ALGAL COMMUNITY STRUCTURE IN ARTIFICIAL PONDS SUBJECTED TO CONTINUOUS ORGANIC ENRICHMENT

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PREFACE

Nine artificial ponds which received one of three treatment diets of pelleted fish food were sampled weekly in a study of the relationship of nutrient concentration to phytoplankton community structure. Variations in nutrient concentration and algal communities were examined with reference to population size and species diversity.

T. C. Dorris was major adviser, and R. W. Jones, R. J. Miller, W. A. Drew and C. G. Beames served on the advisory committee. G. R. Marzolf provided laboratory facilities and considerable assistance, and the Department of Pathology, Parasitology and Public Health, Kansas State University, provided additional laboratory equipment. R. H. Thompson verified algal identifications. Ernest Hilderbrand wrote several programs and operated the computer. The kind assistance of these people is appreciated.

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CHAPTER I

INTRODUCTION

Mechanisms of seasonal succession in algal communities have been studied with reference to many different types of lakes and ponds (Pearsall, 1932; Hutchinson, 1944). In most studies, attempts were made to correlate temperature, light and nutrient variations with changes in the composition and size of algal communities. It was recognized early that nitrate and phosphate are of importance as major nutrient sources for growing algal populations (Pearsall, 1932; Chu, 1943). As the nitrogen-fixing ability of certain blue-green algae was demonstrated, ammonia concentration was included among chemical parameters examined (Dugdale and Dugdale, 1962).

Nutrient and algal community interrelationships are of particular interest in systems which are enriched regularly (Margalef, 1963) or intermittently (Pratt, 1949; Edmondson, et al., 1956; Buljan, 1957), for this influence is basically similar to certain types of pollution. Analysis and understanding of moderately enriched ecosystems must antedate comprehension of effects of massive organic pollution on aquatic systems.

A number of approaches to the study of community composition are possible, including examination of the number of species present and their districtuion among major groups, as well as of patterns of total populations. Quantitative approaches have been developed relating number of species to size of sampling area (Gleason, 1922). More recently, both number of species and total number of individuals have been considered in calculating indices expressing diversity of the community (Fisher, et al., 1943; Williams, 1947; Preston, 1948; Yount, 1956; Williams, 1964). Perhaps the most useful index proposed is based upon the distribution of individuals among species (Margalef, 1958; Patten, 1962; MacArthur, 1965). This index has been used in the present study to evaluate changes which occurred in algal community structure with varying chemical conditions.

It was thought that the relationships among nutrient variables and community composition might be studied advantageously in a partially controlled environment. The nine artificial ponds described in this paper constituted such a situation with the additional advantage that replication of different environments was possible. In this framework one may recognize variations which develop in a supposedly controlled system and which may be subjected to statistical analysis.

The object of this study was to describe and analyze the interrelationships between nutrients and algal community composition in organically enriched artificial ponds. Three regimes of enrichment, each replicated in three ponds, were studied. Variations in total populations of algae and patterns of species diversity were described, and these changes were related to fluctuations in nutrient concentration and zooplankton populations.

All nutrients which have been demonstrated previously to influence algal communities (Fogg, 1965; Lund, 1965) could not be included;

however, an investigation limited to the major nutrients seems justified for as J. W. G. Lund (1965) has said:

> Every experimental approach is open to criticism, but without experiments little progress can be made. It is common sense to test hypotheses from different angles. The differences of opinion...and the frequent absence of any concrete conclusions, are not quite so unsatisfactory as they may seem at first sight, for they represent such testing.

CHAPTER II

DESCRIPTION OF THE AREA

Nine 0.14-acre artificial ponds (Fig. 1) located 0.5 mi. south of Tuttle Creek Reservoir, Pottowatomie County, Kansas, were sampled. These ponds are uniformly rectangular, approximately 0.76 m deep at one end and 1.37 m at the other. In April, 1965, each excavation was lined with black polyethylene and was filled with water pumped from a nearby lagoon which received outfall from Tuttle Creek Reservoir. The axis of all ponds is NE-SW and all are unshaded except for Pond 27 which is shaded in the early morning.

In late April, 950 fingerling channel catfish, average weight 2.32 gm, were placed in each pond for a feeding and growth experiment. Pelleted fish feed weighing 4% of the average total weight of the fish in each pond (determined biweekly) was scattered in the ponds 6 days each week. Treatment diets Z-4, Z-5, and Z-7 (Table I) were applied to three ponds each.

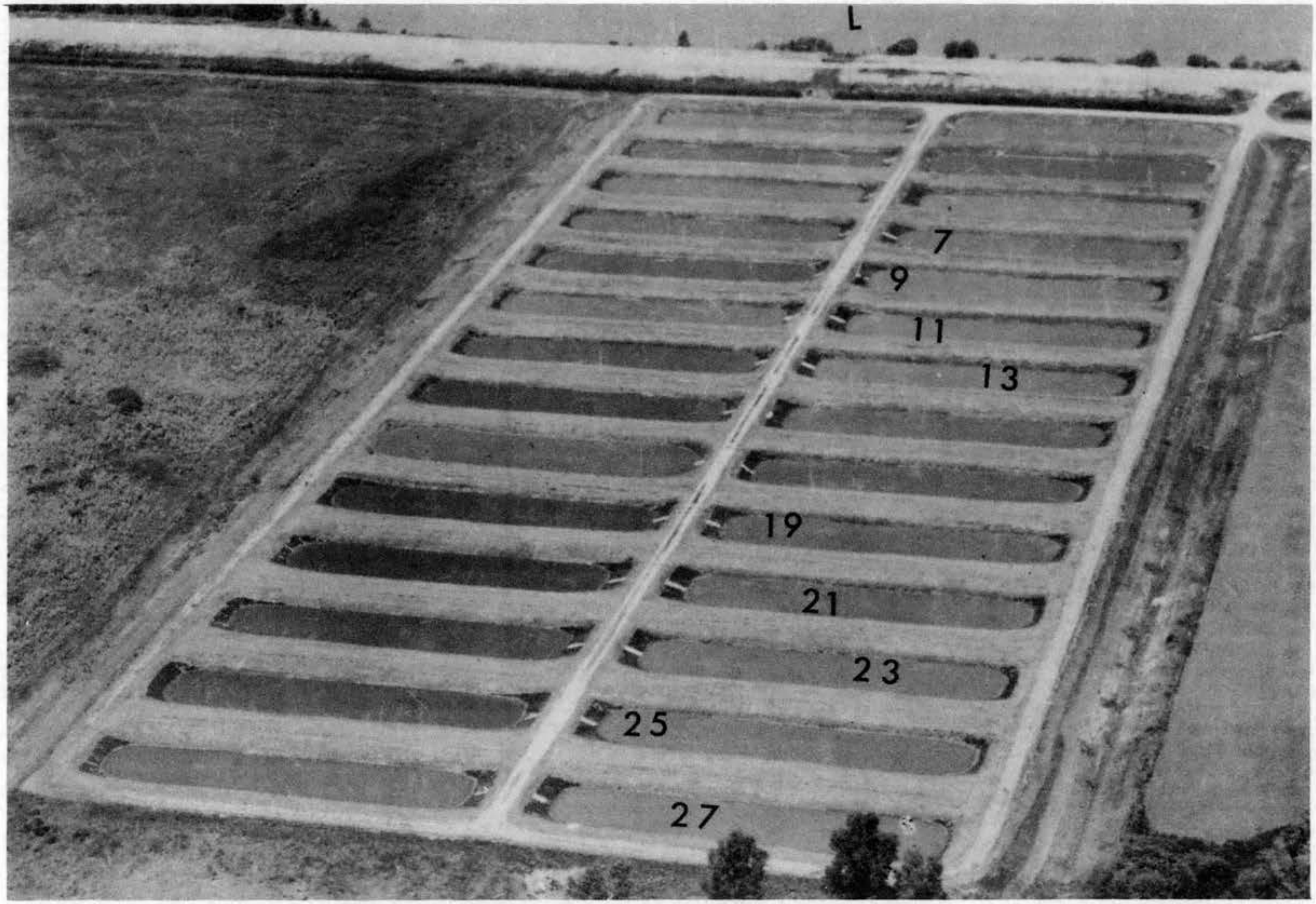

Fig. 1. Aerial Photograph of Ponds and Lagoon (L)

TABLE I

COMPOSITION OF TREATMENT DIETS AND DISTRIBUTION OF TREATMENTS AMONG PONDS

	Treatment Z-4	Treatment Z-5	Treatment Z-7
Recipient Ponds	9, 23, 25	7, 19, 27	11, 13, 21
% Protein	25	25	30
No. Calories per lb. of Food	850	950	1020
Average No. Calories per Day per Pond	1274	1424	1529

Composition of Treatment Diets

Soybean oil meal
Dehydrated alfalfa meal
Ground sorghum grain
Wheat bran
Fish meal
Meat and bone scraps
Blood meal
Distiller's dried solubles
Dicalcium phosphate
Salt
Vitamin B complex
Vitamin B-12
Aurofac-10
d-1 methionine
*Limestone
**Vegetable fat
**Wheat shorts
**Wheat mill feed

*Not in Z-4 or Z-7

**Not in Z-4 or Z-5

CHAPTER III

METHODS

Each of the nine ponds and the lagoon which furnished water for the ponds were sampled at weekly intervals from 23 May to 28 August, 1965. Water samples for duplicate chemical analyses were filtered through a 0.45 u Millipore filter. Total alkalinity and pH were determined according to standard methods (A.P.H.A., 1960). Orthophosphate was determined by the stannous chloride method and nitrite by the sulfanilic acid method (A.P.H.A., 1960). Nitrate was measured by the method of Mullin and Riley (1955) and ammonia using the sodium-phenoxide-sodium hypochlorite method (Riley, 1953; Crowther and Large, 1956). Water temperature was measured.

