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The Effect Of Bacterial Grazers On Phosphorous Cycling

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THE EFFECT OF BACTERIAL GRAZERS
ON
PHOSPHOROUS CYCLING

Submitted in Partial Fulfillment of the
Requirements for Graduation with Honors to the
Department of Biology at
Carroll College
Helena, Montana

Lynda Adyle Neff
March 24, 1981
SIGNATURE PAGE

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March 24, 1981
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ABSTRACT

The effect of grazers (protozoans) on the uptake of phosphorous by bacteria in streams was studied in artificial systems. Comparisons were made between systems with and without grazers. Grazers cause an initially faster uptake of phosphorous by bacteria. They depress the rate of phosphorous regeneration. In the presence of grazers, there are fewer bacteria, as indicated by a lower biomass. Applicability to natural systems is discussed.
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INTRODUCTION

Stream spiralling refers to the recycling of nutrients as they move downstream. Traditionally, it has been largely ignored in nutrient cycle studies. In more recent years, some work has been done in stream spiralling (Elwood and Nelson 1972, Gregory 1978, Cummins and Klug 1979). Specific work with the role of bacterial grazers in nutrient cycling has been limited to soil (Elliott et al. 1979, Anderson et al. 1979), marine (Johannes 1965, Lopez et al 1977, Gerlach 1978), and lake (Javornicky and Prokešová 1963, Barsdate et al. 1974, Fenchel and Harrison 1975, Fenchel and Jorgensen 1977, Fenchel 1977) ecosystems.

Bacteria constitute an important food source for free-living protozoa. Protozoa may be the most important consumers of bacteria in nature. They may constitute a significant link in food chains between bacteria and metazoans (Fenchel and Jorgensen, 1977). This paper is concerned with the effects of protozoans on the cycling of phosphorous by bacteria in streams.
LITERATURE REVIEW

Work done with nutrient cycling has shown that the primary decomposers consist of essentially bacteria and fungi (Fenchel and Harrison 1975, Fenchel and Jorgensen 1977). Bacteria have several properties that explain their dominating role as primary decomposers (Fenchel and Jorgensen 1977). There are bacterial enzyme systems that can efficiently hydrolyze structural plant compounds. Also, bacteria can utilize dissolved inorganic nutrients, e.g., \( \text{NO}_3^- \) and \( \text{PO}_4^{3-} \), while at the same time decomposing nutrient-poor plant tissues. The bulk of dead organic matter in nature consists of structural compounds of plant origin, especially carbohydrates. These are too poor in essential nutrients to sustain bacterial growth without the simultaneous assimilation of mineral nutrients from free water (Barsdate et al. 1974). Once the bacteria have assimilated these nutrients, they become available to bacterivorous or detritivorous animals.

The role of bacterial grazers in the bacterial assimilation of mineral nutrients has been viewed from several different angles. Javornický and Prokešová (1963) found that bacterial metabolism is kept at a higher level due to grazing by protozoa. It follows from this that bacterial mineralization
of the organic detritus is faster in grazed than in ungrazed systems. This was supported experimentally (Barsdate et al. 1974, Fenchel 1977, Gerlack 1978).

Protozoa tend to control bacterial biomass (Javornický and Prokešová 1963, Johannes 1965, Barsdate et al. 1974, Fenchel and Harrison 1975, Fenchel and Jorgensen 1977, Fenchel 1977, Elliott et al. 1979). This ties in with the phosphorous cycling by bacteria. Researchers have found a faster rate of uptake and regeneration of phosphorous in grazed systems versus ungrazed systems (Johannes 1965, Barsdate et al. 1974, Fenchel and Harrison 1975, Fenchel 1977, Gregory 1978, Elliott et al. 1979). According to Fenchel and Harrison (1975) this is the result, not the cause, of a higher bacterial growth rate in grazed relative to ungrazed systems. Barsdate et al. (1974) support this when they say that, in ungrazed systems, bacteria have a high demand for phosphorous of which they release very little.
MATERIALS AND METHODS

Uptake of $^{32}$P$_4$

The coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), and water were taken from the west branch of the Walker Branch watershed on the Department of Energy's Oak Ridge Reservation in eastern Tennessee. All water was filtered using Whatman glass microfibre filters on a vacuum filtration system. The CPOM was in the form of one-inch discs out of large oak and maple leaves. The bacteria and protozoans used were those already on the CPOM and FPOM removed from the stream.

