Multivariate analysis of submersed rooted macrophytes of Lake George, N.Y. and their Significance as ecological indicators

Completed by

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FWI #81-8

MULTIVARIATE ANALYSIS OF SUBMERSED ROOTED MACROPHYTES OF LAKE GEORGE, N.Y. AND THEIR SIGNIFICANCE AS ECOLOGICAL INDICATORS

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ABSTRACT

The distribution patterns of 32 species of submersed macrophytes were studied at 50 sites around the periphery of Lake George. Density measurements (plants/m^2) for each species at depths 1,2,3,5,7, and 9 m were converted to biomass estimates (grams dry weight/m^2). These data were then analyzed in terms of 13 different physical, chemical and biological variables to determine the major factors controlling distribution. Factor analysis indicated depth, eutrophication status and allochthonous influences were primary determinants. Three major depth classes were evident from cluster analysis of presence-absence data: shallow-water, deep-water and cosmopolitan. Cluster analysis also identified the co-occurrence of several plant species. Geographical grouping of the 50 sites into the south lake, narrows and north basin demonstrated important compositional trends in species diversity and dominance. The competitional strategies, ecological requirements and species characteristics are discussed.

INTRODUCTION

Submersed rooted macrophyte communities are important components of aquatic ecosystems. For several years we have studied the ecology of these plants in Lake George. Because of its oligotrophic status, high water clarity and lack of "introduced" species, Lake George offers an ideal ecological setting in which to study natural communites of macrophytes. To date 224 native aquatic plant species have been identified in the lake or around its periphery (Ogden, et al., 1976). Emergent macrophytes are relatively rare, being limited to several marshes and the outlet. The major rooted plant producers are the approximately 40 species of submersed macrophytes found in the littoral zone. Their distribution varies greatly and the number of species present at a given depth drops linearly from 38 at 1m to only 1 at 12m

(Sheldon and Boylen, 1977). The current study was undertaken to better understand the ecology and community structure of this diverse group of organisms and to determine in what manner increased human activity in the southern lake has affected the community structure of these plants.

MATERIALS AND METHODS

In 1973-1974 50 sites were randomly chosen around the periphery of the lake at a distance of 2-4 km apart (Fig. 1). At each site an underwater transect approximately 5m wide was made perpendicular to the shore from the shoreline to about 12m deep while diving with SCUBA. Abundance measurements for each species at depths 1,2,3,5,7, and 9 m were recorded underwater by the diver using a numerical scale (Sheldon and Boylen, 1978). Density data were expressed as plants/m^2. The exponential scale encompassed six orders of magnitude and allowed densities from 0.001 plant/m^2 to 5000 plants/m^2 to be scored. Observations were made in the late summer so that density estimates could be multiplied by the average dry weight of mature shoots for each species to produce an estimation of the mature biomass for each species. The statistical analysis of plant communities has been performed on these resultant biomass estimates.

RESULTS AND DISCUSSION

The plants surveyed at the 50 study sites consisted of 27 species of submersed rooted angiosperms, 2 species of submersed ferns and 1 specie of submersed moss and 2 species of macroalgae. For the most part in this study they will be considered together because they occupy similar ecological niches and are often in competition with each other for space, nutrients and light. Site charactertistics were observed for each of the 50 stations and used to analyze the distribution of the submersed plants. These characteristics included sediment type (grain size), slope for the entire station, fetch, detritus composition, geographical location (Narrows, North Basin or South Lake), bay area, developmental index, diatom eutrophication index (Park and Wilkinson, 1971) and allochthonous influences including beach, marsh, stream and cleared land adjacent to the station.