For plankton counts, four one-liter samples were taken from each of the ponds and one one-liter sample from the lagoon with the Kemmerer sampler. Two samples were taken just beneath the water surface and two at the 0.7 m depth at opposite ends of the ponds. Samples were preserved with Lugol's acetic acid solution and the plankton allowed to settle to the bottom of the bottle (Wright, 1964). One-ml portions of the sediment were examined with an inverted microscope, and phytoplankters were identified and counted at 430X (Lund, et al., 1958). Number of individuals, i.e., physical units such as trichomes, colonies, unicells, representing each species were determined. Twenty

Whipple-disc fields in each of three portions and ten fields in one portion were counted for each of the four samples. This procedure permits detection of a 10% change in total algal population with 80% confidence (Cochran, 1963). The zooplankters encountered in four one-ml portions of the sediment of each sample were identified and counted.

Species diversity indices were calculated from pooled counts of all algae in the four samples from each pond for each date. $\bar{H}$, an expression of species diversity in bits per individual, and R, redundancy, or the expression of the extent to which one or more species dominate a collection, were determined according to the equations derived by Patten (1962).

Primary productivity and community respiration were determined by the light-dark bottle method (Strickland, 1960). Bottles were incubated from sunrise to sunset 12 cm beneath the surface of the ponds. Determinations were made for ponds receiving Z-4, 18 June; Z-5, 19 June; and Z-7, 1 July, 1965.

Correlations among chemical parameters, between chemical parameters and total algal populations, between chemical parameters and species diversity indices and between $\bar{H}$ and P/R ratio for each pond were calculated. An analysis of variance (hierarchical design) was made to determine whether a statistically significant difference existed among treatment means, pond means, and date means for each of the chemical variables (Simpson, et al., 1960). Determinations of least significant differences between means were made for each of these parameters in comparing treatments Z-4 and Z-5 and treatments Z-4 and Z-7 (Steel and Torrie, 1960). The two-tailed sign test was employed to test whether the diversity and redundancy of surface phytoplankton samples differed from those of depth samples (Siegel, 1956).

CHAPTER IV

RESULTS AND DISCUSSION

Physical and Chemical Conditions

Water temperature never varied more than 1°C. among the ponds on any sampling date. Range in temperature (measured in early morning) was from 20°C. in May to 27°C. in late August (Table II). The pH ranged from 7.7 in Pond 27 on 24 August to 8.9 in Pond 21 on 2 August (Table III), a range of values in which most algae may flourish (Ruttner, 1963; Lund, 1965). Total alkalinity ranged from 97 to 170 ppm (Table IV). In general, levels were high in late May, decreased throughout July and increased to previous levels in August in all ponds as well as in the lagoon.

Orthophosphate concentration ranged from 0 to 0.64 mg/liter and, in general, increased throughout the summer (Fig. 2). Phosphorus was continually added in the diet treatments (0.3% phosphorus by weight in each pond). There was no significant difference (0.05 level) between means for any two treatments not between means for any two ponds. Fertilization experiments using isotopes of phosphorus indicate that up to 95% of the phosphorus added to a lake may be removed immediately from solution and taken up and stored by biotic components, especially bacteria (Rigler, 1956). However, in these ponds phosphorus apparently was not removed in this fashion.

TABLE II

WATER TEMPERATURE °C.

	Treatment Pond	Z-4			Z-5			Z-7			Lagoon
		9	23	25	7	19	27	11	13	21	
Date											
18 May 1965		21	21	22	21	21	21	21	21	21	21
25		20	21	20	21	20	21	20	20	21	22
3 June		24	24	24	24	25	25	24	24	24	23
9		22	23	23	23	23	23	23	23	23	23
16		21	22	22	21	22	22	21	21	22	21
24		22	23	23	22	23	23	22	22	23	23
1 July		24	24	24	24	24	24	24	24	24	24
7		26	26	27	26	26	26	26	26	26	26
13		25	25	25	25	25	25	25	25	25	25
22		25	26	26	26	25	26	25	25	26	25
28		27	27	27	27	27	27	27	27	27	25
2 August		25	25	25	25	25	25	25	25	25	24
10		24	24	24	24	24	24	24	24	24	24
17		24	24	24	24	24	24	24	24	24	25
24		26	26	26	26	26	26	26	26	26	26

TABLE III

pH VALUES

Treatment Pond	Z-4			Z-5			Z-7			Lagoon
	9	23	25	7	19	27	11	13	21	
Date										
18 May 1965	8.3	8.4	8.3	8.5	8.3	8.3	8.3	8.3	8.3	8.5
25	8.0	8.1	8.2	8.2	8.3	8.2	8.2	8.3	8.2	8.3
3 June	8.2	8.0	8.6	8.2	8.4	8.5	8.2	8.5	8.5	8.5
9	8.2	7.8	7.9	7.9	8.4	8.2	8.1	8.2	8.3	8.1
16	8.0	8.8	8.0	7.8	8.4	8.1	8.1	8.1	8.6	8.2
24	7.9	8.4	7.9	7.8	8.0	8.1	8.0	8.3	8.2	8.0
1 July	8.1	8.0	7.9	8.0	8.1	7.8	7.9	8.5	8.0	8.1
7	8.6	8.2	8.0	8.6	8.3	7.9	8.3	8.4	8.5	8.3
13	7.8	8.2	7.9	7.9	8.1	8.0	8.0	8.0	8.2	---
22	8.1	8.4	8.1	7.9	8.4	8.0	7.9	8.2	8.2	7.9
28	8.6	8.3	8.1	8.3	8.5	8.0	8.4	8.3	8.9	8.1
2 August	8.5	8.2	8.4	8.4	8.8	8.4	8.1	8.3	9.0	8.3
10	7.9	8.0	7.9	8.2	8.2	8.0	8.1	7.8	8.6	8.1
17	8.0	7.8	7.8	8.4	8.3	7.8	7.9	7.9	8.8	8.2
24	7.9	7.8	7.7	7.8	7.8	7.7	7.7	7.8	8.4	8.6

TABLE IV

TOTAL ALKALINITY (ppm HCO_3^- AND $CO_3^=$)

Treatment Pond	Z-4			Z-5			Z-7			Lagoon
	9	23	25	7	19	27	11	13	21	
Date										
18 May 1965	166	143	155	170	149	168	160	164	145	150
25	150	132	152	158	140	164	150	144	134	149
3 June	123	116	131	137	130	139	127	133	122	142
9	122	112	120	126	111	129	117	123	106	134
16	127	99	126	130	119	125	124	130	107	125
24	139	112	120	139	131	134	137	140	118	122
1 July	107	95	111	105	110	109	109	114	101	115
7	108	106	115	110	109	114	112	120	108	113
13	117	100	121	116	108	119	122	124	109	106
22	120	99	125	122	97	120	120	119	105	110
28	115	97	120	120	99	120	112	114	94	121
2 August	140	134	143	147	129	140	145	142	103	129
10	146	135	138	143	131	136	144	133	114	133
17	138	134	134	135	106	132	130	128	110	133
24	136	131	132	141	108	130	131	129	118	132

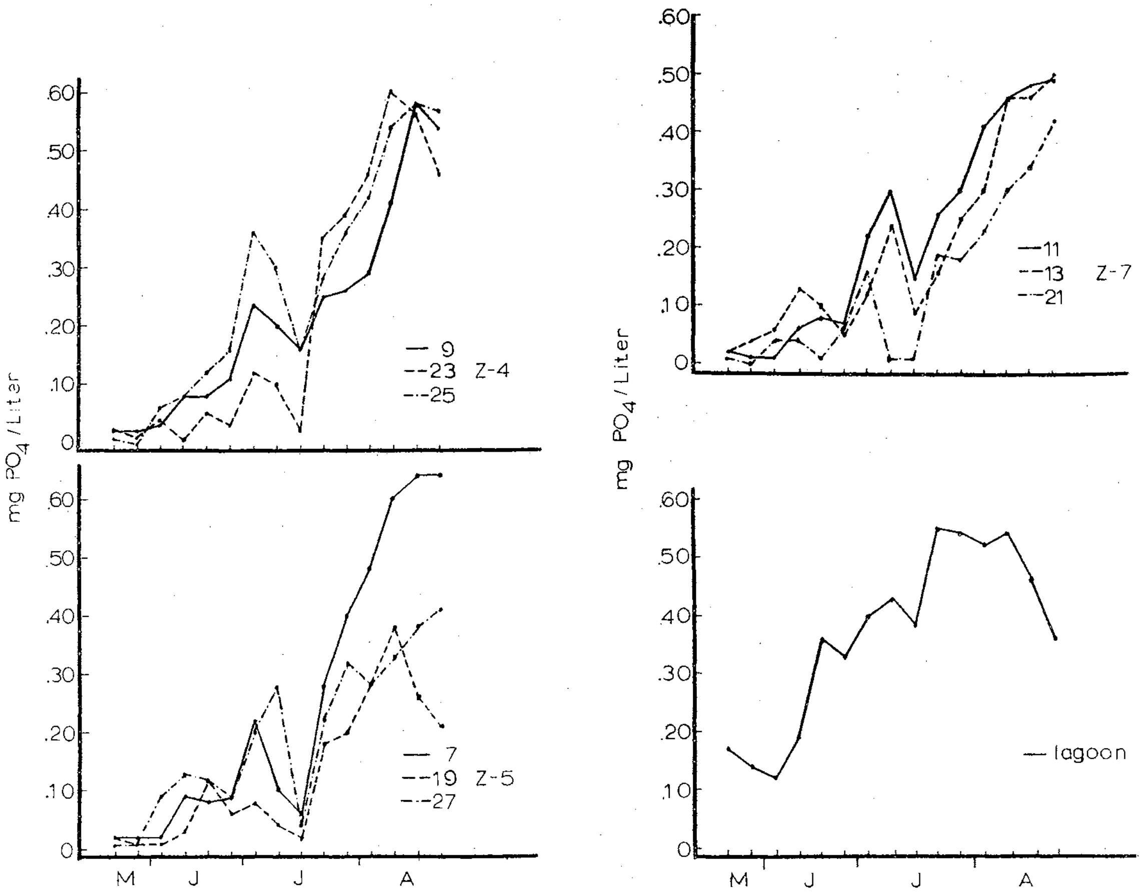

Fig. 2. Orthophosphate Concentration Grouped by Treatment

Nitrite concentration ranged from 0 to 0.05 mg/liter in all ponds and increased slightly during the sampling period (Fig. 3). Concentration in the lagoon fluctuated considerably. No significant difference between means for treatments nor between means for ponds was observed.

