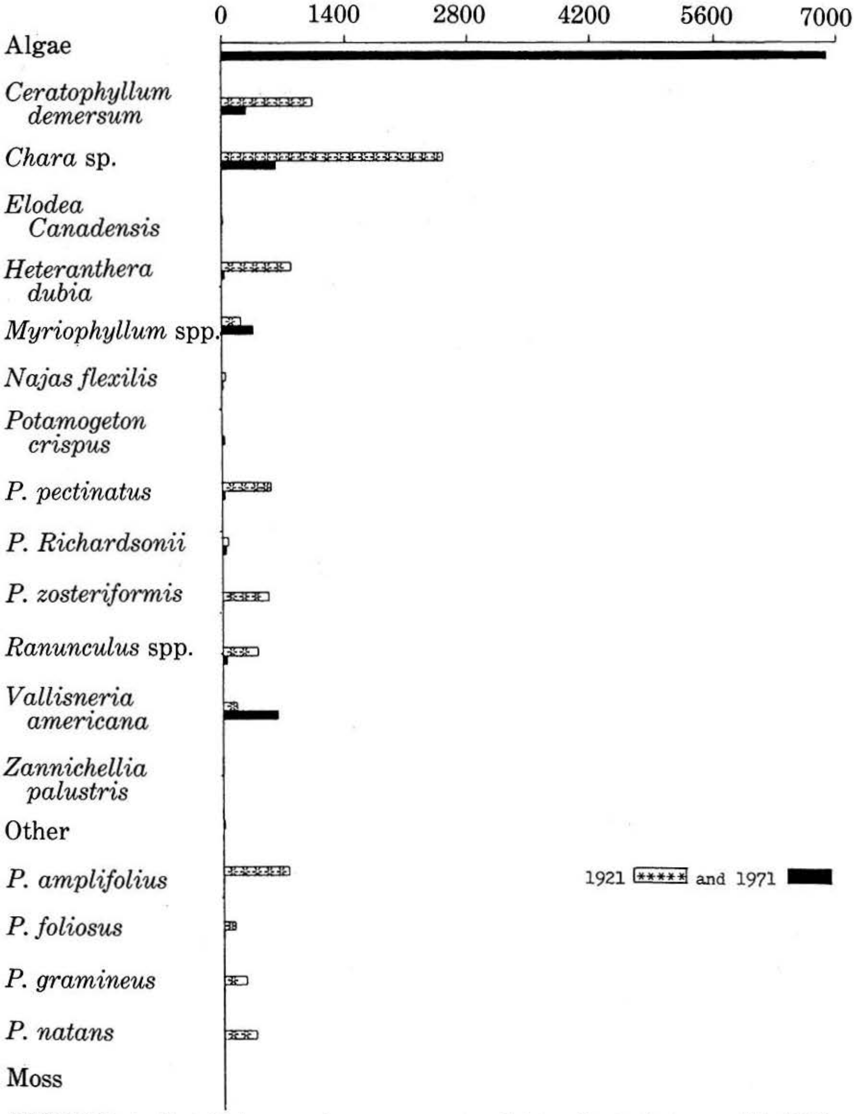

FIGURE 4. Total biomass in grams wet weight collected at zone 1 in 1921 and 1971

The 17 species found in 1921 in zone 2 (Fig. 5), varied in wet weights from 12,974 to 7.0 g whereas the 15 species present in 1971 varied from 4,543.2 g to a trace (X). This involved an obvious shift