Biomass estimates for each species were analyzed in terms of these variables using Sorenson's similarity coefficient. Cluster analysis identified three major depth classes of plants (Fig. 2) indicated by shaded regions: shallow-water species, deep-water species and cosmopolitan species. The shallow-water and deep-water species appear to have specific light requirements. Shallow-water species requiring high light intensity include Elatina

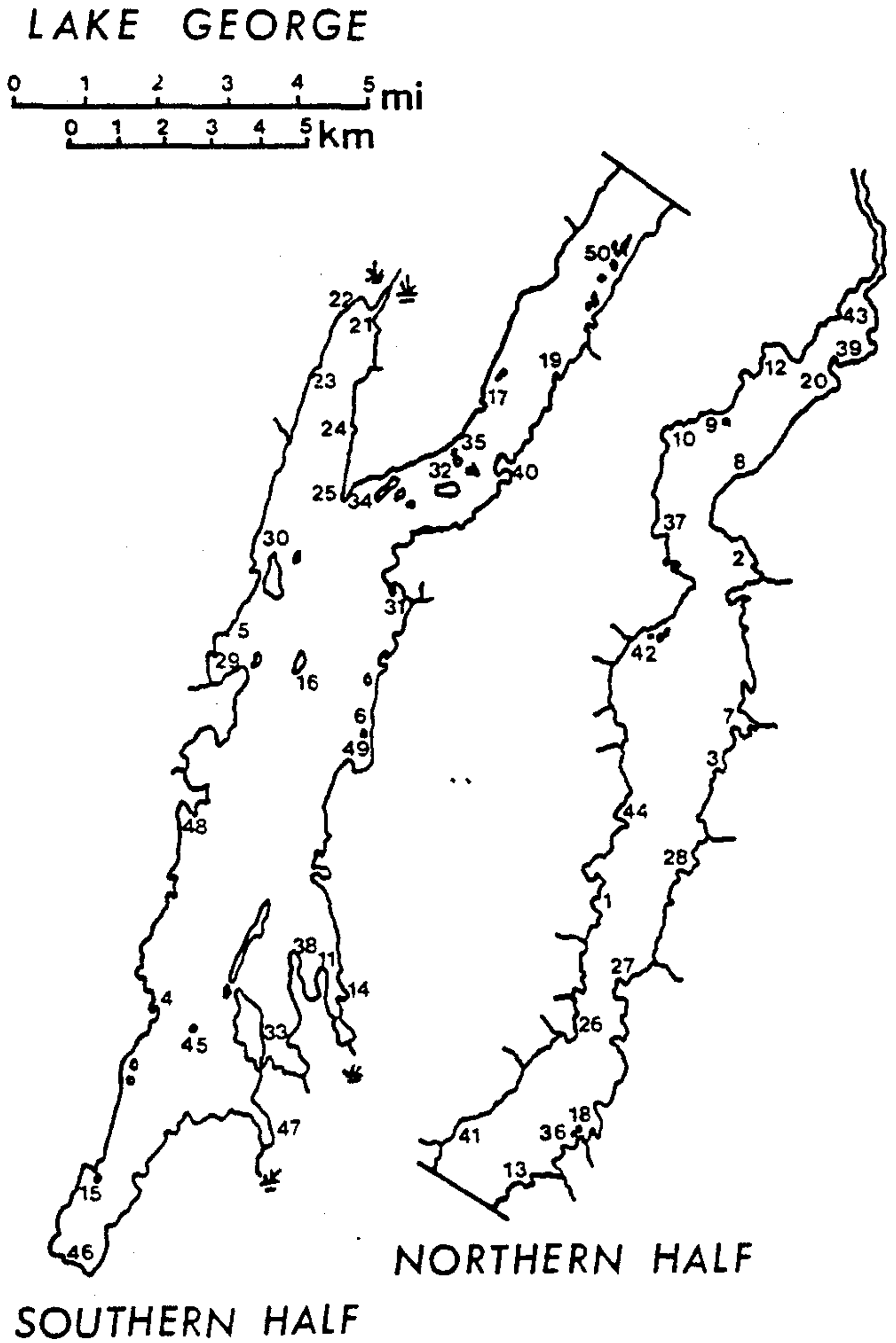

Figure 1. Map of Lake George showing the location of the 50 sampling sites used in the study.

