1977-04-01

Environmental interaction in summer algal communities of Utah Lake

Mark C. Whiting
Brigham Young University - Provo

ENVIRONMENTAL INTERACTION IN SUMMER ALGAL COMMUNITIES OF UTAH LAKE

A Thesis

Presented to the

Department of Botany and Range Science

Brigham Young University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Mark C. Whiting

April 1977

Environmental Interaction in Summer Algal Communities of Utah Lake[1]

by
Mark C. Whiting
Jack R. Brotherson
Samuel R. Rushforth

Department of Botany and Range Science
Brigham Young University
Provo, Utah

Running head: Utah Lake algal communities

[1]This work was financed in part by the National Science Foundation and Brigham Young University.

Environmental Interaction in Summer Algal Communities of Utah Lake

Abstract

Utah Lake is a shallow eutrophic lake located in central Utah. It is characterized by high nutrient and silt loads and by large algal blooms in late summer and early fall. Phytoplankton samples and environmental data were taken from June through August 1974. Phytoplankton species were identified and then quantified in a Palmer counting cell. Environmental continuum theory was employed to describe algal succession and regression analysis was used to discover interactions between algal communities and the environment. Phytoplankton communities in June were characterized by high species diversity. As the lake environment became stressed in late summer due to higher turbidity, nutrient levels, and pH and decreases in available inorganic carbon, species diversity decreased. By August, the phytoplankton flora was composed essentially of only two species, *Ceratium hirundinella* and *Aphanizomenon flos-aquae*.

Environmental Interaction in Summer Algal Communities in Utah Lake

Utah Lake is a shallow eutrophic lake located in central Utah, U.S.A. (Fig. 1). It is the largest naturally occurring freshwater lake in the state, covering some 388 km^2 (Bolland, 1974). Water from the lake is presently used for irrigation and water regulation as well as for recreational boating and fishing.

In the past, commercial fisheries on Utah Lake have been an important resource for the state of Utah. At the time of settlement the fish population was dominated by a variety of Bonneville cutthroat trout (*Salmo clarki*) which was adapted to the eutrophic conditions of the lake. The trout fishery became vital to the survival of the early Mormon pioneers during the drought and crop failures from 1855 to 1858. However, with water manipulation for agriculture and the introduction of exotic fish species, the trout rapidly became extinct in subsequent years. During the depression years of 1929 through 1939 commercial fishing for introduced species, mainly carp and white bass, became an important industry and food source. Current use of Utah Lake fisheries is minimal and limited to carp, which are used for fish meal.

Utah Lake is characterized by late summer and early fall algal blooms, nutrient enrichment, high silt load and total dissolved solids as well as other environmental stresses. Due to the shallowness of the lake (which averages 2.4 m) fine silt-clay sediments are often stirred up by storms giving the lake water a characteristic grey-green color. The average summer Secchi disk reading is 24 cm with a range of 12 to 50 cm. In addition, the lake basin receives the flow of numerous mineral springs high in carbonates and sulfates.

During late summer when water levels are lowest, the lake approaches a slightly saline ecosystem. According to the U.S. Geological Survey (Hem, 1970), lakes with 1000-3000 mg/liter dissolved solids can be considered to be in this category. Summer values for Utah Lake are in the lower part of this range, from 795-1650 mg/liter dissolved solids.

Previous algal studies of Utah Lake were done by Tanner (1930, 1931), Snow (1932), Harding (1970, 1971) and Bolland (1974). Tanner's pioneering works listed several of the algae prominent in the lake. Both Harding and Snow did taxonomic studies dealing with littoral and planktonic algae. Bolland's work dealt with the fossil diatom flora in the lake sediments. Bolland's research indicates that the diatom flora has not changed greatly since presettlement times.

Data for this study were gathered during the summer of 1974. There had been no previous quantitative study of the extant planktonic flora. The study resulted in a floristic paper (Rushforth, *et al.*, in press) as well as estimates of productivity and a description of the seasonal succession of summer algal species in Utah Lake to be reported herein.

Methods

Phytoplankton samples and environmental data were collected from June to August 1974. Samples were taken along three transects at 9 day intervals throughout the study period. The transects (Fig. 1) included 14 sample sites permanently marked with bouys. Transects were chosen to cross three major portions of the lake, each with possible differences in ecological conditions. The Geneva transect crossed the northern part of the lake from the outfall of the settling ponds of Geneva Works of the United States Steel Corporation to the western shore. The mid-lake transect ran west from the Provo Boat Harbor (near the mouth of the Provo River) to the west shore. The southern transect crossed Goshen Bay from Lincoln Beach to the west shore. The Geneva and Boat Harbor transects included five sampling sites while the shorter Goshen transect had four sampling sites.

Phytoplankton samples were collected by pouring known volumes of lake water through a 67 µm mesh plankton net. Algae were washed from the net, collected in 30 ml vials and immediately preserved in formalin acetic acid (FAA). The vials were later subsampled in the laboratory and individual algae were counted in Palmer counting cells (Palmer and Maloney, 1954) at 400X magnification using Zeiss RA research microscopes. Individual algae encountered were identified to the species level. An "individual" for filamentous or colonial forms was considered to be a single filament or colony. Tallies were made for each species as well as the total number of individuals per subsample. The density of organisms in the original lake water was calculated using multiplication factors determined by the volume of filtered lake water. At least 400 individuals were counted in each sample in order to reduce sample variance (Clark, 1956).

Selected water chemistry tests were performed in the field using a Hach DR/EL - 2 Direct Reading Engineers Lab. Tests for dissolved oxygen, free carbon dioxide, pH and Jackson Turbidity readings were performed. In addition, a YSI conductivity meter was used to measure salinity, conductivity and water temperature. Secchi disk readings and general meteorological conditions were also recorded.

