THE MINERAL COMPOSITION OF SEVERAL FRESHWATER ALGAE [1]

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ABSTRACT

Samples of the following 14 genera of algae were collected from various geographical or geological areas during the period from April to November 1965 and subjected to mineral determinations; *Anabaena, Aphanizomenon, Chara, Cladophora, Euglena, Hydrodictyon, Lyngbya, Microcystis, Mougeotia, Nitella, Oedogonium, Pithophora, Rhizoclonium,* and *Spirogyra.* There was considerable variation in the levels of most elements, both within and between genera. Phytoplankton algae had low metal ion contents and high carbon, nitrogen, and phosphorous concentrations. Nonplankton algae generally contained more metallic ions and less carbon, nitrogen, and phosphorous. There was a marked mean accumulation of one or more elements above the usual levels by several genera as follows: nitrogen, cyanophycean genera and *Euglena;* phosphorus, cyanophycean genera; sulfur, *Aphanizomenon, Hydrodictyon,* and *Pithophora*; potassium, *Hydrodictyon* and *Nitella*; calcium, *Chara* and *Pithophora*; magnesium, *Chara*; sodium, *Spirogyra*; boron, *Pithophora* and *Lyngbya.* Both *Chara* and *Pithophora* were extremely rich in most bases and low in carbon when compared to other genera. Almost all genera contained relatively high levels of copper, iron, manganese and zinc. Emission spectrographic analyses of *Chara, Euglena, Microcystis, Pithophora, Rhizoclonium* and *Spirogyra* revealed the presence of substantial quantities of aluminum, barium, cobalt, molybdenum, silicon, and strontium.

These compositional data indicate that algae play an important role in the mineral dynamics of aquatic ecosystems.

INTRODUCTION

The need for data on the elemental or mineral composition of freshwater organisms was realized early in the history of aquatic biology by Birge and Juday (1922). Recently, Mackenthun (1965) emphasized that a knowledge of the levels of nutrients contained in various components of the aquatic biota was vital to certain aspects of nutrient pollution abatement. Such information is also necessary as a foundation for future studies of the biogeochemistry of aquatic ecosystems. In addition, comparative nutritive values of various algae should be of considerable interest to fish culturists.

The assimilation of inorganic ions by green plants represents the base of mineral transfers in most food chains and has far-reaching implications in the nutrition of ecosystems. Since algae usually represent a large portion of the primary producers in aquatic ecosystems, their elemental composition is of particular interest; however, the mineral content of other aquatic organisms should be equally significant.

Several workers have reported the concentrations of a few elements in freshwater algae (Turner 1916; Schuette 1918; Schuette and Hoffman 1921; Birge and Juday 1922; Hamlyn-Harris 1928; Schuette and Alder 1929; Harper and Daniel 1934; Misra 1938; Gerloff and Skoog 1954, 1957, 1957a; Phinney and Peek 1961; Cook 1962; Kevern and Ball 1965). Most of these studies were limited to one or two samples of each alga and in many instances the analytical techniques were somewhat questionable by modern standards.

In view of the relative paucity of information, this study was initiated to determine the levels of a large number of elements in several

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freshwater algae. To obtain some estimate of natural variation, an attempt was made to collect samples of each alga from ponds and lakes differing in fertility and geographic location. This was merely a preliminary investigation and it is hoped that the data obtained will stimulate additional research in this area.

MATERIALS AND METHODS

Samples of *Chara* spp., *Pithophora* sp., *Rhizoclonium* sp., and *Spirogyra* spp. were collected from several different edaphic regions of central and southern Alabama and central Mississippi during the spring, summer, and fall of 1965. With a few exceptions, the samples of *Anabaena flos-aquae, Aphanizomenon flos-aquae, Cladophora* sp., *Euglena* sp., *Hydrodictyon reticulatum, Lyngbya* sp., *Microcystis aeruginosa, Mougeotia* sp., *Nitella* sp., and *Oedogonium* sp. were obtained in Lee County, Alabama.

Phytoplankton samples were concentrated from blooms with either a Servall Continuous Flow Centrifuge or a Wisconsin Type Plankton Net. The phytoplankton residues were handled essentially as described below for nonplankton algae. To prevent trash contamination, nonplankton algae were hand picked and each sample was a composite of plants collected from several locations within the collecting site. Samples were washed in the water of the sampling areas, placed in polyethylene bags, and stored on ice during transit to the laboratory. After identification was confirmed and it was ascertained that the material was essentially a monoculture, the plants were washed in tap water, picked free of debris, and transferred to porcelain evaporating dishes. Algae were dried at 65-70°C. for 72 hours, pulverized with mortar and pestle to pass 40-mesh screen, reheated for three to five days, and desiccated.