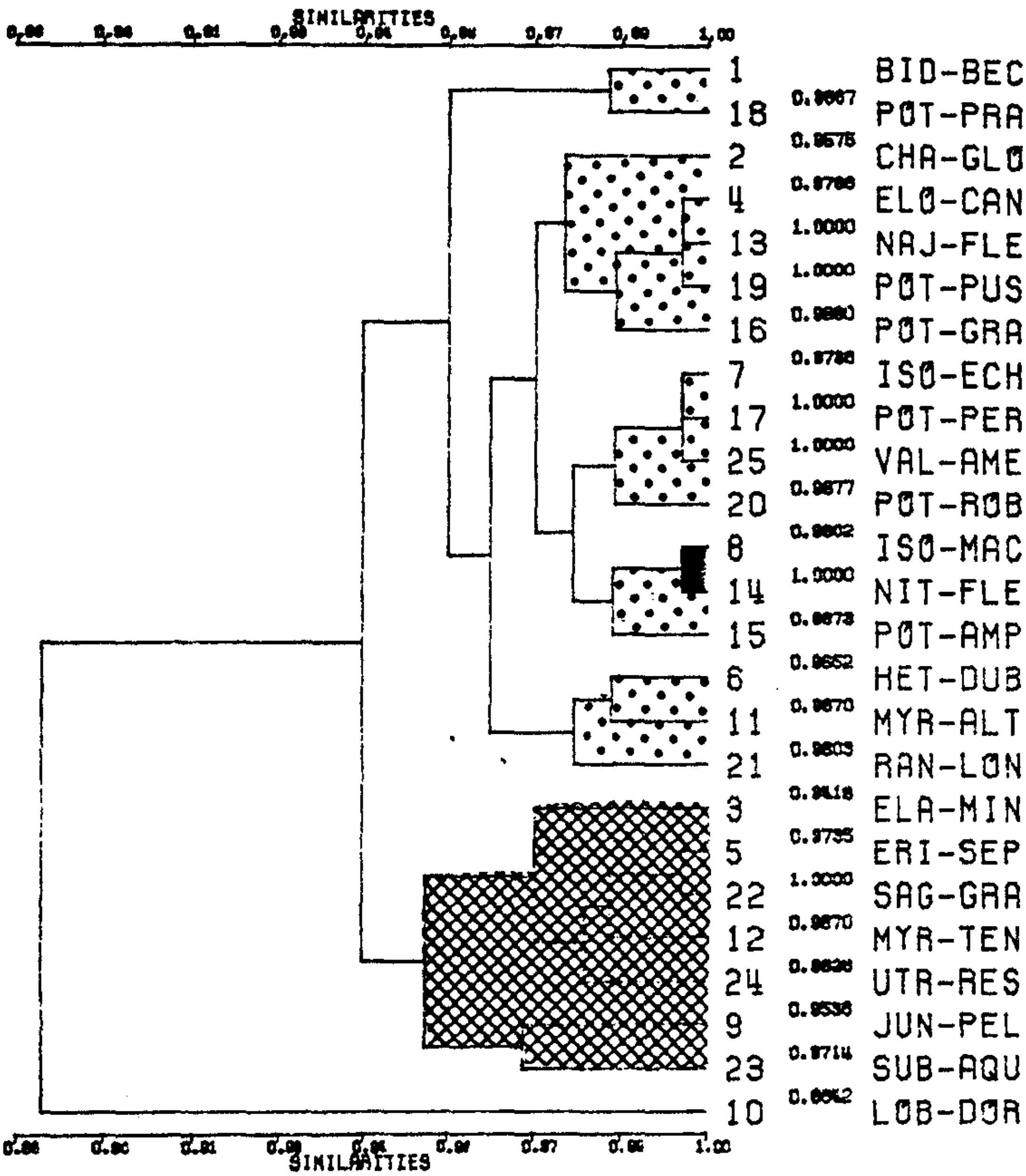

Figure 2. Cluster analysis identifying major depth classes of plants: shallow water species, cosmopolitan species, and deep water species.

minima; Eriocaulon septangulare, Juncus pelocarpus, Lobelia dortmanna, Ranunculus longirostris, Sagittaria graminea and Utricularia resupinata. Shade-tolerant deep-water species include the macroalga Nitella flexilis and the aquatic fern Isoetes macrospora. These species cluster with other cosmopolitan species that prefer deep water such as Isoetes echinospora, Potamogeton robbinsii, Vallisneria americana, Potamogeton perfoliatus, and Potamogeton amplifolius. Cosmopolitan species are numerous and often have a maximum biomass at a particular depth although this depth may change depending on other site characteristics and competition.