Further water chemistry tests were performed in the laboratory. Water samples were collected in opaque Nalgene bottles from approximately 25 cm below the water surface and were refrigerated until analysed. Laboratory analyses included total alkalinity, carbonate alkalinity, total hardness, calcium hardness, magnesium hardness, nitrate, orthophosphate, sulfate and silica. All tests were performed within 24 hours of collection using standard methods (Taras, 1971).

Changes in phytoplankton populations through the summer were evaluated using the continuum methods of Curtis and McIntosh (1950, 1951). Continuum theory is an approach to vegetation and its response to environmental gradients. Continuum study involves the calculation of an index number for each sample which places that sample at some point along an environmental gradient. The index number is considered to reflect the effects of the total environment on a sample expressed in terms of the species composition and their relative abundance. To demonstrate succession, the gradient herein is generated as a time continuum.

To generate the continuum index numbers used in this study, the average density (in numbers of organisms/liter) for each species was calculated for all sites on each sample date. Adaptation numbers were then assigned to each algal species according to which date the species was more than twice as abundant as at any other time. There was one exception, Ceratium hirundinella, which showed two peaks in abundance, with the highest peak not twice as great as the other. Thus, this species was assigned an adaptation number according to when it was most abundant. The adaptation numbers ranged from 1 to 8, corresponding to eight sample dates beginning on June 13, 1974 and ending August 15, 1974. The adaptation numbers for all species present in any one sample were then summed and averaged. The average adaptation number (continuum index number) for a sample corresponds to the point at which it belongs on the time continuum. Sample index values ranged from 1.58 to 7.00. No sample was found to contain all early summer species or all late summer species.

All sample index values were plotted along a number line from 1 to 8, representing the time continuum. The continuum was then divided into six "natural" groups of approximately equal length utilizing naturally occurring breaks as near as possible. The six divisions of the continuum allowed averages of environmental and biotic parameters to be calculated for each unit and plotted to show successional trends along the continuum. The parameters plotted included eight major algal species, nine significant environmental parameters, environmental variation (heterogeneity), community variation and species diversity.

Environmental variation was measured by constructing a similarity index matrix based on environmental data for division of the continuum and then by calculating a coefficient of variation from the matrix index values (Gilmartin, 1974). All data values were adjusted to range from one to ten in order to avoid overweighting some parameters because of their large numerical values.

Community variation was measured as above except the data utilized were taken from the relative densities of the species present. In this instance, community variation is considered to be a measure of the evenness of the contribution each species makes to a sample.

Species diversity was calculated using the Shanon-Wiener formula, as follows:

$$D = -\Sigma p_i \log p_i$$

The term p_i refers to the portion of the sample that each species contributes. The Shanon-Wiener formula expresses diversity in terms of the number of species present as well as the evenness of the contribution that each species makes to the total sample.

The response of individual species to single environmental parameters was assessed using linear regression analysis. Those species with similar significant responses ($\alpha = 0.01$) to the same environmental parameters were grouped together into communities.

Results

A total of 107 phyotplankton samples were taken along with corresponding environmental data. Ninety-five species were identified and ranked by importance values (average relative density X average % presence). The six most important species and their importance values were: *Ceratium hirundinella* (3303); *Aphanizomenon flos-aquae* (1725); *Melosira granulata* (1255); *Microcystis protocystis*

(252); Anabaena spiroides (249); and Anabaena flos-aquae (154) (Fig. 2).

The early summer flora can be characterized by low standing crop (an average of 11,260 organisms/liter in June and σ = 25,700) and by rich species diversity. The June communities were dominated by several species of green algae including Ankyra judayi, Schroederia setigeria, Treubaria triappendiculata, Dictyosphaerium ehrenbergii, Pediastrum duplex and three varieties of Ankistrodesmus falcatus. Associated with these chlorophytes were the blue-greens Anabaena flos-aquae and Microcystis protocystis, the diatom Melosira granulata and the dinoflagellate Ceratium hirundinella.

By early July, the green algae as a group began to decline in importance and were displaced by Melosira granulata, Ceratium hirundinella and Aphanizomenon flos-aquae (Fig. 3). King (1970) and others have indicated that the green algae tend to require free CO_2 for maximum growth and are poor competitors for bicarbonate. Our evidence seems to corroborate this conclusion. Free CO_2 in Utah Lake declined to levels that were undetectable with Hach chemistry (Fig. 4) at the same time the green algae decreased in importance. July standing crop averaged 329,425 organisms/liter (σ = 291,410), almost 30 times the June average.

August phytoplankton communities were much reduced in species diversity, often consisting only of two species; Ceratium hirundinella and Aphanizomenon flos-aquae. These two taxa were usually 10-50 times more abundant than any other species. The decline in other species, especially Melosira granulata, might be attributed to any of a number of factors, such as decrease in availability of inorganic carbon, higher turbidity, higher salinity, or inter-specific competition. The average estimate of August standing crop was 5,405,226 organisms/liter (σ = 15,719,846), almost 16 times the average for July and nearly 500 times the average for June (Table 1).

Biomass estimations for any given day showed large variation from one sample site to the next. This disjunct distribution was probably due to currents and possibly patchiness of the environment. George and Edwards (1973) have shown that zooplankton distribution is strongly correlated with Langmuir circulations. They demonstrated that *Daphnia* tend to aggregate in upwellings between foam lines. Presumably, phytoplankton may also be oriented on relation to Langmuir currents. Floating objects, such as blue-green algae with gas vacuoles, should aggregate in the foam lines. Other algae with well developed powers of locomotion might aggregate between foam lines as do zooplankton.

Analysis of phytoplankton using the Curtis continuum is summarized in Fig. 3. The six species with the highest importance values are plotted against the continuum. *Ankyra judayi* and "epizooites" (two unidentified species of Chrysophyta found on copepods) were also plotted. Although not very important overall, they were included because of their importance in the early summer. Generally, the continuum data indicate similar trends to those already described. The early summer phytoplankton consisted of a diverse group of diatioms, green and blue-green algae. Although present from the beginning of the study, *Aphanizomenon*, *Ceratium* and *Melosira* did not become abundant until July. Melosira showed its maximum growth around mid July. Aphanizomenon and Ceratium continued to become more abundant until the end of the study in August when they made up approximately 90% of the total flora.

