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The Effect of Taconite Tailings on Primary Productivity in the Silver Bay Area of Western Lake Superior*

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Considerable concern has arisen over the possibility that the discharge of taconite tailings into Lake Superior could affect algal primary productivity. In 1972, primary productivity studies utilizing the carbon-14 technique were run in the Silver Bay area. Samples were collected and analyzed on a weekly basis for a three month period that included a five week plant shutdown period. Resultant productivity data indicate that there is no apparent relationship between primary productivity and the discharge of taconite tailings. Productivity trends in the Silver Bay area tend to conform to the known seasonal behavior of phytoplankton in western Lake Superior.

Introduction

Lake Superior, the largest of the Laurentian Great Lakes (31000 mi^2, 79000 km^2), has long had the reputation for being the most pristine of this lake system. Although there is relatively little known about the limnology of this particular water body, its distinction has been justified by those studies which have been done. Superior has been shown to be the most oligotrophic of the lakes, and, as Beeton (65) has concluded, has the highest transparency, lowest total dissolved solids, and lowest specific conductance of the five lakes.

In 1955 the Reserve Mining Company began operating an iron ore beneficiation plant in the Silver Bay area of western Lake Superior. Since then the company has been discharging taconite tailings directly into the lake at the rate of approximately 67000 tons a day. The potential multiple effects of this discharge on Lake Superior have generated considerable controversy which in 1969 culminated in the calling of the first Lake Superior Enforcement Conference. Although ostensibly concerned with pollution throughout the Superior basin, the conference focused its attention on the potential effects of the discharge of taconite tailings into the lake. Included in the conference's list of potential problems was the stimulation of algae by the tailings (U.S. Dept. of Interior, 69).

The potential effect of tailings on primary productivity was investigated in a thirteen-week analysis of primary productivity before, during, and after a plant shutdown. The carbon-14 technique was utilized to measure the changes in algal response to light, and the carbon-14 uptake was interpreted as a measure of primary productivity.

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Methods and materials

More than 950 water samples were collected at four depths during a study period lasting from July 13 to October 18, 1972. The sampling was conducted at five field sites in a fifteen square mile zone around Silver Bay (Fig. 1). This is the region where tailings discharge would be expected to have the most readily discernible effect on algal photosynthetic rates. Samples were collected in 4.2 liter nonmetallic Kemmerer samplers.

The procedure involved retrieving water samples from various light penetration depths in the photic zone and incubating the endemic populations. The sample collection depths (i.e., the depths to which 100, 50, 25 and 1 % of the ambient surface light penetrated the water) were determined with a modified Gemware Submarine Photometer System, Model No. 268WA310. The photocells used were matched Weston barrier layer cells with a spectral sensitivity approximating that of the human eye. Output currents from both photocells were balanced one against the other so that any changes in the intensity of the ambient sunlight would affect both to the same extent. Aboard ship the sample water was emptied into one-gallon plastic containers and transported to the shore laboratory in coolers.

The samples were shaken and distributed into sets of four 300 ml biochemical oxygen demand (BOD) bottles. Three of the four were inoculated with 500μl of carbon-14 bicarbonate solution (New England Nuclear) which had a concentration of five microcuries per milliliter and a pH of 9.5. Two of these three were designated "light" bottles and incubated at light intensity levels chamber contained the expected light and dark sections, but the light chamber was composed of four separate units. Each was covered with a different light attenuation screen to reduce the light to known fractions of the surface illumination, and the bottles were placed in the unit with the same light intensity as that at which they had been collected. In addition, the incubation chamber incorporated a continually flowing stream of lake water in order to maintain a temperature similar to that of the lake.

The samples were incubated for four hours (from 10:00 a.m. to 2:00 p.m.) and were then removed. Both during these incubations and on a daily basis solar insolation (Langleys/day) was recorded on a Yellow Springs Instrument Company Model 67 Integrating Pyranometer. After incubation the contents of the bottles were filtered through a prewashed 0.45 μm pore size millipore filter. The filter and filtering funnel were washed twice with 1% HCl solution. Then the washed filters containing phytoplankton and other particulate matter were put into small petri dishes and placed in a dessicator utilizing calcium sulfate as a drying agent. The filters were allowed to dry at least five days to insure that any excess moisture had been removed.

The filters containing the organisms were placed in glass scintillation vials and prepared for liquid scintillation counting. Each vial was filled with 20 ml xylene-based scintillation cocktail (Aquasol) purchased from New England Nuclear. Vials were counted for either 20 min or 100 000 counts, whichever came first, on a Nuclear Chicago Model 4534 Liquid Scintillation Counter. Counting efficiency was determined by the channels ratio method, and the counter itself was periodically calibrated with standards purchased from the manufacturer.