The association of plants in lakes have been studied in the classical limnological literature and it has been shown that co-occurrence of species is not random but depends on the co-occurring species having the same general tolerances. A similarity coefficient of 1.0 obtained from applying Sorenson's coefficient to presence-absence data indicated several plant associations. The co-occurrence of Nitella flexilis and I. macrospora in the lake was observed. This community was also recognized by Krause (1969) in several European lakes. Three other communities were observed: 1) E. septangulare - S. graminea, in shallow water; 2) I. echinospora - P. perfoliatus - V. americana in sandy sediments with fine silt cover; and 3) Elodea canadensis - Najas flexilis - Potamogeton pusillus, in regions with high silting rates.

A factor analysis of the biomass data indicated that there are three primary factors controlling plant distribution; depth, nutrient input, and sediment type. Several species dominate where nutrient concentrations are high, these include: V. americana, S. graminea, Bidens beckii, P. amplifolius, and P. robbinsii. When nutrient loadings are low, Potamogeton crispus, I. macrospora, L. dortmanna, and Chara globularis are abundant. The physical texture of substrates is a critical influence on plant distribution. Fine sediments favor growth of S. graminea, U. resuspinata, P. zosteriformis, P. praelongus, E. septangulare, P. amplifolius, and P. pectinatus. H. dubia, Najas flexilis, and V. americana are characteristic of sandy soil. In regions of the lake which are adjacent to a marsh, a characteristics flora is often found which consists of V. americana, P. amplifolius, P. robbinsii, S. graminea, whereas L. dortmanna, and P. crispus are absent. High organic matter loadings from these marshes may directly influence growth as well as affecting light quality.

Lake George is a deep, glaciated lake with 3 geologically distinct regions: the South Lake which extends from Lake George Village to the beginning of Tongue Mountain; the Narrows which extends from the beginning of Tongue Mountain to the Mother Bunch Islands; and the North Basin which extends from the Mother Bunch Islands to the north end of the lake. The area of each region and the area of the depth contours for each region has been determined by Boylen and Kuliopulos (1981). The total biomass (metric tons dry weight) per depth contour for each species was estimated using this information (Fig. 3). Macrophyte biomass expressed as the percent of total biomass (excluding the macroalgae) for each region is given in Table 1. In the North Basin, there are 5 dominant species, included are: P. robbinsii (27% of total biomass), E. septangulare, V. americana, I. macrospora, and P. amplifolius. The contribution of many other species is also significant. The same 5 species also dominate the South Lake; however, P. robbinsii (18% of total biomass) is replaced with V. americana as being the most dominant spp. In the Narrows only 3 species appear as being dominant; E. septangulare, I. macrospora, and P. robbinii.

The macroalgal population of Lake George is of great importance both in terms of biomass and nutrient dynamics. C. golularis which often occurs in glacial, soft water, clear lakes, is significant only in the North Basin where it contributed 4.1% of the total plant biomass. The population of Nitella flexilis is extensive throughout the entire lake and is found from 7 to 12 m in the southern lake and from 7.5 to 13 m in the northern lake (Stross, 1979). In our study, plant communities were surveyed to 10m depth which does not consider the N. flexilis population below this depth. The N. flexilis population up to 10m in the total lake contributes 27% of the total plant biomass. The percentage of N. flexilis is 22.7%, 26.6%, and 29.4% in the North Basin, Narrows and South Lake, respectively. A graphic representation of this macroalgal population with depth is given in Fig. 4. C. globularis extends from 1 to 7m throughout the lake; however, below 7m it is out-competed by N. flexilis.