Analysis of environmental parameters using the Curtis continuum is summarized in Fig. 4. Generally, the lake became a more stressful system as the season progressed. Availability of inorganic carbon for photosynthesis decreased through the summer. Temperature and pH increases were slight. Water transparency decreased dramatically in early July and decreased more slowly till the end of the study. Phosphates and nitrates showed maximums in late July then decreased slightly in August.

Environmental stresses on the phytoplankton in the late summer had the effect of reducing biological and environmental diversity. Fig. 5 summarizes diversity trends along the time continuum. Environmental variation decreased through the summer, essentially reducing the number of niches available to organisms. Species diversity (measured by the Shanon-Wiener index) and community variation (the evenness of the contribution made by each species) also decreased through the summer. The last point on the community variation curve is much higher than the overall trend, due to the fact that in August the algal communities were composed of approximately equal contributions of Ceratium and/or Aphanizomenon which normally comprised over 90% of the algae in a given sample.

Simple regression analyis of individual species plotted against environmental gradients shows several significant relationships

(Table 2). Species showing the same significant trends were grouped in species "clusters". The first two clusters are essentially early summer species and are predominately green and blue-green algae. As expected, they generally correlate with environmental parameters that predominate in the early summer, such as high light penetration, free CO_2 and low water temperatures. Apahanizomenon and Ceratium correlate with environmental parameters that were prevalent in the latter part of the season (i.e. high turbidity, high salinity, high phosphates, basic pH and higher temperatures). As mentioned previously, increase in temperature through the season was slight and therefore is probably not a causal relationship even though the correlation with Aphanizomenon and Ceratium was significant.

Discussion

Communities seldom appear as discrete units. In many cases closely allied communities intergrade one with another both in time and space and often exhibit no distinct boundaries between them. This is especially true of aquatic systems and in instances of biological succession. Therefore, the continuum theory as used in this paper is especially useful in the description of the algal communities of Utah Lake. The Curtis continuum has been traditionally used to describe the response of terrestrial vegetation to environmental gradients. However, the principle is just as applicable to aquatic systems where the species involved are mobile and succession is seasonal.

The Curtis Continuum is also especially useful in environments that are highly fluid as in the case of planktonic systems. Thus, we have noted in Utah Lake that certain geographical regions maintain early summer floras for more extended periods of time due to local environmental conditions which approximate earlier seasonal conditions. This was noted particularly in the Provo Boat Harbor and Goshen Bay where spring and river influences are prominant.

Summer phytoplankton communities in Utah Lake are marked by decreases in diversity of the flora as the system becomes more stressed and/or uniform. The phytoplankton of June are a diverse assortment of species representing several algal divisions. Chlorophyta are important and are mainly associated with Cyanophyta and diatoms. The July phytoplankton are still a diverse group, but are predominately *Melosira granulata*, two species of *Anabaena* and *Ceratium hirundinella*. The reduction of species diversity to an almost exclusive *Aphanizomenon-Ceratium* community by August is probably due to competition (especially for reduced sources of inorganic carbon for photosysthesis), release of allelopathic substances by *Aphanizomenon* (Palmer, 1962) and reduction of environmental niches due to decreased variability in the environment.

Silica depletion has been implicated as a factor that is often important in determining succession from diatom dominated communities to blue-greens (Lund, 1965). However, this is not the case in Utah Lake, where silica levels are very high (an average of 19.4 mg/liter for the summer and even higher in August).

Water temperature has been shown to be very important in influencing succession from diatom dominated to blue-green dominated floras (Patrick, 1969). Apparently, this is not the case in Utah Lake. Water temperature is relatively constant throughout the study period and is highest in July when Melosira (the dominant diatom) is most abundant.

King (1970) has shown that under conditions of low alkalinity and high pH alage may be carbon limited. Blue-green algae seem to be most tolerant to these conditions and Chlorophyta seems to be most sensitive. In Utah Lake, there was a continuing decrease in available inorganic carbon (Fig. 6). The disappearance of most chlorophytes corresponds with the period of greatest decrease in carbon availability. In August, when most of the remaining algal species were displaced by Aphanizomenon and Ceratium, carbon stress was most severe. Many samples had a pH of 8.5 or more and carbonate alkalinity near 20 mg/liter. King's data (1970) indicate that these conditions are marginal for growth of assorted blue-greens used in his cultures. From this information, carbon limitation is probably an important factor in determining the composition of the summer phytoplankton communities in Utah Lake.

It is important to note that August communities in the Lake were dominated by Aphanizomenon flos-aquae and Ceratium hirundinella which comprised between 89 and 100% of the total algae standing crop. These communities were often composed of only Aphanizomenon or Ceratium exclusively. We believe this is strong evidence that competitive exclusion is an important factor in regulating the late summer communities of Utah Lake.

References cited

Bolland, Robert F. 1974. Paleoecological interpretation of the diatom succession in recent sediments of Utah Lake, Utah. Unpublished Ph.D. dissertation, University of Utah, Salt Lake City.

Clark, William J. 1956. An evaluation of methods of concentrating and counting phytoplankton of Bear Lake, Utah-Idaho. Unpublished M.S. thesis, Utah State University, Logan.

Curtis, J. T. and R. P. McIntosh. 1950. The inter-relations of certain analytic and synthetic phytosociological characters. Ecology 31:434-455.

______________. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology 32:476-496.

George, D. G. and R. W. Edwards. 1973. Daphnia distributions with Langmuir circulations. Limnology and Oceanography 18:789-800.

Gilmartin, Amy Jean. 1974. Variation within populations and classification. Taxon 23(4):523-536.

Hem, J. D. 1970. Study and interpretation of the chemical characteristics of natural waters. Second edition. Geological Survey Water Supply Paper 1473, U. S. Government Printing Office, Washington, D. C.