Total nitrogen was measured with a Coleman Model 29 A Nitrogen Analyzer II and total carbon with a Coleman Model 33 Carbon-Hydrogen Analyzer. Ash values were obtained according to Jackson (1958). A HNO_3, H_2SO_4, and $HClO_4$ digestion procedure (Jackson 1958) converted calcium, magnesium, potassium, sodium, iron, manganese, zinc, copper, and phosphorus to forms suitable for analysis and the levels of these elements were determined from the ternary acid digestion solution. A Coleman Model 21 Flame Photometer was used for potassium and sodium measurements. The murexide endpoint of the EDTA titration of calcium (American Public Health Association, 1963) was detected with a Photovolt Model 401 Lumetron Colorimeter. Analysis for copper, iron, magnesium, manganese, and zinc were made by the Auburn University Soil Testing Laboratory with a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer. The phosphorus content was obtained by the one, two, four-aminonaphtholsulfonic acid-reduced molybdophosphoric blue method in an HCl medium (L. E. Ensminger, unpublished). The curcumin procedure (Jackson 1958) was used for boron determinations. Total sulfur and sulfate-sulfur methods outlined by Bardsley and Lancaster (1958) were utilized. The colorimetric measurements for phosphorus, sulfur, and boron were made on a Coleman Model 6C Junior Spectrophotometer. The $CaCO_3$ levels for *Chara* were estimated by a modification of a method presented by Jackson (1958). Analyses for aluminum, silicon, strontium, molybdenum, barium, and cobalt were made on selected samples by the Ohio Agricultural Experiment Station using a Jarrell-Ash Atomcounter (model not specified).

Surface water samples were taken at each collection site. Total alkalinity, total hardness, and calcium measurements were made according to the American Public Health Association (1963). The levels of potassium and sodium were obtained by flame photometry and magnesium, iron, manganese, zinc, and copper by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Analyses were normally made in duplicate. Levels of calcium, magnesium, potassium, sodium, iron, manganese, zinc, copper, phosphorus, and boron were also determined in selected samples with the Jarrell-Ash Atomcounter and results were usually within 10-15 percent of the values obtained by the wet techniques listed previously. Element losses due to leaching of ions from the free space of plant cells during washing have been noted (Long *et al.*, 1956), but leaching losses from the algae were certainly smaller than errors that would have resulted from debris had the samples not been washed. All samples contained varying amounts of epiphytic material which affected the reported values accordingly; however, the samples were representative of natural algal populations.

Nonplankton Algae

The majority of the samples subjected to chemical analyses were of the following genera: *Chara*; *Pithophora, Spirogyra,* and *Rhizoclonium.* Except for some senile *Chara* and *Pithophora* populations sampled in October and November, each sample was a composite of plants in various developmental stages. Therefore, the means and 95% confidence limits for the elements in Table 1 are a good estimation of levels expected in natural populations.

TABLE 1. MEANS, 95 PERCENT CONFIDENCE LIMITS, AND NUMBER OF SAMPLES (IN PARENTHESES) FOR THE ASH CONTENT AND LEVELS OF CERTAIN ELEMENTS IN *CHARA, PITHOPHORA, SPIROGYRA,* AND *RHIZOCLONIUM.*