Species diversity is commonly used to determine tropic status or transitions in lakes. When ecosystems are subjected to changing conditions or stress, shifts occur in the percentage composition of species with a few species emerging as dominant. Systems with low diversity can be recognized as having 1 or 2 species that are dominant followed by rapidly decreasing numbers of other species. It reflects the dynamic processes occurring in the lake such as competition, colonization, extinction, grazing and co-existence.

Using the Shannon-Weaver index, the diversity indices of the North Basin, Narrows, and South Lake were determined to be 3.87, 2.89, and 3.33 respectively. Based upon these calculated values, the 3 regions are considered to be moderately to highly diversified. In natural communities, numerical values of the Shannon-Weaver

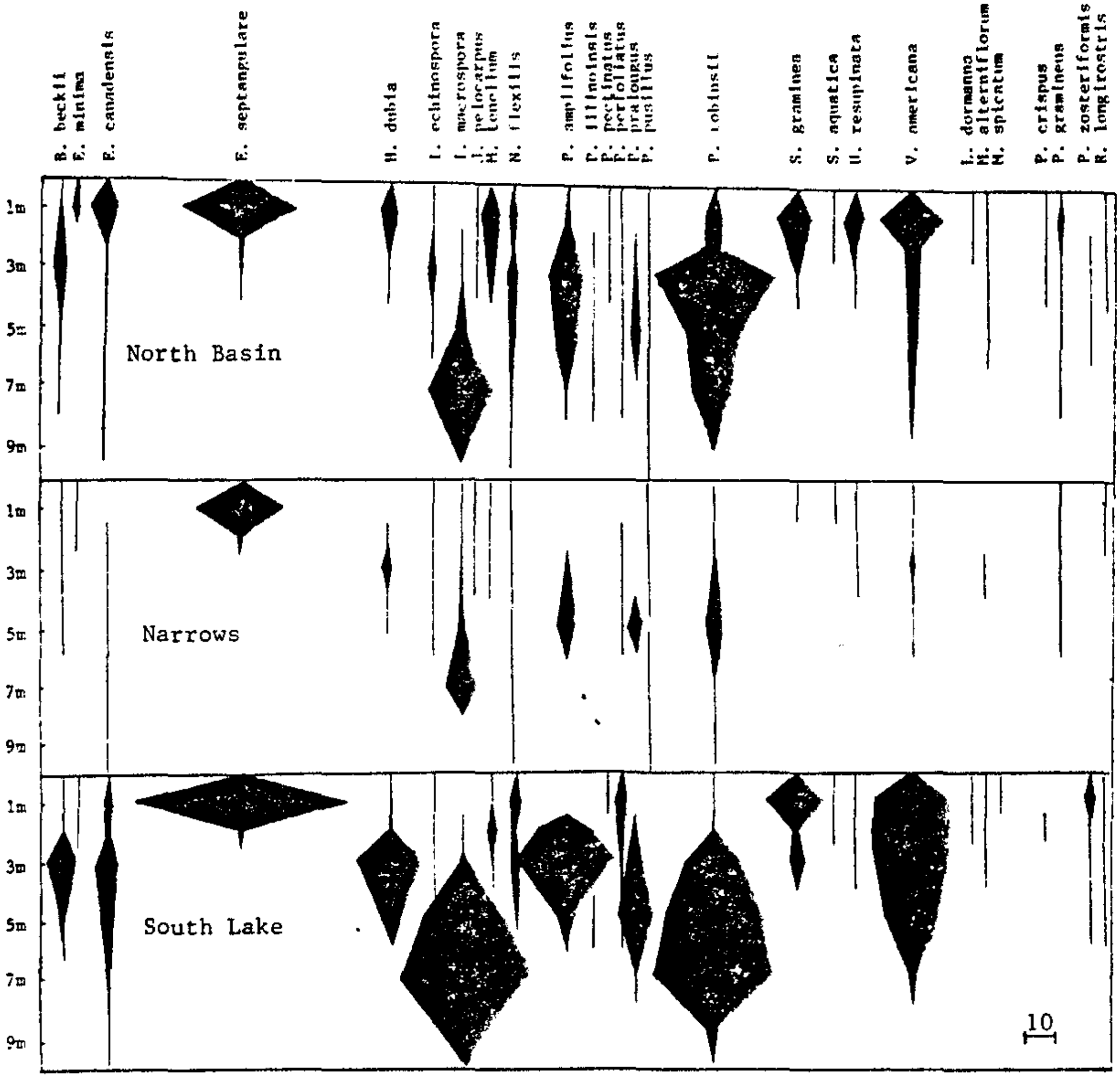

Figure 3. Total rooted biomass estimates for Lake George (Metric tons dry weight).

