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Potential Phytoplankton Productivity of Three Iowa Streams[1]

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A series of experiments were conducted to test the hypothesis that the concentrations of suspended algal populations in central Iowa streams are not limited by nutrient concentrations. River water samples with their natural plankton populations were collected from the Des Moines River, Skunk River, and Squaw Creek and were cultured under controlled conditions without the addition of nutrients. In 23 of 24 experiments significant increases in algal chlorophyll *a* were found with an average replication factor of 14 times. The data indicate that nutrients are not limiting suspended algal densities in the streams. A second series of experiments indicated that nitrate concentrations of up to 20 mg/l nitrate-nitrogen did not inhibit algal growth in these river waters.
INDEX DESCRIPTORS: algal production, Iowa rivers, potamoplankton, water quality.

Previous research has established the importance of nitrogen and phosphorus as controlling factors of phytoplanktion density in lakes (Sawyer, 1947; Schindler, 1971). In streams, however, the role of these nutrients is less certain. Concentrations of phosphorus and nitrogen in Iowa streams are greater than in many eutrophic lakes (Kilkus, LaPerriere, and Bachmann, 1975), yet algal populations generally are smaller than might be expected. Various studies (Drum, 1964; Jones, 1972; Kilkus *et al.* 1975) have indicated that physical variables such as temperature, turbidity, drainage area, and flow volume may be more important than nutrients in controlling algal biomass in Iowa streams. Swanson and Bachmann (1976) developed a model of algal exports in Iowa streams based on the assumptions that the suspended algae arise from benthic populations, that the density of the suspended populations is determined by the rate of loss from the streambed and the amount of flow available for dilution, and that the algal populations are not nutrient-limited. This hypothesis is supported by significant correlations between the amounts of chlorophyll *a* being exported downstream and the areas of the wetted streambed upstream from the sampling points.

The primary objective of this study was to provide an experimental test of the hypothesis that the suspended algal populations in these central Iowa rivers are not nutrient-limited. The procedure was to incubate river water samples with their natural plankton populations under controlled conditions of light and temperature. If the size of the algal populations as measured by chlorophyll *a* concentration increased with time, this would be taken as evidence that nutrients were not limiting in the streams themselves. A second objective was to investigate the possibility that high nitrate concentrations sometimes found in these streams might be inhibiting algal growth. This is suggested by the finding that in individual streams increases in flow volume are accompanied by increases in nitrate concentrations (Kilkus *et al.*, 1975) and decreases in algal populations (Swanson and Bachmann, 1976). Nitrate inhibition was tested by incubating similar cultures in which various concentrations of nitrates were added for comparison with cultures with no additional nitrates.

MATERIALS AND METHODS

Samples were collected from 8 July through 8 August 1974 from three Iowa streams of different sizes (Table 1). The Des Moines River northwest of Ames, Iowa, is wide and meandering, with rock-rubble, sand, sand-gravel, and silt substrates (Drum, 1964; Gudmundson, 1969). The Skunk River at the sampling site consists of pools and riffles in a narrow, meandering channel, with gravel, sand, and silt substrates (Jones, 1972; Zimmer, 1972). Squaw Creek is a tributary of the Skunk River at Ames and has a similar substrate. The upstream watersheds are used primarily for row-crop agriculture.

Four samples were collected from each stream in 1974 (Table 2). Three 1800-ml portions were taken from each sample and were placed in 2-l Erlenmeyer flasks and incubated in an environmental chamber for 13-14 days at 24 C and a 12-hour photoperiod. Samples were mixed by using air stones. At 2-day intervals, the container walls were scraped to suspend attached algal cells, and a 50- to 200-ml subsample was taken for chlorophyll *a* measurement. Determinations were made by using the procedure of Richards with Thompson (1952) with modifications by Yentsch and Menzel (1963) using equations of Parsons and Strickland (1963). Samples and cultures also were analyzed for dominant algal genera.

The following chemical analyses were made on stream samples within 7 hours of collection. Nitrate-nitrogen (mg/*l*) was determined by using the cadmium reduction method described by Strickland and Parsons (1968). Total phosphorus (mg/*l*) was determined with the

Table 1. *Location of streams and sampling sites.*

Stream	Location	Drainage Area (km²)
Squaw Creek Story County	Brookside Park, Ames	505
Skunk River Story County	13th Street Bridge, Ames	816
Des Moines River Boone County	Old U.S. Highway 30 bridge	14,700

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Table 2. *Measurements of physical and chemical parameters of the streams on sampling dates with average initial chlorophyll* a *concentrations and concentrations on the 10th day of culture.*

Stream	Date	Flow m^3/s	Total Phosphorus mg/1	Dissolved Phosphorus mg/1	Nitrate Nitrogen mg/1	Silica mg/1	Chlorophyll *a* mg/m^3	
							Initial	10-day
Squaw Cr.	7/8/74	4.30	0.13	0.08	9.95	22	4	55
	7/18/74	2.18	0.12	0.10	6.95	24	9	126
	7/25/74	1.13	0.12	0.07	6.00	24	17	290
	8/1/74	2.55	0.21	0.15	2.55	13	24	174
Des Moines R.	7/12/74	50.13	0.17	0.08	3.83	13	121	262
	6/22/74	22.62	0.13	0.01	3.00	12	256	298
	8/1/74	23.02	0.20	0.00	0.73	8	198	234
	8/8/74	14.67	0.15	0.00	0.46	3	437	107
Skunk R.	7/8/74	4.30	0.18	0.11	9.55	21	5	809
	7/18/74	3.91	0.16	0.14	4.60	23	14	576
	7/25/74	2.10	0.16	0.12	7.23	21	27	76
	8/1/74	7.90	0.27	0.25	5.92	18	9	241
	7/7/75	14.81	0.20	0.19	10.83	34	9	52
	7/11/75	8.16	0.16	0.13	11.18	19	5	16
	7/15/75	5.21	0.14	0.10	10.97	20	5	62
	7/18/75	3.65	0.12	0.08	9.87	22	14	89
	7/21/75	2.63	0.10	0.04	8.93	19	41	141
	7/25/75	2.21	0.15	0.11	7.84	20	15	146
	7/29/75	1.19	0.11	0.08	6.24	18	17	85
	8/1/75	0.71	0.10	0.05	4.31	16	43	148
	8/4/75	0.42	0.10	0.04	6.70	16	45	151
	8/8/75	0.12	0.07	0.02	1.53	13	58	160
	8/13/75	0.20	0.11	0.07	0.45	10	108	122
	8/22/75	0.40	0.10	0.04	0.88	10	53	140

method described by Murphy and Riley (1962) after a persulfate oxidation (Menzel and Corwin, 1965). Total dissolved phosphorus (mg/*l*) was designated as the phosphorus remaining in the sample after being passed through a Millipore filter type HA and was determined by the same procedure as total phosphorus. Silica (mg/*l*) was determined by using the silicomolybdate method (Hach Chemical Company, 1967) with a Hach DR Colorimeter.

Turbidity (Jackson Turbidity Units, JTU) was measured with a Hach Laboratory Turbidimeter Model 2100. River water temperatures were taken with a mercury laboratory thermometer (range −20° C to 110° C). Weather conditions were recorded for one week preceding sampling and during the sampling period. Flow data were provided by the U.S. Geological Survey, Fort Dodge, Iowa, and Iowa City, Iowa.

In 1975, samples were collected from the Skunk River between 7 July and 20 August and incubated in a similar fashion, except that 500-ml portions were used, and chlorophyll *a* determinations were made only on the 10th day rather than over a series of days. For each experiment, KNO_3 was added to duplicate cultures in amounts necessary to bring the total nitrate-nitrogen concentrations up to 5, 10, 15, and 20 mg/*l*. Cultures containing unaltered river water were used as controls.

RESULTS

The data on the initial river samples and the unaltered cultures are presented in Table 2. An inverse relationship between flow and chlorophyll *a* concentrations in individual streams was noted, as well as a direct relationship between flow and nitrate concentrations. Concentrations of total phosphorus, dissolved phosphorus, and silica were unrelated to flow. This is consistent with previous studies. The largest stream, the Des Moines River, had the greatest average concentration of suspended chlorophyll *a*. Analysis by means of the paired t-test indicates that concentrations of silica, nitrate, and total dissolved phosphorus were significantly lower in the Des Moines River than in the two smaller streams ($P < 0.05$). This may represent consumption by the algal community.

Typical curves of chlorophyll *a* concentrations versus time in the cultures are shown in Figure 1. In most instances they displayed the sigmoid form characteristic of closed, static conditions, beginning either with a lag phase or with a period of slow growth and ending with senescence (Fogg, 1966). Exceptions were the second and fourth samples from the Des Moines River. One showed only a slight increase in density, and the other decreased throughout incubation. Maximum levels of chlorophyll *a* in culture were significantly greater than initial levels for the streams when considered both individually and collectively ($P < 0.01$).

Most of the cultures contained mixtures of diatoms such as *Navicula, Pinnularia, Gomphonema,* and *Stephanodiscus* as well as various green algae such as *Pediastrum* and *Ankistrodesmus*. In 1974, six of the 36 cultures developed large populations of *Scenedesmus*.

In most instances, the cultures reached their maximum chlorophyll concentration by the 10th day, and we used that value in our analyses of the data from the two summers. No statistically significant relationship

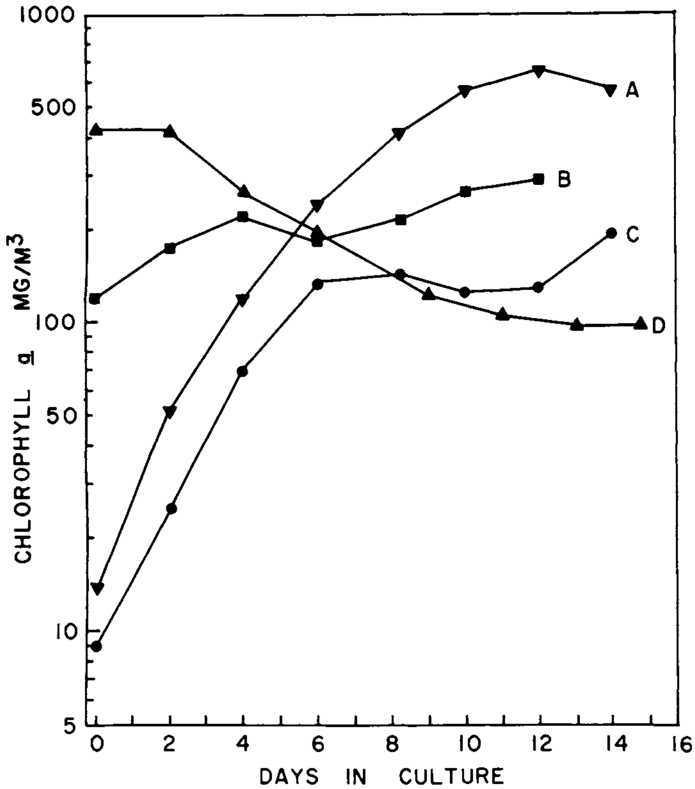

Figure 1. *Chlorophyll* a *levels in river water cultures for some representative experiments.* A. *Skunk River, 18 July 1974.* B. *Squaw Creek, 18 July 1974.* C. *Des Moines River, 12 July 1974.* D. *Des Moines River, 8 August 1974, the only culture without a net increase in chlorophyll* a.

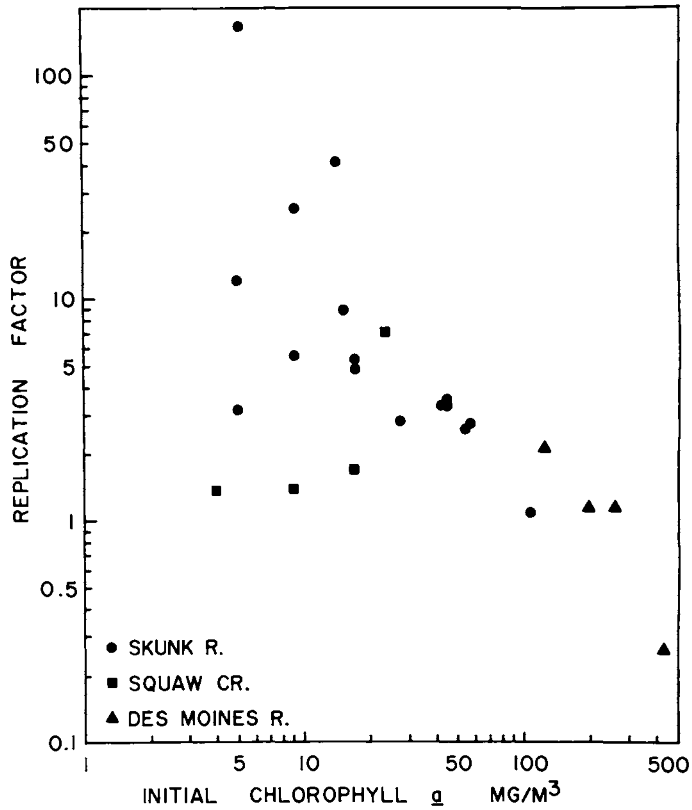

Figure 2. *Ratios of chlorophyll* a *concentrations on the 10th day of culture to the initial concentrations (replication factor) in relation to the initial concentrations.*

was found between the maximum chlorophyll *a* concentration attained and the concentrations of total phosphorus, filtered phosphorus, nitrate nitrogen, or silica concentration.

Another way of analyzing the data is to divide the chlorophyll *a* concentration on the 10th day by the initial concentration to arrive at a replication factor. These factors are plotted in Figure 2 against the initial chlorophyll a concentrations. There is a significant negative correlation ($r = -0.81$) between the Log of the replication factor and the Log of the initial concentration, indicating that cultures with greater initial algal densities showed less relative increase than those with lesser initial densities. This is in agreement with previous research (Pratt, 1940; Vollenweider, 1968). With the high nutrient concentrations found in these waters, growth-inhibiting substances, light, or space, seem more important than competition for nutrients in determining the maximum algal densities attained in culture.

In 23 of 24 experiments, the replication factor was greater than one. The average value was 14.4, with a standard error of 6.7. The single example with a decrease in chlorophyll *a* was from the Des Moines River in which the initial chlorophyll concentration was 437 mg/m^3, the greatest river concentration found in this study. The general conclusion is that these river waters contain sufficient nutrients to support algal crops several times larger than are found under natural conditions.

To analyze the experiments with the added nitrates, the final chlorophyll *a* concentrations of the cultures with added nitrates were divided by the concentrations of the control cultures without added nitrate. If nitrate is inhibitory, the values would be less than one. From Table 3 it can be seen that there is no inhibitory effect of added nitrates on the increase of chlorophyll *a* in culture.

Table 3. *Mean and 95% confidence limits for the ratio of chlorophyll* a *concentrations developed in cultures with added nitrates to the concentrations measured in control cultures.*

NO_3-N mg/l	N	Mean Ratio	95% confidence limits
5	4	1.23	±0.67
10	8	1.14	±0.20
15	12	1.06	±0.11
20	12	1.27	±0.26

DISCUSSION

Previous studies of algal densities and nutrient concentrations in central Iowa streams indicated that nutrients are present in excess amounts and are not controlling the phytoplankton levels. We have provided experimental verification of this hypothesis. When river water samples were brought into the laboratory and incubated without any additional nutrients, the suspended algal populations increased by an average of 14 times. This is strong evidence that nutrients are not limiting suspended algal densities under natural conditions.

These findings illustrate the differences between static and flowing systems. In Iowa lakes, the algal populations increase during the growing season and generally reach their maximum abundance in late summer. At this time their maximum level is determined by nutrient levels, particularly phosphorus (Jones and Bachmann, 1976). In the streams the water and nutrients are continually flowing through the system. The benthic algal populations continually have a fresh nutrient supply, and the suspended cells are not in the system long enough to deplete the nutrients and become nutrient limited.

It might be supposed that, if a river system were of sufficient length, the water in the lower reaches would have been in contact with the algal populations for long enough to allow for nutrient limitation. The lower levels of dissolved phosphorus, nitrate nitrogen, and silica found in the larger Des Moines River in comparison with the smaller Skunk River and Squaw Creek would indicate that such nutrient consumption is taking place. Replication factors in the cultures from the Des Moines River were less than those observed in water from the Skunk River and Squaw Creek, although the greater initial algal densities in the Des Moines River samples may also have played a role in restricting the amount of growth that occurred.

The experimental approach has clarified the relationship between algal and nitrate levels in these streams. Statistical analyses alone were not sufficient to separate the relationships between chlorophyll, nitrates, and volumes of flow because a combination of high nitrates and low flows did not occur in nature. This study indicates nitrate is not inhibitory to algal growth, and that the negative correlations observed between chlorophyll *a* and nitrate levels in field samples were the result of each of these variables being correlated with flow volume, a third independent variable.

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