INTERNAL REPORT 131

PHOSPHORUS CYCLING DURING THE STRATIFIED PERIOD IN LAKE SAMMAMISH

Eugene B. Welch and Dimitri E. Spyridakis
Department of Civil Engineering
University of Washington

September 1974

INTERNAL REPORT 131

PHOSPHORUS CYCLING DURING THE STRATIFIED PERIOD IN LAKE SAMMAMISH

Eugene B. Welch and Dimitri E. Spyridakis
Department of Civil Engineering
University of Washington

ABSTRACT

A steady-state phosphorus cycle was determined for the stratified period May to November in Lake Sammamish, Washington. A steady-state condition for this period is considered at this time since data on some important processes are only sufficient to estimate average values for the stratified period. Nevertheless, such a cycle is instructive in indicating the relative magnitude of recycling to maintain productivity in the epilimnion and associated turnover rates.

PROCEDURES

Assumptions about the significance of some processes have been incorporated with extensive as well as superficial data on other processes. The values used and associated assumptions will be described.

Phosphorus inflow to the lake was derived by taking one-half the annual values determined by monitoring flow and concentration in 13 tributary streams during 1970-1971. The inflow rate for the period May - November was 1.65 mg/m^2 day. Of that total P supply, 25% was dissolved and 50% of the remainder was considered refractory and would therefore permanently sediment from the surface waters. Monitoring of the outflow stream for the same period showed that rate to be about 20% of the inflow rate. Thus the outflow was 0.3 mg/m^2 day.

Measurement of the phosphorus increase in the hypolimnion during the stratified period allowed an estimate of release rate from the sediment - 4 mg/m^2 day. Mean total phosphorus content in the hypolimnetic pool was 30 µg/l, while mean dissolved inorganic phosphorus (PO_4-P) in the epilimnion was 7 µg/l. PO_4-P was used as the pool size in the epilimnion because it is the available form for the phytoplankton.

Mean biomass of phytoplankton and zooplankton were determined to be 7.1 µg/l chl a and 350 µg/l wet weight, respectively. The value for zooplankton was derived from mean values for the total water column, which were then converted to that for the epilimnion considering a concentration factor of two times the water column value.

Mean net phytoplankton productivity was about 900 mg C/m^2 day. This was assumed to be proportional to the uptake rate of PO_4-P. Zooplankton food consumption rate was assumed to be about 50% of phytoplankton productivity. This was determined from two in situ experiments in which the rate of removal of ^{14}C-tagged phytoplankton was observed. Consumption of herbivorous zooplankton by secondary consumers was assumed to be 20% of net zooplankton production.

Respiration rate of zooplankton was measured directly by T. Packard (pers. commun.) using an electron transport technique. A mean of three observations and corrected for the approximate mean density of animals present gave a value of 0.01 x 10^{-3} mg O_2 per animal per hr. Mean experimental temperature was 8.8°C while the period mean was 16.1°C. Correcting for mean temperature and animal concentration gave a value of 1.15 mg O_2 per m^3 per hr (about 2 g per m per day) in the epilimnion. Phytoplankton and bacterial respiration were measured together; 3.5 mg O_2 per m^3 per hr as a mean in the epilimnion. Phytoplankton respiration was assumed to be 10% of gross productivity and was also corrected for temperature (about 3.5 g per m per day). The remainder was considered to be bacterial respiration from decomposing phyto- and zooplankton originated organic matter which is proportional to the assimilation rates of the two groups.

All these values, most of which are mean concentrations, were extrapolated to areal epilimnetic values by multiplying by 10. The mean depth of Lake Sammamish is 17.7 m and the mean depth of the epilimnion, for convenience, is considered about 10 m. Values in units other than P were converted considering that on the average P is about 1% of dry weight, 2% of carbon, 0.7% of oxygen, and equal to chl a. Dry weight of zooplankton is assumed to be 10% of wet weight.