Table 1

Percent Species Composition Per Basin
(Excluding Macroalgae)

Macrophyte species	North Basin	Narrows	South Lake
Bidens beckii	2.680	0.165	2.155
Elatine minima	0.719	0.090	0.036
Elodea canadensis	3.671	0.218	3.347
Eriocaulon septangulare	12.377	40.441	13.127
Fontinalis-nova-anglae	0.000	0.001	0.000
Heteranthera dubia	2.380	4.103	5.264
Isoetes echinospora	0.332	0.768	0.039
Isoetes macrospora	9.352	16.711	16.175
Juncus pelocarpus	0.115	0.069	0.000
Lobelia dortmanna	0.056	0.000	0.076
Myriophyllum alterniflorum	1.474	1.186	0.213
Myriophyllum spicatum	0.000	0.000	0.006
Myriophyllum tenellum	3.647	0.382	0.379
Najas flexilis	2.831	0.346	1.272
Potamogeton amplifolius	9.260	8.709	10.402
Potamogeton crispus	0.203	0.000	0.013
Potamogeton gramineus	1.163	2.976	1.192
Potamogeton illinoinsis	0.025	0.000	0.004
Potamogeton pectinatus	0.005	0.000	0.151
Potamogeton perfoliatus	1.135	0.316	1.315
Potamogeton praelongus	1.138	6.493	3.495
Potamogeton pusillus	0.510	2.071	0.310
Potamogeton robbinsii	26.644	11.281	16.902
Potamogeton spirillus	0.003	0.000	0.001
Potamogeton zosteriformis	0.025	0.000	0.955
Ranunculus longirostris	0.183	0.002	0.036
Sagittaria graminea	5.196	0.017	4.385
Subularia aquatica	0.015	0.062	0.059
Utricularia resupinata	2.727	0.007	0.129
Vallisneria americana	12.134	3.587	18.563

Table 2

Shannon-Weaver Diversity Index[a]

	Depth					
	1m	2m	3m	5m	7m	9m
North Basin	3.24	3.59	2.67	2.80	2.08	0.32
Narrows	0.35	2.20	2.60	2.96	0.70	0.55
South Lake	2.16	2.40	3.00	2.60	1.73	0.42