Harding, William J. 1970. A preliminary report on the algal species presently found in Utah Lake. Great Basin Naturalist 30(2):99-105.

______________. 1971. The algae of Utah Lake, Part 2. Great Basin Naturalist 31(3): 125-134.

King, D. L. 1970. The role of carbon in eutrophication. Journal of Water Pollution Control Federation 42(12): 2035-2051.

Lund, J. W. G. 1965. The ecology of the freshwater phytoplankton. Biological Review 40:231-293.

Palmer, C. Mervin and Thomas E. Maloney. 1954. A new counting slide for nannoplankton. American Society of Limnology and Oceanography Special Publication 21.

Palmer. C. Mervin. 1962. Algae in water supplies. U. S. Department of Health, Education and Welfare, Amer. Pub. Health Service Pub. 657.

Patrick, Ruth, Bowman Crum and John Coles. 1969. Temperature and manganese as determining factors in the presence of diatom or blue-green floras in streams. Proc. Nat. Acad. of Sci. 64 (2): 472-478.

Snow, Edna. 1932. A preliminary report on the algae of Utah Lake. Proc. Utah Acad. Sci. 9:21-28.

Tanner, Vasco M. 1930. Fresh water biological studies at Utah Lake. Proc. Utah Acad. of Sci. 7:60-61.

_______________. 1931. Fresh water studies at Utah Lake. Part 2. Utah Acad. Sci. 8:199-203.

Taras, Michael J., Arnold E. Greenberg, R. D. Hoak and M. C. Rand. Editors. 1971. Standard methods for the examination of water and waste water. Thirteenth edition. Amer. Pub. Health Service Pub.

Rushforth, Samuel R., Larry L. St.Clair, Mark C. Whiting and Thomas A. Leslie. In press. The algae of Utah Lake. Great Basin

Naturalist.

Date	Mean number of organisms per liter
June 4	13,758
June 13	2,230
June 21	20,754
July 3	52,251
July 10	416,128
July 18	541,128
July 27	344,968
Aug. 7	724,061
Aug. 15	10,866,586

Table 1. Mean standing crop estimates of Utah Lake algae in the summer of 1974 according to collection date.

	Correlations	
Species Clusters	Positive	Negative
Ankistrodesmus falcatus var. mirabilis Ankistrodesmus falcatus var. stipatus Dinobryon divergens Merismopedia glauca Holopedium irregulare Treubaria triappendiculata	Light penetration Free CO_2	Dissolved O_2 Conductivity Total alkalinity SiO_2
Anabaena flos-aquae Ankyra judayi Epizooites Microcystis incerta Pediastrum duplex Chlamydomonas globosa	Total alkalinity Calcium hardness	Water temperature Total hardness
Carteria stellifera Scenedesmus quadracauda	Total hardness	Nitrates Magnesium hardness
Aphanizomenon flos-aquae Ceratium hirundinella	Turbidity Salinity Phosphates pH Water temperature	

Table 2. Species correlation patterns with respect to environmental parameters as analysed by regression analysis. Species with similar responses are grouped. All correlations listed are at the 0.01 significance level.

