Phosphorus dynamics, eutrophication and fisheries in the aquatic ecosystems in India

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Phosphorus (P) is the most limiting nutrient element in the inland aquatic ecosystems. In Indian context also, many water bodies are deficient in the readily available form of the nutrient. The present effort was to understand the P-dynamics in relation to fish production. While feed and fertilizer are the main inputs of P for the culture systems, the element is accumulated in the bottom mud to a great extent. Fish harvests accumulate 10–20% of P. In culture systems with water exchange, significant amount of P flows with the discharge/exchange water. The wetlands, rivers and reservoirs in the country show gradual accumulation of the element and eutrophication is becoming a serious concern mostly due to anthropogenic activities. East Kolkata wetlands are a unique example where fish is used as the bio-remediating agent. In general, mangrove plants also have good capacity to recover from adverse effects of commercial shrimp farming. There is scope to utilize advanced mathematical models to optimize the production and at the same time, conserve the resources. As a whole, there is ample scope for improvement and to understand the P-dynamics in different water resources of India.

Keywords: Brackishwater, eutrophication, freshwater, phosphorus dynamics, river.

Introduction

OUT of the two major biologically active nutrients, viz. phosphorus (P) and nitrogen (N), the phosphorus cycle is modelled in a less detailed manner than the nitrogen cycle. Nitrogen although necessary for life, does not command the same attention as phosphorus does, because nitrogen is more abundant and has many sources for use by biological communities. On the other hand, phosphorus performs as the key element in governing production at primary level in most of the water bodies and it is the most critical single element in the maintenance of aquatic productivity. While majority of the unpolluted large water bodies are deficient in its readily available form of the element in both water and sediment phases, the relatively smaller water bodies also retain the element much below its critical level of 50 μg/l in water and 1.3 mg P/100 g in sediment for fish culture practices[1,2].

Changes in land use and global hydrological cycles over the last decades are due to rapid increase in world population, associated food production and energy use. Mobilization of bio-available forms of nitrogen and phosphorus in watersheds which move through the rivers and ultimately reaches the seas has become an important issue. Due to human activities, bio-available N has nearly doubled and bio-available P tripled in the environment[3].

It has been emphasized that phosphorus being the key element for biological activity on earth, it needs to be conserved by initiating more efforts into its recovery from waste waters. This could help in harnessing increased productivity and manage the negative impacts of eutrophication in our waters. The data generated indicate that the total phosphorus content in sediments varies widely within a lake system and on regional and seasonal bases depending upon geochemistry, hydrodynamics and related limnological factors. In India, harnessing water productivity through fishery and aquaculture is a major food production activity. In fish/prawn culture with different farming practices, use of nutrients, especially nitrogen and phosphorus is judiciously practised to achieve higher production levels. In this context, based on the available information, an attempt has been made to assess the P-dynamics in our aquatic systems and related fish production activities.

Phosphorus in freshwater aquaculture

Input of nutrients through inorganic sources has long been a common practice of pond fertilization. Phosphorus through phosphate fertilizer is the most important nutrient regulating the productivity of fish ponds as 1 kg P_2O_5 gives rise to 2.5–28.2 kg of carp production under different conditions. In most cases, nitrogen is not considered

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as a limiting nutrient of pond productivity. Phosphorus limitation of phytoplankton occurs when the N : P ratio of the nutrient supply is substantially higher than the mean atomic ratio of N to P in phytoplankton cells (15 : 1); an ambient ratio less than 15 : 1 results in N limitation[4].

Fish culture systems

Freshwater aquaculture involves production of a variety of fish species, Indian major carps (rohu: *Labeo rohita*, catla: *Catla catla* and mrigal: *Cirrhinus mrigala*) and giant freshwater prawn, popularly known as scampi (*Macrobrachium rosenbergii*) in pond system involving manures, fertilizers and feeds in various combinations by following different management protocols. These input nutrients are distributed in water, fish harvest biomass and pond sediments. Generally, the fate of major proportion of nutrients received from various inputs into ponds, end up in discharge waters and pond sediments[5].