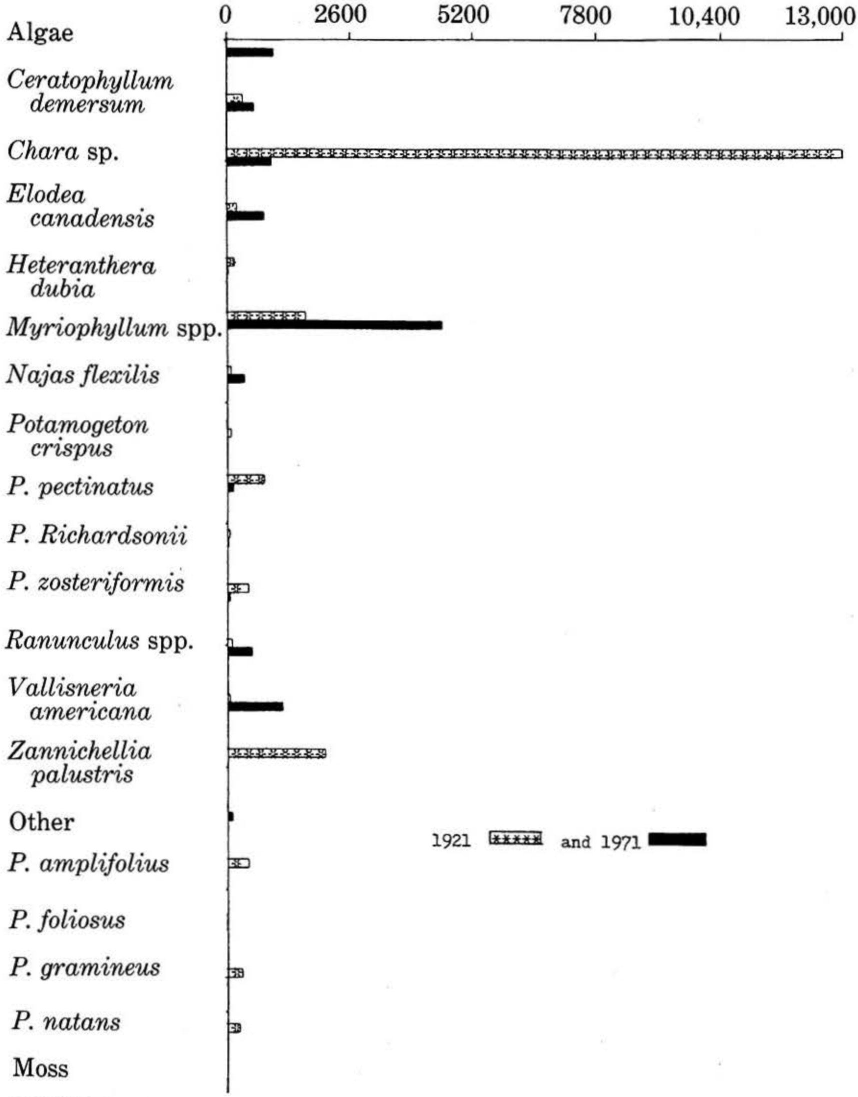

FIGURE 5. Total biomass in grams wet weight collected at zone 2 in 1921 and 1971

from *Chara* sp. to *Myriophyllum* and *Vallisneria* dominance at zone 2 during the 50 year period.

Of the 13 taxa found in zone 3 (Fig. 6) 50 years ago, the wet weights ranged down from 10,815 g. Although 11 of the 13 species