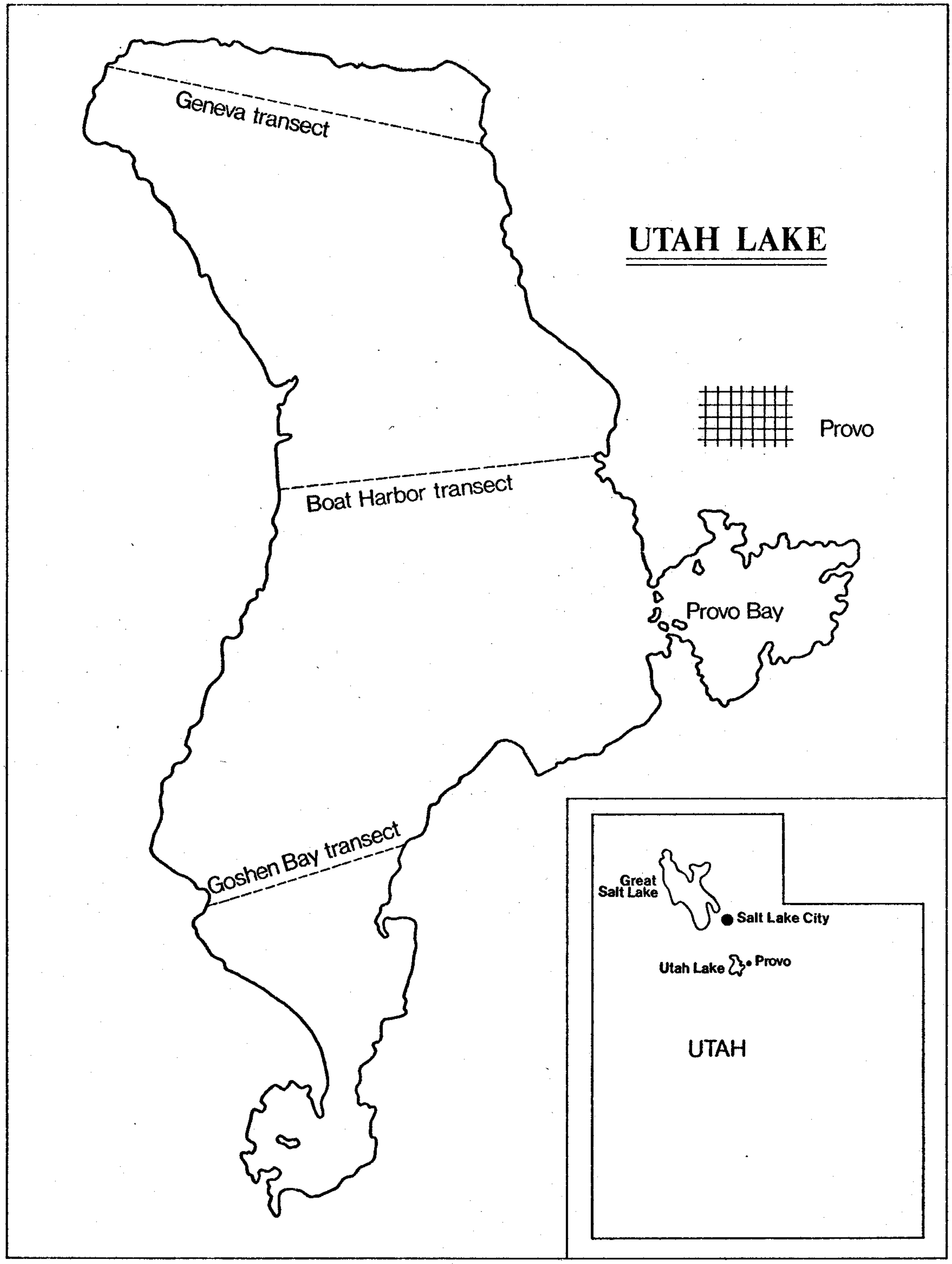

UTAH LAKE
Geneva transect
Boat Harbor transect
Goshen Bay transect
Provo
Provo Bay
Great Salt Lake
Salt Lake City
Utah Lake
Provo
UTAH