Ammonia concentration in all ponds and the lagoon fluctuated widely ranging from 0 to 370 ug/liter and generally increased throughout the summer (Fig. 4). No significant differences among treatment or pond mean concentrations were observed. It might be expected that dense populations of catfish would have produced higher ammonia levels in ponds than in the lagoon because the primary nitrogenous excretory product of fresh-water fish is ammonia (Prosser and Brown, 1961). However, mean ammonia concentration was higher for lagoon samples.

Nitrate concentration in ponds was usually much lower than in the lagoon (Fig. 5). Pond values were lower than those cited by Hutchinson (1957) for a number of eutrophic situations; however, they were compatible with those observed by Dugdale and Dugdale (1962) in an enriched lake. Sharp increases in nitrate concentration were observed, 24 June in Ponds 25 and 27 and 1 July in Ponds 19, 21, and 23.

The water source for the lagoon was a new reservoir overlying recently cultivated land. Although nitrate concentrations in the lagoon were high, only small algal populations developed. In ponds, the generally larger algal populations may have removed dissolved nitrate resulting in concentrations lower than those in the lagoon.

Chemical and biological conditions in the lagoon might be expected to differ from those in the ponds since the lagoon is a much larger water mass. In addition, lagoon water level fluctuated widely depending upon variations in outflow from the reservoir. These characteristics