To measure the uptake of $^{32}$P$_4$, ten microsystems were set up in the dark in a Kysor Sheror growth chamber at 10°C. Fig. 1 illustrates the laboratory apparatus for the individual microsystems. Table 1 illustrates the composition of each of the ten microsystems.

To the sterile systems, 6.5 ml. of formalin were added, giving a concentration of 0.5%. This killed all living organisms in these systems.

For those systems without grazers the CPOM, FPOM, and water were pasteurized. The pasteurization basically followed the guidelines of Javornický and Prokešová (1963). The water was heated to 50°C and held there for five minutes.
Fig. 1. Laboratory apparatus for the uptake of $^{32}\text{PO}_4^-$. Ten of these systems were in a dark Kysor Sherof growth chamber maintained at $10^\circ\text{C}$. 

Stream Water

170X90 mm.
Fyrex Dish

Magnetic Stirring Rod

Fyrex Petri Dish

FFON, loose

Leaf Disc

Stirrer
Table 1. Composition of the ten microsystems used to study the uptake of $^{32}\text{P}O_4$ by bacteria. The grazers are protozoans.

<table>
<thead>
<tr>
<th></th>
<th>0.5% formalin</th>
<th>$H_2O$</th>
<th>Pastuerized</th>
<th>Pasteurized Reinoculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_2O$ only</td>
<td>Control Sterile</td>
<td>Control Live</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 1-inch leaf discs</td>
<td>CPOM Sterile</td>
<td>CPOM Live</td>
<td>CPOM w/o grazers</td>
<td>CPOM w/ grazers</td>
</tr>
<tr>
<td>FPOM barely cover bottom of dish</td>
<td>FPOM Sterile</td>
<td>FPOM Life</td>
<td>FPOM w/o grazers</td>
<td>FPOM w/ grazers</td>
</tr>
</tbody>
</table>
This kills protozoans to give a bacterial system free of grazers. A major departure from the guidelines was in the apparatus used. An open waterbath was used as illustrated in Fig. 2.

After pasteurization, systems with grazers were reinoculated with a small amount of untreated FPOM. For twenty-four hours, the systems were allowed to readjust to the various treatments and to the growth chamber. Before being spiked (addition of a tracer), the reinoculated CPOM was placed in a separate system from the inoculum. The systems were spiked with $1.6061 \times 10^6$ DPM (decays per minute) of $^{32}$P. The systems were then sampled for $^{32}$P activity in the water. The following sampling intervals were used: 5 minutes, 1 hour, 2 hours, 4 hours, 8 hours, and 24 hours. Further sampling and further use of these microsystems was impractical due to an increased temperature in the growth chamber. After twenty-four hours the temperature increased to 35-38°C for over thirty-six hours. I decided that further work with these systems would be questionable due to wall growth (algae) and protozoan kill. For each of the samples, 5 ml. of water was removed with a syringe. A Whatman GF/C glass microfibre filter was then attached. The sample was then filtered under pressure into a small beaker. One milliliter of this was mixed with 10 ml. of Instagel and counted in the scintillation counter.

For the uptake of $^{32}$PO$_4$, one sample of each of the ten systems was taken at each sampling time. The uptake parameter
Apparatus for pasteurization.

A. The pasteurization of FPOM (fine particulate organic matter) and CPOM (coarse particulate organic matter).

B. The pasteurization of stream water.

The systems were heated to 50°C for five minutes. This kills protozoans to give a bacterial system free of grazers.
was done twice. The results from the first trial were rejected because the system heated up to approximately 27°C before it was spiked. During sampling, it again warmed up.

Regeneration of $^{32}P_O_4$

The FPOM and CPOM used for this parameter were taken from the first time the $^{32}P_O_4$ uptake was done. Three samples of CPOM from each of the sterile, live, pasteurized and reinoculated systems were removed from the microsystems and placed in an artificial stream. The same was done with two samples each of the FPOM and the live and the pasteurized systems. The CPOM was placed in nylon mesh bags and anchored with rocks on the edge of the bags. The FPOM was placed in 10 ml. beakers and set on the bottom of the stream.