Corrections were made for time of counting and quenching, and the final amount of phytoplankton activity was determined by subtracting the "dark" bottle count from the mean value of the "light" bottle counts. The counts were then converted to the desired gravimetric units by used of the following proportionality equation:

$$\frac{\text{Amount of carbon-14 added}}{\text{Amount of carbon-14 fixed}} = \frac{\text{Amount of carbon-12 present}}{\text{Amount of carbon-12 fixed}}$$

The amount of stable carbon available (carbon-12) had been earlier calculated from alkalinity determinations by nomographic methods (APHA, 71). The amount of carbon fixed per solar day was determined through use of a correction factor (derived from the proportional equation of total solar insolation per day versus total insolation during the experiment).

Results

Average primary productivity values for all samples at all stations in the survey are shown in Fig. 3. The three month productivity trend was determined by averaging all values measured at all stations in a single day. A line of best fit was drawn through the productivity values to indicate the general productivity trend relative to the study time span and plant shutdown.

Table 1. Carbon-14 primary productivity study data — July 13, 1972 Total daily solar insolation (Langley's/day)

Sample station no.	Sample collection and incubation light levels (% transmission)	Mean productivity(μgC/1.d.)
1	100	1.81
	50	1.44
	25	5.02
	1	1.76
2	100	1.49
	50	2.42
	25	3.25
	1	2.44
3	100	1.20
	50	6.96
	25	12.09
	1	1.61
4	100	0.78
	50	2.17
	25	3.30
	1	1.69
5	100	1.00
	50	3.16
	25	*
	1	1.50

*Values rejected due to sample preparation error.

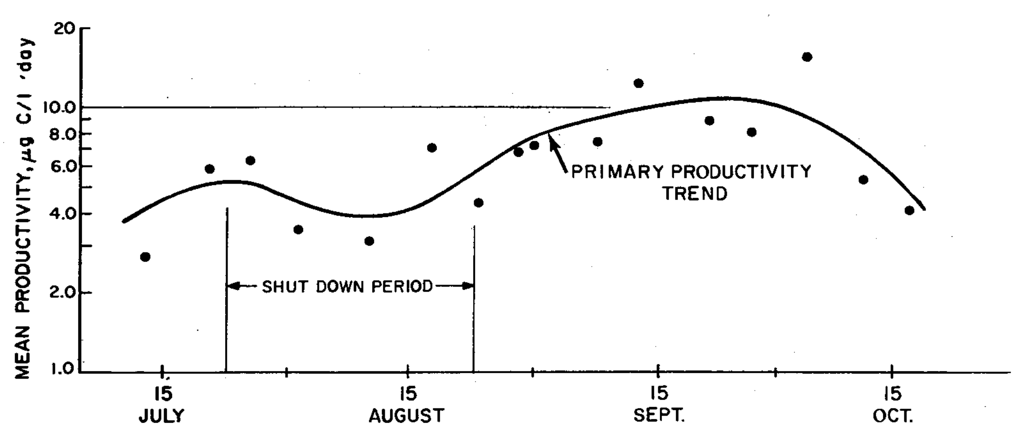

Fig. 3. Productivity in the Silver Bay area.

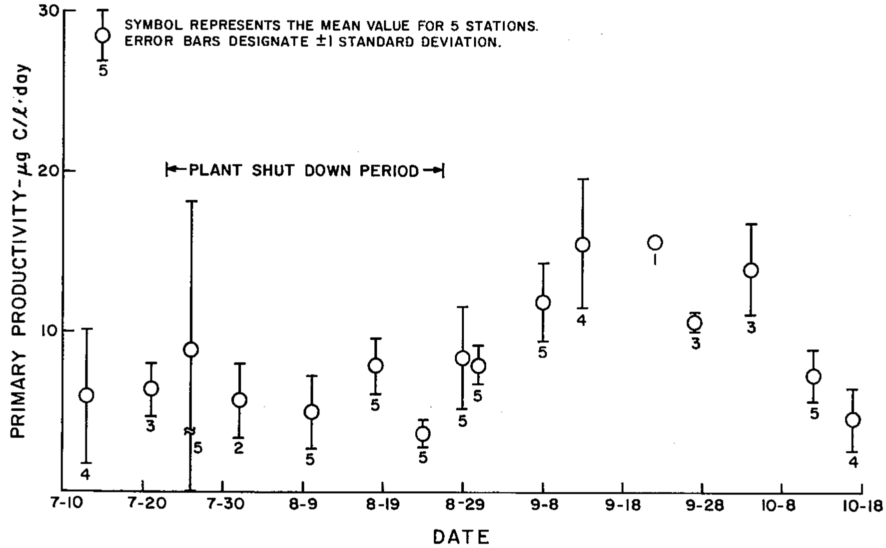

Fig. 4. Mean primary productivity for 25% light transmission samples.

In general, the productivity trend in the Silver Bay study indicates that algal photosynthetic activity remained relatively stable from mid-July to mid-August. It can be seen that at about that time a gradual increase in productivity began and lasted about 40 days, reaching its zenith in late September-early October. Thereafter, productivity showed a gradual decline which continued throughout the remainder of the study.