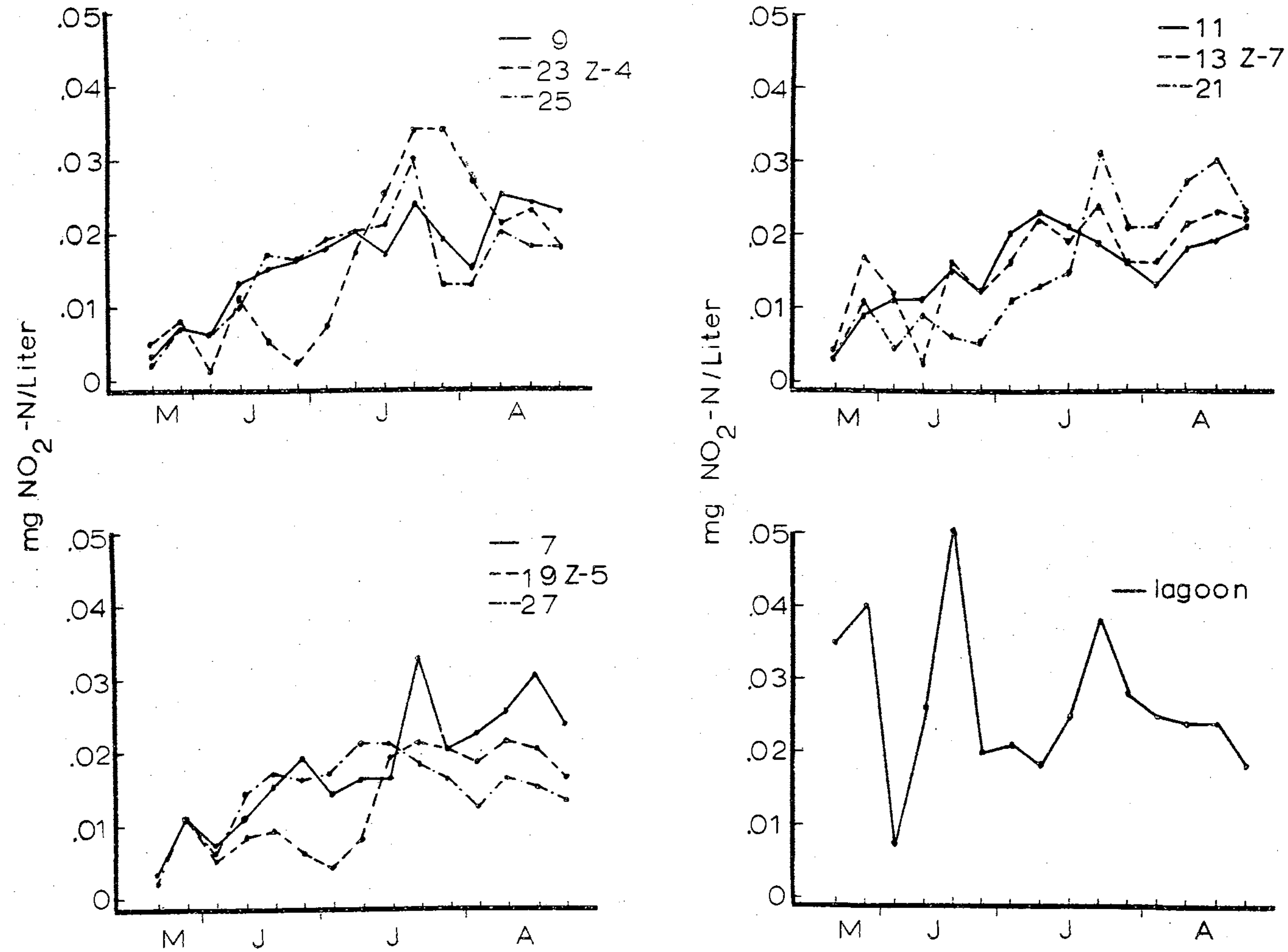

Fig. 3. Nitrite Concentration Grouped by Treatment

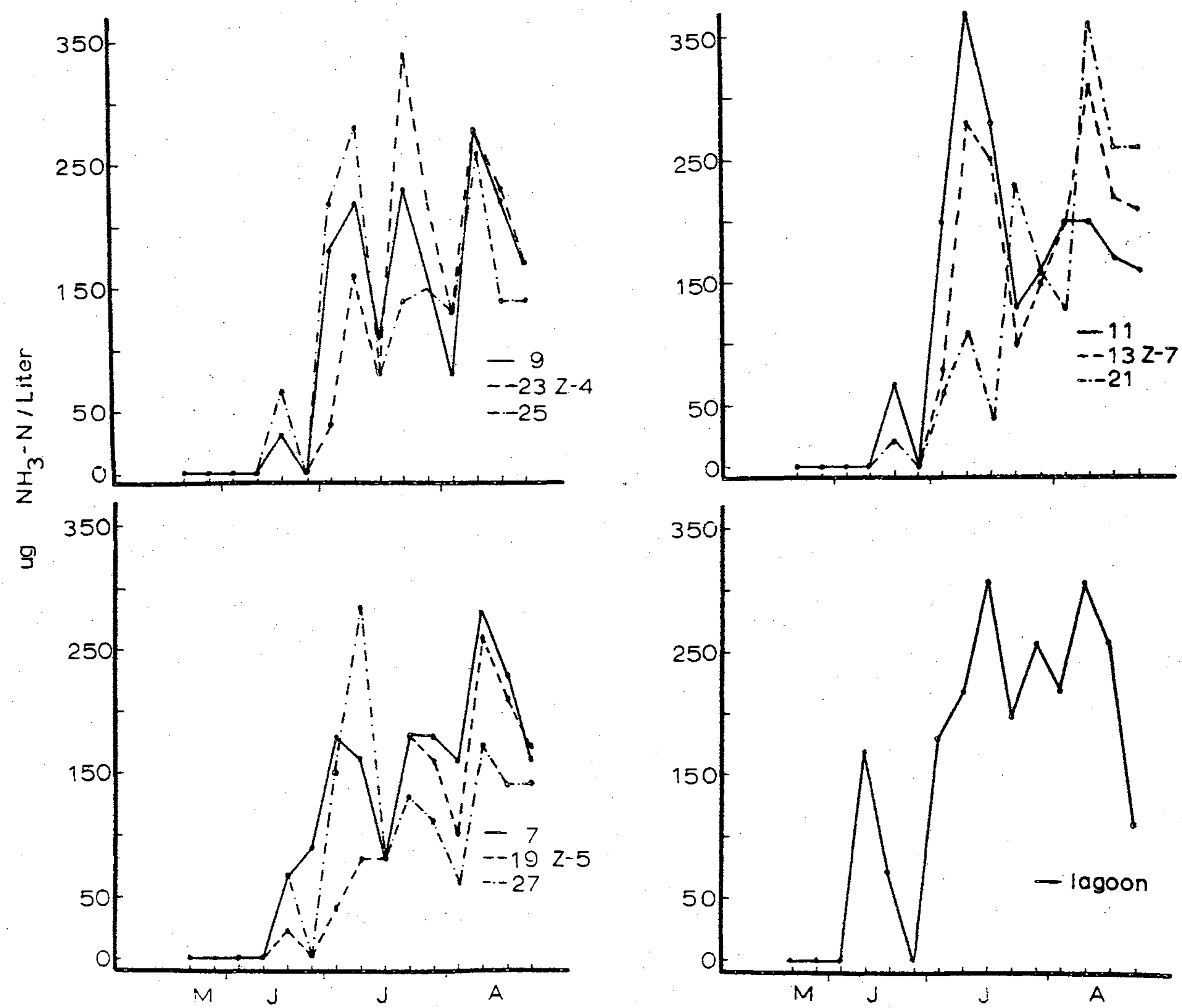

Fig. 4. Ammonia Concentration Grouped by Treatment

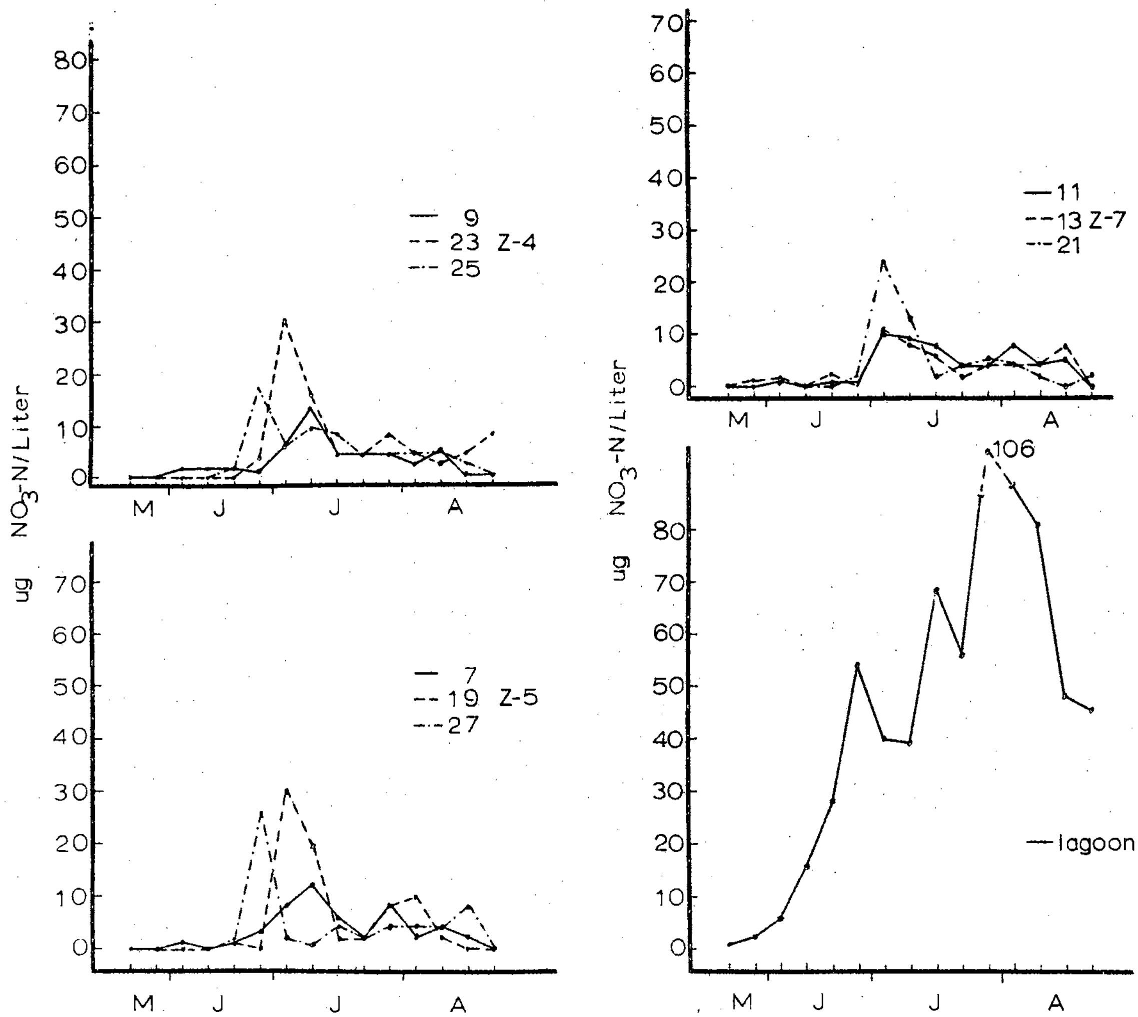

Fig. 5. Nitrate Concentration Grouped by Treatment

preclude conclusive comparison of lagoon and ponds in view of the much less intensive sampling of the lagoon.

In general, differences or fluctuations in nutrient concentration could not be correlated with diet treatment. Correlation coefficients were calculated for all combinations of chemical variables, but only those for nitrite and ammonia were significant. In ponds receiving treatment Z-4, the correlation coefficient was 0.784; for Z-5, it was 0.809. A positive correlation between these two reduced forms of nitrogen is expected.

Algal Populations

The similarities in physical and chemical characteristics of the ponds would suggest concomitant similarities in algal communities, and some respects, algal communities were alike. Chlorophyta dominated all communities throughout the summer in number of species and in total number of individuals (Table V). Diatoms were not abundant at any time. Cyanophyta were not abundant except that Anabaena flosaquae and A. circinalis dominated Pond 19 in late July. Green algae are usually dominant in summer, and blue-green forms are abundant in late summer and early fall (Ruttner, 1963; Fogg, 1965; Lund, 1965). The absence of large populations of blue-green algae was surprising for they often are abundant in enriched or fertilized bodies of water (Hasler and Einsele, 1948; Edmondson, et al., 1956; Hynes, 1960).

Among ponds, number of species ranged from 6 in Pond 25 in late May and early July to 30 in Pond 19 in mid-July (Table VI). Mean number of species ranged from 12 in Pond 25 to 21 in Pond 19. Mean in the lagoon was 8. In general, the lagoon exhibited a less developed

TABLE V

ALGAL SPECIES OBSERVED IN PONDS AND LAGOON

Cyanophyta

Merismopedia punctata
Anabaena flosaquae
A. circinalis

Chrysophyta

Botryococcus sp.
Dinobryon sp.
*Melosira granulata
Cyclotella sp.
Stephanodiscus hantzschii
Calloneis silicula
Cylindrotheca gracilis
Rhopalodia gibba
Fragilaria sp.
Synedra sp.
Cocconeis sp.
Epithemia sp.
Navicula sp.
*Nitzschia sp.

Euglenophyta

Trachelomonas sp.
*Phacus pyrum
P. pleuronectes
*Euglena sp.

Chlorophyta

Pteromonas sp.
*Phacotus lenticularis
Chlamydomonas sp.
Scenedesmus bijuga
*S. dimorphus
*S. quadricauda
*Crucigenia rectangularis
C. tetrapedia
*Actinastrum hantzschii
Closterium acerosum
Cosmarium punctulatum
Staurastrum sp.
Pediastrum boryanum
P. duplex
P. simplex
*P. tetras

Chlorophyta

*Coelastrum cambricum
*C. microporum
*C. sphaericum
Micractinium pusillum
Dictyosphaerium planktonicum
Schroederia schroeteri
Elakatothrix gelatinosa
*Sphaerocystis schroeteri
Oedogonium sp.
*Oocystis sp.
Nephrocytium limneticum
Chodatella citriformis
C. subsalsa
Ankistrodesmus falcatus
*Closteriopsis longissima
Selenastrum sp.
Kirchneriella lunaris
Tetraedron minimum
T. caudatum
T. trigonum
Gemellicystis neglecta

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*Species found in lagoon as well

TABLE VI

NUMBER OF ALGAL SPECIES IN PONDS AND LAGOON

Treatment	Pond	Range in No. of Species	Mean No. of Species
Z-4	9	10-25	18
	23	14-24	19
	25	6-17	12
Z-5	7	10-20	16
	19	11-30	21
	27	8-21	14
Z-7	11	9-24	16
	13	10-23	17
	21	9-23	17
none	Lagoon	4-12	8

flora than did the ponds. However, the paucity of species may reflect, in part, sampling error, for only one one-liter sample was taken from the lagoon each week.

Fluctuations in total numbers of individuals varied widely among ponds (Fig. 6). Sharp increases and decreases in population size might suggest considerable sampling error. However, 95% confidence limits shown for selected points indicate that these sharp changes in population size were real.

Within each group of ponds treated with the same diet, a single pond supported a very large population of algae in late July and August, viz., Pond 23 in group Z-4, Pond 19 in Z-5, and Pond 21 in Z-7. Algal populations of bloom proportions often are composed of only a few species, (Fogg, 1965), but in these three ponds fairly large numbers of species were observed. Pond 19 supported 28 species, Pond 21, 21 species and Pond 23, 19 species. At this time, number of species in other ponds ranged from 10 to 23.

Algae in these three communities began to increase in numbers in early July. At this time the predominant species in all ponds were *Sphaerocystis schroeteri*, *Scenedesmus bijuga*, *Coelastrum cambricum*, and *Oocystis* sp., and these species remained preponderant as the populations continued to increase in size.

On 1 July, at the beginning of the population expansion, the three ponds exhibited sharp increases in nitrate concentrations, to 30 ug/liter in Pond 23; 31 ug/liter in Pond 19, and 25 ug/liter in Pond 21 (Fig. 5). It appears that these four species were able to utilize the suddenly abundant nutrient, and population growth was rapid.