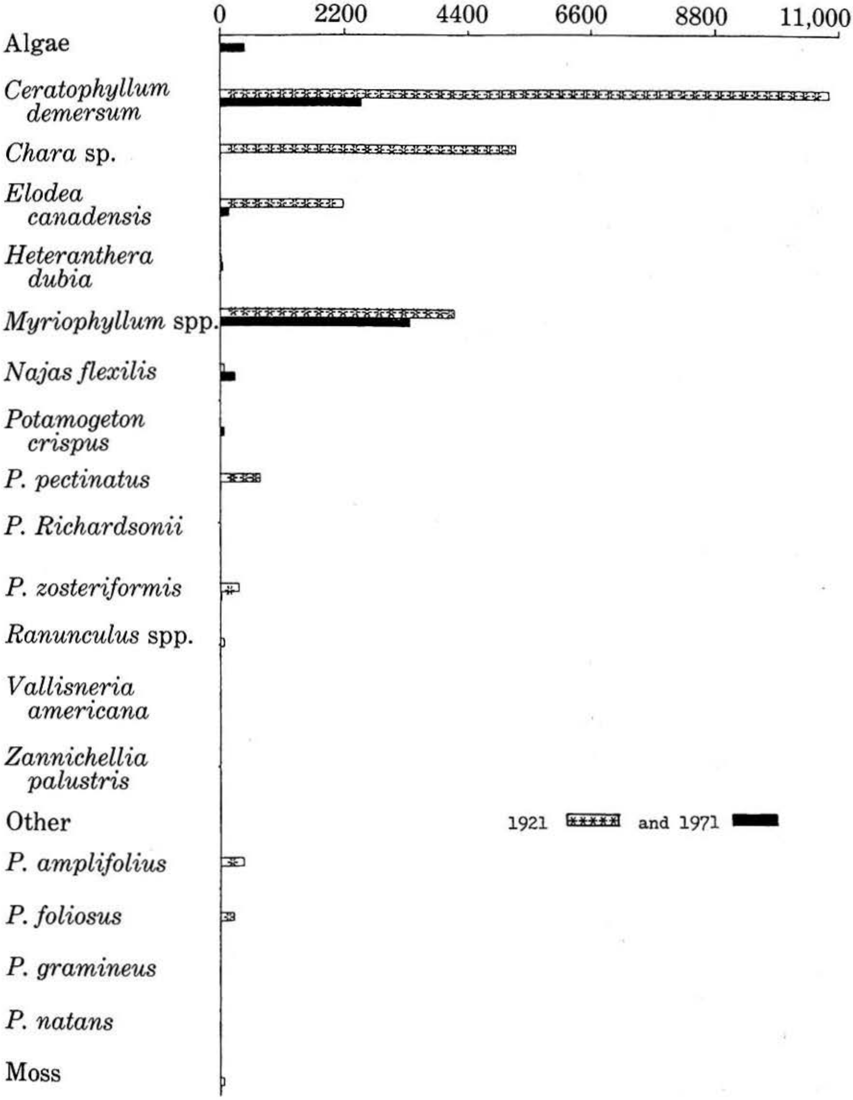

FIGURE 6. Total biomass in grams wet weight collected at zone 3 in 1921 and 1971

were present in 1971, their 3,370 g wet weights showed a reduction of about two-thirds in zone 3 and a shift of dominance from *Ceratophyllum demersum* and *Chara* sp. to *M. spicatum* and *C. demersum.*

The change in the diversity of the macrophytes is not clear because of the four *Potamogeton* species not found in the quadrats in 1971; it cannot be stated, then, that they moved to another zone or that they disappeared from the lake. These include *Potamogeton amplifolius, P. foliosus, P. gramineus* and *P. natans* which were present in all zones in 1921 except for *P. natans* (not reported in zone 3 by Rickett). In 1971, *Zannichellia palustris, Elodea canadensis* and *P. crispus* seem to be newcomers in zone 1; *P. crispus* and a trace of *Lemna trisulca* were observed in zone 2, and in zone 3, *P. crispus* was the only new plant which grew here if the changes in identification of both the *Myriophyllum* genus and the *Ranunculus* genus are agreeable and *P. crispus* was not lumped in with another similar species in 1921.

The total wet weight biomass in zones 1 and 3 diminished percentagewise in almost the same relationship (-73% and -74%), while in zone 2 it decreased the least (-53%). When attached filamentous algae were included, there is a gain in biomass in zone 1 (+16%) but still loss for both zones 2 (-48%) and zone 3 (-72%). The zone 3 figure reflects the relatively low total of algae in the deepest zone, while the zone 1 figure reflects the higher total weights of the algae there (Table 7 of Bumby 1972).

CHANGES IN TOTAL BIOMASS AMONG THE SELECTED STATIONS

Figures 7A, 8A, and 9A represent graphically the wet and dry weights of the submerged macrophytes present in 1921 and 1971 at each station within the separate zones. The station numbers are arranged according to the decreasing values of the total wet weights in g/10 m^2 of the plants tabulated by Rickett in 1921. Figures 7B, 8B and 9B include the wet and dry weights of the attached filamentous algae which were recorded in the 1971 study along with the weight of the macrophytes. These graphs are based on the data in Bumby (1972) Appendices A, B and C. The recent and past situations at these stations are quantitatively presented for the macrophytes and for the biomass of the algae in 1971 (by weight) which can be seen when any station in B is compared with the same station in A.