Phosphorus budget in aquaculture systems

Different experimental trials on phosphorus dynamics were conducted using various fish and prawn combinations with inorganic fertilizers and organic manures either in combination or separately[4,6,7]. Data generated under these experiments are presented in Tables 1 and 2.

The data in Table 1 reveals that in culture of 3-carps, viz. catla, rohu, mrigal and prawns, using both inorganic and organic sources of P, the maximum input of P comes from feed (92.85%) and the maximum output of P (70.48%) goes into pond sediment, whereas fish and prawn harvest accounts for 19.14%. In case of fish-alone experiment, it is observed that the maximum P comes from inorganic fertilizer (77%), but the maximum P output (67.4%) goes into sediment, and fish biomass accounts for only 10.88% of P. In the prawn-alone culture system, maximum P (98%) input comes from feed and the maximum output P (73.58%) goes again to pond sediment and prawn harvest retained only 10.42% of P. In all experiments, it is observed that maximum P gets loaded into pond sediments.

The results of the experiments conducted using only organic manures are shown in Table 2. Datasets on fish and prawn culture systems reveal that maximum input of P (98%) comes from feed, whereas maximum output of P goes into sediments and up to 19.46% is harvested as fish and prawn biomass. However, in case of prawn-alone experiment, the feed provides maximum (98.7%) input of P, whereas maximum output of P (75.88%) goes into sediments while only 9.87% of total P was harvested as prawn biomass. Therefore, all experimental trials indicated that maximum P-output gets into pond sediments.

In the experiments, it was also noticed that with progress of the culture period, the concentration of total P in water also increased. Among the two forms of water P, the water soluble orthophosphate content was much less, confirming that maximum P content is in particulate form. In the culture systems which are confined, the accumulation of nutrients in the system itself is significant, since there is no exchange of water.

Discharge water from the polyculture ponds of freshwater prawn and Indian major carps

The volume of effluents from the grow-out ponds varied from one system to the other. It was 4400 m^3 from 0.4 ha and 6600 m^3 from 0.6 ha (ref. 7). Harvested water had a total P of 0.34 kg. Nutrient load was equivalent to 0.135 kg of P per 1000 kg production of freshwater prawn and carps. The total load of different nutrients in the harvested water increased with the progress in culture period. The P loading by the rainbow trouts in the Ksrasu stream, Turkey was reported to be 6.25–14.50 kg per 1000 kg production of trout[8]. For the Nordic trout, P loading was in the range of 4.8–6.0 kg per 1000 kg production of fish[9,10]. It is evident that the nutrient discharged from Indian major carp and scampi polyculture ponds were much lower than the trout farms owing to lower stocking density in polyculture, using less feed, that resulted in discharge of small amount of nutrients compared to trout farms.

In most of the cases, harvested water from the aquaculture ponds is discharged into other aquatic systems. Sometimes, it is used to irrigate paddy and vegetables. A significant portion of the nutrient is either blocked in the bottom mud or used by different flora and fauna. In the closed systems, accumulation of excess nutrients generated from the uneaten feed might have supported the growth of fish and scampi by enhancing the growth of natural fish food organisms. P accumulates more in the bottom mud than in the overlying water. As water exchange is comparatively less in closed culture practices, the loss of P through harvested water is insignificant. Thus, experiments emphasized the importance of bottom mud in storing P.

Brackishwater aquaculture

Coastal aquaculture has been recognized as a thrust area among the fisheries development programmes of the country. Extensive estuaries, backwaters, lagoons, coastal lakes, tidal creeks and mangrove swamps are major brackishwater fishery resources. Although estimates of available brackishwater areas have varied, 1.19 million ha is considered amenable for brackishwater aquaculture[11]. Shrimp farms have been constructed on a variety of coastal lands – intertidal fallow land, dry and saline fallow land, unproductive and marginal agricultural land, and to a lesser extent in wetlands such as marshes and mangroves.

Table 1. Input–output of phosphorus in different fish and prawn culture systems

	Culture of 3-carps + prawn		Culture of 3-carps alone		Culture of prawn alone	
Parameters	Total phosphorus (kg/ha)	Total phosphorus (%)	Total phosphorus (kg/ha)	Total phosphorus (%)	Total phosphorus (kg/ha)	Total phosphorus (%)
Input						
Water	0.09	0.08	1.50	1.00	0.06	0.30
Inorganic fertilizer	6.46	5.25	115.20	77.00	0.26	1.18
Organic manure	2.24	1.82	30.00	20.06	0.12	0.54
Feed	114.05	92.85	2.90	1.94	21.44	97.98
Total	122.84	100.00	149.60	100.00	21.88	100.00
Output						
Fish/prawn	23.50	19.14	16.28	10.88	2.28	10.42
Water	0.78	0.63	7.50	5.02	0.60	2.75
Sediment accumulation	86.58	70.48	100.82	67.39	16.10	73.58
Others	11.98	9.75	25.00	16.71	2.90	13.25

Table 2. Input–output of phosphorus in different culture systems with organic manure alone

	Culture of 3-carps + prawn		Culture of prawn alone	
Parameters	Total phosphorus (kg/ha)	Total phosphorus (%)	Total phosphorus (kg/ha)	Total phosphorus (%)
Input				
Water	0.04	0.08	0.04	0.25
Inorganic fertilizer	–	–	–	–
Organic manure	1.09	2.02	0.17	1.05
Feed	52.80	97.90	16.00	98.70
Total	53.93	100.00	16.21	100.00
Output				
Fish/prawn	10.50	19.46	1.60	9.87
Water	0.32	0.60	0.27	1.67
Sediment accumulation	38.54	71.46	12.30	75.88
Others	4.57	8.48	2.04	12.58

Phosphorus in brackishwater fish/shrimp ponds

The productivity of brackishwater fish/shrimp ponds was directly related to the availability of nutrient elements in the bottom mud similar to other closed culture systems. The main nutrient limiting phytoplankton in brackishwater ponds is phosphorus. Higher amount of available phosphorous in brackishwater pond soils has been reported in a few research publications[12] and may be considered favourable for brackishwater fish culture, not only because phosphorus is one of the essential nutrient elements for pond productivity, but also due to its importance in the growth and multiplication of blue green algae, which form major fish food in brackishwater ponds[13]. The algae grow on the surface of the bottom soils and derive their nutrients either directly from the soil or from the soil–water interphase. Some coastal saline soils under brackishwater aquaculture condition were reported to contain comparatively high amount of available phosphorus (2.6 mg/100 g soil) compared to nearby soils under freshwater aquaculture (1.6 mg/100 g soil)[14]. However, availability showed a declining trend with increase in water salinity due to higher rate of fixation of phosphorus as insoluble calcium phosphates[15]. The average concentration of phosphorus observed was 461 mg/kg in brackishwater shrimp ponds in Thailand[16]. The solubility of soil phosphorus in water tends to increase as a function of increasing concentrations of dilute-acid extractable phosphorus[17] in soils containing iron and aluminium phosphates.

Pathway of phosphorus in brackishwater shrimp farming

Feed accounts for most of the phosphorus added to each pond in semi-intensive or intensive shrimp aquaculture, and the concentration of P, was very high when water was not exchanged during the culture period. Out of the total phosphorus input, 11–15% was assimilated in the shrimp and 84% was retained in the sediment at harvest[18,19].

Thus, large quantity of P was retained by the sediment or lost to the neighbouring environment from shrimp farming. There was no trend for dissolved organic P, whereas an increase was observed in particulate phosphorus and P content in pond mud during the experimental period. Conclusion of the experiment was that P accumulated in the sediment, but not in the water.

In shrimp culture ponds, feed is the major source of P (almost 90%); a large portion of it is lost to the system, and only one-sixth of it is assimilated by shrimp[18,20]. Even in exceedingly eutrophic waters, dissolved phosphate concentration is less than 5–20 μg/l and rarely exceeds 100 μg/1 (ref. 21).

Studies on phosphorous pathway in yard experiments revealed that out of total inputs, feed contributed 69.8%–90.6% of P. Accumulation of P into sediment, its retention in the shrimp, as output in the discharge water at harvest and unaccounted P ranged from 38.8% to 66.7% (significantly high in treatments with soil bottom substrate), 10.5–12.8%, 12.4–28.9% and 5.3–19.7% respectively[22,23].

Phosphorus budgeting – gains and losses

Increasing P gain through fertilizer application was highly correlated with net P loss through water exchange. The residual variation in P loss was significantly correlated with increasing feed P gain, after accounting for fertilizer P. About 82.5% of the variation in P loss through water exchange was explained by P inputs, feed and fertilizer. Water (51%) and feed (47%) are the major inputs accounted for P gain into ponds, whereas fertilizer (2.4%) and shrimp (0.1%) contributed a little. About 60% of total P loss was primarily through discharge water (everyday water exchange – 56% and pond drainage – 4.5%) and 9% was incorporated in the harvested shrimp and the remaining 31% (almost one-third of P input) was not recorded in the sum of P losses. The average conversion efficiency of P from feed into flesh of shrimp was 20% (8.4–43%) and these efficiencies were significantly high during rainy season compared to dry period.

Phosphorus discharge from aquaculture systems into coastal waters

P concentration in discharge waters from aquaculture ponds is a key environmental concern, as it leads to eutrophication in surface waters through P enrichment[24,25]. The culture species retain some portion of applied P and the remaining is lost through discharge water and adsorption by the pond mud. The concentration of P in pond discharge is found to be noticeably higher than in inflow pond water. The water from cultured ponds, is discharged through several short and small streams into the sea and the P concentration will rise in the mixing zones (entry point of streams into the estuary). Much of the P is also adsorbed by the sediment in mixing zones and streams and this increased concentration of P in waters and sediments may lead to development of plankton blooms restricted to the location and lead to changes in overall planktonic and benthic communities.

Unless the pollution load in pond discharge water exceeds the assimilative capacity of a water body, adverse environmental changes will not occur. Moreover, the environmental impact level due to discharge water depends on the location of the site, tidal amplitude, tidal flow, water retention period, type of culture adopted and the management methods followed. The problem is that the assimilative/carrying capacity of receiving waters is seldom known and unless a careful study is done, it is difficult to predict the effect of pond discharge on a given body of water[26,27].

There was no significant difference in concentration of nutrients (nitrate and phosphate) among the sampling stations near shrimp hatcheries though the values were slightly high in discharge water[28]. Phosphorus budget studies in Madagascar reported that 2.3 g of net phosphorus was lost by water exchange per kilogram of shrimp production[29]. The shrimp farm discharge water contained large input of P (about 23.5 tonnes of P) and the receiving water body contains a large volume of water (4.8×10^9 m^3). The increase of P in the water body would be 0.005 mg/1, if the annual P load is supplied in a single dose into the bay and estuary is mixed uniformly. However, the shrimp farms assimilating the P will not cause a large increase in the P concentration in the receiving water body with good tidal action, freshwater availability during the rainy season and with good flushing capacity.

Phosphorus flow into mangroves

The P budget studies showed surplus quantity of phosphorus in mud than the total input through feed and 0.41 kg P flowed into the mangrove enclosure[19]. The reducing conditions in the pond mud were responsible for P release. The deteriorating condition in the bottom pond environment was minimized by water circulation between the mangrove enclosure and shrimp pond. The results of nitrogen and phosphorus budgets in semi-intensive and intensive shrimp aquaculture indicated that about 2–22 ha of mangrove forest was necessary for 1 ha of shrimp culture pond to maintain the quality of water and bottom mud[30].

Phosphorus in inland open waters

In freshwater environments, available phosphorus is mostly retained in trace levels (<5–20 μg/l) limiting primary productivity and fish production. It seldom exceeds 100 μg/l. The natural contents of P in sediments of

Table 3. Water phosphate (mg/l) in different stations of middle stretch of River Ganges

River stretch	Haridwar	Kanpur	Allahabad	Varanasi	Patna	Rajmahal
1960	–	0.07–0.21	0.09–2.0	0.08–0.12	0.07–0.11	0.07–0.12
1980	Tr	0.01–2.10	0.11–0.32	0.12–0.73	–	–
1996	0.04	Tr–2.5	Tr–0.80	Tr–1.00	Tr–0.01	0.06–0.11

Modified after Sinha *et al.*[63]; Vass *et al.*[64]. –, Indicates data not available, Tr = presence in traces.

aquatic environments, are also insufficient to meet the production requirements and a significant amount is supplemented through washing from watersheds, domestic and industrial wastes, and by way of application of fertilizers. Microbes, with their strong metabolic activity, reduce the sediment and modulate P availability through decomposition processes. Organic matter in the form of autochthonus aquatic production and allochthonus plant matters, human and animal wastes, holds a large amount of P in aquatic environments. Microbial enzymes such as phosphatases play crucial roles in releasing the element from organically bound forms[31–34]. Laboratory investigations on sediment phosphorus fractionation and enzymatic studies at CIFRI showed that sediment microbial activities played a key role in releasing soil-bound P. The sediment-bound organic P, calcium P and iron P accumulated in winter was partly liberated in summer, releasing the much needed available form of phosphorus into water. A natural mobilization of 62–76% of sediment Ca–P pool concomitant with increase in microbial activity and decline in sediment pH in summer was recorded in floodplain wetlands, where pH was slightly alkaline.

Phosphorus in rivers

The timescale data generated by CIFRI over the years at major sites on river Ganges, revealed distinct change in water phosphate content. In the Deoprayag–Rishikesh zone of the river, water phosphate content was recorded 0.04–0.08 mg/l. In the 1960s, when the river system was not much stressed, the values were fairly within acceptable limits. Gradually, the water quality got impaired and the middle stretch was affected more. The dataset presented in Table 3. It reveals that at Kanpur, Allahabad and Banaras, water phosphate content has significantly increased up to 2.5 mg/l over a period of two decades. In comparison, the concentration at Hardwar remained low (0.04 mg/l). Patna and Rajmahal recorded phosphate content within reasonably acceptable levels. So, timescale changes varied from station to station.

Water phosphate content in different stretches of river Ganges is presented in Table 4. In the middle and lower stretches (between Kanpur and Katwa), high content was recorded, but the highest average level of 0.24 mg/l was recorded in the freshwater zone of the estuary near Haldia. It implies that majority of P-loading gets washed down to estuarine zone in this river system. The strong tidal activities in the estuarine region are still protecting the stretch from high nutrient accumulations. To address different issues of River Ganges in a holistic manner, the Government of India set up the 'National Ganga River Basin Authority' in 2009.

Information on water-P levels in different river systems in India, other than Ganges, are presented in Table 5. Moderately good content of water phosphate was recorded in the rivers Ravi, Sutlej, Beas and Yamuna. In rivers Brahmaputra and Mahanadi, the content was meagre. In rivers Damodar, Krishna and Narmada, the effluent receiving areas exhibited high P content. Such stretches are Barnpur to Durgapur of river Damodar, estuarine stretch of River Krishna and Bharuch to Bhadbut stretch of River Narmada. In River Cauvery, even though the sediment is sand dominated, presence of significant amount of available phosphorus was recorded mostly in a part of Tamil Nadu stretch, probably due to washing from the agricultural fields. In the Delhi stretch of river Yamuna, moderate content of water phosphate was recorded (0.03–0.26 mg/l) with relatively higher content during monsoon due to washing from agricultural fields[35].

Phosphorus in floodplain wetlands

Water phosphate contents in floodplain wetlands of West Bengal (locally known as *beels*) have been thoroughly studied. In the closed *beels*, the phosphate level was recorded to be moderate (up to 0.1 mg/l, Table 6) and in some cases high (up to 1.08 mg/l). In the open *beels*, the content was relatively low (up to 0.1 mg/l).

Phosphorus in reservoirs

Indian reservoirs are characterized by low level of phosphate and seldom exceed 0.1 mg/l in pollution-free reservoirs. The reservoirs of Rajasthan, however, have high level of phosphate (traces–0.93 mg/l), receiving major inputs from the catchments. In Mansarovar, a highly eutrophic reservoir in Madhya Pradesh, very high concentration of 4–13 mg/l has been reported. In the reservoirs, which are free from pollution, the lack of soluble form of P does not indicate lower production level due to its quick conversion and recycling. Planktons have the

Table 4. Water phosphate in different stretches of River Ganges[64]

Ganges stretches	Upper (Deoprayag–Kanauj)	Middle (Kanpur–Patna)	Lower (Sultanpur–Katwa)	Estuary (Freshwater Nabadwip–Haldia)	Estuary (Marine Kakdwip–Frazergunj)
Phosphate P (mg/l)	Tr–1.66 (0.04)	Tr–0.86 (0.042)	0.035–0.60 (0.058)	0.04–1.82 (0.24)	0.06–0.51 (0.082)

Table 5. Water phosphate trend in different rivers in India

Rivers	Ravi	Sutlej	Beas	Brahmaputra	Damodar	Brahmani	Mahanadi	Godavari	Krishna	Cauvery	Narmada
P (mg/l)	0.17–0.20	0.12–0.15	0.18–0.29	Tr–0.02	Tr–0.35	Tr–0.03	Tr–0.01	0.06–0.18	0.04–0.30	0.02–0.94	Tr–0.10

Table 6. Water phosphate in different types of wetlands in West Bengal

Wetland type	Closed wetlands (average values of 12 wetlands)	Open wetlands (average values of 7 wetlands)
Phosphate–P (mg/l)	0.1–1.08	Nil–0.1

capability to assimilate 95% of P in 20 min. Even some of the algae have the capability to convert soluble inorganic P into more insoluble organic form within a minute[36]. In the reservoirs of Cauvery river system, observed level of available phosphorus in sediments ranged from 0.15 to 0.30 mg/100 g; in Kulgarhi reservoir of MP, it was 0.2 mg/100 g in Gularia reservoir of MP, it was 1.2 to 1.8 mg/100 g. In the hypereutrophic Krishnagiri reservoir of Tamil Nadu, the maximum total P concentration was 870 mg/100 g with inorganic P 68–83%. Results indicated that high total P and Fe–P content in the sediments may increase the risk of phosphorus release. High concentration of surface sediment phosphorus clearly indicates a greater threat of eutrophication in Krishnagiri reservoir[37].

Eutrophication

Eutrophication is a natural ageing process of aquatic ecosystems. Although it is a very slow process, the aquatic environments are ultimately transformed into terrestrial habitats. The accumulated excess nutrients in the water body stimulate the growth of phytoplankton (microscopic free-floating aquatic plants, e.g. algae). Eutrophication is also induced by anthropogenic activities such as fertilizer application in agriculture and land-use changes that accelerate the phytoplankton growth in aquatic ecosystems. Accumulation of excess amount of nutrients in the ecosystem through connected rivers, streams, or groundwater is expressed as loading. It also refers to the amount added to a unit area or volume of lake over a specified period, which also involves any significant internal loading (recycling from sediments) versus external loading (inputs from catchment and the atmosphere). Effluent from septic systems and wastewater, fertilizer runoff, urban developments, drinking water treatment, detergents, animal waste, forest fires, synthetic material, phosphate mining, industrial discharge, etc. are the anthropogenic factors affecting the phosphorus concentration in aquatic environment[38,39].

In India, the problem of eutrophication was thoroughly studied in the natural high mountain and rural lakes and River Jhelum in Kashmir Himalayas focusing on eutrophication status, evolution, factors responsible, etc. by various resarchers[40–46]. The impact of excessive phosphorus loading in Dal Lake of Kashmir has been published relatively recently[47]. The pollution-associated problem and dominance of specific group of planktons in Lake Mirik from Darjeeling Himalayas has been studied[48]. Much research has been done on various facets of eutrophication from different parts of the world and some of these are on Lake Erie in USA[49], Lake Lugano between Italy and Switzerland[50]; Danish lakes[51–53], lake Kstoria in Greece[54]. The eutrophication problem in lakes of China[55] and the role of land-use on stream eutrophication in USA[56] has been studied. The relationship between bloom formation, domination of cyanobacteria, role of nanoplankton and total potamoplankton biomass with phosphorus loading and eutrophication has been described[57–59].

Grey water footprint (GWF) is a newly developed concept in the field of eutrophication, which indicates the status of the water body. It is defined as the volume of freshwater required to assimilate the load of pollutants based on existing ambient water quality standards. Overall GWF and water pollution level (WPL) of 15 major rivers of the world have been calculated[60]. Out of these rivers, Ganges and Indus were from India. For River Ganges with discharge of 703 km^3/year, the GWF was 2653 km^3/year, overall WPL 3.77 and the prime factor among different forms of P was particulate water phosphorus. For River Indus with discharge of 38 km^3/year, the overall GWF was 78 km^3/year, overall WPL 2.04 and the prime factor was dissolved organic phosphorus.

Eutrophication and fisheries

In an aquatic ecosystem, eutrophication may have a number of impacts on the quality and quantity of fish. One of the most pronounced impacts is the general tendency of increase in fish stock due to an increase in the level of primary production. Data of 20 north temperate water bodies from USA has been studied[61] and a relationship between mean epilimnetic total phosphorus concentration and fish yield has been derived. From the fisheries as well as water quality management point of view, establishing such a quantitative relationship has great advantages. In the study, fish yield was correlated with the principal controlling factor governing algal biomass production; the phosphorus load was normalized with mean depth, hydraulic residence time and area of the water body. The technique is very useful for developmental purposes and evaluation of management plans. In eutrophic water bodies, the dominance of carps is routinely noticed. In highly eutrophic water bodies, big populations of stunted fishes are recorded. This happens due to inadequate predation on the species. The increased turbidity due to higher plankton population and suspended sediment load actually restricts visual power of the predators for preying. A number of reports are available indicating loss of profitable fisheries due to increase in plankton population arising out of increase in phosphorus load, resulting in increase in oxygen demand and ultimate depletion of hypolimnetic oxygen level.

Many researchers have reported the deleterious effect of higher nutrient status in the estuaries and adjoining areas resulting in the development of algal blooms, red tide formation, etc. This induces oxygen depletion due to its higher consumption in respiration and also for decomposition of the dead planktons in adverse weather conditions, mostly in summer months. The decreased oxygen level causes fish mortality on mass scale.

Release of more number of fishes and frequent harvesting of fish stock is a very popular technique to control eutrophication. Thus, fish is being used as bioremediating agent to maintain health of water bodies. With the management of fish populations, the water quality of a water body can be significantly managed. Aquaculture in east Kolkata sewage fed wetlands, is unique example in this direction.

In estimating the effect of the nutrient loadings in an aquatic system on fisheries, models have now been developed. One such example is lake eutrophication, effect–dose-sensitivity (LEEDS) model to predict how large a fish farm could be sustained in a lake, without resulting in serious eutrophication problems. By application of LEEDS model, reversal of eutrophication in about 5–6 years was demonstrated in a Swedish lake that received P-load from a 4000 tonne capacity rainbow trout production farm[62]. Eutrophication has both beneficial and detrimental effects on fisheries. In general, increase in overall fish yield is noticed with the increased level of primary production. However, under such circumstances, the diversity of fish species changes and the increased yield is contributed by the less desirable or non-remunerative fish species.

Conclusion

There is paucity of detailed information on our current understanding of ecosystem interactions and responses to P-loads, eutrophication, its reversal in varied water bodies located in different agro-climatic regions of India. This information from the target aquatic ecosystems will be very critical for planning eutrophication reversal strategy with regard to the total phosphorus load that is being discharged into water bodies of the country. It requires serious and urgent efforts towards detailed studies on all aspects. It is hoped that this issue will be taken note of by the concerned authorities/agencies to initiate research in this very important aspect in respect of aquatic ecosystems.

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