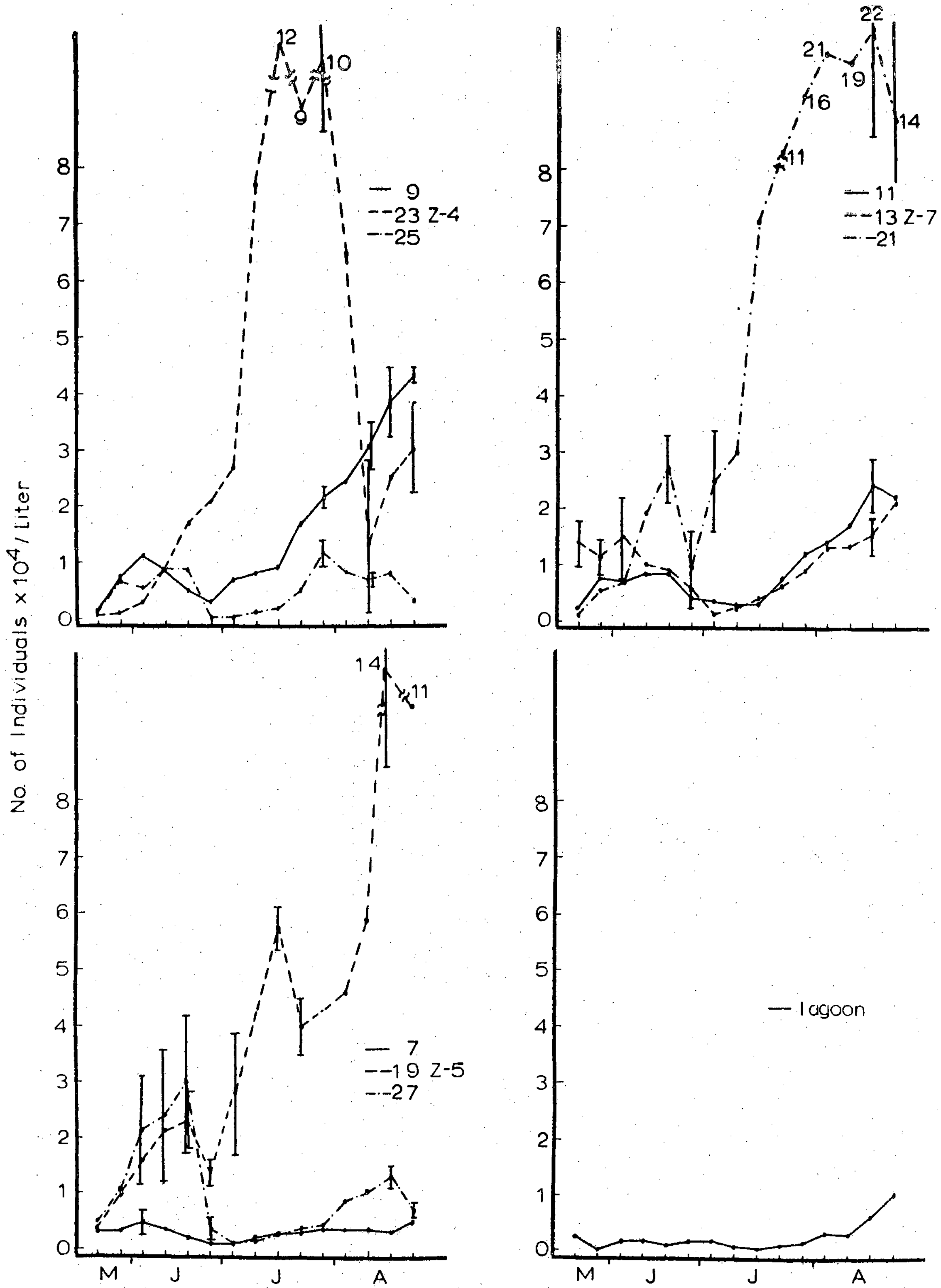

Fig. 6. Total Algal Populations Grouped by Treatment. Bracketed Vertical Lines Indicate 95% Confidence Limits.

Two additional peaks in nitrate concentration were observed, but concomitant increases in algal populations did not occur. One of these peaks of 16 ug/liter occurred in Pond 25 on 26 June. The abundant species at this time were _Oocystis_ sp. and an unidentified small colonial green alga. It appears, however, that these species were unable to increase in numbers with moderate dissolved nitrate increase, for total population levels did not exceed 10,000 individuals per liter following the nitrate increase.

Oocystis sp. populations in Ponds 19, 21, and 23 were approximately the same size, 3,000 to 4,000 individuals per liter, at the time of nitrate concentration increase as was the population in Pond 25 on 26 June. In Ponds 19, 21, and 23, these populations continued to increase after the peak in nitrate concentration of 25 ug/liter or greater. In Pond 25, however, following an increase to 16 ug/liter, _Oocystis_ sp. populations declined. Two possible explanations for this decline might be suggested. Perhaps nitrate increase to 16 ug/liter in Pond 25 during the logarithmic phase of population growth was insufficient to trigger further population expansion. Work with other species of algae has indicated that populations are especially sensitive to nutrient concentration changes in this period of development (Spencer, 1954; Fogg, 1965; Fournier, 1966). Another explanation might be that _Oocystis_ sp. was in some way benefited by its association with large populations of _Sphaerocystis schroeteri_, _Scenedesmus bijuga_ and _Coelastrum cambricum_, and in the absence of substantial populations of these species, its growth was limited.

The second additional peak in nitrate concentration occurred in Pond 27 on 26 June. The sequence of events in this pond (Fig. 7)

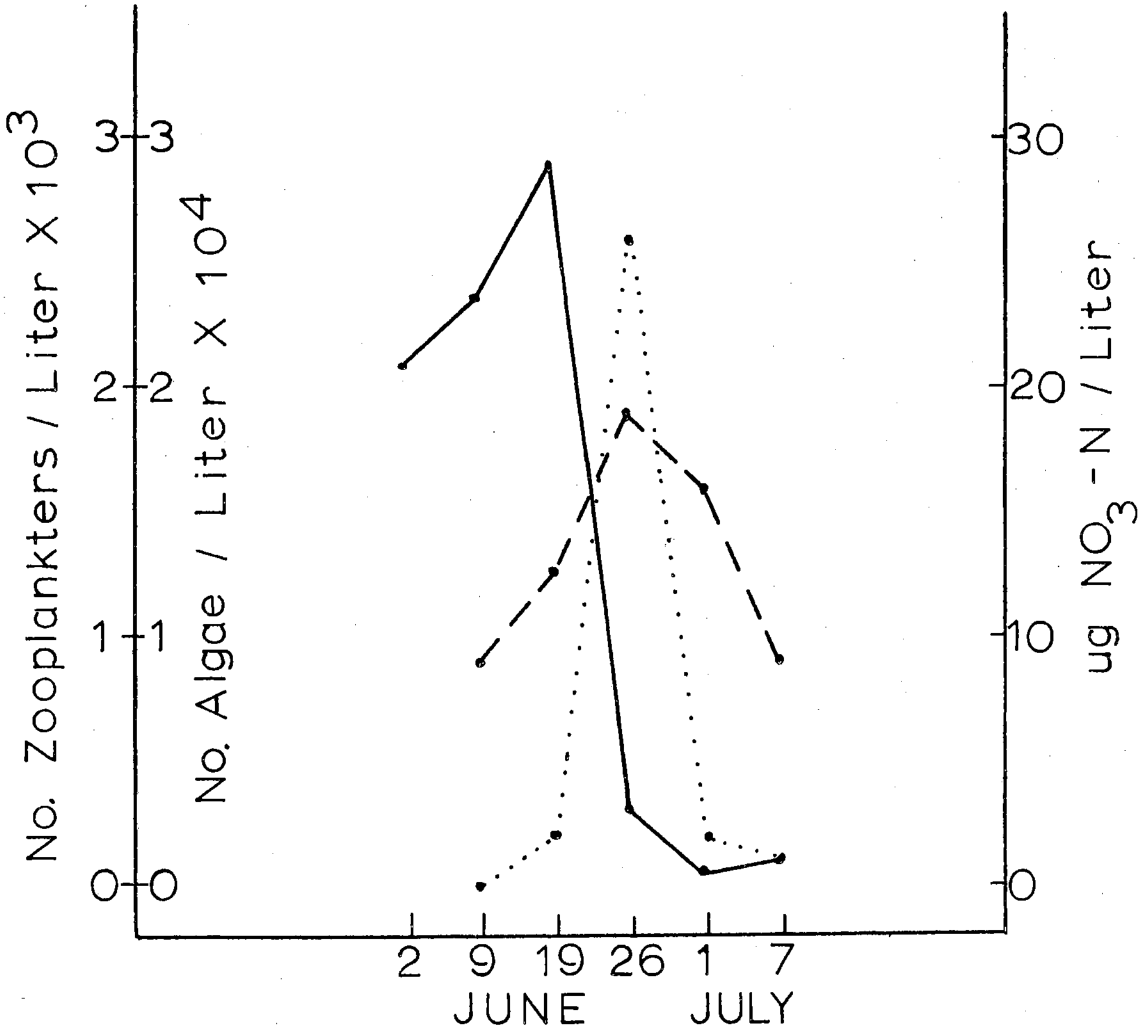

Fig. 7. Nitrate Concentration, Algal and Zooplankton Populations in Pond 27 in Early Summer. Algal Populations = ——; Zooplankton Populations = – – ; Nitrate Concentration = ...

differed from that in Pond 25. In early June, numbers of Oocystis sp. and Chodatella subsalsa increased moderately, reaching a maximum on 19 June. By 26 June, nitrate concentration had risen to 26 ug/liter. In the previously cited three instances, 25 ug/liter of nitrate was sufficient to support the growth of large populations of Oocystis sp. However, in Pond 27, the algal population size decreased sharply, concurrently with nitrate increase, and never achieved large size thereafter.