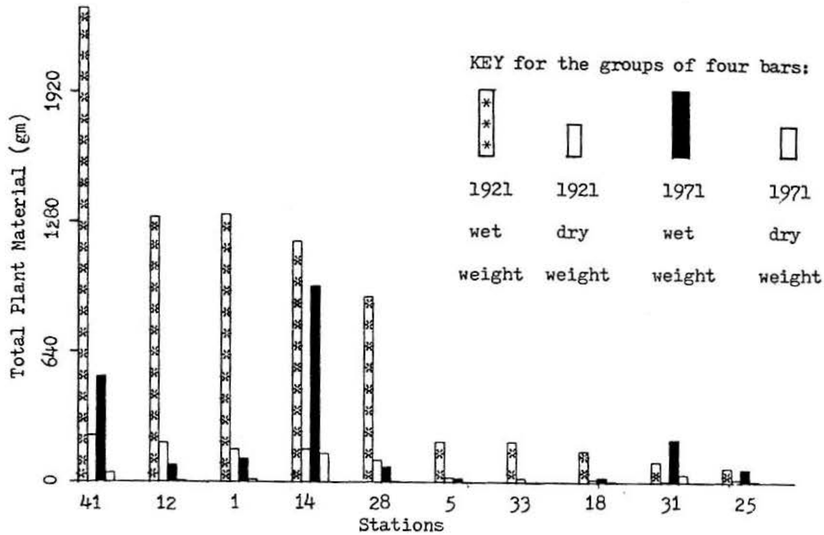

FIGURE 7A. Total macrophytic biomass in grams wet and dry weights collected at the ten stations in zone 1 in 1921 and 1971

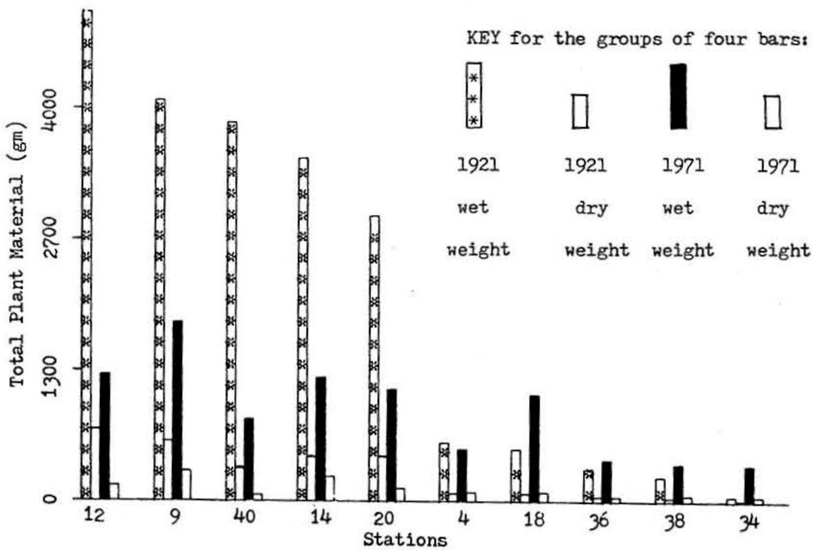

FIGURE 8A. Total macrophytic biomass in grams wet and dry weight collected at the ten stations in zone 2 in 1921 and 1971

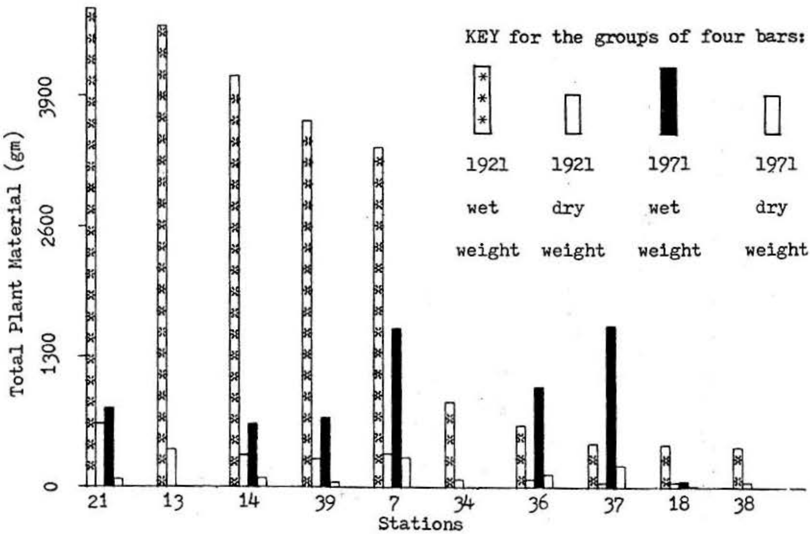

FIGURE 9A. Total macrophytic biomass in grams wet and dry weights collected at the ten stations in zone 3 in 1921 and 1971