[a] $H = -\sum_{i=1}^{s} p_i \log_2 p_i$ where $p_i = \frac{N_i}{N}$

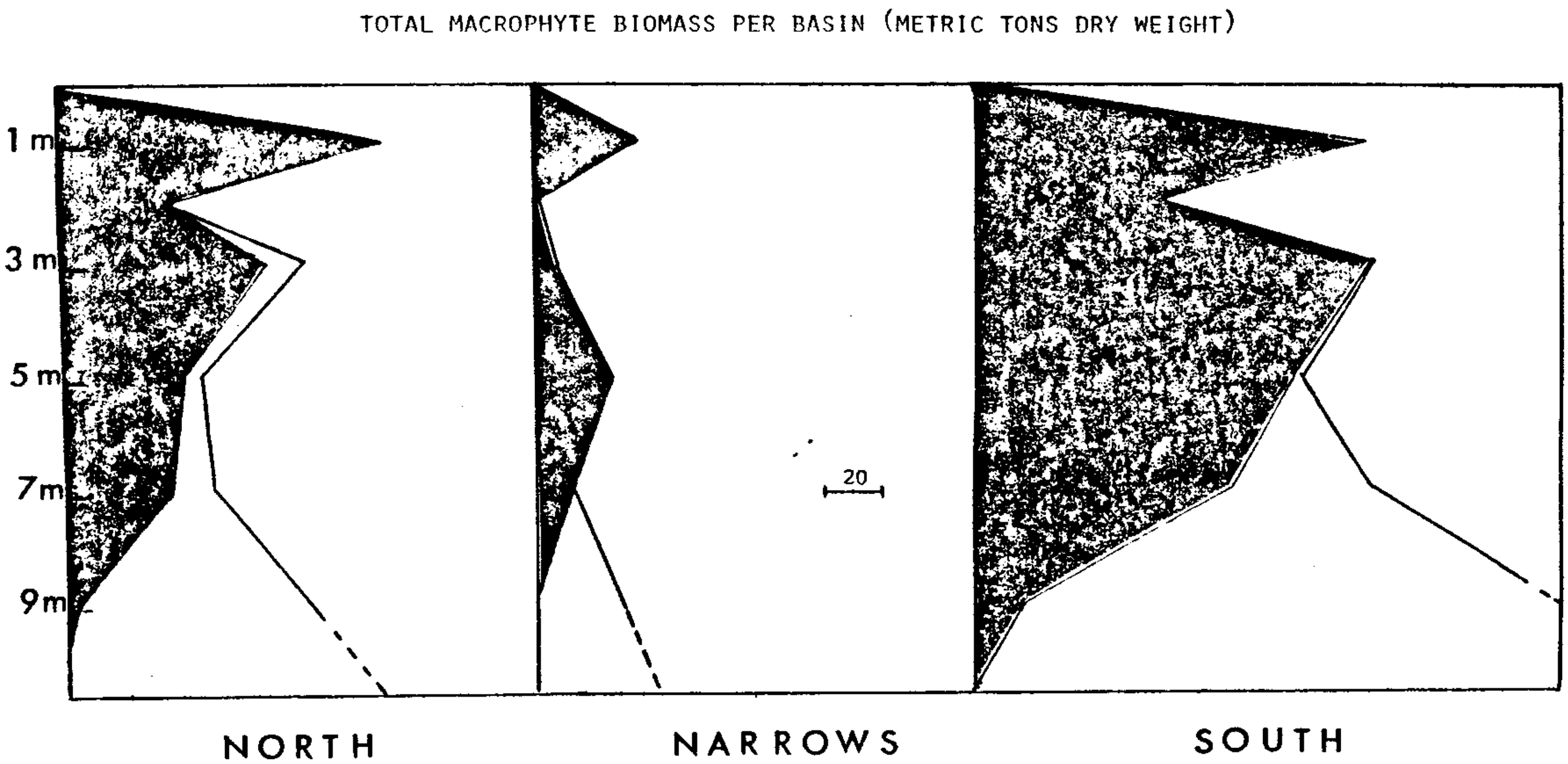

Figure 4. Shaded region represents the total macrophyte biomass excluding the macroalgae. Unshaded region represents the total biomass including macroalgae.

index of diversity rarely exceeds 5 bits per individual. The North Basin and South Lake are similar in diversity and species composition in contrast to the Narrows. The relatively lower diversity of the Narrows can be attributed to its harsh environment. Fast moving currents and little sediment cover permit only a few tolerant species to inhabit the region. E. septangulare, which dominates 30% of the total biomass is a shallow-water species particularly suited for these conditions because of its large root holdfast and ability to obtain nutrients from the water column. In the North Basin and South Lake E. septangulare is less dominant contributing only 13% of the total biomass as a result of higher competition. Shallow waters of these regions have deeper sediment layers and higher nutrient concentrations.

The values given above for "point diversity" disregard the spatial distribution of species. Determination of diversity for each depth contour in a region indicates that species diversity generally decreases with depth (Table 2). In the North Basin, maximum diversity occurs at 2m and at 3m in the South Lake. Nutrient enrichment in the shallower depths (1-2m) in the South Lake may select for only a few dominant species. In contrast, the high wave energy and rocky talus creates a stressful environment in the Narrows excluding almost all species except E. septangulare, which produces 95% of the total biomass at the 1m depth contour. In all 3 regions, diversity is extremely low at 9m where light is limiting to growth..