A possible explanation for this apparently contradictory situation may lie in the dynamics of zooplankton populations during this period. On 26 June, just when additional dissolved nitrate became available to the algae, the zooplankton population, composed primarily of Bosmina sp., reached a peak. Oocystis sp. has an overall diameter of 25 u, and Chodatella subsalsa has a diameter, including spines, of about 35 u. Bosmina sp. is a moderately large cladoceran which appears to be able to grace algae of this size. It is possible, then, that Bosmina sp. was responsible for decimating these two populations, thus preventing them from utilizing the nitrate. Preferential grazing of algae by specific zooplankters has been suggested as an important influence upon algal populations (Uhlmann, 1961; Edmondson, 1965). Such selective feeding habits of zooplankters are largely a matter of conjecture, however, and proof of such behavior must await controlled feeding experiments.

In general, size of algal populations was not strongly correlated with nutrient concentration (Table VII). Significant correlations between population level and orthophosophate concentration were observed

TABLE VII

CORRELATION COEFFICIENTS

Treatment Pond	Z-4			Z-5			Z-7		
	9	23	25	7	19	27	11	13	21
*$N-PO_4$	.9312	.2269	.1258	.2507	.5972	-.1843	.7629	.4942	.8396
$N-NO_3$	-.2151	.2420	-.4844	-.4944	-.0918	-.2249	-.0861	-.4889	-.1134
$N-NO_2$	.6455	.7919	-.1599	-.1158	.6296	-.2338	.2690	-.0421	.8802
$N-NH_3$	.6101	.5334	-.0758	-.2245	.7459	-.4143	.1112	.0150	.8532
**$\bar{H}-PO_4$	.6642	-.0812	.6466	.5356	.5295	.7620	.1935	.7799	.1974
$\bar{H}-NO_3$	.0385	-.3747	.2294	.3924	.1697	-.0252	-.3678	.0431	.3231
$\bar{H}-NO_2$	.8009	-.6465	.7019	.7270	.0366	.2426	.2510	.2956	.1453
$\bar{H}-NH_3$	.6640	-.3623	.7937	.8102	.2905	.5512	-.0863	.5949	.1555
***$\bar{H}$-R	-.8508	-.9840	-.8073	-.9267	-.9344	-.5652	-.1846	-.5764	-.6175

*N = total no. of algal individuals

**$\bar{H}$ = diversity (bits/individual)

***R = redundancy

only in Ponds 9, 11 and 21. Nitrite levels were paralleled by population size only in Pond 21 and ammonia levels only in Ponds 19 and 21.

Zooplankton Populations

In most ponds, zooplankton populations (Fig. 8) decreased during May and June and leveled off during July and August. Rotifers, especially Keratella sp. and Polyarthra sp., predominated in May and early June; cladocerans, particularly Bosmina sp., in late June and throughout July; and cyclopoid copepods in August. Copepod populations may have been underestimated because copepods may evade sampling devices (Hardy, 1956).

Zooplankton populations did not appear to directly control fluctuations in the phytoplankton community. With the single exception in Pond 27 discussed above, grazing of specific algae by zooplankters appears not to be the likely explanation for marked shifts in phytoplankton population levels.

Species Diversity

In general, species diversity, as measured by $\bar{H}$, exhibited a parallel increase in all pond phytoplankton communities throughout the summer except in Ponds 7 and 23 (Fig. 9). A high value of 4.0 bits/individual was recorded, and the lowest value was 0.58. Ponds 7 and 23 each supported a widely fluctuating community. In general, redundancy (R), a measure of the tendency for a few species to dominate the community, was low in all ponds (Fig. 10). On five occasions R was 0.5 or greater. In Ponds 7 and 25 high R in mid-June was the result of large populations of Oocystis sp. In Pond 13, Chodatella subsalsa was responsible for