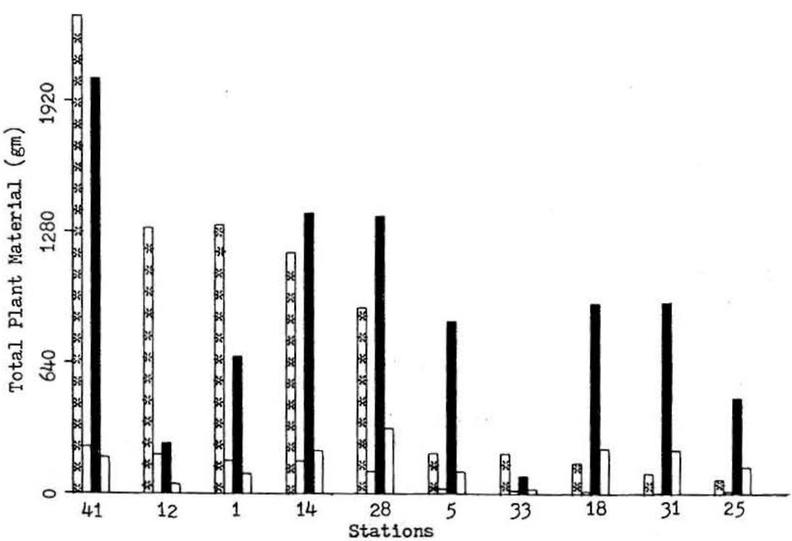

FIGURE 7B. Zone 1 with algae included in 1971 quantities

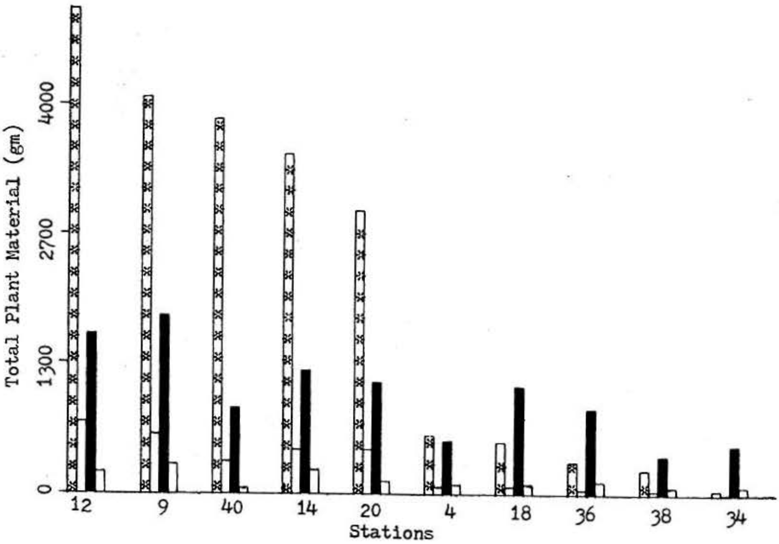

FIGURE 8B. Zone 2 with algae included in 1971 quantities

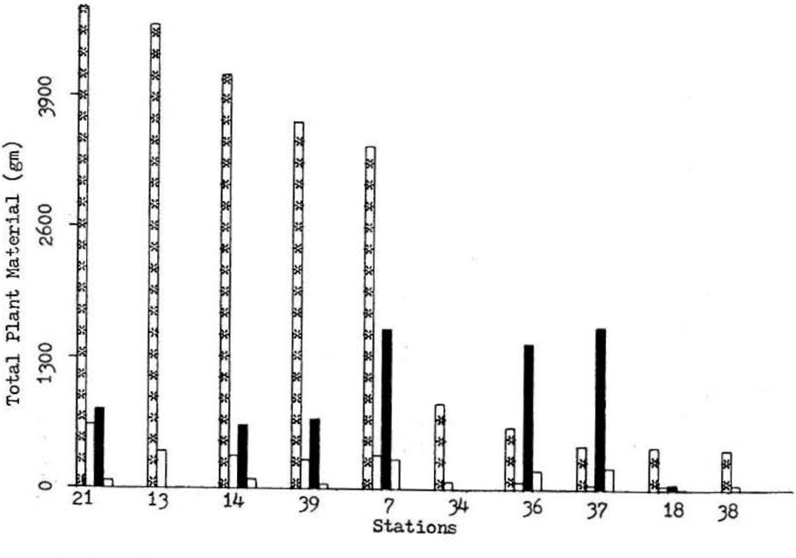

FIGURE 9B. Zone 3 with algae included in 1971 quantities

From these data, it appears that a comparison of the wet weight biomass at the low weight stations at three zones in 1971 and 1921 showed no specific pattern of change; i.e., some stations increased and some decreased. However, the high weight stations at all three zones showed a definite pattern of decrease in the wet weight biomass. The numerical decreases in total macrophyte biomass occurred at all 1921 high weight stations at every depth in the order: zone 1 least, zone 2 next, and zone 3 largest total decrease. At zone 3, stations 34 and 13 were devoid of vegetation and station 38 only had 3.2 g; the first two are located at areas where sewage effluent enters the lake (Fig. 2). This trend continues even when the weight of the attached filamentous algae is included in the biomass. Thus, it appears that the missing nutrients accompanying the reduction in macrophytic biomass have not been entirely incorporated into the attached filamentous algae growing in the littoral zone. This suggests that most of the nutrients may be accounted for in other biota, and the abundance of the phytoplankton (especially blue-green algae) observed in the summer of 1971 seems to corroborate this possibility. Although this work is chiefly on submerged macrophytes, some obervations were made on the plankton in ten water samples collected from three stations different from those used for the macrophytes (see Fig. 1). Many blue-green algae were found on or near the surface waters of the lake in 1971 including *Microcystis aeruginosa*, *Anabaena flos-aquae*, *Aphanizonemon flos-aquae* and *Gloeotrichia echinulata;* these were present in 50% to 70% of the samples. Diversified populations of diatoms, green algae and zooplankton were also present, too. (Bumby 1972).

THE PHYSICAL DATA

Secchi disc readings of Green Lake water taken in this 1971 study and by Lueschow *et al.* (1970) place this water body within the range of eutrophic Great Lakes such as Ontatio and Erie, according to Beeton (1965). However, there seems to be no change in light transmission, since Juday's 1942 study. The clinograde dissolved oxygen curve is well above the minimum levels for life in 1971 and also in the 1966 study by Hasler (1967).

