

ENVIRONMENTAL MICROBIOLOGY

Aquatic Environment

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01 – Jul - 2006

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Key words

Aquatic, Winogradsky column, Autochthonous microorganisms, Allochthonous microorganisms, Fresh water, Marine, Estuary, Eutrophication, Algal blooms, Impact of eutrophication, prevention of eutrophication

Introduction

Water covers more than 70% of the earth's surface. The physical and chemical properties of water are of great ecological importance. The comparatively high specific heat, latent heat of fusion and latent heat of evaporation of water play a significant role in the temperature regulation of organisms. The aquatic environment falls into three major categories viz., freshwater, estuarine and marine systems. Freshwater occupy relatively small portion of the earth's surface than other habitats. Being good solvent water has many chemicals dissolved in it in nature. By utilizing these substances in their varied metabolic activities aquatic plants, animals and microorganisms bring about changes in the chemical composition of water. The freshwater environment includes lakes, ponds, swamps, springs, streams and rivers. These environments are collectively designated as limnetic and their ecology is referred to as limnology. Marine environments are the world's oceans. Estuarine environments occur at the interface between freshwater and marine environments. Heterotrophic microorganisms (bacteria, protozoa, and fungi) play an important role in the decomposition of organic material in aquatic environments. The material may arise from endogenous sources, e.g., phytoplankton photosynthesis in the sea or from exogenous sources such as organic pollutants. The process of decomposition of the organic material is known as self-purification. In a closed system, e.g. the oceans or lakes, this is part of the natural cycle of the production and decomposition of organic material, i.e. photosynthesis and respiration. Photosynthesis in planktonic environments is usually dominated by the algae; all living organisms participate in the respiration-decomposition part of the cycle. The contribution made by microorganisms is enormous.

Freshwater Environments

The freshwater environments are classified based on their chemical and physical properties. The freshwater environments with standing water are called lentic habitats e.g., lakes and ponds. Freshwater environments with running water are called lotic habitats e.g., rivers and streams. The freshwater environments contain autochthonous microorganisms with characteristic features viz., ability to grow at low nutrient concentrations which is characteristic of non-polluted freshwater bodies and the water bodies that do not receive significant inputs from terrestrial sources, most of them are motile either by means of flagella or other mechanisms. Some microorganisms exhibit unusual shapes that increase the surface area to volume ratio, allowing for efficient uptake of limited nutrients. Hot spring microorganisms have additional adaptive features.

In any body of water, the amount of animal life is directly proportional to the amount of plant life in it. Since, organisms in freshwater are not arranged in taxonomic order some sort of classification on an ecological basis is useful. First, organisms may be classified as to major niches based on their position in the energy or food chain:

Autotrophs (Producers): Green plants and chemosynthetic microorganisms.

Phagotrophs (Macroconsumers): Primary, secondary etc., herbivores, predators, parasites etc.

Saprotrophs (Microconsumers or Decomposers): Subclassified according to nature of the organic substrate decomposed.

Organisms in water may be classified as to their life forms or life habit, based on their mode of life as follows:

Benthos: organisms attached or resting on the bottom or living in the bottom sediments.

Periphyton: Organisms attached or clinging to stems and leaves of rooted plants or other surfaces projecting above the bottom.

Plankton: Floating organisms whose movements are more or less dependent on currents. While some of the zooplankton exhibit active swimming movements that aid in maintaining vertical position, plankton as a whole is unable to move against appreciable currents.

Nekton: Swimming organisms able to navigate at will.

Neuston: Organisms resting or swimming on the surface.

Organisms may be classified as to region or subhabitat. In the ponds and lakes three zones are generally evident:

Littoral zone: The shallow water region with light penetration to the bottom typically occupied by rooted plants.

Limnetic zone: This level will be at the depth at which light intensity is about 1% of full sunlight intensity. The community composed only of plankton, nekton, and sometimes neuston.

Euphotic zone: The combined littoral and limnetic zones are known as the euphotic zones.

Profundal zone: The bottom and deep water area which is beyond the depth of effective light penetration.

In streams, two major zones are generally evident:

Rapids zone: Shallow water where velocity of current is great enough to keep the bottom clear of silt and other loose materials, thus providing a firm substrate.

Pool zone: Deeper water where velocity of current is reduced and silt and other loose materials tend to settle to the bottom, thus providing a soft bottom.

The water surface is the uppermost layer which represents the interface between the hydrosphere and the atmosphere. It is characterized by high surface tension, a property due to interfacing of water with a gas. Under undisturbed conditions microorganisms form a surface film. Primary producers inhabit such surfaces as they have unrestricted access to CO₂ from the atmosphere and to light radiation reaching the water surface. Secondary producers also proliferate here using non-polar organic compounds accumulating in the surface tension layer and the high concentrations of oxygen available from the atmosphere.