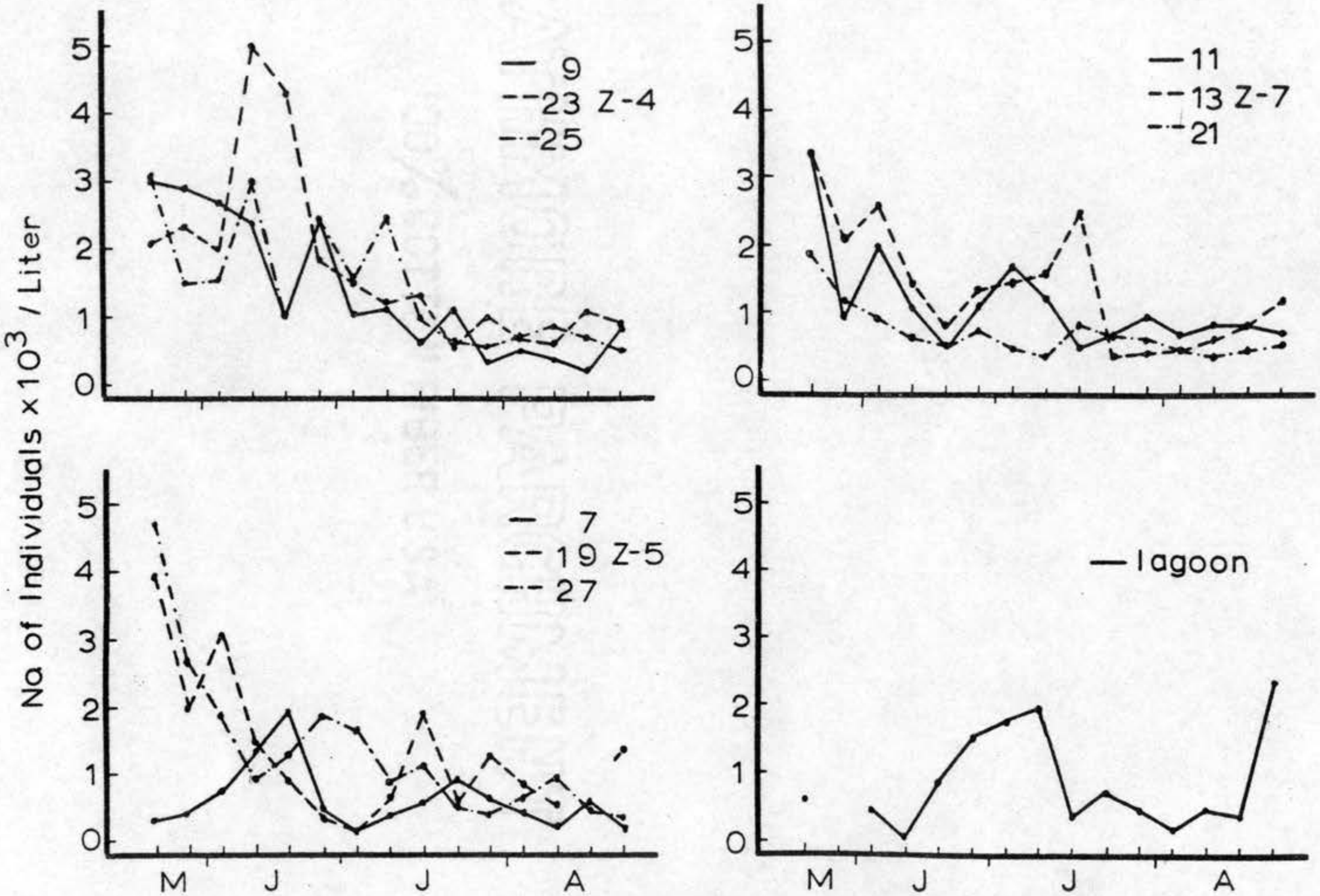

Fig. 8. Total Zooplankton Populations Grouped by Treatment

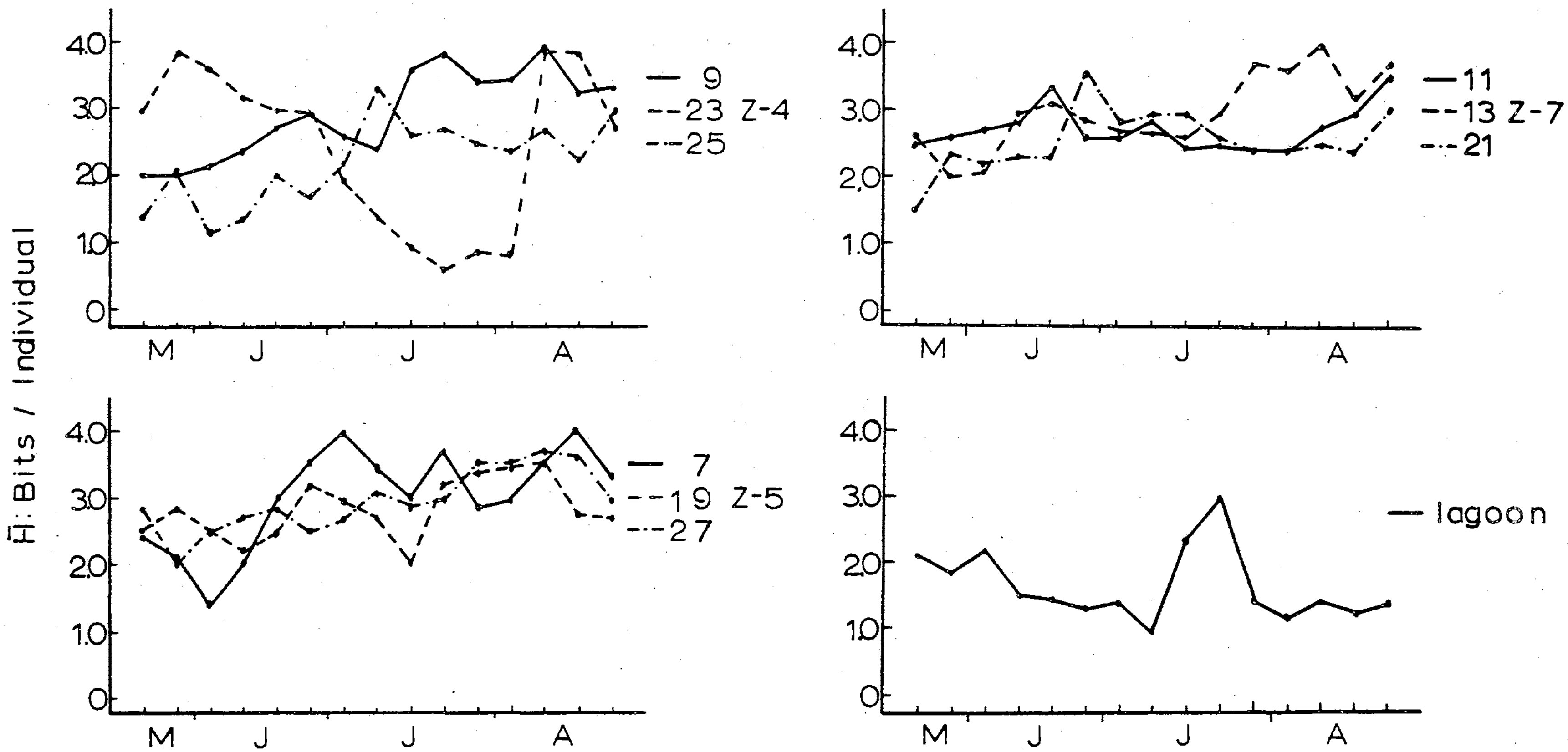

Fig. 9. Species Diversity ($\bar{H}$) of Phytoplankton Communities Grouped by Treatment

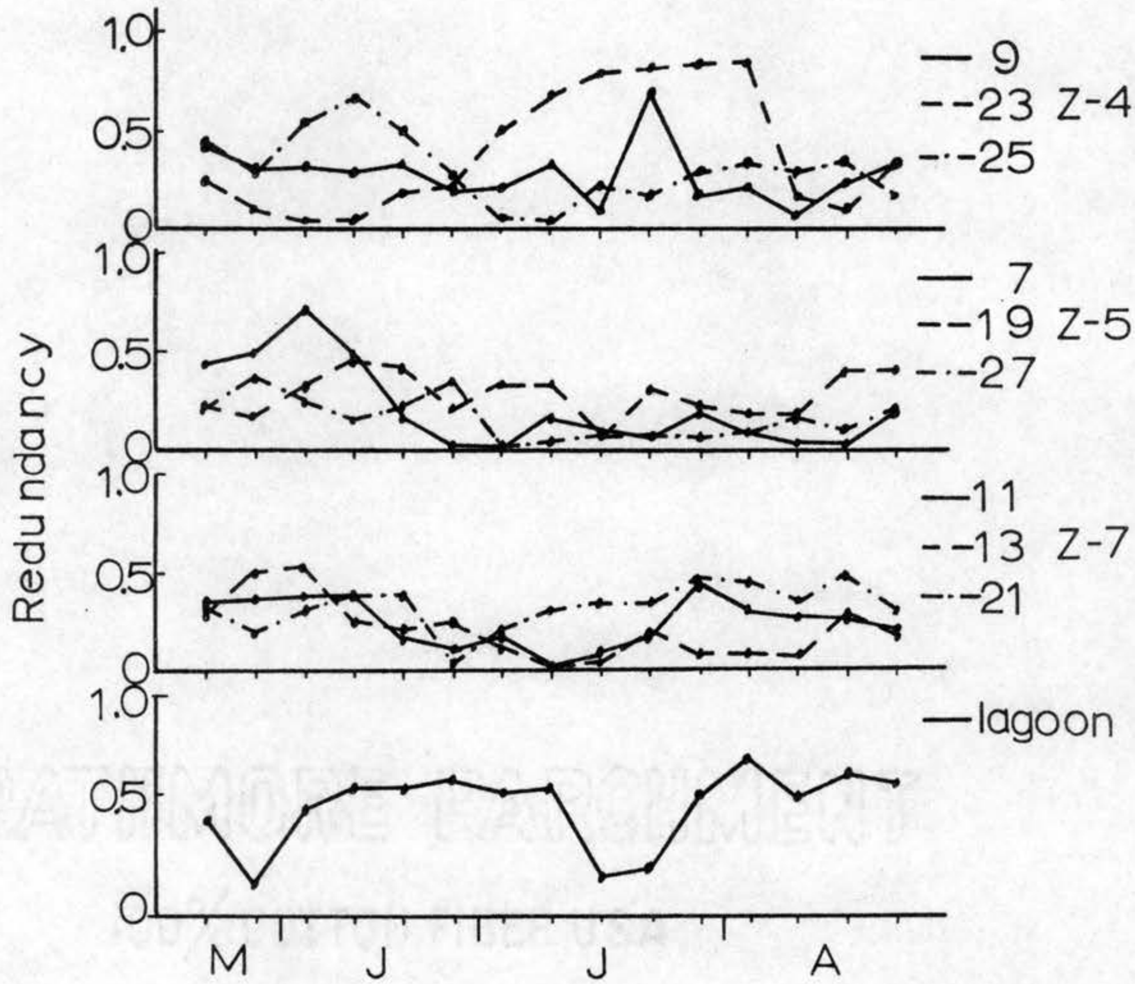

Fig. 10. Redundancy (R) of Phytoplankton Communities Grouped by Treatment

high R in early June. In late July and early August, high R was associated with an abundance of Coelastrum cambricum in Pond 23, and an August peak in R in Pond 19 resulted from large populations of Sphaerocystis schroeteri and Anabaena flosaquae.

Ponds 19, 21, and 23 supported extremely large algal populations at some time during the summer. Predomination by a few species is usually associated with bloom populations (Fogg, 1965), and it would be expected that redundancy would be high in those cases. However, only Pond 23 exhibited persistently high R values during the bloom period, and R in Ponds 19 and 21 was less than 0.5 during these periods.

In general, diversity patterns did not parallel nutrient concentration patterns. Strong correlations between $\bar{H}$ and nutrient concentrations were observed in only a few ponds (Table VII). In Ponds 9, 25, and 7, $\bar{H}$ was positively correlated with the reduced forms of nitrogen, and in Ponds 13 and 27, with phosphate level. Negative correlation coefficients between $\bar{H}$ and R were noted for all ponds, but these were significantly large only in Ponds 9, 23, 25, 7, and 19.

Odum (1956) has suggested that the ratio of primary productivity to respiration (P/R) provides an index of the trophic structure of a community. A community in which productivity exceeds respiration (P/R greater than 1.0) is autotrophic, and that in which P/R is less than 1.0 is heterotrophic while a P/R ratio of 1.0 is indicative of a stable community in a steady-state condition. Communities in experimental ponds were all autotrophic with P/R ratio ranging from 1.38 in Pond 7 to 4.6 in Pond 11 (Table VIII). Communities in which nutrients are added continuously are generally autotrophic.

TABLE VIII

RATIO OF PHOTOSYNTHETIC PRODUCTION TO COMMUNITY RESPIRATION

Treatment	Z-4			Z-5			Z-7		
Pond	9	23	25	7	19	27	11	13	21
ppm O_2 Produced/125 ml	2.1	5.4	2.1	1.1	2.6	2.4	4.6	2.6	4.1
ppm O_2 Consumed/125 ml	1.2	2.9	1.5	0.8	1.5	1.4	1.0	0.9	1.8
P/R	1.75	1.86	1.40	1.38	1.73	1.71	4.60	2.89	2.28
Date	18 June			19 June			1 July		

Margalef (1963, 1965) proposed that stable communities, communities in equilibrium, are characterized by high species diversity, and that unstable communities exhibit low species diversity. P/R ratios characteristic of autotrophic, unstable communities were observed in all of the experimental ponds (Table VIII). However, diversity indices for the same period were not consistent with the theoretical expectation of an inverse relation between P/R ratio and diversity (Fig. 9). For example, in Pond 11, which had the highest P/R ratio (4.6), $\overline{H}$ was 2.6, and in Pond 7, which exhibited a low P/R ratio (1.38), $\overline{H}$ was 3.0. Pond 25 was quite similar to Pond 7 with a P/R ratio of 1.40. The two ponds might be expected logically to have similar $\overline{H}$ values. However, $\overline{H}$ of 2.0 in Pond 25 was much lower than $\overline{H}$ in Pond 7. Sufficient comparative data are not available to establish whether these diversity values are high or low. However, the correlation coefficient of -0.09 for $\overline{H}$ and P/R ratio indicates that $\overline{H}$ and P/R are not inversely related as suggested by Margalef and Odum. Rather, these parameters are not significantly correlated.

These data describe a situation in which the criteria of Odum and Margalef for equilibrium and non-equilibrium communities conflict. Perhaps the range of P/R ratios and diversity values observed in these ponds was too narrow to apply the generalizations of Odum and Margalef. Their hypotheses may be useful only in comparing communities exhibiting extreme differences in structural and functional characteristics. Therefore the criteria may be of limited value in classifying communities.