DISCUSSION

Biological evidence, such as the decrease in the biomass of the macrophytes which this study shows, is more indicative of changes in the quality of the water in Green Lake than are the physical data collected in 1971. The 1971 stations devoid of vegetation at zone 3 (stations 34 and 13) and one with only 3.2 g (station 38) could reflect effect of sewage; this situation may be more prevalent in other areas of the lake not included in this study. (Fig. 2). The macrophyte change, the increase in the seston and the assumed but undocumented increase in phytoplankton are probably more indicative of change in light intensity in the littoral area than shown by the light penetration data, obtained only at Deep Station (Fig. 1). Macrophytes are greatly affected by the intensity and quality of light which are determined by turbidity, the color and ". . . the absorptive effect of the water itself" (Reid 1961).

The overall lower biomass, found in 1971 as compared with 1921, could be due in part to the shift in species composition. The magnitude of the decrease of the eight species which declined was simply much greater than the increase of the five species which increased in total biomass (Table 3 of Bumby 1972). The 1921 average percentage of dry weight was not an important difference to cause the lower biomass in this study (Table 1). Other studies have shown little change in the frequency of plants through a summer (Swindale and Curtis 1957), but the weights of the different species of plants can vary during a summer; viz., *Zannichellia palustris* and *Potamogeton crispus* mature early in the summer, while *Vallisneria americana* matures late in the summer. However, the similarity of collection times and techniques between Rickett's and the present study should rule out this problem. Belonger (1969) cited Dane's report of 1959 which showed that over a three year period, there was a definite change in aquatic plant distribution in New York ponds: thus, ". . . Appreciable changes can occur over relatively short periods." Consequently, the fact of analyzing only one summer for the approximations for both the 1921 and 1971 studies cannot be ignored.