The $^{32}P$ on the leaf discs was counted using a Geiger-Mueller counter. Counting was done on one side of the leaf discs through the nylon mesh bags. At the same time, 1.0 ml. samples were taken from the FPOM. These samples were dried, weighed, ashed, reweighed and then digested in concentrated hydrochloric acid. Samples of 1.5 ml. were mixed with 15 ml. of Instagel and counted in the scintillation counter.

**ATP Content**

The ATP content was measured from FPOM and CPOM with and without grazers from non-spiked systems. These systems were part of the first time the $^{32}P_O_4$ uptake work was done. One
disc of CPOM or 1 ml. of FPOM was mixed with 0.1 ml. trans-NRB. Trans-NRB removes the ATP from the live cells. The samples were then frozen for later analysis.

For analysis, a one-in-ten dilution of the sample solution was done with Lumac buffer to give a pH of approximately 7.6. I then added to 0.5 ml. of this solution 0.5 ml. of NRB. 0.2 ml. was spiked with 0.02 ml. of 0.1 ppm ATP. The comparison of the readings from these was used to determine the ATP content of the original samples. The measurement of ATP content was done with a Lumac Celltester M1030.

After the ATP analysis was done, the FPOM and CPOM samples were dried overnight at 80°C. Then the samples were weighed. There were three samples from each of the four systems analyzed.
RESULTS

Uptake of $^{32}\text{PO}_4$

The results from the uptake of $^{32}\text{PO}_4$ are shown in Figs. 3 and 4. They have been corrected for loss due to filtering and decay. They indicate how much $^{32}\text{P}$ (DPM/ml.) was left in the water after the indicated time. The difference between the initial concentration of $^{32}\text{P}$ and the amount in the water at a given time is assumed to be the amount taken up on the CPOM and FPOM. It is taken up either through assimilation by bacteria or by absorption on the surface of the detritus.

Regeneration of $^{32}\text{PO}_4$

Fig. 5 is the linear regression (see Appendix) for the results of the release of $^{32}\text{PO}_4$ from CPOM. The results are in DPM/ml. corrected for decay. These results indicate how much is left on the leaf discs. From these results the estimated turnover time, in days, is calculated. Table 2 shows these results. Table 3 shows the average concentrations of $^{32}\text{P}$ at equilibrium. The terms "fast compartment" and "slow compartment" refer to relative rates of release of $^{32}\text{P}$. In Figs. 5 and 6, the fast compartment is represented by the steeper slopes at the beginning of the curves. The
Fig. 3. $^{32}$PO$_4$ uptake from water with FPOM. The results reflect the activity left in the water after the indicated time since spiking with $1.6061 \times 10^6$ DPM of $^{32}$P. They are corrected for loss in filtering and decay.

*Initial concentration $^{32}$P
Fig. 4. $^{32}\text{P}_4$ uptake from water with CPOM. The results reflect the activity left in the water after the indicated time since spiking with $1.6061 \times 10^7$ DPM of $^{32}\text{P}$. They are corrected for loss in filtering and decay.

*Initial concentration $^{32}\text{P}$
Fig. 5. $^{32}$P release from CPOM in the artificial stream: total concentration. The $^{32}$P was counted with a Geiger-Mueller counter. The results are corrected for decay.
Table 2. Estimated turnover times of phosphorous from CPOM in an artificial stream. These results are calculated from $^{32}$P release data over a period of fourteen days.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(Turnover Time (days))</th>
<th>Fast Compartment</th>
<th>Slow Compartment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterile</td>
<td></td>
<td>0.57</td>
<td>13.0</td>
</tr>
<tr>
<td>Live</td>
<td></td>
<td>1.21</td>
<td>18.2</td>
</tr>
<tr>
<td>Pasteurized</td>
<td></td>
<td>1.07</td>
<td>10.1</td>
</tr>
<tr>
<td>Pasteurized-Reinoculated</td>
<td></td>
<td>1.02</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Table 3. Mean concentrations of $^{32}$P for CPOM at equilibrium. These results are calculated from $^{32}$P release data over a period of fourteen days.