Determination	Genus			
	Chara	*Pithophora*	*Spirogyra*	*Rhizoclonium*
	Percent Dry Weight			
Ash	43.41 ± 4.70 (58)	27.77 ± 3.06 (38)	13.33 ± 2.15 (28)	17.16 ± 5.92 (11)
C	29.28 ± 1.64 (59)	35.38 ± 1.22 (38)	41.84 ± 1.11 (30)	38.65 ± 2.48 (14)
N	2.46 ± 0.26 (59)	2.57 ± 0.31 (38)	2.70 ± 0.32 (30)	3.16 ± 0.71 (14)
P	0.25 ± 0.03 (59)	0.30 ± 0.05 (31)	0.21 ± 0.04 (30)	0.34 ± 0.16 (14)
S	0.55 ± 0.08 (58)	1.42 ± 0.13 (38)	0.25 ± 0.04 (28)	0.27 ± 0.05 (13)
Ca	8.03 ± 1.09 (59)	3.82 ± 1.20 (31)	0.70 ± 0.10 (30)	0.60 ± 0.38 (13)
Mg	0.92 ± 0.12 (59)	0.20 ± 0.02 (31)	0.38 ± 0.09 (30)	0.19 ± 0.18 (14)
K	2.35 ± 0.30 (59)	3.06 ± 0.53 (32)	0.95 ± 0.24 (30)	2.37 ± 0.59 (14)
	ppm Dry Weight			
Na	1280 ± 290 (59)	740 ± 190 (32)	14200 ± 2600 (30)	814 ± 184 (14)
Fe	2520 ± 382 (59)	2836 ± 592 (31)	1552 ± 421 (30)	2084 ± 1180 (14)
Mn	2926 ± 710 (59)	929 ± 460 (31)	1649 ± 542 (30)	1521 ± 1306 (14)
Zn	89 ± 37 (59)	29 ± 15 (31)	60 ± 21 (30)	109 ± 58 (14)
Cu	19 ± 4 (56)	23 ± 9 (31)	41 ± 15 (29)	68 ± 29 (14)
B	7 ± 1 (58)	65 ± 8 (28)	4 ± 2 (23)	3 ± 2 (10)

The relatively low carbon and high ash levels of *Chara* were related to $CaCO_3$ deposition (Welch 1952). The mean $CaCO_3$ content was estimated at 25 percent and some samples from waters of high alkalinity were up to 50 percent lime. There was a direct relationship between total alkalinity and the quantity of $CaCO_3$ deposited on the surfaces and in the tissues of *Chara.* The following typical analyses of heavily lime-encrusted plants from hard waters (1) and plants from soft waters (2) indicate that amounts of certain elements in the heavily encrusted plants differ greatly from values found for *Chara* samples having less encrustation.

Sample	Ash	C	N	P	S	Ca	Mg	K
1	81.54	13.26	0.43	0.11	0.08	19.66	0.09	0.56
2	43.40	28.54	0.88	0.27	0.69	7.69	1.16	2.32

When the amount of $CaCO_3$ was subtracted from the dry weight and the carbon in carbonate combination was subtracted from the total carbon of several lime-encrusted samples, the remaining material theoretically contained approximately 40 percent carbon. Therefore, the lower mean carbon value for *Chara* (Table 1), as compared to other algae, is due to lime deposition and the actual living portions of *Chara* have a carbon content similar to the other genera. In the data above, the lower levels of nitrogen, phosphorus, sulfur, magnesium, and potassium for sample 1 are also due, at least in part, to the reduction of organic material per unit weight of *Chara* by $CaCO_3$ deposition. Several *Pithophora* samples also contained $CaCO_3$ and the amounts of several elements decreased accordingly. There was no evidence of lime deposition by *Rhizoclonium* or *Spirogyra.*

The mean nitrogen and phosphorus levels were approximately equal for all genera. The nitrogen content seldom exceeded four percent and phosphorus was usually below 0.5 percent in individual samples. The N/P ratio for most samples ranged from eight to 12. The C/N ratios were: *Pithophora* 17.62 ± 4.66, *Spirogyra* 17.33 ± 2.78, *Rhizoclonium* 14.08 ± 3.43, and *Chara* 13.21 ± 2.00. There was a strong accumulation of sulfur by *Pithophora.* The sulfate (0.33 ± 0.12% for 33 samples) usually accounted for less than ¼ of the total sulfur in *Pithophora,* so the bulk of sulfur was assumed to be in organic combination.

Levels of calcium and magnesium were particularly high in *Chara,* usually above six and 0.5 percent, respectively. There were also fairly high calcium values in *Pithophora.* With the exception of *Spirogyra,* potassium was very abundant. Some samples contained five to six percent potassium. A marked accumulation of sodium was present in all *Spirogyra* samples, but samples of other genera seldom contained above 0.5 percent.

Although there were considerable variations between samples, these genera had substantial mean quantities of iron, manganese, zinc, and copper. The boron content was less than 10 ppm in most samples of *Chara, Spirogyra,* and *Rhizoclonium,* but *Pithophora* concentrated relatively large quantities.