Volker and Smith (1965) listed several of these factors pertinent to Green Lake in their study of a decrease in number and frequency of species of aquatic flora in Lake East Okoboji over a 46 year period. Increased human activity in and around its shores altered several factors believed to be responsible for the change. Factors which may be responsible for reduced vegetation are as follows: first, the increased nutrients in the lakes from agricultural fertilizers and increased sewage effluent from the increased population in the area; and, second, the increased siltation and turbidity due to real estate development in low areas, inlet waters and motorboat activity. Sculthorpe (1967) quoted Southgate (1957) that low concentrations of anionic detergents in most treated sewage effluents of that period, can be deleterious to some hydrophytes. Edmondson (1968, p. 165) points out that ". . . even drainage from fertilized fields is less rich than sewage effluent. . ." and that ". . . moderately hard-water lakes are probably more sensitive to sewage enrichment than soft-water lakes, all other things being equal."

The other school of thought is presented by Lind and Cottam (1969) who hypothesize that, because of human activity and natural aging, lakes become rich in nutrients with consequent tremendous increases in algae and macrophytes. This latter view does not explain the 1971 decline in Green Lake macrophytes in all zones and especially in the deepest zone. When the filamentous algae are included, an increase in biomass is evident in the shallow zone as measured in early summer; later, as the water warms, these autotrophs disappear. Perhaps the nutrients no longer in the macrophytes moved into the phytoplankton of the lake in 1971; more quantitative investigations in this area would be helpful.

The decrease in the aquatic macrophytes in Green Lake could be followed by blooms of phytoplankton, according to Mulligan (1969) who cited the 1903 report of Kofoid that algae blooms did not occur in a lake with large growths of benthic plants. Mulligan also wrote of Pond's (1905) observation that floating aquatic macroflora and phytoplankton competed for the same nutrients. Thus, the decrease in biomass of *Chara* sp. and *Ceratophyllum demersum* (both without root systems) could reflect increase in the phytoplankton with their competitive advantage of higher nutrient loading rates. However, other plants with root systems have diminished also, according to this study, so other factors are undoubtedly involved. The decline of *Chara* sp. in Green Lake may have a very significant effect on the lake because Schuette and Adler (1929) pointed out that this alga, which made up about half of the macrophytes found in Rickett's entire study, can cause deposition of almost 1000 metric tons of $CaCO_3$.

In early studies, Marsh (1898) noted there was never any large amount of "vegetable matter" in Green Lake. An *Anabaena* sp. usually appeared over the entire lake in July and August for a short time but was never enough to form a "scum" except in 1896, when an *Anabaena* sp. appeared in late June and lasted into August. Marsh also noted that diatoms were always abundant. Juday (1942) computed that the estimated standing crop of plankton in Green

Lake was 2944 kg/ha wet weight, which was one-third larger than in Lake Mendota. Green Lake is much deeper and the clarity of the summer water permitted the zone of photosynthesis to reach a depth of about 15 m.

From the present study, it appears that additional seston in the water of the littoral zone (originating from the inlet water, sheet runoff from rich farm land and from real estate development in low areas, motorboat activity and probably additional phytoplankton) has changed the penetration of light so that macrophytes, especially in the deepest littoral zone, have been significantly reduced. A change in the dominance of *Chara* sp. may be particularly significant to the total biomass results in 1971. Also, aggressive weedy species of foreign origin, e.g., *Potamogeton crispus* and *Myriophyllum spicatum* which are successful in polluted water, have moved into the aquatic community.

Perhaps Green Lake, so different from Lake Mendota in 1921 (Rickett 1924), is approaching the Mendota status of 50 years ago with *Chara* sp. less important, *Vallisneria americana* increasing in abundance, *Cladophora* sp. becoming dominant in the shallow zone among the autotrophs, and the seston in the water becoming a more important factor.

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