Table 1 presents the results obtained for July 13, 1972. The data presented in this table are typical of data obtained throughout the study. In general, these and subsequent results show the highest levels of primary productivity for the 25 and 50% light transmission samples. This is in accordance with expected results since surface inhibition of photosynthesis normally occurs in natural waters.

Figure 4 presents the results of the mean primary productivity in the Silver Bay region for the 25% light transmission samples. The error bars for each value represent ± one standard deviation of all samples taken at all stations at that depth (25% light transmission) for the sampling date. The results for this depth in general show the highest overall mean primary productivity and the least standard deviation.

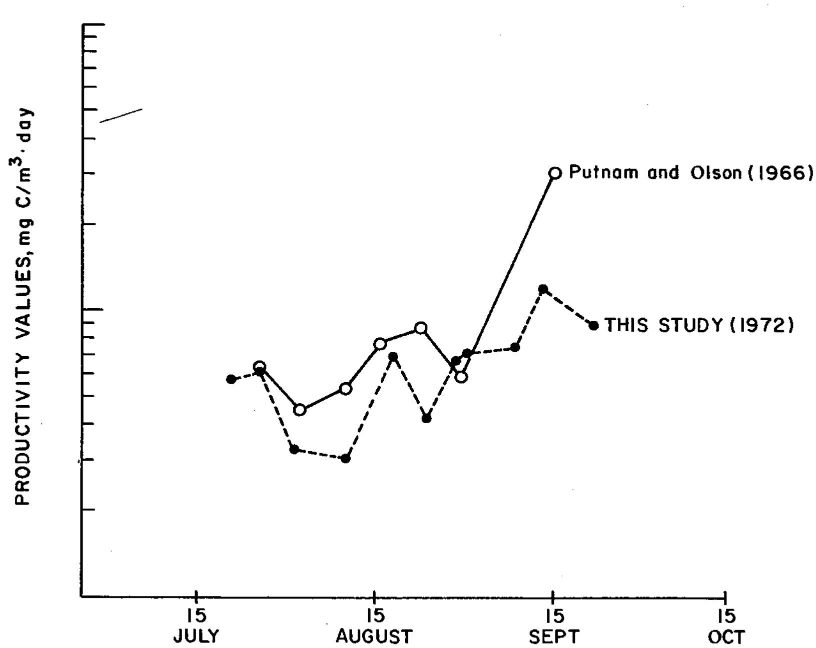

Fig. 5. Comparison of 1966 and 1972 primary productivity in the western arm of Lake Superior.

Discussion

Olson and his associates have previously conducted studies on primary productivity in western Lake Superior. Putnam (66) surveyed productivity during a period which coincided with the period of the current study. Although they took samples about 30 miles (50 km) from Silver Bay, as Fig. 5 shows, their results (plotted as the mean values for all samples down to 10 m) are similar to those for Silver Bay in 1972. They postulated that the high productivity values for mid-September might be indicative of the approach of a fall maximum. Both the 1966 and 1972 investigations show an increase in primary productivity in September.

If the discharge of taconite tailings was affecting primary productivity of phytoplankton in either an inhibitory or stimulatory way, then a noticeable increase or decrease in productivity should have accompanied the plant's shutdown, with an opposite reaction likely upon its reopening. As can be seen, this did not occur. Instead, the increase in productivity that began in mid-August (when no tailings were being discharged) was gradual, and it continued even after the plant resumed operations. During the latter part of the study (August 26 to October 18), productivity values in fact fluctuated despite the constant addition of tailings to the lake. Further, at all stations the maximum productivity occurred a full month after the plant reopened, and was followed by a sharp decline in October.

The data for primary productivity at the 25% incident light level (Fig. 4) also show that there is no apparent relationship between taconite tailings and primary productivity in the region of Silver Bay. The fact that the mean levels of primary productivity did not change from before to during plant shutdown, coupled with the fact that after the plant started operation again the primary productivity remained at essentially the same values as during the shutdown, supports the conclusion that the discharge of taconite tailings neither inhibits nor stimulates algal productivity in the Silver Bay area. Examination of algal seasonal cycles, and especially those in this particular body of water, would suggest that Silver Bay phytoplankton productivity trends correspond to expected seasonal behavior of algal populations.

The results of this investigation are supported by the studies of Plumb and Lee (74, 75), who found that the factor limiting algal photosynthesis in Lake Superior is the available phosphorus content of the water. They also found that the phosphorus present in taconite tailings was not available for algal growth.

In addition, the results of Meyer and Wheeler (73) support the conclusions from this investigation. They found that the numbers and types of algae in the Silver Bay region of Lake Superior were essentially the same as those found in other parts of the north shore of the western arm of the lake. This was true throughout the summer and fall periods.

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