The final process considered is the release and recycling of P from the plankton through cellular excretion and autolysis of particulate matter. These two processes are lumped together for convenience and are considered to be 50% of assimilation by the plankton and to occur following respiration loss and zooplankton consumption. Autolysis, in sterile media, has been shown to contribute a large fraction of regenerated P in a short time. Although 50% may result in an underestimate of this process, it may be adequate for a first approximation of both processes.

RESULTS AND DISCUSSION

The flow diagram of P movement in Lake Sammamish during the stratified period is shown in Figure 1. There are several points of interest to note as well as certain limitations to point out.

The principal objective of this exercise was to estimate the fraction of the P supply rate to phytoplankton that is regenerated within the epilimnion. This value is 84%. Of the P assimilated by phytoplankton about 16% is sedimented to the hypolimnion or lost in the outflow. To make up this loss rate from the epilimnion, 5% of the phytoplankton requirements will come from inflow leaving a remaining 11% to come from some unknown source.

Vertical movement through the thermocline is considered insignificant and loss rate from aerobic littoral sediments has been suggested to be slow (Fitzgerald 1970); however, storms may cause intensive mixing that erodes away at the thermocline causing a limited vertical movement of P. Golterman (1972) discussed the significance of particulate P mixed vertically in shallow water as a source for phytoplankton. Although the rate of P release from aerobic sediments (the littoral in Lake Sammamish) is slow it is a source which depends upon the rate of mixing. Thus, slow release from littoral sediment, including newly settled detrital matter, together with vertical migration through the thermocline by means of wind-caused mixing and vertical migration of zooplankton are the probably sources for the deficit P requirement - in this case 11% (2.4 mg per m^2 per day).

If the loss from phytoplankton and zooplankton originated detritus (including fecal pellets) by autolysis is greater than 50% as assumed, then sedimentation of P will be less than 16% which necessarily reduces the deficit value to less than 11%. This may be the case since Golterman cited his earlier work in which 50% of particulate P was solublized under sterile conditions in a few hours. Johannes (1968) cited eight literature sources in which an average of 70% of the required P for daily phytoplankton productivity was supplied by regeneration from live zooplankton which would include respiration. Zooplankton are no doubt very important in recycling P in Lake Sammamish.

The rate of phytoplankton consumption by zooplankton may be too high since it represents a biomass turnover rate of about 1.3/day. Although zooplankton can grow that rapidly, it is unlikely their mean rate would be that high. The feeding rates used may not be representative of the entire period, but they were all that were available.

A phytoplankton turnover rate of 0.3/day is very realistic, however. It turns out that the P turnover rate is the same. Golterman (1972) cites results by Rohde and others of 0.07-0.14/day, much slower than that suggested in Lake Sammamish. Such rapid turnover rates suggest that regeneration in the epilimnion accounts for P retention and the deeper the epilimnion the greater the opportunity for regeneration and hence reduced losses to the hypolimnion.

The problem remains one of partitioning the rates of regeneration and defining the quantity sedimented on a dynamic basis. Determination of sedimentation rates now in progress will allow more accurate estimates of transport rates from the hypolimnion and littoral to the pelagic epilimnion by difference.

REFERENCES

FITZGERALD, G. P. 1970. Aerobic lake muds for the removal of phosphorus from lake waters. Limnol. Oceanogr. 15:550-555.

GOLTERMAN, H. L. 1972. Vertical movement of phosphate in fresh water. TNO Rev. 27:96-101.

JOHANNES, R. E. 1968. Nutrient regeneration in lakes and oceans. Adv. Microbiol. Sea 1:203-213.

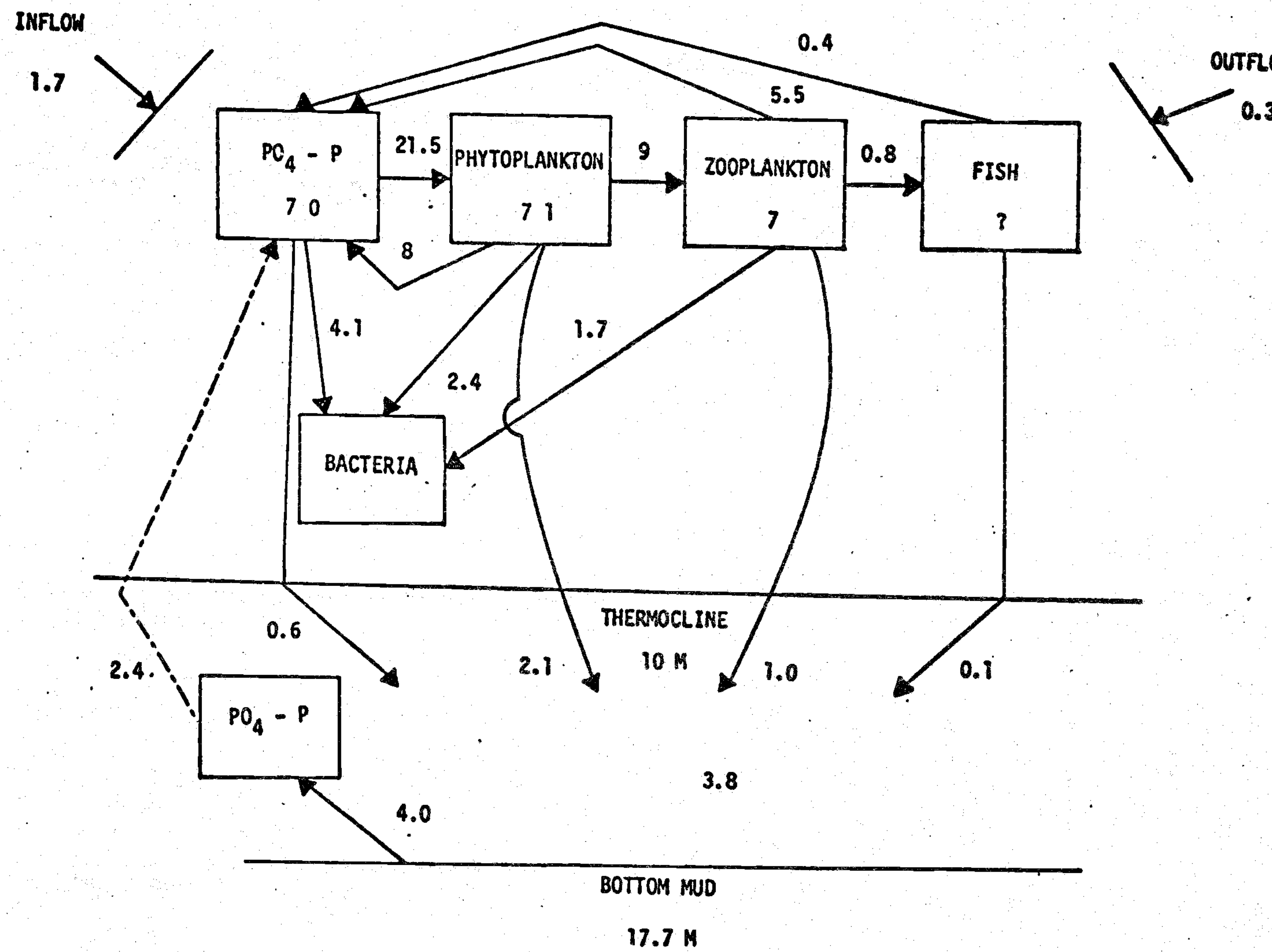

Figure 1. Steady-state P cycle in Lake Sammamish, Washington, during May-November (stratified period) using data for that period during 1970-1972. Transfer rates in milligrams per square meter per day and biomass or pool sizes in milligrams per square meter (84% P recycled, 11% P hypolimnien, 5%¢P inflow).