Fig. 1. Utah Lake, showing geographical position with respect to the state of Utah, Provo, and the Great Salt Lake.

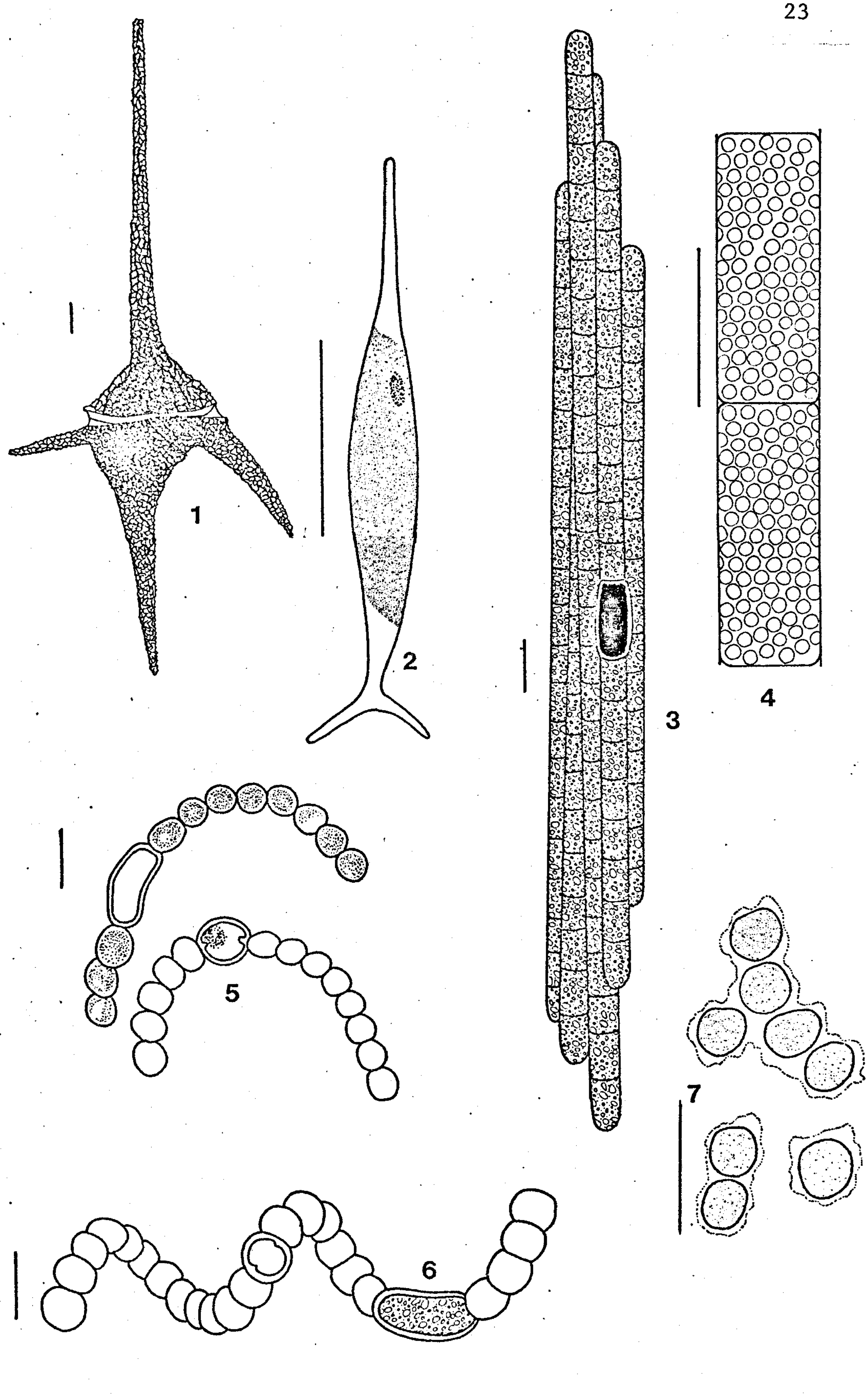
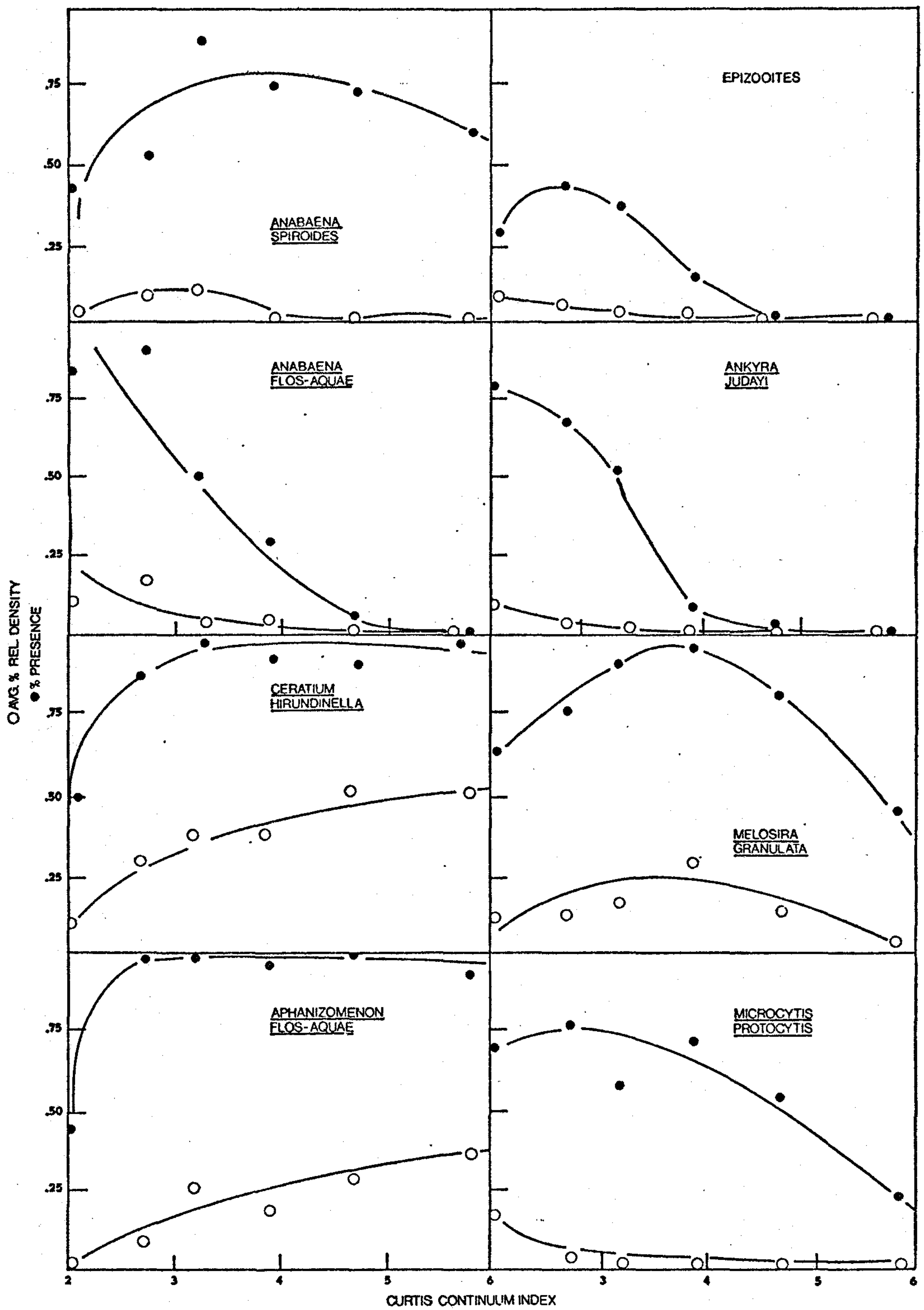

