Sediment raking as a tool for enhancement of phosphate and productivity of water in tropical pond system

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Abstract
Changes of orthophosphate in water, induced by raking of surface sediment in various ways, were compared. Twelve limnocorals were installed in a shallow mesotrophic pond using four treatments with triplicate replication: (1) raking of surface sediment (R) by means of a rake for 5 min per week (2) fish (F), by introducing six common carp and two silver carp per limnocorral, (3) raking plus fish (R+F) and (4) control (C), without raking and fishless. After day 122, treatments were reversed in limnocorals by removing (netting) or introducing fish and stopping or initiating raking. Samples of water and sediment were collected from each limnocorral at weekly interval and monitored for orthophosphate (OP), primary productivity, phosphate solubilizing bacteria (PSB) and sediment available phosphorus. Raking in presence of fish caused 280 and 160\% increase in OP concentrations in surface and bottom water, respectively, as compared with raking in absence of fish. Net effects of fish and raking were 13–81 and 26–241\% in surface water and 48–100 and 46–95\% in bottom water. This implied that in bottom water, net raking effect was 13–161\% greater than net fish effect. Increase in PSB population, due to raking plus fish (R+F) was 6–82\% higher than increase by fish alone (F). Responses of available-P in sediment were opposite to that of water, being highest in concentration in control (C) followed by fish (F), raking (R) and raking plus fish (R+F). The primary productivity showed variations parallel with that of orthophosphate of water. This suggests that raking accelerated the transformations of available-P from sediment to overlying water mediated through oxygen-dependent sediment water exchange mechanisms.

Introduction

Pond sediment performs several important functions serving as buffer to stabilize environmental conditions of the pond ecosystem. It is known that bottom mud of eutrophic waters acts as sink in phosphorus, whereas it acts as a source of P to the overlying water in oligotrophic system (Pomeroy et al., 1965; Boyd, 1982). As phosphorus equilibrium between water and sediment is largely regulated by the biological uptake process, it is likely that more phosphate would be released from the sediment to the overlying water if this equilibrium is disturbed (Boyd, 1995). Kimel & Lind (1970) showed that as much as 90\% of the orthophosphate (OP) added to undisturbed sediment water system was absorbed by sediment within 4 days. Clearly the phosphorus absorption capacity of the sediment is dependent upon the initial P content (Shrestha, 1994). Tracer studies with $^{32}$P (Hayes & Philips, 1958) indicated that phosphorus equilibrium patterns were basically similar in
various types of soils (Olsen, 1958; Eren et al., 1977).

Sedimentation, adsorption or precipitation, chemical transformation and phosphorus uptake are some of the mechanisms for phosphorus dynamics in natural waters (Williams & Mayer, 1972; Bostrom et al., 1988; Wetzel, 2001). Exchanges of phosphorus across the sediment water interface are mainly influenced by pH, redox potential, ion exchange, oxygen tension, iron concentration, etc. It has been demonstrated that in all but the upper few millimetres of the sediment, exchange is controlled by motions on molecular scales with correspondingly low diffusion rates (Wetzel, 2001). Water soluble P is transformed into less soluble or insoluble forms in sediment as the ions bind to various soil solid phases (Morel et al., 1989). In anaerobic sediment, iron, aluminium and calcium are slightly soluble, whereas in the oxidized state phosphorus ions are absorbed on colloidal ferric hydroxide and precipitated in the bottom. In acidic soils, inorganic phosphorus reacts with iron and aluminium to form highly soluble compounds, iron phosphate (FePO$_4$ \cdot 2H$_2$O) and aluminium phosphate (AlPO$_4$ \cdot 2H$_2$O) (Boyd, 1995). Apart from influence of physico-chemical factors, the biota occurring in the bottom of natural waters impart in exchange processes between water and sediment through bioturbation (Zicker et al., 1956; Lamarra, 1975; Anderson et al., 1978; Keen & Garliardi, 1981; Jana & Sahu, 1994; Das & Jana, 1996).

Tropical water bodies are unique systems that differ from temperate ones in terms of shallowness nature and higher accumulation of organic matters of autochthonous and allochthonous origin. Bhakta & Jana (2002) demonstrated the release of sediment phosphorus especially in eutrophic systems into the overlying water and this release, therefore, could reduce the dose of phosphate fertilizer applied to the pond; the initial fertilizer dose could be adjusted with this effect in mind. It is likely that physical scoring of bottom sediments would perhaps increase the phosphate level of water, help release noxious gases, and thereby contribute to ecosystem health of the ponds. However, information on these aspects is seldom available for tropical ponds which are economically most important due to their immense aquaculture potentials in tropical countries. The purpose of the present study was to examine the effect of physical scoring of bottom sediments in a tropical pond on the phosphate level in water and sediment and primary productivity of phytoplankton in surface water of pond ecosystem.

Materials and methods

The experiment used 12 limnocorals (area 2.00 m$^2$, diameter 1.60 m, depth 1.75 m) made of polyethylene sheets attached with a frame which were buried into the pond sediment made mainly of clay particles. The limnocorals were installed in an adjoining area of a mesotrophic pond (4 ha) with a mean water depth of 1.25 m. The in situ enclosures were allowed to stabilize for 2 weeks prior to experiment. Four treatments were applied with triplicate replication. The cross-classified treatments were set to examine the effect of (i) raking (R), (ii) fish presence (F), (iii) raking plus fish (R + F), and (iv) a control situation – fishless without raking (C). Acclimated advanced fries of omnivorous benthivore, common carp, Cyprinus carpio (3.02 ± 0.01 g) and a planktivorous filter-feeder surface feeder, silver carp, Hypophthalmichthys molitrix (2.3 ± 0.02 g) obtained from a fish farm (The Ganges fish farm, Kalyani) were stocked into the allotted limnocorals (F and R + F) using a density of 6 for common carp and 2 for silver carp, resulting in an areal biomass of 113.6 ± 0.5 kg ha$^{-1}$. The rationale of combining two species (common carp and silver carp) was to mimic the resulting effects of an overall fish community in a fish pond as common carp has an effect on sediment bioturbation and silver carp is an open filter feeder and do not forage on the sediment surface.

Using a suitable rake, physical scoring of surface sediment (4 cm) was performed every week in each limnocorral for 5 min at a fixed hour of the day (9.00 h) immediately after collection of samples of that week. The experimental conditions of the limnocorals, after day 122, were interchanged between control and treatments. This was done by netting all the live fishes from the limnocorals used early for examining the raking and fish effects, and placing them into limnocorals used as control. Simultaneously, raking was suspended in the former and resumed in the later. Similarly, the raking effects were replaced by fish and vice versa.