Disparate sampling and analytical techniques make comparison of freshwater ecosystem productivity difficult. Physical, chemical, and biological factors vary greatly between systems. As a result, species distribution and production are usually unique to the dynamics of a particular system. Spacial and temporal heterogeneity are also important criteria when comparing systems. The average biomass (g dry weight/m^2) can be used to compare the standing crop of ecosystems if one considers these factors. The average seasonal maximum biomass per depth contour for the 3 regions studied are given in Table 3. The seasonal maximum average biomass for all depths are 41.8, 22.5, 45.0 g/m^2 for the North Basin, Narrows, and South Lake, respectively. These biomass estimates can be compared with seasonal maximum biomass values given by Wetzel (1975): 202 g/m^2, Lake Mendota, Wisconsin (hardwater, eutrophic); and 16.8 g/m^2, Weber Lake, Wisconsin (softwater, oligotrophic).

A comparison of the total biomass estimates for each of the 3 regions excluding the macroalgae population, indicates that the South Lake has 1.9 times more biomass than the North Basin and represents 59.6% of the total lake biomass (Table 4). The North Basin is 3.5 times more productive than the Narrows and represents

Table 4

Total Macrophyte Biomass Per Basin
(metric tons dry weight)

Macrophyte Species	North Basin	Narrows	South Lake
Bidens beckii	8.137	0.144	11.976
Chara globularis	17.516	0.030	0.670
Elatine minima	2.184	0.079	0.199
Elodea canadensis	11.148	0.191	18.598
Eriocaulon septangulare	37.585	35.398	72.954
Fontinalis-nova-anglae	0.000	0.001	0.000
Heteranthera dubia	7.226	3.591	29.255
Isoetes echinospora	1.007	0.672	0.214
Isoetes macrospora	28.398	14.627	89.891
Juncus pelocarpus	0.350	0.060	0.000
Lobella dortmanna	0.171	0.000	0.421
Myriophyllum alterniflorum	4.477	1.038	1.182
Myriophyllum spicatum	0.000	0.000	0.033
Myriophyllum tenellum	11.076	0.334	2.108
Najas flexilis	8.597	0.303	7.069
Nitella flexilis	94.346	13.671	232.217
Potamogeton amplifolius	28.119	7.623	57.810
Potamogeton crispus	0.617	0.000	0.073
Potamogeton gramineus	3.533	2.605	6.623
Potamogeton illinoinsis	0.075	0.000	0.023
Potamogeton pectinatus	0.016	0.000	0.837
Potamogeton perfoliatus	3.446	0.277	7.308
Potamogeton praelongus	3.456	5.683	19.421
Potamogeton pusillus	1.549	1.813	1.725
Potamogeton robbinsii	80.911	9.874	93.930
Potamogeton spirillus	0.000	0.000	0.003
Potamogeton zosteriformis	0.077	0.000	5.305
Ranunculus longirostris	0.555	0.002	0.202
Sagittaria graminea	15.778	0.015	24.372
Subularia aquatica	0.046	0.054	0.329
Utricularia resupinata	8.280	0.006	0.717
Vallisneria americana	36.847	3.140	103.165
Total per region	415.530 (31.4%)	119.231 (9.0%)	788.628 (59.6%)
Total per lake	1323.389		
Total per region (excluding macroalgae)	303.669 (32.1%)	87.530 (9.2%)	555.741 (58.7%)
Total per lake (excluding macroalgae)	946.940		

Table 3

Average Macrophyte Biomass Per Depth Contour (g dry weight/m^2)

	Depth					
	1m	2m	3m	5m	7m	9m
North Basin	46.308	30.952	48.759	27.794	38.257	58.658
Narrows	47.449	2.831	11.672	24.957	15.375	33.451
South Lake	45.307	29.794	56.429	28.169	43.933	67.781

31.5% of the total lake biomass. The Narrows is the least productive region as a result of its restrictive environmental conditions, contributing 9.0% of the total regions biomass.

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