In most ponds and lakes, summer phytoplankton exhibits high diversity during a period of relatively low nutrient levels. As

Hutchinson (1961) has suggested, the "paradox of the plankton" is that a large number of species, all of which apparently are competing for the same sorts of materials, are able to coexist in an environment, such as the epilimnion of a lake, which is unstable and relatively unstructured. Lund (1964) has taken issue with Hutchinson's characterization of the epilimnion as unstable. His work with 30 species of algae in English lakes indicated that epilimnetic algae as well as zooplankton exhibit distinct patterns of vertical and horizontal distribution. In his opinion the epilimnion is a highly structured environment, but patterns of structure are constantly changing, allowing many species to coexist.

The experimental ponds of this study may not represent model epilimnions; however, they were well mixed water masses physically. Were they well mixed biologically well? Species diversity and redundancy values of surface phytoplankton samples were compared with values for deeper samples in each pond throughout the summer. Had surface and depth communities been distinct, the proportion of values from surface samples which were greater than those from depth samples should have been either very large or very small. If the proportion were close to 50:50, neither surface nor depth samples being consistently larger, then the communities might be described as vertically mixed. The result of a two-tailed sign test, at the 0.05 alpha level, indicated that the proportion was indeed nearly 50:50 in every pond for both R and $\overline{H}$. Therefore, the communities appear to have been mixed. In this situation, Hutchinson's hypothesis of unstructured environment appears to be true. In these ponds, uniform diversity persisted in the unstable environment.

The variability of results among ponds and the lack of consistency with results of other investigators in some respects, e.g., extreme variability in size of algal populations in ponds treated similarly, observed phosphorus levels, sudden unexplained nitrate increases, might be due to sampling error. However, 95% confidence limits on plankton samples indicate adequate sampling of algal communities. Such observations of nutrient concentrations as the 0.80 correlation coefficient between ammonia and nitrite determinations for all ponds, which is a good agreement in determination of reduced forms of nitrogen by different methods, indicate good sampling program relative to nutrient concentration determinations.

In view of the assumed adequacy of sampling, the apparent explanation for this variability in results lies in the natural variability of bodies of water and the contained communities. This extreme variability has been alluded to by many investigators (Hutchinson, 1944; Talling, 1951; Lund, 1965). In spite of this generally recognized variation, many workers continue to report the results of fertilization on one body of water as definitive. The present study demonstrates the extremes in conditions which may develop in a supposedly controlled system of environments and suggests the weakness in conclusions drawn from one body of water and the problems and advantages associated with the comparative approach.

CHAPTER V

SUMMARY

1. Nine artificial ponds subjected to one of three experimental treatments of organic enrichment exhibited no statistically significant differences in mean concentration of dissolved nitrate, nitrite, ammonia or phosphate.

2. Phytoplankton communities were dominated by Chlorophyta, and number of species ranged from 6 to 30 in ponds.

3. Phytoplankton communities differed considerably both in population size and in pattern of fluctuation among ponds treated similarly. In general, population variations were not correlated with nutrient variations. Phytoplankton populations ranged from 400 to 220,000 individuals per liter in ponds.

4. Development of large algal populations began concurrently with sharp increases (25 ug/liter or more) in nitrate concentration in some ponds.

5. Zooplankton communities exhibited no recognizable trends in population size, but a shift in dominant forms from rotifers in June, to cladocera in July and copepods in August was observed.

6. Species diversity ($\bar{H}$) ranged from 4.0 to 0.58 bits/individual. In general, diversity was not positively correlated with nutrient concentrations.

7. Redundancy (R) for ponds closely paralleled each other. Among ponds supporting very large algal populations, only one exhibited consistently high R values for that period.

8. The theoretically expected inverse relation between P/R ratio and $\bar{H}$ was not observed. Correlation coefficient for these two parameters was -.09.

9. Species diversity and redundancy of algal communities were neither significantly larger nor significantly smaller in surface samples vs. deeper samples in any pond indicating vertical mixing of communities.

LITERATURE CITED

American Public Health Association. 1960. Standard methods for the examination of water and waste water. A.P.H.A. 11th Ed. 626 p.

Buljan, M. 1957. Report on the results obtained by a new method of fertilization experimented in the marine bay "Mljetska Jezera." Acta Adriat. 6: 1-54.

Chu, S. P. 1943. The influence of the mineral composition of the medium on the growth of planktonic algae. II. The influence of the concentration of inorganic nitrogen and phosphate phosphorus. J. Ecol. 31: 109-148.

Cochran, W. G. 1963. Sampling techniques. John Wiley and Sons, New York. 413 p.

Crowther, A. B. and R. S. Large. 1956. Improved conditions for the sodium phenoxide-sodium hypochlorite method for the determination of ammonia. Analyst 81: 64-5.

Dugdale, V. A. and R. C. Dugdale. 1962. Nitrogen metabolism in lakes. II. Role of nitrogen fixation in Sanctuary Lake, Pennsylvania. Limnol. Oceanog. 7: 170-177.

Edmondson, W. T., G. C. Anderson, and D. R. Peterson. 1956. Artificial eutrophication of Lake Washington. Limnol. Oceanog. 1: 47-53.

Edmondson, W. T. 1965. Reproductive rate of planktonic rotifers as related to food and temperature. Ecol. Monogr. 35: 61-111.

Fisher, R. A., A. S. Corbet, and C. B. Williams. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. J. Anim. Ecol. 12: 42-58.

Fogg, G. E. 1965. Algal cultures and phytoplankton ecology. Univ. of Wisconsin Press, Madison. 126 p.

Fournier, R. O. 1966. Some implications of nutrient enrichment on different temporal stages of a phytoplankton community. Chesapeake Sci. 7: 11-19.

Gleason, H. A. 1922. On the relation between species and area. Ecology 3: 158-162.

Hardy, A. C. 1956. The open sea. Houghton Mifflin Co., Boston. 335 p.

Hasler, A. D. and W. G. Einsele. 1948. Eutrophication of lakes by domestic drainage. Ecology 28: 383-395.

Hutchinson, G. E. 1944. Limnological studies in Connecticut. VII. Examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology 25: 3-26.

________. 1957. A treatise on limnology. John Wiley and Sons, New York. 1015 p.

________. 1961. The paradox of the plankton. Amer. Nat. 95: 137-146.

Hynes, H. B. N. 1960. The biology of polluted waters. Liverpool Univ. Press, Liverpool. 202 p.

Lund, J. W. G., C. Kipling, and E. D. LeCren. 1958. The inverted microscope method of estimating algal numbers and the statistical basis of estimation by countin. Hydrobiologia 11: 143-170.

Lund, J. W. G. 1964. Primary production and periodicity of plankton algae. Verh. int. Ver. Limnol. 15: 37-56.

________. 1965. The ecology of the freshwater phytoplankton. Biol. Rev. 40: 231-293.

MacArthur, R. H. 1965. Patterns of species diversity. Biol. Rev. 40: 510-533.

Margalef, D. R. 1958. Information theory in ecology. Gen. Systems 3: 36-71.

________. 1963. On certain unifying principles in ecology. Am. Nat. 97: 357-374.

________. 1965. Ecological correlations and the relationship between primary productivity and community structure. Mem. Ist. Ital. Idrobiol. Suppl. 18: 355-364.

Mullin, J. B. and J. P. Riley. 1955. The spectrophotometric determination of nitrate in natural waters with particular reference to sea water. Anal. Chim. Acta 12: 464-479.

Odum, H. T. 1956. Primary production of flowing water. Limnol. Oceanog. 1: 102-117.

Patten, B. C. 1962. Species diversity in net phytoplankton of Raritan Bay. J. Mar. Res. 20: 57-75.

Pearsall, W. H. 1932. Phytoplankton in the English lakes. 2. The composition of the phytoplankton in relation to dissolved substances. J. Ecol. 20: 241-262.

Pratt, D. M. 1949. Experiments in the fertilization of a salt water pond. J. Mar. Res. 8: 36-59.

Preston, F. W. 1948. The commonness, and rarity, of species. Ecology 29: 254-283.

Prosser, C. L. and F. A. Brown. 1961. Comparative animal physiology. W. B. Saunders Co., Philadelphia. 688 p.

Rigler, F. H. 1956. A tracer study of the phosphorus cycle in lake water. Ecology 37: 550-562.

Riley, J. P. 1953. The spectrophotometric determination of ammonia in natural waters with particular reference to sea water. Anal. Chim. Acta 9: 575-589.

Ruttner, F. 1963. Fundamentals of limnology. Univ. of Toronto Press, Toronto. 295 p.

Siegel, S. 1956. Nonparametric statistics. McGraw-Hill Book Co., New York. 312 p.

Simpson, G. G., Anne Roe, and R. C. Lewontin. 1960. Quantitative zoology. Harcourt, Brace and Co., New York. 440 p.

Spencer, C. P. 1954. Studies on the culture of marine diatoms. J. Mar. Biol. Assoc. U. K. 33: 265-290.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., New York. 481 p.

Strickland, J. D. H. 1960. Measuring the production of marine phytoplankton. Fish. Res. Bd. Canada Bull. 122. 172 p.

Talling, J. R. 1951. The element of chance in pond populations. The Naturalist. (London) Oct.-Dec.: 157-170.

Uhlmann, D. 1961. Über den Einfluss von Planktonorganismen auf ihr Milieu. Int. Rev. Hydrobiol. 46: 115-129.

Williams, C. B. 1947. The logarithmic series and its application to biological problems. J. Ecol. 34: 253-272.

________. 1964. Patterns in the balance of nature. Academic Press, New York. 324 p.

Wright, R. T. 1964. Dynamics of a phytoplankton community in an ice-covered lake. Limnol. Oceanog. 9: 163-178.

Yount, J. L. 1956. Factors that control species numbers in Silver Springs, Florida. Limnol. Oceanog. 1: 286-295.

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