1
2
3
4
5
6
7

Fig. 2. Dominant phytoplankton species in the Summer Utah Lake flora. 1, *Ceratium hirundinella*; 2, *Ankyra judayi*; 3, *Aphanizomenon flos-aquae*; 4, *Melosira granulata*; 5, *Anabaena flos-aquae*; 6, *Anabaena spiroides*; 7, *Microcystis protocystis*. Each scale equals 10 μm.



EPIZOOITES
ANABAENA SPIROIDES
ANABAENA FLOS-AQUAE
ANKYRA JUDAYI
CERATIUM HIRUNDINELLA
MELOSIRA GRANULATA
APHANIZOMENON FLOS-AQUAE
MICROCYTIS PROTOCYTIS
○ AVG. % REL DENSITY
● % PRESENCE
.75
.50
.25
2
3
4
5
6
CURTIS CONTINUUM INDEX

Fig. 3. Relative density and % presence of common algal species in the Utah Lake summer 1974 flora plotted on the Curtis continuum index.

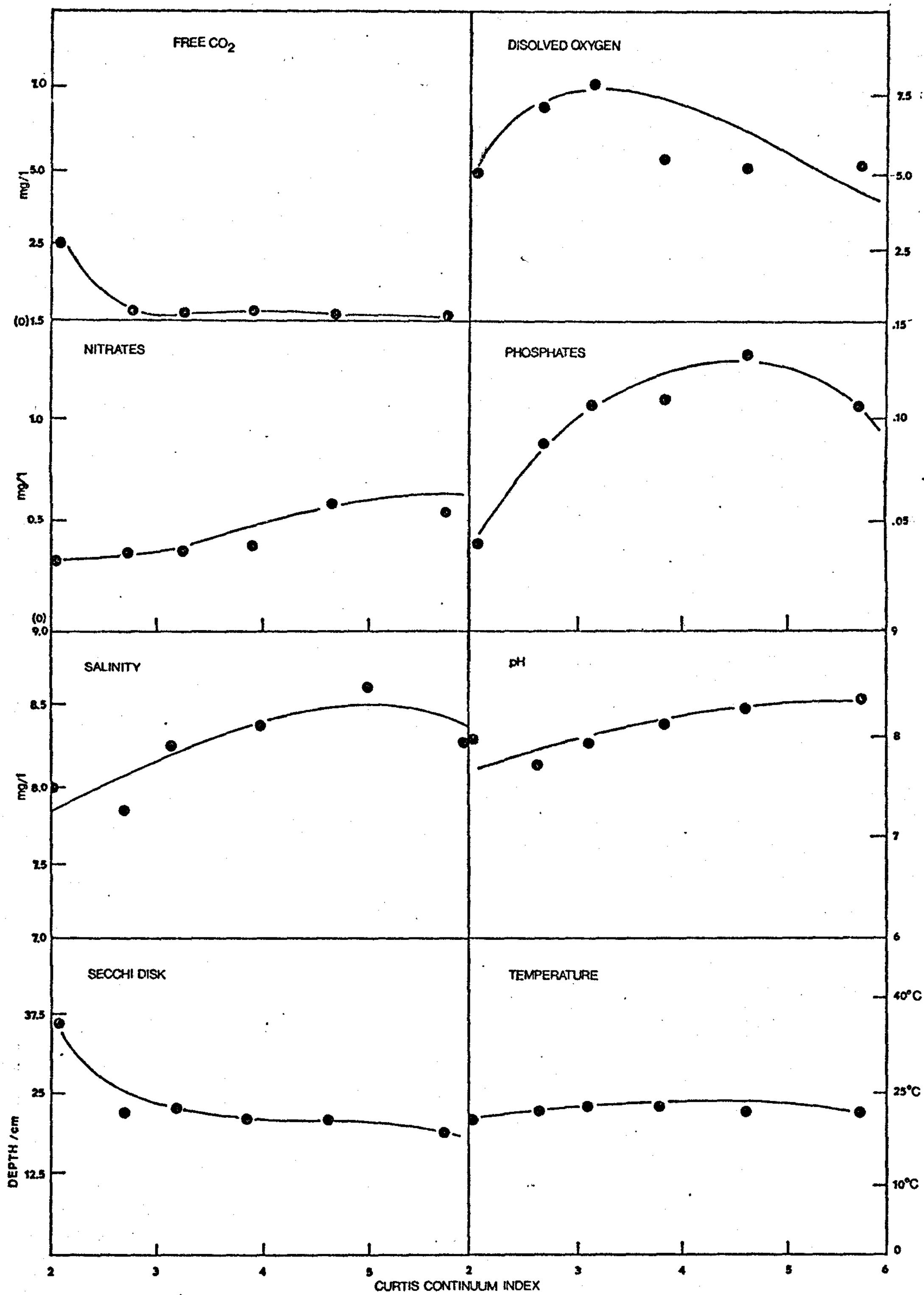
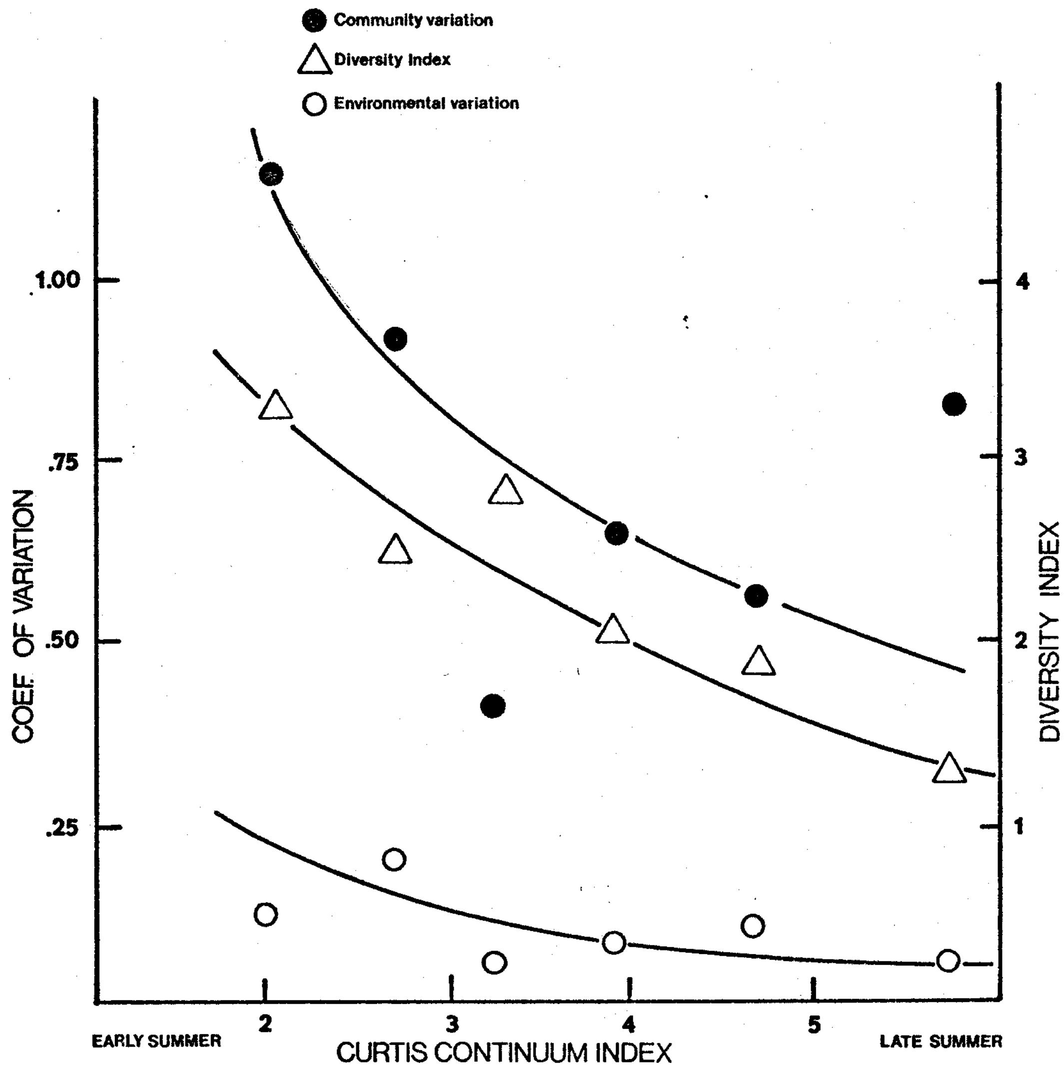

FREE CO_2
DISOLVED OXYGEN
NITRATES
PHOSPHATES
SALINITY
pH
SECCHI DISK
TEMPERATURE
mg/1
DEPTH /cm
CURTIS CONTINUUM INDEX
7.0
5.0
2.5
(0)1.5
7.5
.15
1.0
0.5
(0)
.10
.05
9.0
8.5
8.0
7.5
9
8
7
6
37.5
25
12.5
40°C
25°C
10°C
0
2
3
4
5
6

Fig. 4. Selected environmental gradients in Utah Lake in the summer of 1974 plotted on the Curtis continuum index.