Results of aluminum, silicon, strontium, barium, molybdenum, and cobalt determinations are presented in Table 2. Only molybdenum and

TABLE 2. LEVELS OF SILICON, ALUMINUM, STRONTIUM, BARIUM, MOLYBDENUM, AND COBALT (DRY WT. BASIS) IN *CHARA, PITHOPHORA, SPIROGYRA,* AND *RHIZOCLONIUM.*

Determination	Genus and Number of samples (N)			
	Chara (N=11)	*Pithophora* (N=11)	*Spirogyra* (N=5)	*Rhizoclonium* (N=1)
	Percent Dry Weight			
Si	0.89	1.32	1.32	1.63
Al	0.28	0.41	0.28	0.45
	ppm Dry Weight			
Sr	604	162	293	83
Ba	150	59	200	200
Mo	27	42	28	45
Co	2.71	1.49	2.06	0.26

cobalt are generally considered essential for plant growth (Meyer et al., 1960), but silicon is required by diatoms. Upper limits of detection (strontium 700 ppm, barium 200 ppm, and molybdenum 45 ppm) were exceeded in several cases. Means were computed using the upper limits and reported as mean values. Relatively large amounts of all elements were present; however, the values were so variable that the means were hardly indicative of the level found in any given sample. There appears to be a strong accumulation of strontium by *Chara* which is of considerable interest because of the presence of radioactive strontium 90 in the biosphere (Odum and Odum 1959).

Six populations of *Chara* and *Pithophora* were sampled at monthly intervals to determine what changes occurred in the elemental composition with age. Since all populations did not reach senescence at the same rate and only two *Chara* populations persisted until October, monthly means for the elements were not calculated. Typical population of both algae were selected in order to illustrate the changes in ash, carbon, and nitrogen (Fig. 1). The decrease in ash content of *Chara* was due primarily to losses of calcium and potassium but there were slightly lower levels of most elements in the older plants. The high nitrogen content in the senile *Chara* may have resulted from the decrease in $CaCO_3$ which increased the proportion of organic material. Dense growths of *Lyngbya,* an alga with a high nitrogen content invaded the decaying mat of chara. Incomplete removal of this epiphytic material may have also been a nitrogen-increasing factor. The ash increase and carbon and nitrogen decrease in *Pithophora* were correlated with a rising $CaCO_3$ content. Most cations, particularly potassium, decreased while levels of phosphorus, sulfur, and boron remained relatively stable. From the above data it appears that the changes in composition of these two algae occur in reverse order.

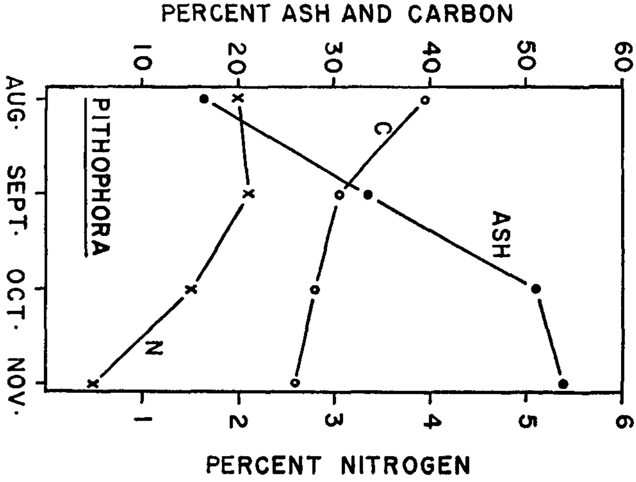
Mean concentrations of certain elements in samples of other green algae and a nonplankton cyanophycean, *Lyngbya,* are given in Table 3. Values for these algae were similar to levels for algae in Table 1. The means are based on a limited number of samples, but a few trends are recognizable. The *Lyngbya* samples were high in nitrogen, boron, and potassium when compared to most green algae. Relatively elevated sulfur, potassium, and boron values were found in *Hydrodictyon* and *Cladophora.* Particularly high concentrations of zinc were found in *Nitella* and *Mougeotia.*

Upon examination of the means in Tables 1 and 2 and the individual sample values of the original data the following appears to be the most usual composition (dry weight basis) of the nonplankton algae included in this study:

Analysis	range (percent)	Analysis	range (ppm)
Ash	12 - 20	Na	500 - 4000
C	38 - 42	Fe	1500 - 3000
N	2 - 3	Mn	1500 - 3000
P	0.2 - 0.3	Zn	30 - 150
S	0.3 - 0.5	Cu	20 - 100
Ca	0.5 - 2	B	4 - 10
Mg	0.2 - 0.4		
K	1 - 3		

It should be emphasized, however, that certain genera accumulated considerable quantities of one or more elements when compared to the usual ranges. The best examples of this accumulation were as follows: nitrogen—*Lyngbya*; sulfur—*Pithophora* and *Hydrodictyon*; calcium—*Chara* and *Pithophora*; magnesium—*Chara*; potassium—*Hydrodictyon* and *Nitella*; sodium—*Spirogyra*; boron—*Lyngbya* and *Pithophora.* There are insufficient data to include the elements determined by emission spectrographic analysis in these considerations. The accumulation of high levels of a particular mineral should not be viewed from a physiological standpoint since plants commonly absorb and concentrate elements in excess of their actual metabolic requirements (Meyer *et. al.,* 1960).

The levels of a few elements were determined in one or two samples of the following algae; *Chara* (Schuette and Alder, 1929; Misra, 1938), *Cladophora* (Schuette and Hoffman, 1921; Birge and Juday, 1922), *Nitella* (Hamlyn-Harris, 1928; Misra, 1938), and *Spirogyra* (Birge and Juday, 1922; Harper and Daniel, 1934). The data were generally in agreement with the analyses reported for these genera in the present study.



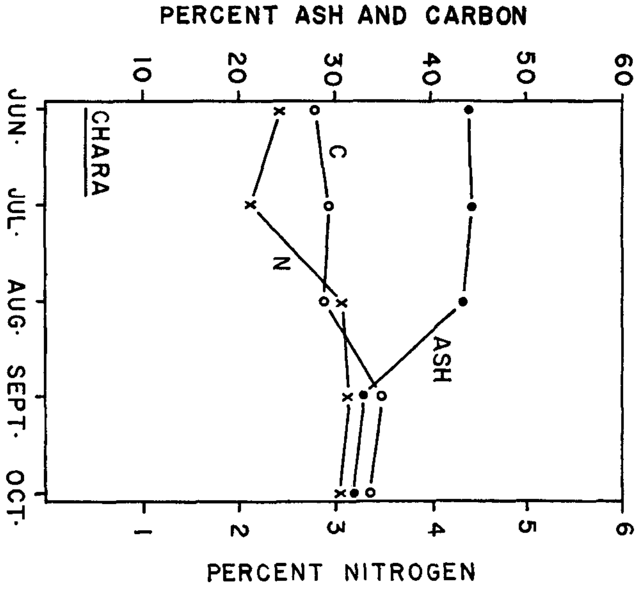


Figure 1. Changes in ash, carbon, and nitrogen content in *Pithophora* and *Chara* with age of plants.

TABLE 3. ASH CONTENT AND LEVELS OF CERTAIN ELEMENTS IN SAMPLES OF SEVERAL NONPLANKTON CHLOROPHYCEANS AND A NONPLANKTON CYANOPHYCEAN, *LYNGBYA*.

Genus	No. of Samples	Percent Dry Weight								ppm Dry Weight					
		Ash	C	N	P	S	Ca	Mg	K	Na	Fe	Mn	Zn	Cu	B
Hydrodictyon	5	17.94	39.96	3.87	0.24	1.41	0.69	0.17	4.21	3780	1313	1963	129	114	——
Nitella	3	19.11	38.43	2.70	0.23	0.34	1.89	0.95	3.73	2850	2180	2388	240	39	9.8
Oedogonium	3	12.69	40.84	2.64	0.08	0.15	0.44	0.16	3.03	590	1729	1645	119	75	8.1
Mougeotia	2	14.54	40.74	1.77	0.25	0.36	1.68	0.57	1.20	4900	1080	60	520	143	8.0
Cladophora	1	23.38	35.27	2.30	0.56	1.58	1.69	0.23	6.08	1800	2300	1040	10	190	84.6
Lyngbya	3	17.20	40.23	5.01	0.31	0.28	0.45	0.14	0.42	560	3866	5320	161	101	112.0

Phytoplankton

Several workers (Schuette, 1918; Birge and Juday, 1922; Gerloff and Skoog, 1954, 1957, 1957a; Phinney and Peek, 1961) have made ash, nitrogen, and phosphorus determinations on some phytoplanktonic cyanophyceans; *Anabaena, Aphanizomenon,* and *Microcystis.* Information on the levels of other elements is scarce.

Initially phytoplankton samples for this study were collected with a high speed centrifuge, but preliminary analyses (Table 4) indicated that the residue contained a high proportion of low organic content detrius not retained by the plankton net. Therefore, the elemental analyses reported in Table 5 are based upon net plankton. Results of ash (four to seven percent), nitrogen (six to ten percent), and phosphorus (0.5 to 1.2 percent) were almost identical with previously reported data.

TABLE 4. A COMPARISON OF ASH, CARBON, AND NITROGEN VALUES FOR NET AND CENTRIFUGE PLANKTON.

	Collection	Percent Dry Weight		
Pond[a]	Technique	Ash	C	N
		Anabaena		
A	Centrifuge	40.05	36.87	4.13
B	Centrifuge	60.25	18.65	2.84
C	Net	5.19	49.70	9.43
		Aphanizomenon		
D	Net	7.05	48.84	8.85
D	Centrifuge	30.77	34.60	6.89
E	Net	7.88	46.13	8.23
E	Centrifuge	16.16	44.10	7.90
F	Net	6.70	47.98	8.63
G	Centrifuge	—	34.90	4.82

[a] Letters used to designate different ponds or sampling dates.

The phytoplankton contained much greater amounts of carbon, nitrogen, and phosphorus, but lesser levels of ash and most macronutrients than did the nonplankton algae. Although nonplankton algae contain substantial quantities of essential elements, the phytoplankton, due to its high protein and carbonaceous content, is a much more desirable food source. Phytoplankton appears to contain levels of micronutrients, with the exception of manganese comparable to nonplankton forms. Copper and zinc were particularly abundant in *Euglena* and *Aphanizomenon.*

Emission spectrographic analyses were also made on single samples of *Microcystis* and *Euglena.* The results (ppm dry weight) were as follows:

	Si	Al	Sr	Ba	Mo	Co
Microcystis	500	620	671	200	1.89	0.26
Euglena	400	1200	9	7	1.37	0.55

Ecological relationships

Nonplankton algae are a serious problem in pond fish culture (Smith and Swingle, 1941; Swingle, 1947). Competition of nonplankton with plankton algae for nutrients decreases phytoplankton production and subsequently reduces fish yields (Lawrence, 1958). Inorganic fertilization of ponds containing dense *Chara* and *Pithophora* growths has been observed to result in the additional production of these plants instead of causing phytoplankton blooms. Although reliable biomass data are not available, typical populations of *Chara, Pithophora, Rhizoclonium, Hydrodictyon,* and *Spirogyra* in ponds have been roughly estimated at several hundred pounds of dry weight per acre. From the data presented in Tables 1, 2 and 3 it is obvious that these undesirable algae contain a

TABLE 5. ASH CONTENT AND LEVELS OF CERTAIN ELEMENTS IN SAMPLES OF SEVERAL PHYTOPLANKTON ALGAE.

		Percent Dry Weight								ppm Dry Weight					
Genus	No. of Samples	Ash	C	N	P	S	Ca	Mg	K	Na	Fe	Mn	Zn	Cu	B
Microcystis	4	6.20	46.46	8.08	0.68	0.27	0.53	0.17	0.79	410	2751	322	48	37	3.6
Aphanizomenon	3	7.21	47.65	8.57	1.17	1.18	0.73	0.21	0.68	1900	833	167	120	187	—
Anabaena	1	5.19	49.70	9.43	0.77	0.53	0.36	0.42	1.20	1800	800	80	0	70	—
Euglena	1	4.12	48.14	5.14	0.67	0.19	0.05	0.07	0.34	160	1545	240	73	290	3.8

considerable mass of essential nutrients and may limit further plant growth due to nutrient depletion. The marked accumulation of certain trace elements, for example boron assimilation by *Pithophora*, could easily result in the depletion of boron in an ecosystem inherently low in boron and thereby limit further plant growth.

Phytoplankton blooms may also reach several hundred pounds standing crop of dry biomass per acre (Birge and Juday, 1922; Mackenthun, 1965) and contain respectable quantities of nutrients.

The distribution of the algae did not appear to be correlated with the concentration of particular elements in the water; however, larger biomasses of *Chara* and *Pithophora* were generally found in hard waters rather than in soft waters. Juday (1942) reported that hard water Wisconsin Lakes supported larger standing crops of algae than soft water lakes.

Enrichment factors (Brooks and Rumsby, 1965) calculated from the ratio of the level of element in algae to the level of that element in water ranged from 3000 to 12,000 for most elements, but manganese was concentrated 100,000 to 250,000 times. A strong enrichment of manganese has also been reported for vascular aquatic plants (Mayer and Gorham, 1951 and Denton, 1966).

Water analyses revealed that most of the algae were collected from ecosystems of differing nutrient statuses. Correlation coefficients (r) were computed for *Chara, Pithophora, Rhizoclonium,* and *Spirogyra* to determine if a positive correlation existed between the amounts of a particular element in the waters and the corresponding levels in the algae samples. Except for calcium in *Chara* ($r = .719$ for 49 d.f.), *Pithophora* ($r = .582$ for 28 d.f.), and *Spirogyra* ($r = .650$ for 22 d.f.) and magnesium in *Pithophora* ($r = .498$ for 29 d.f.), r values were non-significant. In all genera there was a positive correlation between total hardness of the water and ash content of the plants.

Elevated accumulation of most elements occurred when samples of algae from waters of high concentration were compared to samples from water of low content of the nutrient in question, but the relationship did not hold for waters at intermediate levels.

Most samples were obtained from dense populations which practically filled relatively small ponds (0.25 to 10 acres). Therefore, at the time of sampling a large portion of the total available supply of most ions had probably been assimilated by the plants and the water sample was not a true appraisal of the nutrient states. Several studies have revealed a proportional increase in the concentrations of various nutrients in algal cells when the level of the particular nutrients was increased in culture media (Gerloff and Skoog, 1954, 1957, 1957a; Scott, 1943). For this reason the non-significant r-values are not very informative. It follows that the water analyses are of very limited value in assessing the fertility of small ponds, particularly during the major vegetative season. Analyses of bottom soils, water, and biota in conjunction with equilibrium rates between various phases of the system will be necessary to establish the level of availability of a particular element in an aquatic ecosystem. Further support for this thesis can be derived from the fact that chemical analyses of the waters during rapid decomposition of several algae populations did not reveal substantial increases in most elements; however, there was generally a twofold or greater increase in potassium and some increase in ammonium. Similar results were reported by Lawrence *et. al.* (1963) for studies in plastic pools. The failure of most elements to increase in the water is probably due to increased assimilation by other components of the existing biota and equilibrium of the mineralized elements with the bottom soils.

When compared to the normally expected values terrestrial vascular plants given by Jackson (1958) and Millar (1955), algae accumulate comparatively high levels of microelements. Vascular aquatic plants also have much higher levels of iron, manganese, zinc, and copper (Denton, 1966) and boron (C. E. Boyd unpublished data) than land plants. Aquatic plants are probably very dominant factors in both the minor element metabolism and the biogeochemistry of freshwater. The function of aquatic plants in the microelement dynamics of aquatic ecosystems should be a very fruitful area for further research.

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EFFECTS OF HYDROGEN SULFIDE ON CHANNEL CATFISH *(Ictalurus punctatus)*[1]

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ABSTRACT

The natural production of sulfides is responsible for poor channel catfish production in many acid lakes in Northeast Texas. The TLm of un-ionized hydrogen sulfide for channel catfish fry ranged from 0.8 ppm at pH of 6.8 to 0.53 at pH 7.8. At pH 7.0 the TLm of this gas is 1.0 ppm for fingerling catfish, 1.3 for advanced fingerlings and 1.4 for adult channel catfish. Small fish were also killed quicker when exposed to these concentrations. Maximum concentrations of hydrogen sulfide are produced in the spring. Channel catfish populations can be maintained by continued stocking of adult fish or by raising the pH with agricultural limestone, which in turn lowers the toxic un-ionized hydrogen sulfide.

INTRODUCTION

Fishery surveys of several lakes in Northeast Texas indicated that very few channel catfish (*Ictalurus punctatus*) were present even after repeated introductions of hatchery fish. When such impoundments were drained or treated with fish toxicants, only a few large catfish were found and in some cases none were recovered. An analysis of the chemical, biological and physical conditions of 53 area lakes indicated that

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[1] Contribution of Dingell-Johnson Project F-8-R, Texas