| Treatment               | Fast Compartment | Slow Compartment |
|                        | dpm $^{32}$P/mg | AFPM % of total | dpm $^{32}$P/mg | AFPM % of total |
| Sterile                | 86              | 60               | 56              | 40               |
| Live                   | 127             | 25               | 381             | 75               |
| Pasteurized            | 697             | 72               | 268             | 28               |
| Pasteurized-Reinoculated| 774             | 65               | 422             | 35               |
Fig. 6. $^{32}$P release from CPOM in the artificial stream: percent initial concentration. The $^{32}$P was counted with Geiger-Mueller counter. The results are corrected for decay.
turnover rate of phosphorous is more rapid in this compartment. The slow compartment is represented by the less steeply sloped part of the curves. Here, the turnover rate of phosphorous is slower. The cut-off point between fast and slow compartments is derived from the exponential model used for the linear regression (see Appendix).

Fig. 6 is a graph of the percent initial concentration of \( ^{32}P_O_4 \) left at each reading.

Table 4 shows the results from the regeneration of \( ^{32}P_O_4 \) from the FPOM. The results are in DPM/ml. corrected for decay.

**ATP Content**

Table 5 shows the results of the ATP analysis. These results are averages of three samples.
Table 4. $^{32}\text{P}$ release from FPOM in the artificial stream. The results are in DPM/mg. FPOM. These results are corrected for decay from the time the FPOM was placed in the stream.

<table>
<thead>
<tr>
<th>Time In Stream (days)</th>
<th>FPOM w/o grazers</th>
<th>FPOM w/ grazers</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3250</td>
<td>3797</td>
</tr>
<tr>
<td>1</td>
<td>3853</td>
<td>1885</td>
</tr>
<tr>
<td>2</td>
<td>1295</td>
<td>2192</td>
</tr>
<tr>
<td>3</td>
<td>2917</td>
<td>2192</td>
</tr>
<tr>
<td>4</td>
<td>2468</td>
<td>3410</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1351</td>
<td>1352</td>
</tr>
<tr>
<td>11</td>
<td>1744</td>
<td>1385</td>
</tr>
<tr>
<td>14</td>
<td>2154</td>
<td>692</td>
</tr>
<tr>
<td>16</td>
<td>731</td>
<td>1391</td>
</tr>
<tr>
<td>18</td>
<td>705</td>
<td>1301</td>
</tr>
</tbody>
</table>
Table 5. ATP content of CPOM and FPOM with and without grazers. This was measured using a Lumac Celltester M1030. Each value is an average from three samples.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>ATP Content (mg. ATP/mg. dry weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPOM w/ grazers</td>
<td>0.124</td>
</tr>
<tr>
<td>CPOM w/o grazers</td>
<td>8.86</td>
</tr>
<tr>
<td>FPOM w/ grazers</td>
<td>2.48</td>
</tr>
<tr>
<td>FPOM w/o grazers</td>
<td>4.74</td>
</tr>
</tbody>
</table>
DISCUSSION AND CONCLUSIONS

Uptake of $^{32}\text{PO}_4$

The results for $^{32}\text{P}$ uptake on CPOM and on FPOM appear to be the reverse of each other. The CPOM without grazers, as compared to the CPOM with grazers, has a faster initial uptake, with less total uptake. The FPOM with grazers, as compared to the FPOM without grazers, has a faster initial uptake, with less total uptake. I think the best possible explanation for this anomaly is in the method of reinoculation. The reinoculated CPOM system was totally dependent on grazers moving from the untreated FPOM to the pasteurized CPOM before the CPOM was transferred. The inoculum remaining in the reinoculated FPOM system would also be taking up $^{32}\text{P}$. In the CPOM system, therefore, the grazers may have been at a very low concentration. In the FPOM system, the untreated inoculum provided grazers at a high concentration. The same kind of reasoning may be used in regard to the bacterial population, which may have been reduced by the pasteurization. Then time must be allowed for bacterial growth as well. This reasoning especially makes sense in light of the fact that the CPOM without grazers and the FPOM without grazers both followed the same pattern in the uptake of $^{32}\text{P}$. Since the inoculum remained with the
reinoculated FPOM, grazers may be assumed to be present.

On this basis, I will make my conclusions regarding the uptake of phosphorous based on the FPOM results. In the presence of grazers, the initial uptake of phosphorous is faster. The final uptake of phosphorous is actually less. This may be explained in the following way. Initially, the bacteria take up phosphorous. Then the grazers consume the bacteria, leaving room for more bacteria to grow. The new bacteria take up more phosphorous. Eventually, this growth of new bacteria reaches an equilibrium. The ungrazed do not reach this equilibrium. The continual growth of new bacteria keeps taking up more phosphorous. This continues even after the grazed bacteria have reached an equilibrium in their uptake.

Regeneration of $^{32}\text{PO}_4$

The irregularity of the results from the release of $^{32}\text{P}$ from FPOM (see Table 4) makes interpretation difficult. The small size of the samples and the amount of time involved in processing them resulted in very low counts of $^{32}\text{P}$. Such low counts led to the probability of large error.

Table 2 shows that the presence of microbes (non-sterile treatments) slows down the turnover rate of phosphorous. In Table 3 it may be noted that the equilibrium concentration of phosphorous is lower for the sterile system. The results from the live and pasteurized-reinoculated systems should have been the same. There are several possible reasons for
them not being the same. One is that the pasteurization process may have altered the CPOM in some way so that the phosphorous turnover was affected. Another is that reinoculation was not successful. The latter possibility is more likely. Visual assessment of Figs. 5 and 6 show that the pasteurized-reinoculated CPOM acts like the pasteurized CPOM. This is confirmed by the turnover times (Table 2) and the average concentrations of $^{32}\text{P}$ at equilibrium (Table 3). There are two significant differences between the sterile CPOM and either the pasteurized or the pasteurized-reinoculated CPOM. This indicates that bacteria are still present after pasteurization.

Therefore, I think it would be legitimate to compare the live CPOM with the pasteurized CPOM. There is a significant difference between these two groups. The turnover rate is faster on ungrazed (pasteurized) than on grazed (live) CPOM. For grazed CPOM there is more phosphorous in the slow compartment. For ungrazed CPOM there is more phosphorous in the fast compartment. This indicates that the grazers play some part in keeping phosphorous on the CPOM. This may be due to bacteria not having a chance to release their phosphorous after death when grazers are present. Without the grazers, the bacteria die before they are consumed. Then they release their phosphorous to the surroundings.

**ATP Content**

ATP is found only in live systems. Its presence is
related to the biomass through a standard curve. This standard curve is different for different organisms. For my work, the ATP content was used as a guide to the relative biomass of bacteria.

The results from the ATP analysis show that systems without grazers have more bacteria in them than those with grazers. This could be due to grazers keeping down the bacterial population. Where there are no grazers to control their numbers, the bacterial population keeps growing. This unlimited growth would give rise to more microbes than in a system controlled by grazers.

**Nutrient Cycling**

My research has shown that grazers (protozoans) very plainly affect the cycling of phosphorous by bacteria. The indication is that they increase the rate of uptake. They also increase the retention time. At the same time, grazers tend to limit the numbers of bacteria.

I think that these results may be extended to include other nutrients. Only further research can prove this one way or the other.

This research was done in artificial systems. The uptake of phosphorous and the ATP analysis were done in closed systems with a current. This means that what moves out of a compartment may have a chance to come back to the same compartment. This is opposed to an open system where once a nutrient moves it is highly unlikely to return to the same
position. Therefore, further research is necessary to determine whether an open system (a stream) will give the same results. Regeneration of phosphorous was measured in an artificial stream (open system with a current). The results should be close to findings in a natural stream. All areas of this study need to be repeated in a natural stream in order to apply the results to stream spiralling.
APPENDIX

Exponential model to which the $^{32}\text{P}$ retention data for CPOM were fit

$$A_t = A_1 e^{-k_1 t} + A_2 e^{-k_2 t}$$

where $A_t$ is the amount of $^{32}\text{P}$ on the CPOM at time $t$, $A_1$ is the initial amount of $^{32}\text{P}$ in the fast component, $A_2$ is the initial amount of $^{32}\text{P}$ in the slow component, $k_1$ is the turnover rate of phosphorous in the fast component, and $k_2$ is the turnover rate of phosphorous in the slow component.
LITERATURE CITED