Community variation
Diversity index
Environmental variation
1.00
.75
.50
.25
COEF. OF VARIATION
4
3
2
1
DIVERSITY INDEX
EARLY SUMMER
2
3
4
5
LATE SUMMER
CURTIS CONTINUUM INDEX

Fig. 5. Trends in species diversity, community variation, and environmental variation in Utah Lake in the summer of 1974 plotted on the Curtis continuum index.

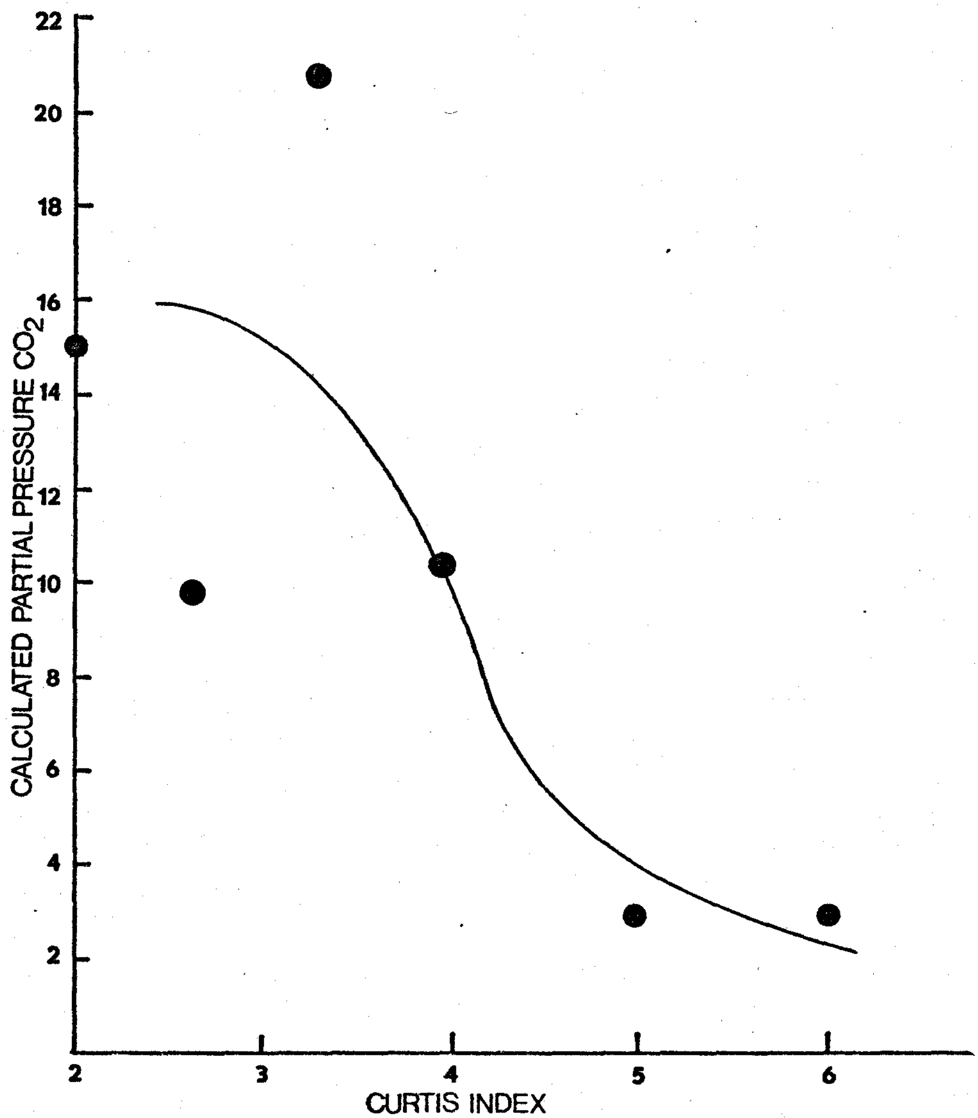

22
20
18
16
14
12
10
8
6
4
2
CALCULATED PARTIAL PRESSURE CO_2
2
3
4
5
6
CURTIS INDEX

Fig. 6. Partial pressure of CO_2 in Utah Lake in the summer of 1974 calculated from disassociation constants plotted on the Curtis continuum index.

ENVIRONMENTAL INTERACTION IN SUMMER

ALGAL COMMUNITIES OF UTAH LAKE

Mark C. Whiting

Department of Botany

M.S. Degree, April 1977

ABSTRACT

Utah Lake is a shallow eutrophic lake located in central Utah; it is characterized by high nutrient and silt loads and by large algal blooms in late summer and early fall. Phytoplankton samples and environmental data were taken from June through August 1974. Phytoplankton species were identified and then quantified in a Palmer counting cell. Environmental continuum theory was employed to describe algal succession and regression analysis was used to discover interactions between algal communities and the environment. Phytoplankton communities in June were characterized by high species diversity. As the lake environment became stressed in late summer due to higher turbidity, nutrient levels, and pH and decreases in available inorganic carbon species diversity decreased. By August, the phytoplankton flora was composed essentially of only two species, *Ceratium hirundinella* and *Aphanizomenon flos-aquae*.

COMMITTEE APPROVAL: