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Eutrophication: An Ecological Vision

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Abstract

The present review deals with the studies conducted on the impact of phosphorus on growth of aquatic plants causing eutrophication in well-known water bodies the world over. The review covers the definition and concept of eutrophication and the adverse effects on quality and ecosystem functioning. The eutrophication of several water bodies leads to significant changes in the structure and function of the aquatic ecosystem. Several activities of human interest, including navigation and power generation, are hampered. A large number of lakes in the United States, Europe, and Asia have recently been found to be highly eutrophic. Water, the precious fluid, is not uniformly distributed throughout the surface of the earth. Most of the water bodies world over are surrounded with densely populated human settlement areas and agricultural fields. The size of smaller water bodies in human settlement areas is on the decrease with rise in population. After treatment, a large quantity of sewage from the households is regularly discharged into the water bodies. The runoff brings down fertilizers and other chemicals from agricultural fields. The phosphorus contained in these effluents is known to promote excessive growth of plants. This review is an account of the role, sources, and monitoring of phosphorus, as well as its cycle. The natural phosphorus cycle originating from the weathering of phosphate rock is now a two-way operation, due to significant addition of phosphorus from anthropogenic sources.

The detergents that are the major source of phosphorus inputs into water bodies (through sewage and drainage systems) have been thoroughly discussed. The major part of detergents comprises builders containing polyphosphate salts. An environment-friendly and effective synthetic builder is yet to be developed to replace existing phosphorus containing builders of detergents. The utility of the alternative builders available has been reviewed. Nitrogen has also been reported to affect the phytoplankton production in eutrophic waters in temperate regions. Several environmental factors have also been found to add to the problem of eutrophication in addition to nutrients. Several limiting factors—namely, CO_2 level, temperature, pH, light, and dissolved oxygen—are known to affect eutrophic water bodies. Eutrophication not only results in algal bloom but also affects wetland plants and activates early onset of natural succession at a relatively faster rate. Some of the plant species reported and studied world over are the best indicators of the level of eutrophication. The studies on the change in structure, function, and diversity of the ecosystem have been used as parameters to assess the level of eutrophication. In several countries adequate control measures have been adopted in to control eutrophication. But these measures were found to be only partially effective in controlling the phosphorus unloading in water bodies. In this review some control measures are suggested, with emphasis on biological control. The review concludes by taking into account the ecological prospective of the water—the precious fluid and a basis of life on the earth.

Introduction

Water, a precious natural resource, is essential for a multiplicity of purposes. Water constitutes the major bulk (70%–90%) of all living cells. Water is an essential, life-supporting factor in every cell (microcosm), individual organism, ecosystem, and cosmos. Freshwater is utilized in drinking, several domestic and household purposes, industrial cooling, power generation, agricultural irrigation, and waste disposal. Since time immemorial, water bodies (river, lakes, and oceans) have been the cheapest route of transportation. Nature has not provided any alternative or replacement of water (essential for all life forms). Today, in almost all spheres of human activity, a far larger amount of water is drawn out than what is actually required. Due to careless and excessive uses, a major bulk of water is drained out in an impure state as waste. At many places in India, clean water is no longer available for domestic uses. The rapid rise in demand for freshwater is a manifestation of an equally rapid growth in the number of consumers. However, reckless overconsumption, misuse, pollution, eutrophication, and depletion of the underground water table, not simple population growth, are the actual causes of degeneration of freshwater.

Beeton (2002) predicted that climate change and pollution are global problems that will affect all lakes, large or small. Diversion of water out of or away from large lakes will become more of a threat as global human population growth continues and water supplies from rivers and groundwater become depleted. Most of the aquatic ecosystems of varying characters worldwide receive regular inputs of a range of nutrients in varying quantities. High amounts of nutrients are unloaded into water bodies from human settlements via sewage. These nutrients result in the extensive growth of aquatic flora. Eutrophication is a kind of nutrient-enrichment process of any aquatic body, which results in an excessive growth of phytoplanktons. This undesirable overgrowth of aquatic plants and their subsequent death form a greenish slime layer over the surface of the water body. The slime layer reduces light penetration and restricts reoxygenation of water through air currents. The death and decay of aquatic plants produces a foul smell and makes the water more turbid (Beeby, 1995; Rao, 1998).

Eutrophication, or the promotion of the growth of plants, animals, and microorganisms in lakes and rivers, has been a very slow, natural process. If this is allowed to occur uninterrupted, it results in an excessive deficiency of oxygen in the water. Thus organisms that thrive under anaerobic conditions are favored more and more at the expense of aerobic organisms (Mengel & Kirkby, 1996). In surface waters, phosphorus concentrations exceeding 0.05 mg L^{-1} may cause eutrophic conditions (Hinesly & Jones, 1990). Eutrophication of drainage ditches by overfertilization with nitrogen and phosphorus causes a shift mainly from submerged aquatic vegetation to a dominance of floating duckweeds. This results in anoxic conditions, loss of biodiversity, and hampering of the agricultural functions of such ditches (Janse & Puijenbroek, 1998). The change in eutrophic conditions is reflected in the occurrence, pattern of distribution, and diversity of the biotic community (Tiwari, 1998).

Many natural water bodies are described as oligotrophic, for they have clear-water ecosystems in which primary and secondary productivities are limited by a shortage of major nutrients (Beeby, 1995). These oligotrophic water bodies, if brought under natural succession, require thousands of years to become eutrophic. The enrichment of aquatic ecosystems through the discharge of human wastes from settlements and excessive fertilizers from agricultural lands brings down the water bodies under an undesirably increased rate of eutrophication.

Nitrogen and phosphorus are essential elements required by plants and animals for maintaining their growth and metabolism. Small amounts of nitrates and phosphates occur in all aquatic ecosystems and maintain a balanced biological growth in such ecosystems. In wastewater, these nutrients are abundant as phosphates, nitrates, and ammonia or combined organic nitrogen. These compounds often enter the water bodies directly from the fertilizer manufacturing and processing units or from the agroecosystems having excessive applications. In their model, Welch and Crooke (1987) predicted the decline in phosphorus loading by diverting effluents away from Lake Washington, which became eutrophic as the city of Seattle expanded.

Eutrophication is one of the serious kinds of water pollution directly affecting the fauna due to the loss of dissolved oxygen. It leads to an early and relatively faster mortality rate of fish and thus spoils the desired water qualities of ponds and lakes. Fishing and navigation in eutrophic water become difficult due to enmeshed and heavy growth of plants. Hydroelectric generation from such water storage is adversely affected as nutrient rich water acts chemically upon the turbines. At the end of an algal bloom, the decomposing debris also spoils the desired water characteristics and may result in the growth of disease-causing bacteria. Uncontrolled eutrophication leads to a rapid upwelling of a water body. The limited storage and water-recharging capacity of smaller freshwater bodies is reduced by silting. Small lakes and many ponds steadily lose their aquatic entity and become permanently terrestrial in nature. Eutrophication leads to significant changes in water quality. It lowers the value of surface waters for the industrial and recreational uses. Overpopulation of algae makes water unfit for swimming. Algae growing in long strands often twine around boat propellers and make boating difficult. Eutrophic waters tend to be scummy, cloudy, or even soupy green. The rapidly growing aquatic plants may wash onto the shore in storms or high winds. Where these plants die, decay produces a bad smell all around such water bodies (Penelope & Charles, 1992).

DEFINITION

Lakes and estuaries accumulating large amounts of plant nutrients are called “eutrophic” (from the Greek words *eu* meaning “well” and *trophe* meaning “nourishment”). Eutrophication may be defined as the sum of the effects of the excessive growth of phytoplanktons leading to imbalanced primary and secondary productivity and a faster rate of succession from existing to higher seral stage as caused by nutrient enrichment through runoffs that carry down overused fertilizers from agroecosystems and/or discharged human waste from settlements. Eutrophication is a plant-growth-promoting process resulting from accumulation of nutrients in lakes or other water bodies. It is in fact a very slow, natural process, but it can be greatly accelerated by human activities that increase the rate of nutrient input in a water body.

Among various natural resources, water is an important resource and one of the prime necessities of life. Water quality is deteriorating steadily due to rapid industrialization and urbanization. Undesirable changes in the physicochemical characteristics of water bring about water pollution, which in turn affects the planktonic flora of the water body in question. Algal growth is limited by the available supply of phosphorus or nitrogen. Oligotrophic water bodies contain less than 5–10 μg L^{-1} of phosphorus and less than 250–600 μg L^{-1} of nitrogen. The mean primary productivity in oligotrophic water is reported between 50–300 mg carbon m^{-2} day^{-1}. In moderately eutrophic water bodies the phosphorus content is 10–30 μg L^{-1}, and the nitrogen content is 500–1100 μg L^{-1}. The primary productivity in eutrophic water is reported to be above 1 g carbon m^{-1} day^{-1} (Likens et al., 1977). If excessive amounts of phosphorus and nitrogen are added to the water, algae and aquatic plants can grow in large quantities. When these algae die, they are decomposed by bacteria. The decomposers use up the dissolved oxygen of the water body. The dissolved oxygen concentrations often drop too low for fish to breathe, leading to fish kills (Murphy, 2002).

EUTROPHICATION STUDIES ON LAKES

Lakes can be synthetically characterized as plain lakes, very shallow, polymictic, eutrophic, or hypereutrophic. During the peak of the growth season three types of the large lakes are distinguished: 1) lakes with relatively low phytoplankton biomass and abundant rooted macrophytes; 2) lakes with high inorganic turbidity, scarce macrophytes population, and low phytoplankton biomass; and 3) lakes clearly limited in their productivity by light availability and are the result of direct human action on their drainage basins (Quiros et al., 2002). Limnological studies on lakes, rivers, and streams have been emphasized owing to deterioration of water quality due to eutrophication (Saxena et al., 1988).

Lake Erie is a fitting example of eutrophication due to humanmade problems. This lake is surrounded by four American states and one Canadian province. It is approximately 240 miles long and 57 miles wide. The lake has a shallow western basin (average depth of 24 feet), a deep eastern basin (maximum depth of 210 feet) and a central basin (average depth of 60 feet). The lake is biologically the most productive of the Great Lakes because it is the shallowest and warmest, and it is excessively rich in nutrients (Reutter, 1989). The human activities around the lake have enhanced the nutrient input rate and accelerated the natural aging process known as eutrophication. This aging process brought down the lake under a faster cycle of succession. This succession is the process by which a water body becomes a marsh, then a bog, and finally a drier terrestrial body (Reutter, 1989). According to an estimate, more than 80 tons of phosphates were added daily in the lake in 1965, and each 400g of phosphate induces an algal bloom to add about 350 tons of algal slime (Sharma, 1998). Nutrient (such as phosphorus) enrichment in the Lake Erie has resulted in huge blooms of floating blue-green algae and the attached green alga, *Cladophora* spp. These blooms have rolled onto beaches in large mats resembling green steel wool. The blooms impaired the light penetration in the lake, reduced photosynthesis and oxygen production. When the bloomed algae died, the decomposers further depleted the dissolved oxygen (Reutter, 1989). Interestingly, all forms of phosphorus entering Lake Erie were not biologically available to phytoplanktons. Therefore, reducing total phosphorus input is not as important as reducing the input of usable phosphorus (bioavailable or soluble reactive form). It is also known that detergents, sewage, and agricultural fertilizers are major sources of phosphorus in a form capable of stimulating the growth of algae (Reutter, 1989).

Lake Washington became eutrophic as the city of Seattle expanded and discharged more of its effluent into the lake. Models accurately predicted the decline in the phosphorus concentration of the water when the effluents were diverted. These models helped to demonstrate that phosphorus was the key nutrient in the eutrophication of the ecosystem (Welch & Crooke, 1987). Lake Okeechobee, in southeastern Florida, is a shallow mixing basin with annual total phosphorus concentrations of 50–100 μg L^{-1}. The minima in orthophosphorus and inorganic nitrogen were found to be seasonally limited (Schelske, 1989). Owing to seasonal and spatial gradations in phosphorus and nitrogen concentrations, the empirical models based on annual phosphorus loadings were not adequate to predict chlorophyll concentration or other trophic state variables in the lake (Schelske, 1989). Lake Apopka is another large, shallow lake in Florida. The lake was made hypereutrophic by phosphorus loading from floodplain farms and has high levels of nutrients, phytoplankton, and suspended matter (Coveney et al., 2002).

In Lake Lugano, between Italy and Switzerland, a faster rate of eutrophication is reported due to excessive discharges from human settlements around the lake, owing to population increase and immigration (Barbieri & Simona, 2001). In 1960s Lake Lugano received about 55% of its phosphorus input from metabolic sources and 45 % from detergents and cleaning products. Field investigations were conducted on Jaroslawieckie Lake, in Poland, during the summer of 1996. The lake had several plant communities in corresponding variable environments. Most habitats of this lake were eutrophic. Analysis of the phytoplankton samples and bottom sediment showed a succession of algae, corresponding to the increasing trophic levels

(Pelechaty et al., 1997). Most freshwater lakes in the northern and western portions of the Netherlands are very shallow (<2 m). These lakes vary in area from a few hectares to a few thousand hectares. The input to the lakes of phosphorus and nitrogen and of polluted waters from the rivers and canals have been the major cause of eutrophication (Gulati & van Donk, 2002).

In Uruguay there was no upper limit for phosphorus content in detergents. Detergents contributed 58% of the daily phosphorus load (2.5 tons) to the Río de la Plata at Montevideo. Consumption of phosphorus-based fertilizers in Uruguay showed an oscillatory pattern of increase and decrease between 1959 and 1985 but stability, at around 40,000 tons per year, from 1985 to 1990. Based on soil-erosion levels, population settlements, and fertilizer-use data, the water bodies were phosphorus sensitive in the three zones of the country; namely, central-south, western zone, and the eastern rice fields (Sommaruga et al., 1995).

The majority of Danish lakes are highly eutrophic due to high nutrient input from domestic sources and agricultural activities. Several factors—reduced nutrient retention, more rapid removal in catchments, and channelization of streams—also play a role in eutrophication (Jeppesen et al., 1999). Control measures have resulted in 73% reduction in total phosphorus concentration of point-source-polluted streams since 1978, but reduction of the total nitrogen concentration has not been significant (Jeppesen et al., 1999). Surface runoff rich in agricultural wastes and underground seepage from urban and rural areas enriched the Lake Kastoria in Greece with nutrients and intensified eutrophication (Koussouris et al., 1991).

Lake Peipsi (3555 km^2, mean depth 7.1 m), consisting of three parts—Lake Peipsi, Lake Pihkva, and Lake Lammijarv—is located on the border of Estonia and Russia. The Lake Peipsi part is unstratified eutrophic possessing mesotrophic features. The Lake Lammijarv part has some eutrophic features, and the Lake Phikva part is a typically unstratified eutrophic. The mean concentrations of total phosphorus and nitrogen in the surface water were 42 and 767 mg m^{-3}, respectively. The biomass of phytoplankton fluctuated between 1 and 125 g m^{-3}; that of zooplankton, from 0.088 to 6.344 g m^{-3}, with a summer average of 3.092 g m^{-3}. The species diversity was up to 129 taxa, and the dominant species were typical of eutrophic lakes, including *Phragmites australis* (Haberman et al., 2000).

Lake Taihu, in China, is in the mesoeutrophication stage owing to the nutrients unloading from local industries and agricultural areas. The main eutrophic area of this lake is Meiliang Bay. The chemical oxygen demand was 4.63 mg L^{-1} in 1993. Total nitrogen and total phosphorus contents were 3.93 mg L^{-1} and 0.107 mg L^{-1}, respectively, in 1995. The *Microcystis* spp. among five major component phytoplankton species occupied 85% of the algal biomass and led to an algal bloom in summer that, in turn, affected the supply of water to the city of Wuxi (Weimin et al., 1997). Eutrophication is one of the main factors causing increased growth of green algae and turbid waters in Donghu Lake, also in China (He et al., 2002). Excessive growth of *Eicchornia crassipes* and *Alternanthera pheloxirodes* has been noted in the shallow, eutrophic Donghu Lake. The blooming in terms of biomass and height of the species was noted in the month of November in 1996 and 1998. *Alternanthera pheloxirodes* showed the beginning of bloom in September; *E. crassipes,* in October (Liu et al., 2004).

City Park Lake is a shallow, urban, hypereutrophic lake in Baton Rouge, Louisiana. The lake has become highly eutrophic and suffered from frequent algal blooms and fish kill (Ruley & Rusch, 2002).

Garg et al. (2002) studied three lakes of Bhopal (Upper Lake, Lower Lake, and Mansarovar Lake) in India, to assess the potential fertility of lentic waters and to analyze the floral ecology. The highest level of eutrophication was found in Mansarovar Lake. The nutrient unloading into the lake initially promoted the growth of phytoplanktons. But the higher nutrient levels eliminated the sensitive phytoplankton due to competition with other species (Garg et al., 2002). Hydrobiological study of Lake Mirik in the Darjeeling Himalayas was conducted by Jha and Barat (2003). The study revealed higher concentration of nutrients in certain pockets of the lake, due to increased human influences that spoiled the quality of potable water. Bellandur Lake is one of the major lakes of Bangalore, India. The addition of effluents from urbanized Bangalore city has changed the characteristics of the lake from a natural, oligotrophic lake to an artificial reservoir of domestic sewage and industrial effluents (Chandrashekar et al., 2003). Singhal and Mahto (2004) studied the characteristics Robertson Lake in the urban area of Jabalpur, India and found low species density, fast shallowing, dominance of detritus food webs, and water unsuitable for human consumption. To gain more insight into the gravity of damage caused by eutrophication to our depleting water resources, a brief account of the ecological aspects of distribution and water cycle is given herewith.

Water Resources

Water is a most essential natural resource. The main sources of water are rainfall, surface water (ponds, rivers, lakes), and groundwater (wells, water pumps). The water has great ecological significance. It constitutes 70% of the weight of organisms, so it is a significant medium for biological activities. About 70% of the earth's surface is covered by water constituting aquatic ecosystems. Water is an agent of: 1) energy transfer in ecosystems; 2) geological activities that cause weathering rocks to form soil; 3) a nutrient distribution medium as a solvent for soluble salts or a suspending medium for insoluble salts; 4) atmospheric temperature regulation as the water vapors act as an atmospheric blanket and absorb heat radiation, thus regulating the temperature of the earth's upper crust; and 5) an atmospheric scavenger as water vapors absorb gaseous pollutants and particulate matters and wash them down.

WATER CYCLE

The cycle involves evaporation, transpiration, cloud formation, and precipitation. Only a minor amount of water remains in circulation between the atmosphere and water bodies on the earth's surface, living organisms, underground water bodies, and oceans. The melting water locked into ice caps is brought down by streams and rivers. Ultimately a bulk of it is drained into lakes and oceans, from which it evaporates. It is brought back to the land as precipitation from clouds, which recharges the underground and surface water bodies. Each gram of ice requires 80 g cal of energy to be converted into a liquid state and another 536 g cal to be vaporized. In dimictic lakes of the temperate regions, semiannual temperature inversions cause movement of water from a surface layer to deeper layers and vice versa. Figure 1 shows the circulation of water between land surface and ocean via atmosphere and its locking into underground water. A major amount of the evaporated water from the oceans and large lakes is precipitated back into the oceans and lakes. Only a portion of the evaporated water is transported to the land through the atmosphere, where some of it is evaporated back to the atmosphere. Part of the precipitation on the land is intercepted by the forests, green plants, crops, and a large number of organisms and other objects on the earth. The component of water available on the earth's surface circulates among all organisms of the terrestrial and aquatic ecosystems. The pattern of this water cycle is shown in Figure 1. During the circulation of water between ocean and land the highest global average of water (available on the land) is reported in the months of March and April. In India, however, the larger quantity of water on the land is received in the monsoon months, from mid-June to September. The excessive availability of water on land varies from region to region and according to the local climate.

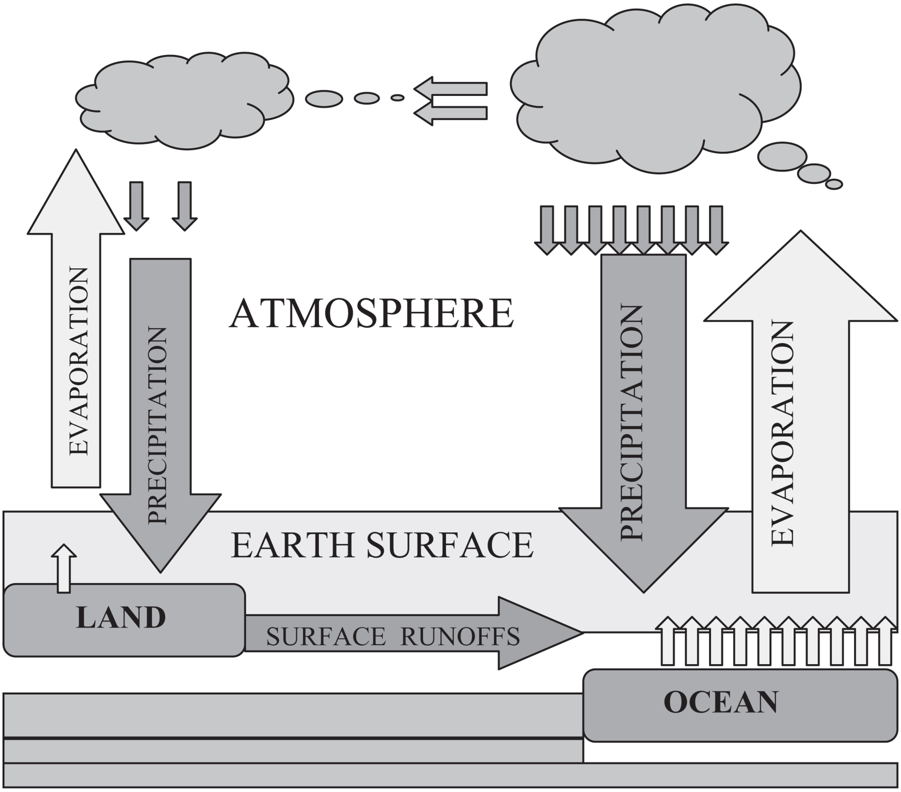

Fig. 1. The water cycle. About 80% of the water evaporated from oceans in the form of clouds settles down into the oceans as a result of precipitation, and the remainder is dispersed and eventually preciptitates onto land. About half of the latter is evaporated back into the atmosphere, so 10% of the precipitation over land returns to the ocean through surface runoff. Thus only a minor amount of the total precipitation remains available for the growth of plants and other organisms as well as for recharging of the water bodies and underground water.

DISTRIBUTION

Nearly 5% of the total estimated water in the earth and in the atmosphere is in free circulation, and the remaining 95% is locked into the lithosphere and sedimentary rocks. About 99 parts of the 5% of freely available water (4.95%) is in the oceans, and only 1 part (0.05%) is potentially available for circulation on land. Among various water resources on earth, oceans account for 97.6%, ice caps and glaciers, 1.87%; groundwater, 0.5%; rivers, lakes, and inland seas, 0.02%; soil moisture, 0.01%; and atmosphere, 0.0001% (Asthana & Asthana, 1998). There are three major global resources of water: a) precipitation over the earth's surface in the form of rain, dew, and snow; b) surface water; as rivers and lakes; and c) underground water. The water bodies having still water are referred to as "lentic" (ponds and lakes). Those water bodies having running water are called "lotic" (rivers). These two ecosystems differ considerably in ecological, chemical, and physical characteristics. Lentic water bodies are stagnant and enclosed by land on all sides. Such water bodies have no exit for water outflow.

Most Indian rivers have nearly 80% of their discharge during the monsoon months. The total live or effective storage capacity has now reached 3.65 Mm^3. Storage as expressed in percentage of total flow shows Pennar to be the highest, with 61%, followed by Mahi, 56%, Tapi, 45%, and Krishna, 44%. All these rivers have reached the saturation level of nearly 50%. The rest range from 34% (Indus) to 7% (Ganges), 6% (Narmada), and 4% (Subarnarekha). Power generation is another cause of ecodegradation in these water bodies due to dams and canals (Sharma, 1998). However, the discharge of nutrients—specifically, the phosphorus input—is the major cause of the degradation of characteristics, species structure, and size of the water bodies.

Phosphorus and Its Role

Phosphorus is a macronutrient necessary for all living cells. It is an important component of adenosine triphosphate, adenosine diphosphate, nicotinamide adenosine dinucleotide phosphate, nucleic acids, and phospholipids in cell membranes. Phosphorus may be stored in intracellular volutin granules as polyphosphates in both prokaryotes and eukaryotes. It is a limiting nutrient for algal growth in lakes.

ROLE OF PHOSPHORUS IN EUTROPHICATION

The average concentration of total phosphorus (inorganic and organic forms) in wastewater has been reported to vary in the range of 10–20 mg L^{-1} (Bitton, 1999). Approximately 15% of the U.S. population contributes phosphorus-containing wastewater effluents to lakes, resulting in eutrophication of those water bodies (Hammer, 1986). Phosphorus concentration in clean waters is generally very low. Phosphorus is used extensively in fertilizers and other chemicals and commonly accumulates in higher concentrations in the water bodies around agricultural fields or densely populated areas. In water bodies, the phosphorus may be present in various forms. All forms of phosphorus are not readily available to plants. Total phosphorus is a measure of all forms of phosphorus (dissolved or suspended) found in any water sample. The soluble reactive phosphorus is a measure of orthophosphate. The soluble inorganic (a filterable fraction) phosphorus is the form directly taken up by plant cells. While monitoring the water bodies, the latter form of phosphorus would be of special significance to determine the stage of eutrophy and oligotrophy.

Natural waters are normally deficient in phosphorus and other plant nutrients. Such natural water bodies support only a limited growth of algae and higher aquatic plants. An additional loading of phosphorus in any of the various forms—orthophosphate, pyrophosphate, metaphosphate, mono- and di-hydrogen phosphate, etc.—results into an undesirably extensive growth of algae and/or other aquatic plants like water hyacinth (Ambasht & Ambasht, 1992). The death and decay of the bloomed aquatic flora further deteriorate the natural water bodies. The organic form of phosphorus is decomposed by bacteria in the bottom of the eutrophic water bodies and converted into inorganic form, which readily diffuses upward to the photic zone. The inorganic form of phosphorus is recycled again by the aquatic flora via absorption, photophosphorylation, growth, death, and decay. Notestein et al. (2003) suggested that phosphorus rather than nitrogen was implicated as the nutrient that potentially limits periphyton growth in the coastal stream of Florida.

Clastic sediments were found to act as a sink of phosphorus in a German lowland river, especially in summer months. The particulate iron was reported to be the sorption site of phosphorus. The organic river substrate was, however, found to be a source of phosphorus rather than a sink (Schulz & Herzog, 2004). England and Wales were found vulnerable to the transfer of sedimentary phosphorus from agriculture to river. Estimates of phosphorus transfer risks were carried out on a larger grid size of resolution of 25 km^2 (Chapman et al., 2003). The phosphorus concentration in the River Stour exceeded the standard limit of the Environment Agency (Kelly & Wilson, 2004).

SOURCES OF PHOSPHORUS

There are several sources of phosphorus. It is essential in metabolism and is usually present in animal wastes. Any nearby cattle feedlots, hog farms, dairies, and barnyards may be common sources of phosphate runoff that reaches a water body. Polyphosphates often used in water treatment may enter the water body and be converted into orthophosphate. Polyphosphate storage has been demonstrated in bacteria, yeasts, filamentous fungi, and photosynthetic algae (Kulaev, 1979). Phosphate mining and processing are the other sources of phosphate in nearby rivers or lakes in some areas. Phosphorus bound to soil particles may also be released to a water body as a result of a forest fire or soil erosion. In freshwater systems phosphorus has been identified as the "limiting nutrient" to phytoplankton development. This nutrient is mainly brought to aquatic environment from the weathering of rocks, the leaching of soil, and rain (natural source). But a major part of phosphorus is unloaded into aquatic bodies from agricultural runoff and domestic sewage. The phosphorus pollution is attributable mainly to floor and utensil cleaning rather than to direct food wastes. The phosphate is a relatively immobile element and may be carried to streams through soil erosion and storm runoffs from overfertilized or excessively fertilized agricultural fields, nurseries, lawns, and orchards. Certain synthetic chemicals, such as pesticides, construction materials, flame retardants, and plasticizers, are the other sources of phosphate discharges. Fertilizers generally contain phosphorus in the form of orthophosphate.

Domestic sewage is also high in phosphates. More than 50% of it comes from human waste and 20%–30% from detergents. Animal feedlots are sources of both nitrates and phosphates (Penelope & Charles, 1992). In water bodies around villages, towns, and cities, enough phosphorus is released from detergents, sewage and industrial effluents. Some fraction of phosphate fertilizers applied to agricultural fields runs off to water bodies (Ambasht & Ambasht, 1992). India's River Nandira, a tributary of the Brahmani, receives the partially treated or untreated wastewater of a fertilizer factory, causing considerable change in color, odor, pH, and chemical characteristics of the river water. The phytoplankton occurring in the unpolluted sites disappeared with a proportionate increase in the pollution load of the Nandira (Tripathy & Adhikary, 1990).

MONITORING OF PHOSPHORUS

Studies on the impact of abiotic factors on the biotic components of two ponds in Jammu, India revealed that the deficiency and availability of calcium and phosphorus were related to phytoplankton density (cell L^{-1}) in the ponds. In certain months, the higher amounts of phosphate-phosphorus accumulated in one of the two ponds studied (Kant & Raina, 1990). The phosphorus was presumably released due to death and decomposition of the phytoplanktonic population. The complete presence, absence, or insignificant amount of phosphate-phosphorus in certain months of the year were related to the locking of phosphorus within the macrophytes and phytoplankton during its bloom (Kant & Raina, 1990).

PHOSPHORUS CYCLE

Phosphorus enters all water bodies continuously in runoff water and inlet streams. Phosphorus is also regularly lost from the water bodies through outlet streams and by incorporation into the sediments/mud. When a lake has anoxic bottom water in summer and stratifies, the top

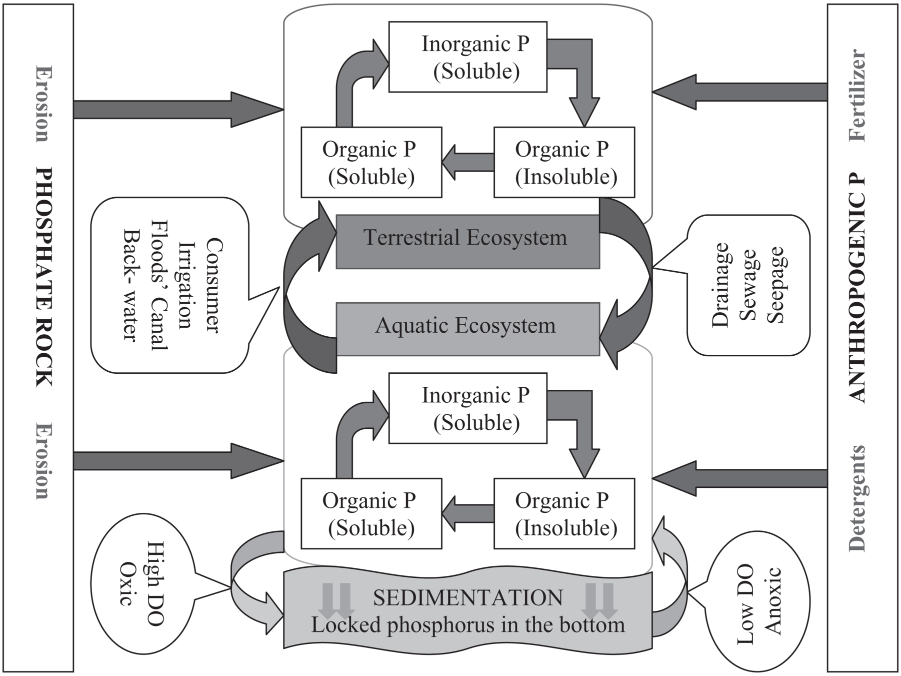

Fig. 2. The phosphorus cycle, phosphorus movement, and phosphorus-enrichment processes.

few millimeters of mud is chemically reduced to a condition that allows the phosphorus to release back into the water. The bottom water thus becomes phosphorus rich. Stirring of the lake by winter storms brings the phosphorus-rich water to the surface, completing an annual cycle and fertilizing the lake for a spring plant bloom. An almost similar pattern of phosphorus cycle is common in other water bodies. Figure 2 shows the phosphorus cycle, phosphorus enrichment, and movement between terrestrial and aquatic ecosystems. In the figure two major sources of phosphorus input are shown. The weathering of phosphate rocks forms the natural source of the operation of the phosphorus cycle. Detergents, fertilizers, and household wastes are the anthropogenic sources of phosphorus. The latter source of phosphorus input is the main cause of eutrophication (Fig. 2).

In certain lakes and ponds, algae were found growing at an unprecedented rate. This was attributed to the extensive use of sodium tri-polyphosphate in detergent industries and its discharge down through the drainage. Phosphates also find their way into these water systems from agroecosystems and domestic water discharges. In the last few decades, the excessive use of detergents and phosphate fertilizers is so concurrent that the causes of eutrophication are not attributable to either of the two sources. The detergent industries are looking for an efficient substitute for sodium tri-polyphosphate. Phosphates are the major ingredients of most detergents and favor the luxuriant growth of algae. The detergent builders contribute significantly (approximately 50%) to the phosphate present in sewage effluents. Nitrilotriacetic acid was considered to be an alternative but later proved to be hazardous to human health. At present no acceptable substitute is available for polyphosphate builders in detergents. The best alternative is to minimize the use of phosphates in detergents (Rao, 1998).

Detergents and Their Role

DEFINITIONS

Many definitions of synthetic detergents have been proposed, all of which are of a very wide scope. After several years of deliberation the Comiti International de Dirivis Tensio Actifs defined the detergent as a "product, the formulation of which is specially devised to promote the development of detergency. . . . A detergent is a formulation comprising essential constituents (surface active agents) and subsidiary constituents (builders, boosters, fillers and auxiliaries)" (Campbell, 1998). Perhaps the most widely used detergents are sodium salts of alkylbenzene sulfonic acids. A long chain of the alkyl group is attached to a benzene ring by the action of Friedel-Crafts catalyst and an alkyl halide, alkene, or alcohol. Sulfonation and neutralization yields the detergent (Morrison & Boyd, 2000).

Of the two basic components of detergent—surfactants and builders—the surfactants, or surface-active agents, are the main cleaning agents. Various brands of Indian detergents, including those of multinational companies prevalent in the market, usually contain only 10%–30% surfactants. The remainder comprises builders as polyphosphate salts (Rao, 1998; Sharma, 1998). In addition to the two basic components, certain products contain small amounts of optical whiteners to increase cleaning efficiency. About 1 ppm of surfactant produces foam in river and sewage treatment plants. This concentration is nontoxic to human beings but gives an off taste to drinking water. Just 0.1 ppm of surfactant reduces the rate of oxygen absorption in water to about half (Rao, 1998).

Orthophosphates and certain polyphosphates are major constituents of many commercial cleaning preparations. In 1950s and 1960s, sodium phosphate was often used as a builder in household detergents to increase cleaning power. The extensive use of detergents led to major eutrophication problems. In the 1960s efforts were made by governments, detergent manufacturers, and consumers to reduce the use of phosphates in detergents. As a result, phosphorus concentrations in many streams and lakes decreased. This was due to limits on the phosphate content of detergent and also additional treatment used in wastewater treatment plants to remove phosphorus. Many states have a ban on phosphates in detergents (Campbell, 1998).

SYNTHETIC DETERGENT

Although the start of the synthetic detergent industry is not shrouded in the veils of history as were the beginnings of the soap industry, it is nevertheless not easy to pinpoint exactly when the detergent industry as such came into being. The term "synthetic detergent" needs to be defined. In the United States the terms "surfactant" and "syndet" are being used, but in Europe the term "tenside" (for tensio-active material) is more common. The first synthetic detergents seem to have been developed by the Germans in the World War I period to allow fats to be utilized for other purposes. Chemically these detergents were of the short-chain alkyl naphthalene sulphonate type, made by coupling propyl or butyl alcohols with naphthalene and subsequent sulphonation, and they appeared under the general name of "Nekal." These products proved to be only fair to moderately good detergents but good wetting agents, and they are still being produced in large quantities for use as textile auxiliaries (Campbell, 1998).

In the late 1920s and early 1930s long-chain alcohols were sulphonated and sold as the neutralized sodium salts without any further additions except for sodium sulphate as an extender. In the early 1930s long-chain alkyl aryl sulphonates with benzene as the aromatic nucleus and the alkyl portion made from a kerosene fraction appeared in the U.S. market. These products were earlier available to the industries as sodium salts. Proteolytic enzymes were tried as additives to washing powders in Germany in the 1920s with only moderate success and again in Switzerland in the

1930s. A little later, enzymes of organic origin appeared on the market. Heavy-duty detergent formulations were introduced from 1947 onward. Initially these organic products were tetra sodium pyrophosphate; later these formulations had sodium tripolyphosphate. With the advent of carboxy methyl cellulose and tri-polyphosphate builders, the detergent industry was on the rise until 1970. Later, a combination of restrictions on the use of phosphates and international shortages of raw materials reduced detergent production (Campbell, 1998).

Role of Some Other Nutrients

Nitrogen may limit phytoplankton production in temperate eutrophic waters, especially when phosphate concentrations are high (when nitrogen:phosphorus ratios are low). The variations in the chemical composition of natural waters are believed to be an important factor in regulating the abundance, composition, and geographical and periodic distribution of phytoplankton. In phosphate-deficient water bodies or those having reasonably good growth of blue-green algae (which fix enough of the atmospheric nitrogen), the phosphates become limiting, because some of it is used to counterbalance the high nitrate content (Reynolds, 1984). Inorganic and organic nitrogen fluxes in the Ria Vigo (in the northwestern Iberian Peninsula) have been quantified in order to recognize the contrasting nitrogen budget scenarios and understand the biogeochemical response to eutrophication events (Prego et al., 2002).

A large-scale increase in the nutrient input in the water bodies induces faster plant growth, imbalanced trophic structure, and reduced dissolved oxygen concentrations (Campus-Ortega, 1998; Moss, 1988). A majority of lakes and freshwater bodies the world over are excessively loaded with a number of plant nutrients. Aquatic ecosystems respond variably to nutrient enrichment and altered nutrient ratios, along a continuum from freshwater through estuarine, coastal, and marine systems. Although phosphorus is mainly considered as the limiting nutrient for phytoplankton production in freshwater systems, the effect of atmospheric nitrogen and its contribution to the acidification of freshwater can also be detrimental. Among nitrogen, phosphorus, and silicon, nitrogen is generally considered as the primary limiting nutrient for the accumulation of phytoplankton biomass (Rabalais et al., 2002). Seasonal phosphorus and nitrogen accumulation and release by two macrophytes stands—mart weed (*Polygonum amphibium*) and marsh cudweed (*Gnaphalium uliginosum*)—growing in a eutrophic reservoir in Spremberg, Germany were investigated by Kleeberg and Heidenreich (2004). The rate of release of phosphorus was faster than the rate of accumulation, and the nitrogen accumulation rate was higher than the release rate (Kleeberg & Heidenreich, 2004).

Nutrient input into a more stable ecosystem causes eutrophication. It induced changes in the ecosystem functioning and increased primary production in the Pagasitikos Gulf, in Greece (Triantafyllou et al., 2001). Nitrates can enter natural waters from several sources. City sewage and agroecosystems in India are the two major sources of nitrates. A considerable bulk (about one-half) of human and animal wastes are nitrates. Fertilizer, which runs off croplands or suburban lawns (in some countries) during rainstorms, contains large amounts of nitrates (Penelope & Charles, 1992). Danish coastal waters were found to be heavily eutrophic, with high particulate concentrations and turbid waters. The chlorophyll concentration was strongly linked to the total nitrogen concentration. In summer the total nitrogen concentrations accounted for about 60% of the variability in chlorophyll concentrations among the different coastal systems (Nielsen et al., 2002).

In lentic and lotic water bodies, nitrogen and phosphorus cycling is closely related to sunlight. In a water body with a phosphate:nitrate ratio of 1:15, all of the phosphate, but only about half of the nitrate, is used up by aquatic plants. The phosphate in such a water body becomes limiting, and nitrate accumulates in abundance. However, a water body with a nitrate:phosphate enrichment level at the ratio of 4:15 uses up all the nitrate, and the nitrate thus becomes limiting. The acceptable level of total inorganic phosphate in water is 0.03 to 0.04 mg L^{-1}. In most of the lakes and rivers in which eutrophication is encountered, the principal cause is excessive enrichment of water by phosphates and nitrates. In and around cities and industries, phosphate content has increased 20–25-fold during the last 10–15 years (Muller & Helsel, 1999).

Nitrogen and phosphorus, the most frequently discussed of all nutrients, enter lakes from many sources. The three major nutrients in fertilizer required for crop growth are nitrogen, phosphorus, and potassium. These nutrients, when unloaded into water bodies, promote phytoplankton (microscopic plants or algae) growth. This is important because phytoplankton represents the base of the food chain in lakes. The zooplankton feed upon phytoplankton, and small fish feed upon zooplankton. The smaller fish are consumed by large carnivorous fish. The growth of phytoplankton, or the primary productivity, is the first step in the food chain of a lake. The extent of algal production indicates to a certain degree the productive capacity of a lake. However, there are limits beyond which algal growth becomes detrimental to other aquatic life (Reutter, 1989). In freshwater lakes and rivers, phosphorus is often the growth-limiting nutrient, because it occurs in the least amount relative to the needs of plants. In estuaries and coastal waters, nitrogen is generally the growth-limiting nutrient (Murphy, 2002).

Kant and Raina (1990) compared the phytoplankton population of the two ponds in the Jammu and Kashmir region. The increase in population of phytoplankton was related to the amount of magnesium available. The concentration of magnesium consistently reduced and became untraceable with the increase in the standing crop of phytoplankton because of its utilization in chlorophyll formation. The depletion of magnesium (due to its binding into chlorophyll molecule) acts as a limiting factor for the growth of phytoplankton. The calcium in these ponds was found inversely related to population sizes and fluctuations in the water temperature (Kant & Raina, 1990). The additions of nutrients to the lakes were largely bound to the inedible component of the phytoplankton. This ecosystem component consisting mainly of blue-green algae (Cyanophyta) is avoided by planktivorous fish and zooplanktons because of their toxicity and taste (Campbell, 1998). Shen (2002) found that algal growth was directly related to the concentration of phosphorus and nitrogen in water. The number of algae increased when total phosphorus in the water was 0.1–0.75 mg L^{-1}. The specific growth of algae was highest when the concentration of total phosphorus was <0.5 mg L^{-1} and that of total nitrogen was <1.0 mg L^{-1}. The effect of phosphorus was greater than was that of nitrogen. Physicochemical characteristics and water pollution have been studied on Lake Banjara in India for a period of two years. In this lake chlorides, calcium and magnesium were within stipulated range where as the total solids and the total hardness of water exceeded the limits set by the Indian Standards Institution and the World Health Organization, indicating the impact of sewage and domestic waste (Swaranlatha & Rao, 1998).

Impact of Organic Matter

Some food-processing industries (meat, vegetables, cheese) contribute significantly to the phosphorus that is unloaded into the freshwater bodies and leads to eutrophication (Vuillemin, 2001). The organic inputs (carbohydrates, proteins, and lipids) from the food industry increased the biological oxygen demand level due to degradation of lipids and carbohydrates by microorganisms in fresh water bodies (Jones, 2001). In West Bengal, India, high nutrient content was found in a water body receiving washing from a rice mill (Chattopadhyay & Kushari, 2003). Deteriorated water quality below Indian Standards Institution, World Health Organization, and U.S. Public Health Service standards owing to discharge of sewage has recently been observed in the Cauvery River in India (Lalitha et al., 2003). The unprocessed effluents of leather tanneries contribute a significant amount of tannin to the Ganges River in Kanpur, also in India.

Role of Environmental Factors

The environments inhabited by plankton are heterogeneous. Temporal changes in mean temperature, irradiance, and nutrient availability are among the more obvious variables (Reynolds, 1984). The population of cyanophytes dominated the phytoplankton community upon phosphorus increase. On increase in phosphorus one can predict the relative dominance of cyanophytes from the balance between nitrogen and phosphorus (Welch & Crooke, 1987). The range of factors that can influence eutrophication dynamics may be fully investigated when long-term data with respect to time series are available (Lau & Lane, 2002a, 2002b). The algal bloom caused by phosphorus inputs also modifies several abiotic factors of the water body. These factors directly govern the growth, diversity, and density of the biotic components. The impact of algal bloom on any one or some of these factors indirectly influences the structure and characteristics of the water bodies. The influence of nutrient inputs on some of these factors is discussed below.

CARBON DIOXIDE LEVEL

Cyanophytes are more capable of utilizing low levels of carbon dioxide and become more buoyant at low levels of carbon dioxide and high water pH. It keeps them in the upper layers of the water column with abundant sunlight. In addition, some species produce dense mats of vegetation and inhibit the growth of other phytoplankton, and they also limit the swimming of zooplankton. These factors together mean that a slow-moving freshwater ecosystem can rapidly become dominated by blue-green algae, displacing not only members of the phytoplankton but some of the animal community as well. The reduction of light reaching the lake floor also inhibits submerged and rooted macrophytes, and sediments become anoxic as large amounts of planktonic biomass are added to them (Kant & Raina, 1990).

The fluctuations in free carbon dioxide values correspond directly with the fluctuation in the standing crop of phytoplankton. As the diversity and density of phytoplanktons increase through various months, the amount of free carbon dioxide for photosynthetic activity becomes limiting. The pH changes in these ponds are governed by the amount of free carbon dioxide, carbon trioxide, and bicarbonate (Kant & Raina, 1990) Inflow nutrient concentration, inflow volume, and inflow water temperature show very regular and reasonable impacts on the quality of lake water (Imteaz et al., 2003). Yin (2002) reported that monsoons served as a flushing mechanism in two ways: They reduced seasonal eutrophication by nutrient enrichment in summer, and they prevented long-term (annual) accumulation of organic matter in the sediments due to nutrient enrichment in the region. Because of the monsoon-influenced processes and low phosphorus in the Pearl River estuary, the estuary and adjacent coastal waters of Hong Kong appeared to be more resilient to enrichment of nitrogen.

TEMPERATURE

Temperature always influences fertility. If a lake is cold, a high nutrient loading may fail to make it eutrophic. A relatively high influx of nutrients from the watershed is locked into the toxic mud under an oxygen-rich hypolimnion. A large volume of water implies a large oxygen reserve. Thus a very deep lake can retain oxygen in the hypolimnion all summer, even though the surface waters are fertile, and deep lakes can retain the essential properties of oligotrophic lakes despite significant nutrient loading from the watershed (Colinvaux, 1993). The high water temperatures that excluded certain zooplankton species, and the inedibility of the filaments, further increased the dominance of cyanobacteria. In Mansarovar Lake in India, maximum phytoplankton density was observed during winter, with minimum temperature, conductivity, pH, and chloride contents of the lake water (Kulshreshtha et al., 1989). The effect of temperature on algal growth was more obvious than the other factors. The most favorable temperature for algal growth was 30° C (Shen, 2002). The discharge of sewage and drainage water has resulted in the change in temperature, pH, and metal concentration of a monsoon-fed freshwater pond in Coimbatore, India (Francis et al., 1997).

HYDROGEN ION CONCENTRATION (pH)

The pH is an important environmental factor. It is a plant-growth-limiting factor. The change in pH is directly related to the availability and absorption of nutrients from solution. Ionization of electrolytes or the valence numbers of different ion species are influenced by changes in pH. The absorption of phosphate is accelerated by an acidic pH (Devlin & Witham, 1986). An acidic pH has been reported to promote growth of *Spirodela polyrrhiza* at a faster rate. A pH of 6.0 was found most suitable. But the growth retardation in *S. polyrrhiza* has been noted below pH 6.0 and/or above 9.0. A low pH also affected the chlorophyll *b* formation (Aziz & Mobina, 1999). But George and Heaney (1978) suggested that high pH values promote the growth of phytoplankton and result in bloom.

LIGHT

Light plays an important role in the growth, diversity, and density of aquatic flora. Algal growth has been reported to increase with light intensity, and luminescence of 4000 lux was found most favorable (Shen, 2002). As eutrophication progresses, a decline of submerged macrophytes occurs in many shallow lakes, probably due to low light intensity caused by algal blooming. It is suggested that the adaptation strategy of *Potamogeton maackianus* under a certain range of low light stress is to accelerate the elongation of the main and lateral shoots and to increase their density (Ni et al., 1999).

The light has been almost completely absorbed by the plankton of the top few meters, so that too little light penetrates to the thermocline and beyond to support photosynthesis. But there is a rain of corpses into the deep water, whose decomposition requires oxygen. Since the deep water is cut off from the air until fall overturn, an oxygen deficit develops in the deep water, and the bottom mud is reduced. Eutrophication in an estuary is a complex process, and climate change is likely to affect each estuary differently due to interactions with nutrient loading and physical circulation. Hence, it is essential to consider the effects of climate change in the context of individual estuarine function to successfully manage eutrophication (Howarth et al., 2000).

DISSOLVED OXYGEN

The minima and maxima in the concentration of dissolved oxygen are found to be directly related to the maxima and minima of the phytoplankton. Slight variations in the relationship of dissolved oxygen and phytoplankton in winter is attributable to the lowering of water temperature. This in turn increases the capacity of water to hold more dissolved oxygen, possibly due to the decreased photosynthetic activity of the phytoplankton brought about by temperatures beyond the optima. This would otherwise act as limiting factor for photosynthetic activity (Kant & Raina, 1990). The direct relationship between phytoplankton and dissolved oxygen content has been observed by a number of researchers (Lande, 1973; Misra et al., 1975; Saad, 1973; Schindler, 1971).

Eutrophication versus Plant Diversity

Any change in the natural quality of water is best reflected in the change in natural flora and fauna of the aquatic ecosystem (Kulshreshtha et al., 1989). The process of eutrophication reduced the number of rare species and increased the abundance of mesoeutrophentic to hypereutrophentic species, particularly *Fragilaria berolinensis,* in the eutrophicated broad area of De Nieuwkoopse Plassen in the Netherlands (Van Dam & Mertens, 1993). In a shallow lake under eutrophic succession, the population of *Chara* spp. was positively, and that *Potamogeton pectinatus,* slightly negatively, related to Secchi depth (Van Den Burg et al., 1999). Lake Geneva underwent rapid eutrophication until 1980, followed by a reversal that is still in progress. However, *Potamogeton pectinatus, P. perfoliatus, P. lucens,* and *Elodea canadensis* showed no significant changes in their distribution, with the two former species dominant throughout. Tracy et al. (2003) reported that aquatic macrophyte diversity and community have a strong relationship to variations in nitrogen (nitrate and ammonia).

The impact of eutrophication on aquatic macrophyte diversity in weakly mineralized streams in the northern Vosges Mountains, in northeastern France, was studied by Thiebaut and Muller (1998). Macrophyte-specific richness and abundance increased along an upstream-to-downstream zonation, which was characterized by an increase in mineralization and nutrient level. A comparison of aquatic macrophyte diversity of two streams reflected the impact of human-induced perturbations (fish farms, domestic sewage) in such weakly mineralized and poorly buffered waters. Disturbed sites with very high nutrient loading were characterized by low vascular plant richness and by the presence of filamentous algae (Thiebaut & Muller, 1998). Vadineanu et al. (1992) studied the phytoplankton and submerged macrophytes in the aquatic ecosystems of the Danube Delta and observed that the species changes were found to be linked to accelerated eutrophication of the lakes, with increased phosphorus loading and a reduction in the nitrogen:phosphorus ratio. Vaithiyanathan and Richardson (1999) observed distinct changes in the macrophyte species composition in response to phosphorus enrichment. Marshes in the unenriched and enriched areas were dominated by *Cladium jamaicense* and *Typha domingensis,* respectively. Open-water areas were characterized by *Eleocharis* spp., *Utricularia* spp., *Chara zeylanica,* and *Nymphaea odorata* in oligotrophic areas and by floating plants and *Polygonum* spp. in eutrophic areas.

A shift in primary producers from eelgrass to macroalgae in response to increased nutrient loading altered the habitat, physicochemical structure, and food webs. The nitrogen decreased shoot density and biomass of the eelgrass and promoted a record increase in the algal biomass (Deegan et al., 2002). Enhanced nutrient concentrations and loading have been observed in several coastal areas of the North Sea, resulting in increased production and changes in the species composition of phytoplankton (Colijn et al., 2002).

Garg et al. (2002) studied three lakes of Bhopal (Upper Lake, Lower Lake, and Mansarovar Lake) in India and assessed the potential fertility of the lentic water and its aquatic flora. Eutrophication was highest in Mansarovar Lake. The observations of Garg et al. (2002) indicated that different species of phytoplankton could subsist up to a certain nutrient level, beyond which competition between cyanophytes and other algae enhanced and eliminated the sensitive plankton flora.

Eutrophiocation versus Wetland Plants

Wetlands are ecologically complex hydrological and biogeochemical systems endowed with specific structural and functional characters. A number of wetlands in India have been studied with emphasis on macrophyte communities (Adoni & Yadav, 1985; Kaul, 1970; Kaul et al., 1978; Trisal & Kaul, 1983). Much of the information has been compiled on wetlands ecology by Gopal et al. (1982). Macrophytes play an important role in energy flow and organic matter input during recycling of nutrients in water bodies (Mickel & Wetzel, 1978).

The experiments by Smolders et al. (1995) revealed that internal eutrophication processes causing eutrophication without any nutrient input play an important role in wetlands. Purple loosestrife (*Lythrum salicaria*) rapidly displaced the native vegetation in North American wetlands. The conversion of wetland vegetation from cattails (*Typha* spp.) to loosestrife is expected to cause significant changes in wetland function by altering the timing of litter input and downstream phosphorus loads. The conversion of a riverine flowing through wetland from *Typha* to loosestrife may effectively accelerate eutrophication of downstream water bodies (Emery & Perry, 1996).

Eutrophication versus Succession Pathways

Succession is the process by which a water body becomes a marsh, then a bog, and finally a drier terrestrial body. Human activities around the aquatic bodies have enhanced the nutrient-input rate and accelerated the natural aging process known as "eutrophication." This aging process brought down the water body under a faster cycle of succession (Reutter, 1989). Eutrophication is a noticeable problem of aquatic environments all over the world. In the Netherlands, the abundance of many aquatic macrophytes has shown a steep decline, and the eutrophic habitats are now characterized by floating species like *Lemna* spp., *Spirodela polyrrhiza,* and *Azolla filiculoides*. Weimin et al. (1997) found China's Lake Taihu in the mesoeutrophication stage. The dominant phytoplankton species noted were *Microcystis, Anabaena, Melosira, Cyclotella,* and *Cryptomonas*. In summer *Microsystis* spp. occupied 85% of algae biomass and resulted in an algal bloom.

Benndorf and Henning (1989) found that the seasonal increase in the toxicity of *Microcytis aerugicosa* in a reservoir was due to the selective consumption of nontoxic strains by *Daphnia*. The toxic varieties inhibit the invertebrate's filtering rate and so are avoided; leaving patches of the strain that can go on to dominate the ecosystem. Thus in a cyanophyte-dominated community with eutrophic and calm waters the grazing activity of the *Daphnia* may actually promote the growth of a toxic phytoplankton as the season progresses. Moss et al. (1991) found that, in the absence of fish predation, larger *Daphnia* species could flourish only where cyanophytes were absent. In the presence of the filamentous *Oscillatoria,* only smaller species of zooplankton were found. These alterations in the community structures modify the environment of water body and in turn pave the way for the development of another community of a higher trophic level.

Bioindicators of Eutrophication

Bioindicators act as a measure of prevailing environmental conditions. Also referred to as "ecological indicators," bioindicators provide information on the ecosystem condition. They may be used to observe the functioning and cause-and-effect relationships within an ecosystem. The biological indicator of eutrophication may be a single species or an assemblage of several species. The diversity and distribution of species in an ecosystem depends upon the ecological amplitude of species and the existing environment of the ecosystem. Some of the biological parameters are given below.

STRUCTURAL DIVERSITY

Indicators for eutrophication differ for rivers and for lakes. For river ecosystems the bioindicators describe the diversity and occurrence of life cycles along the longitudinal and lateral dimension. For lake ecosystems two bioindicators are selected that are characteristic for the switch between the two equilibrium states: the area and biomass of macrophytes, indicating that turbidity has lessened to the extent that macrophytes can grow; and the ratio between prey fish and predatory fish, which has to be 1:1 to 2:1 to guarantee a long-term, stable, clear lake (Lorenz, 2003). Phytoplankton, aquatic vegetation, and fish play important roles as indicators of eutrophication (Sekulic et al., 1998). Some biotic components given below have been used as biological indicators of eutrophication.

Algae

Aquatic vascular plants are good indicators of water quality (Shimoda, 1984). Algae are commonly used for biological assessment of water quality and indicators of eutrophication (Garg et al., 2003; Patrick, 1950). Fast-growing, ephemeral algae are increasingly observed in shallow coastal waters worldwide. This is generally considered a symptom of coastal eutrophication (Sundback et al., 2003). Eutrophication causes predictable increases in the biomass of algae in lakes and reservoirs, in streams and rivers, and in wetland and coastal marine ecosystems (Smith, 2003). Significant effects of sewage discharge on flora and fauna of Moa Point Bay (New Zealand) have been observed by Rogers (2003). The area around the point of discharge had limited biodiversity, but *Ulva lactuca*, a seaweed-like lettuce (a typical inhabitant of areas with high nutrient input) was found in abundance (Rogers, 2003). Growth and continuous blooms of *Microcystis* and also the existence of *Stigeoclonium* indicate organic pollution in Banjara Lake, in India (Swaranlatha & Rao, 1998).

Macrophytes

Schnitzler et al. (1996) studied the response of aquatic macrophyte communities to levels of phosphorus and nitrogen in an old swamp on the upper Rhine plain in eastern France and worked out the utility of some aquatic macrophytes as bioindicators of eutrophication. *Vallisnaria americana* is reported to be the efficient biomonitor of organic contamination and stressed aquatic ecosystems (Biernacki et al., 1996; Lovett-Doust et al., 1994; Potter & Lovett-Doust, 2001). Some significant bioindicators of eutrophication studied and listed by Stojanovic et al. (1998) include *Wolffia arrhiza, Lemna gibba, L. minor, L. trisulca, Spirodela polyrrhiza, Ceratophylum demersum, Elodea canadensis, Vallisnaria spiralis, Stratiotes aloides, Nupher lutea, Bolboschoenus maritimus, Typha angustifolia, T. latifolia,* and *Phragmites communis*. These species were reported to be the best indicators of eutrophication caused by organic effluents and nutrients (Stojanovic et al., 1998). The growth of *Spirodela polyrrhiza* was found to be directly related to the nutrient concentration of water (Ansari & Khan, 2002). The population and growth of *Lemna minor* and *Spirodela polyrrhiza* were studied as a measure of eutrophication caused by household detergents (Ansari, 2005).

Diatoms

The epiphytic diatom assemblage indicates eutrophication by nitrogen and phosphorus concentrations (Denys, 2003; Winter & Duthie, 2000). The changes in geochemistry and diatom assemblages are probably linked to increases in nutrient supply (from sewage and diffuse agricultural sources) and hence to increases in primary production (Gibson et al., 2003). The phosphorus could be considered as the driver of increased diatom production (Foy et al., 2003). Epilithic diatom assemblages were used to evaluate water quality in the Karasu River basin in Turkey, which was polluted by industrial, agricultural, and urban wastes (Gurbuz & Kivrak, 2002). Diatoms are generally recognized as indicators in temperate streams, but Juttner et al. (2003) also reported diatoms indicating stream quality in the tropics and subtropics in the Kathmandu Valley and Middle Hills of Nepal and India. The diatom population and water analysis revealed that England's River Stour was eutrophic. Biological analysis of samples taken downstream and upstream of a sewage-treatment plant showed little difference in the diatom population. However, chemical analysis showed that nitrogen acted as a limiting factor for some part of the year (Kelly & Wilson, 2004).

Plant Pigments

Wei et al. (2000) found that chlorophyll *a* was suitable as one of the biological indicators to show the trend of eutrophication of Lake Kasumigaura, in Japan. However, it will be limited, because the diversity index is employed only to test the biotic response to the change of water environment. Phytoplankton photopigments were also reported as indicators of estuarine and coastal eutrophication. The photopigment indicators can be routinely incorporated in water-quality monitoring programs to assess environmental controls on ecosystem structure and function at varying spatial and temporal scales. Chlorophyll, however, may not be a consistent parameter of eutrophication, because the response differs with change in trophic structure.

Kufel (2001) also suggested that chlorophyll in eutrophic lakes correlates well with nitrogen and phosphorus. However, chlorophyll-nutrient relationships varied with the trophic status of the lake. Chlorophyll *a* was found to be a function of the level of orthophosphate concentration in the shallow, eutrophic Chinese Lake Donghu (Zhou et al., 2004). Significant seasonal variation in the chlorophyll *a* of the planktons in the northern coast of Karawang, West Java, Indonesia has been reported, as have variations in physical and chemical characteristics. These variations have been attributed to eutrophication resulting from nutrient enrichment of coastal water suspected to be caused by organic wastes from agricultural and aquacultural practices (Sachoemar & Yanagi, 1999).

ECOSYSTEM FUNCTIONING

Primary productivity has been used as a biological parameter to monitor the overall response of vegetation to a prevailing environment in terrestrial ecosystems (Khan, 1985). Changes in the rate of primary production as an indication of trophic status of aquatic ecosystems have been one of the major indicators of their health (Herrera-Silveira et al., 2002). Phytotreatment of pond systems caused reductions of dissolved and particulate nitrogen and, to an extent, of phosphorus. The flooded areas used for phytotreatment permit the growth of huge quantities of macroalgae, which remove nitrogen and phosphorus from the effluent (Porrello et al., 2003a, 2003b). Bonsdorff et al. (2002) suggested several parameters—transparency, oxygen/hypoxia, nutrients, primary production, chlorophyll *a,* algal mats, macroalgae, zoobenthos and fish—to quantify eutrophication.

Control Measures

Phosphorus is a major nutrient in controlling the growth of algae. Phosphorus in Lake Erie is often the limiting factor. Algae growth can be controlled by reducing input of any one of the essential nutrients. Phosphorus is the nutrient over which one has the greatest control (Reutter, 1989). In freshwater lakes and rivers, phosphorus is a growth-limiting nutrient, because it occurs in far lesser amount than the quantity required for optimum plant growth. If excessive amounts of phosphorus and nitrogen are added to the water, algae and other aquatic plants can be produced in large quantities. Removal of bloomed algae in which phosphorus is bound and of sediments before anoxic state at bottom may also be helpful in remediation of eutrophic ecosystems.

BIOLOGICAL CONTROL

Partial recovery from an algal to a macrophyte-dominated state in a eutrophic freshwater system requires managed phosphorus limitation and unmanaged macrophyte growth (Perkins & Underwood, 2002). Aquatic macrophytes like *Eichhornia crassipes* and *Salvinia auriculata* cause significant reduction of nitrogen and phosphorus compounds in the water. This information was thought to be helpful in developing adequate management strategies for aquatic macrophytes, intended to check the eutrophication process in Imboassica Lagoon, in Brazil, by Petrucio and Esteves (2000). Some aquatic weeds, such as *Typha, Phragmites,* and *Glyceria* spp., in ditches were expected to be useful in removing nutrients from the eutrophic water body (Beltman et al., 1990). Wychera et al. (1990) studied macrophytes of the New Danube River flowing through Vienna and suggested that the constant harvesting of macrophytes would be necessary to manage the process of eutrophication if a power plant were built on its bank. Potential removal of particulate matter and nitrogen through water hyacinth (*Eicchornia crassipes*) roots was also reported by Billore et al. (1998), and removal of water hyacinth may prove beneficial in controlling eutrophication. Alternatively, water hyacinth may be used in the formation of compost. Some aquatic macrophytes are capable of purifying eutrophic lake water. The water peanut, *Alternanthera philoxeroides,* improves the transparency of eutrophic lake water (Wang et al*.,* 1999).

Hydrodictyon reticulatum was reported to actively remove 67.3% nitrogen and phosphorus in six days under different environmental conditions (Liu et al*.,* 2004). The dissolved phosphorus can be removed in irrigation drainage water by planted floats. The floats are designed to implement horizontally spreading water plants to the surface of irrigation drains, fields, or treatment ponds in order to eliminate dissolved phosphorus and to allow harvest of the standing crop and therefore removal of the accumulated phosphorus. The results indicated that the float technology could utilize creeping-stem water plants in order to remove soluble reactive phosphorus from the water column (Wen & Recknagel, 2002). Seaweeds can remove up to 90% of the nutrient discharge from an intensive fish farm. Mass culture of commercially valuable seaweed species is likely to play an increasingly important role as a nutrient-removal system to alleviate eutrophication problems due to fed aquaculture (Luning et al., 2002).

The potential of three estuarine macroalgae (*Ulva rotundata, Enteromorpha intestinelis,* and *Gracilaria gracilis*) as biofilters for phosphate in effluents of a sea bass (*Dicentrarchus labrax*) cultivation tank was reported by Martinez-Aragon et al. (2002). Abe et al. (2002) collected the aerial macroalga *Trentipohlia aurea* from Japan, which was investigated in relation to the removal characteristics of nitrate, nitrite, ammonium, and phosphate ions. The biomass was recorded 1.5 times higher in medium with sufficient nitrogen and phosphorus source in ordinary medium. In the experiment about 37% of nitrite and 32% nitrate removal was observed. Thus *T. aurea* has the potential for use in the purification of wastewater.

Some phytoplanktivorous fish can be utilized for weed management and counteracting eutrophication (Opuszynski & Shireman, 1995). Processing of nutrients in shallow habitats removes phosphorus from water naturally, and periphyton influences phosphorus removal from the water column in flowing waters and wetlands. Periphyton plays several roles in removing phosphorus from the water column, including phosphorus uptake and deposition, filtering particulate phosphorus from the water, and attenuating flow, which decreases advective transport of particulate and dissolved phosphorus from sediments (Dodds, 2003). Lake managers have opted to increase macrophyte abundance to improve water quality and transparency and thus to restore eutrophic water to the oligotrophic stage (Lau & Lane, 2002b). In freshwater bodies phytoremediation has been suggested to be effective in reducing the toxicity of water caused by microorganisms releasing ammonia and sulphide while degrading protein released from the food industry (Jones, 2001).

ROLE OF MICROORGANISMS

Several microorganisms are reported to be efficient scavengers of phosphates from sewage sludge. Eight strains of a bacterium (*Acinetobacter calcoaceticus*) were found to remove substantial amounts of phosphates from an acetate medium–based pilot plant (Lawson & Tonhazy, 1980). Two varieties of *A. calcoaceticus* (var. *lwoffi* and var. *anitratus*) were found to be efficient phosphate-removing bacteria in acetate-enriched pilot plants (Florentz & Hartemann, 1984).

MECHANICAL CONTROL

In India about 50% of the phosphate present in sewage come from household detergents (Rao, 1998). In the United States 20%–30% of the phosphate in sewage is contributed by detergents (Penelope & Charles, 1992). Increased capacity and improved sewage treatment are the most effective ways to reduce the phosphorus load. In the Great Lakes regions of the United States and Canada a phosphorus-effluent target limitation of about 0.01 mg L^{-1} has been established for municipal sewage-treatment plants. These plants discharge more than 1 million gallons of sewage water per day. This target has been achieved by most of the municipal wastewater treatment systems in both nations. Treatment plants in Ohio had been discharging an average effluent concentration of 7 mg L^{-1}. The phosphate in these plants is precipitated out of sewage before the release of treated water into lakes or rivers. Through a precipitation method, about 80%–90% or even more of the phosphate was being removed from sewage without much increase in the cost (Bitton, 1999).

The average concentration of total phosphorus (inorganic and organic forms) in wastewater is within the range of 10–20 mg L^{-1}, much of which comes from phosphate builders in detergents. Common forms of phosphorus in wastewater are orthophosphates (50%–70% of phosphorus). Phosphates and phosphorus are tied to organic compounds. Orthophosphate comprises approximately 90% of phosphorus in biologically treated effluents (Meganck & Faup, 1988). Since phosphorus is mainly responsible for the eutrophication of surface waters, it must be removed by wastewater treatment processes before the effluents are discharged into surface waters. Several biological and chemical mechanisms are responsible for phosphorus removal in wastewater treatment plants (Arvin, 1985; Arvin & Kristensen, 1983). These processes include chemical precipitation, phosphorus assimilation by microorganisms, polyphosphate accumulation by microorganisms, and microorganism-mediated, enhanced chemical precipitation. Sucrose tricarboxylic acid is obtained by reacting aqueous 5%–20% sucrose with oxygen in the presence of a phosphorus-activated carbon catalyst at atmospheric pressure, pH 5–9 (6–8), and high temperature. The product is converted to the sodium salt by batch neutralization with 30% sodium hydroxide on gradual heating from room temperature to 60–95 (70–80)° C over several hours. During the procedure the pH is maintained at 8 and adjusted to 9 at the end of the reaction. The product has superior detergent properties with no tendency to cause eutrophication of waterways (Leupold et al., 1990). The eutrophication process may also be controlled temporarily by direct killing of aquatic plants. Copper sulfate and sodium arsenate are employed for killing algae and rooted plants, respectively (Khitoliya, 2004).

Eutrophication and persistent pollutants were believed to be the two main environmental problems in European marine and freshwater ecosystems because they tend to interact with each other (Skei et al., 2000). In fact, the co-occurrence of water pollutants and eutrophication is the major problem in all developed and developing countries. Phosphorus loading to Lake Erie has been reduced through the wastewater treatment plants and by limiting the amount of phosphorus in laundry detergents. Phosphorus loadings to Lake Erie are approaching the annual target load of 11,000 tons (the target load is specified in the Water Quality Agreements). Continued emphasis on phosphorus reduction is needed to restore water quality and reduce eutrophication. Eutrophication is thus a limiting factor in supply of clean water for drinking, fishing, navigation, and so forth. Biggs (2000) suggested that managing nutrient supply could reduce not only the magnitude of maximum biomass but also the frequency and duration of benthic algal proliferation in streams. Reduction in phosphorus loading is an essential measure for long-term eutrophication control in aquatic ecosystems (An & Kim, 2003).

Microorganisms, especially planktons, thrive well, combat the pollution load, and proliferate in polluted waters. There is every reason for concern over the alarming but gradual increase in the pollution level: Although the waters revealed an appreciable quantity of planktonic cells, immediate remediation is needed to have a cleaner environment throughout (Sivaswamy & Prasad, 1990). The extent of dependence of the growth of aquatic flora upon the phosphorus concentration in any eutrophic water body has led to the assumption that reduction in nutrient loading would result in oligotrophy. However, it later became apparent from the complexities encountered in certain enriched freshwater bodies that the problem would not be cured so easily.

LEGISLATIVE MEASURES

To control eutrophic conditions in streams and lakes, laws restricting phosphate levels in detergents were proposed and became law in some states in the United States. Phosphate is the nutrient that limits plant growth in water bodies the world over, and detergents are the major source of phosphates. The best option is to cut down the use of phosphates in detergents in an effort to stop eutrophication. In the United States, all of the Great Lakes states have legislative controls limiting the phosphorus content of laundry detergents to 0.5 percent by weight. Presently, Canada's limit is 2.2 percent (Hartig, 1981). Hartig et al. (1990, 1991) proposed various remedial action plans to restore the degraded areas of the Great Lakes in Ontario, Canada.

A complete ban on phosphates in detergents would remove about 20%–30% of the phosphates in sewage. In a number of areas, either a ban on or a reduction in the amount of phosphate allowed in detergents has been tried to reverse eutrophication in lakes. Detergent phosphorus bans in Maryland and Michigan are reported to have significantly reduced phosphate loading to Chesapeake Bay and the Detroit River, respectively. By 1988 all of the states with major watersheds bordering the Great Lakes had passed statutes limiting detergent phosphate to 0.5%, and Ontario had declared a limit of 2.2% (Penelope & Charles, 1992).

Ecological Vision

Until the early 1960s the surfactant present in synthetic detergents was alkylbenzene sulphonate. This showed remarkable resistance to biodegradation (the so-called hard detergents) and has been replaced with a new surfactant called "linear alkyl sulphonate," which is of compatible cost and cleaning potential but is not rapidly biodegradable. At present, one of the most pressing problems is not the effect of the surfactant itself but the release of polyphosphate builders into natural waters. The extensive use of phosphate-based detergents and agricultural fertilizers is one of the main causes of the worldwide eutrophication of rivers and lakes. To ameliorate such problems, partial or total substitution of phosphates in laundry detergents by synthetic, non-phosphorus-containing complexing agents is practiced in several countries.

To date, a complete replacement has not been found, but, in the Scandinavian countries particularly, formulations of household detergent powders are beginning to appear with appreciable portions of the phosphate replaced with nitrilotriacetic acid, which is a better sequestering agent than tripolyphosphate but has none of the other properties exhibited by the phosphate. The use of nitrilotriacetic acid has, however, been found to be harmful for health (Rao, 1998). Some of the hydroxypolycarboxylic acids not containing nitrogen are also being considered. Testing methods were developed, and it was proved that linear alkyl benzene is biodegradable. Germany introduced legislation prohibiting the discharge of non–biologically degradable material into sewer systems. In the United States, detergent manufacturers agreed voluntarily to switch over from propylene tetramer benzene to linear alkyl benzene by June 1965. In the United Kingdom, a similar type of "gentlemen's agreement" was entered into (Campbell, 1998).

Muller and Helsel (1999) suggested that, in order to reduce nutrient loads on lakes to within the limits permitted by the Organisation for Economic Co-operation and Development, not only will all sewage inputs need to be prevented, and non-phosphate detergents used, but losses from agricultural land must be reduced. Some scientists have categorized trophic status according to phosphorus concentration. Lakes with phosphorus concentrations below 0.01 mg L^{-1} are indicative of mesotrophic lakes, and eutrophic lakes have phosphorus concentrations exceeding 0.02 mg L^{-1} (Muller & Helsel, 1999). No rationale or state criteria have been established for concentrations of phosphorus compounds in water. However, to control eutrophication, the U.S. Environmental Protection Agency makes the following recommendations: Total phosphate (as phosphorus) should not exceed 0.05 mg L^{-1} in a stream at the point at which it enters a lake or reservoir and should not exceed 0.1 mg L^{-1} in streams that do not discharge directly into lakes or reservoirs (Muller & Helsel, 1999).

Phosphate levels greater than 1.0 mg L^{-1} may interfere with coagulation in water treatment plants. As a result, organic particles that harbor microorganisms may not be completely removed before distribution. Eutrophic growth of aquatic plants seems to continue. Removal of detergent phosphates, by itself, will not usually accomplish such a large reduction because other inputs, such as runoff from agricultural lands, are much greater sources of phosphates. Those countries whose economies are based on agriculture have to take adequate measures in controlling the use of fertilizers, specifically phosphorus. Research and proper advice to farmers on the optimum requirement of the nutrients needs to be emphasized. Urban waste and sewage must be treated to reduce phosphorus before it is discharged into a water body.

Discussion

It is evident from the present review of literature that eutrophication studies have focused mainly on lakes, including some well-known salt and freshwater lakes in the United States, Italy, the Netherlands, Denmark, Greece, Uruguay, Russia, China, and India. The problem of eutrophication has increased during the past 50 years. Population growth, coupled with economic development and changes in life style, during this period has added to the problem. Johnson et al. (2001) speculated that population increase and rapid economic development in next 25 years will substantially increase the demand for freshwater resources. The availability of freshwater for human consumption will be one of the great issues of the twenty-first century. Eutrophication has become a major cause for concern in the developing world, including South

American, African, and South Asian countries. Scientific interest in eutrophication has consistently been significant during the last 25 years. Emphasis on this area of research has risen suddenly in recent years. Brönmark and Hansson (2002) predicted that eutrophication, acidification, and contamination by toxic substances are likely to increase as threats to freshwater resources and ecosystems. Vörösmarty et al. (2000) speculated that population growth and the associated increase in demand for water would greatly outweigh climate change in determining the status of global water systems by 2025.

The problem of eutrophication, in addition to being dependent upon nutrient inputs, is greatly influenced by number of environmental factors. The growth of algae and its diversity are dependent upon the quality and quantity of light, temperature inversion, and geographical location of a water body. Variation in eutrophication level is directly dependent upon the pattern of phosphorus cycling. The phosphorus cycling varies in the monomictic, dimictic, and polymictic lakes. Temperature limits the rate of cell division in all organisms. The ecological amplitude of temperature varies from organism to organism. Temperatures below the lower or above higher tolerable limit retard cell division, presumably by affecting enzyme structure (Giese, 1979). Ghosh et al. (1995) noticed a temperature-related growth of duckweed. The growth rate of duckweed decreased when the temperature was brought down below 10° C. The freezing cold temperature completely inhibited the growth rate of duckweed. Significantly higher yields and numbers of fronds of *Spirodela polyrrhiza* Dh116 and *S. punctata* Dh122 were observed at 33° C and 25° C, respectively (Aziz & Mubina, 1999). Several plant processes, including enzyme reactions, metabolisms, and carbon dioxide fixation are temperature dependent (Giese, 1979; Teshow, 1970). The temperature also affects the pH and viscosity of water (Garg, 1998; Teshow, 1970). An acidic pH accelerates the absorption of phosphates (Devlin & Witham, 1986). The death and decay of rapidly growing aquatic plants increases the turbidity of water and reduces the dissolved oxygen (Rao, 1998).

The growth of aquatic flora is promoted when the soluble inorganic form of phosphorus is available to the plant. The organic phosphorus bound into sediment is released under anoxic conditions. It is again made available to the upper layer of water body when temperature inversion results in the circulation of water. The water-mixing period in shallower tropical lakes may be consistently longer in a year. Shen (2002) studied the impact of limiting factors on the eutrophication of the river networks in Zhejiang, China and determined the effects of light intensity, temperature, and nutrients (nitrogen and phosphorus) on algal growth. The amount of algae increased with an increase in light intensity and temperature. The illuminance of 4000 lux and 30° C temperature were the most favorable conditions promoting algal growth in eutrophic water bodies. The effect of temperature was more prominent than the impact of light intensity. It is evident from this review that eutrophication induced significant change in the diversity of phytoplankton and increased primary productivity. The change in diversity and production of autotrophs directly affect the aquatic organisms of higher trophic levels. Changes in the rate of primary production indicated the trophic status of aquatic ecosystems and their health (Herrera-Silveira et al., 2002). Changes in biodiversity have directly affected the primary productivity (Lévêque, 2001), detritus processing (Jonsson & Malmqvist, 2000), and nutrient transport at the water-sediment interface (Mermillod-Blondin et al., 2002; Palmer et al., 1997). Further loss of species in higher trophic levels may have strong repercussions down the food chain (Brönmark et al., 1997; Carpenter, 1988).

Consistent change in the diversity of organisms modifies the aquatic environment at a faster rate. Autogenic succession of eutrophic water bodies modifies their own environment, from an inorganic rich state to an organic rich state. leading to change in the diversity of the trophic structure. In eutrophic water bodies, early onset of succession consistently reduced the size and depth of the water body. The shallow eutrophic water bodies in densely populated areas of human settlement are under the direct threat of reducing their size and water-recharging capacities. Like other organisms, humankind also preferred to settle beside freshwater bodies (lentic or lotic). The problem of eutrophication has increased greatly with population growth, excessive use of fertilizers, and increase in industrialization. It is now evident that the water bodies of the highly populated countries like China, India, Bangladesh, Pakistan, and Indonesia, the industrialized countries of Europe, and the Great Lakes region of the United States and Canada are under the direct threat of eutrophication. Floral and faunal diversity is threatened in coastal areas that receive direct input of nutrients from some of the major rivers, like the Amazon, the Nile, the Ganges, the Mississippi, the Brahamputra, and the Thames.

In the review several aquatic species have been suggested as indicators of eutrophication. Some aquatic plants accumulate nutrients in higher concentration. Consistent removal of the accumulators soon after they bloom may reduce the phosphorus level in the water bodies. As suggested in the discussion of control measures, biological measures are usually effective in smaller, shallow, and lentic water bodies. The mechanical control of phosphorus input through the sewage treatment plants and an international understanding as well as awareness in reducing the use of phosphorus builders in detergents appear to be more effective ways to save water. We suggest a more coordinated scheme to assess and preserve water bodies for our own needs and for those of future generations.

Conclusion

Water is an important resource of prime necessity in life-supporting systems. Rapid eutrophication in the past 25 years has led to significant changes in water quality. The eutrophication results in physical, chemical, biological, and ecological changes in water bodies. Studies on eutrophication have revealed that the nutrient inputs into shallower and warmer parts of lakes are more severely altered (Reutter, 1989). Enrichment of nutrients in a water body accelerates its aging process and leads to faster succession. About 400 g of phosphate has been reported to promote an algal bloom to the extent of 350 tons (Sharma, 1998). The literature review revealed that all saltwater and freshwater lakes in densely populated areas are under the direct threat of eutrophication. In one of the European lakes, about 55% of the phosphorus came from metabolic sources and 45% from detergents and cleaning products until 1960 (Barbieri & Simona, 2001). The world population since then has increased greatly. In Uruguay the use of phosphorus-based fertilizers has shown an oscillatory pattern of increase from 1959 to 1985 and stability from 1985 to 1990, but detergents were reported to contribute 58% of the daily phosphorus load (Sommaruga et al., 1995). It has been established that detergents, domestic sewage, and fertilizers are the three major humanmade sources of nutrient enrichment in and eutrophication of natural water bodies.

Water bodies located near large cities are likely to receive more phosphorus from domestic effluents containing detergents. However, urban water bodies also receive major quantities of phosphorus from fertilizers and other agriculture-related activities. Eutrophication of smaller water bodies reduce the water-recharging capacity in these areas, so groundwater is likely to become depleted partly due to eutrophication and partly due to exploitation through pumping. The review shows that the emphasis in eutrophication studies has been in the areas of estimating the physicochemical properties of water, the diversity of aquatic flora and fauna, the sources of phosphorus, and the cycling of phosphorus in some of the world's major water bodies. Information on the overall outcome of eutrophication in terms of reduction in size and depth of water bodies is lacking. There is no information on whether eutrophication leads to changes in the water body that directly affect the transpiration rate. The change (if any) in the regional and global pattern of precipitation has not been determined either. Some studies in these areas would be of special interest.

Some effective control measures, including awareness programs pertaining to the present threat to water resources on the blue planet need to be implemented. As evident from the proposed phosphorus cycle (Fig. 2), the phosphorus input from one of the two sources—erosion of phosphate rocks (a natural source) and anthropogenic sources such as detergents and fertilizers—needs to be checked. The main emphasis needs to be on controlling excessive phosphorus inputs from the anthropogenic source. A check on the excessive erosion of phosphate rocks, probably due to deforestation, is also required. We hereby propose that biological control through phytoremediation, together with mechanical removal of sediments from the water body, would be an effective control measure. The depletion of the water resource may be checked if efforts are made at international and local government levels to adopt legislative measures and develop an alternative phosphorus-free detergent builder. Awareness and educational programs at government and nongovernmental organization levels would be much more effective than mere legislative measures.

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