There is a characteristic autochthonous microflora at the water-air interface, the neuston. Neuston region includes organisms belonging to algae, bacteria, fungi and protozoa. The neuston contains both primary producers and consumers. Representative bacteria include *Pseudomonas*, *Hyphomicrobium*, *Achromobacter*, *Flavobacterium*, *Alkaligenes* and *Leptothrix*. These include gram positive and gram negative, pigmented and non-pigmented, motile and non-motile, rod and coccus, stalked and nonstalked forms. The blue-green photosynthetic forms include *Anabaena* and *Microcystis*. The fungi include zoosporic forms e.g., *Saprolegnia*, *Achlya*, *Chytridium*, *Hyphochytridium*, *Blastocladium* and *Hyphomycetes* e.g., *Cladosporium* and various yeasts. The algal genera include *Chromulina*, *Botrydiopsis*, *Navicula*, *Sphaerotheca* and *Nautococcus*. Protozoa include *Vorticella*, *Clathrulina* and *Arcella*. Some of these organisms are also found in the underlying water column.

Composition and Activities of Freshwater Communities of Lake

In freshwater environments, the microbial populations of lakes have been much extensively studied than those of rivers. Many similarities exist, but rivers always contain high proportions of **allochthonous microorganisms**. Rivers offer less varied habitats than lakes. Members of the genera *Achromobacter*, *Flavobacterium*, *Brevibacterium*, *Micrococcus*, *Bacillus*, *Pseudomonas*, *Nocardia*, *Streptomyces*, *Micromonospora*, *Cytophaga* and *Vibrio*

are widely occurring in lake water. The stalked bacteria e.g., *Caulobacter* and *Hyphomicrobium* are reported to occur in lake waters especially in association with submerged surfaces.

Autotrophic bacteria are autochthonous members of the microflora of lakes and usually play a very important role in nutrient cycling of the lake. Photoautotrophic bacteria normally found in lakes include the cyanobacteria and the purple and green anaerobic photosynthetic bacteria. The *Microcystis*, *Anabaena* and *Aphanizomenon* are dominant plankton forms in freshwater habitats. The important members of the freshwater microbial communities e.g., *Nitrosomonas*, *Nitrobacter* and *Thiobacillus*, play an important role in nitrogen, sulfur and iron cycling within lakes.

There are important differences in the vertical distribution of bacterial populations within a lake. These differences reflect vertical variations in abiotic parameters such as light penetration, temperature and oxygen concentration. The cyanobacteria are found typically in high numbers near the surface where light penetration is adequate to support their photoautotrophic metabolism. Photoautotrophic members of the Chlorobiaceae and Chromatiaceae are autochthonous members of freshwater microbial communities at greater depths, where oxygen tensions are reduced, and sufficient hydrogen sulfide is present, but where there is still sufficient light penetration. Rhodospirillaceae occupy similar environments but rely on reduced organic electron donors instead of sulfur compounds. Heterotrophic bacteria are distributed throughout the vertical water column, but typically reach maximum near the thermocline and near the bottom where available organic matter is high.

Among the aquatic fungi, majority of them are zoosporic. Some zoosporic fungi in aquatic ecosystems are saprophytes. Others are parasites of freshwater algae, higher aquatic plants and animals, such as crustaceans and fish. Some zoosporic fungi even parasitise other zoosporic species. Zoosporic fungi are important in both flowing freshwater ecosystems and in lakes. Many fungi in freshwater lakes, rivers and streams are associated with foreign organic matter and thus should be considered as allochthonous members of such ecosystems. e.g., many ascomycetes and fungi imperfecti are found on wood and dead plant materials in rivers and lakes. The associated fungi disappear as soon as the plant material is degraded. Weakly fermentative members of yeasts e.g., *Torulopsis*, *Candida*, *Rhodotorula* and *Cryptococcus* are most commonly found in rivers, streams and lakes.

Algae are clearly important autochthonous members of freshwater ecosystems. Phytoplankton contributes significant inputs of organic carbon which supports the growth of heterotrophic organisms in freshwater ecosystems. Numerous species of green algae, dinoflagellates, and diatoms are found in most freshwater ecosystems.

The photosynthetic prokaryotes have been divided into three distinct, well defined groups viz., the cyanobacteria (blue green algae), the purple bacteria and the green bacteria. Although both green and purple bacteria carry out anoxygenic photosynthesis and contain bacteriochlorophyll a as one of several pigments, they constitute two remarkably different groups of phototrophs with respect to their major cytological properties. e.g. all green bacteria are non-motile except *Chloroflexis* whereas the vast majority of purple bacteria are motile, exhibiting both photo- and chemotactic response to environmental stimuli. The photosystems of the purple bacteria are located on intracytoplasmic unit membrane systems which are continuous with the cytoplasmic membrane, whereas in the green bacteria they are predominantly in chlorobium vesicles. However, all phototrophic bacteria regulate their

photopigment content in response to light intensity, the specific concentrations reaching a maximum value in dim light under anaerobic conditions. The extent of this regulation is limited in the strictly anaerobic green and purple non-sulphur bacteria by either high light under anaerobic conditions or oxygen in strongly aerated cultures.

The diversity of structural and physiological organization is greatest in the Rhodospirillaceae. Since they have the capacity to thrive as anaerobic phototrophs and as facultatively microaerophilic to aerobic chemo-organotrophs they make the ideal choice of prototroph for basic studies.

Protozoa are autochthonous members of freshwater aquatic ecosystems. Protozoa are important grazers of phytoplankton and bacteria. Amoeboid, ciliated and flagellated protozoa are found in streams, rivers and lakes. These include *Paramecium*, *Didinium*, *Vorticella* and *Amoeba*.

Viruses occur in freshwater ecosystems in association with other organisms. There are viruses that infect other aquatic microorganisms, aquatic plants, and aquatic animals. Viruses can be transported in a dormant state in rivers and other freshwater bodies until a suitable host is encountered.

Estuaries

The freshwater runoff in the form of rivers and groundwater seepage interfaces with marine waters in estuaries. Estuaries are areas of mixing of freshwater and marine water and are typically highly productive regions than either the ocean on one side or the freshwater input on the other since nutrients carried by rapidly flowing rivers are deposited at the river mouth or delta. Estuaries are subjected to tides and exhibit tidal flushing. Materials entering estuaries from rivers oscillate with the tides through the estuary with a net movement to the open sea. Estuaries are usually shallow and largely euphotic. Large portions of the estuaries are overgrown with semi submerged higher plants. e.g., mangrove forests in tropical estuaries. Photosynthesis in estuaries almost always exceeds respiratory activities. Estuaries tend to be physically constructed so as to trap nutrients that enter the estuary or that are produced within the estuary. In an ideal estuary there is a salinity gradient from <5‰ at the upper and to >25‰ at the mouth of the estuary. The distinction between autochthonous and allochthonous organisms is particularly difficult in such transition zones. Both freshwater and marine organisms are only transitional members of estuaries.

Marine Environments

The oceans occupy 71% of earth's surface. For the most part, the environmental conditions in the marine environment are remarkably uniform. This uniformity is due to various mixing mechanisms that include tidal movements, currents and thermocline circulation. The environmental conditions are highly consistent. Both geographical and seasonal variations are very moderate. Definite zones can be recognized. The littoral or intertidal zone, occurs at the seashore. The sublittoral zone extends from the low tide mark to the edge of continental shelf. This region also known as neritic or nearshore zone. The term pelagic is used to designate open water or the high sea. The benthos or benthic region is the bottom, regardless of the overlying zone. Salinities are normally in the range of 33-37‰, with an average of 35‰. The pH of seawater is generally 8.3-8.5. Temperatures below 100 m depth are usually between 0 °C and 5 °C.

The highest biomass of microorganisms in marine waters is normally near the surface and decreases with depth.

A salt concentration of 33-35 ppm represents the optimum salt concentration for genuine marine microorganisms. True marine bacteria do not grow without salt. Marine bacteria require the ions in marine waters to maintain proper membrane functions e.g., sodium and chloride are required for active transport. Some marine bacteria have multiple membranes surrounding the cell. Exposure to freshwater disrupts these membrane layers causing loss of viability in these bacteria. Marine bacteria are capable of growth at low nutrient concentrations found in the oceans. Since approximately 90-95% of the marine environment is below 5 °C, most marine bacteria must be capable of growth at low temperatures. Except in tropical surface waters, most marine bacteria should be psychrophilic or psychrotropic. Bacteria found in deep ocean trenches are exposed to great hydrostatic pressures. In such areas barotolerant bacteria are important members of the autochthonous community. The seawater-air interface is the habitat for pleuston, the marine equivalent of the neuston, which includes bacterial and algal inhabitants. *Pseudomonas* and various pigmented genera such as *Erythrobacter*, *Erythromicrobium*, *Protaminobacter* and *Roseobacter* are major bacterial populations. Populations of primary producers including cyanobacteria, diatoms and drifting Phaeophycophyta are sometimes found in Pleuston layer. Representatives of fungi and protozoa are occasionally found in the Pleuston.

Most marine bacteria are gram negative and motile; often greater than 95% of the bacteria isolated from seawater samples are gram negative. There is relatively high proportion of proteolytic bacteria in marine environments as compared to freshwater or soil habitats. *Pseudomonas* or *Vibrio* species are often found to be dominant genera in marine environment. *Flavobacterium* species are also found in relatively high numbers.

Eutrophication

Eutrophication is the enrichment of an aquatic ecosystem with chemical nutrients, especially compounds containing nitrogen, phosphorous or both. Although traditionally thought of as enrichment of aquatic systems by addition of fertilizers into lakes, bays or other semi-enclosed waters, there is gathering evidence that terrestrial ecosystems are subjected to similarly adverse effects. The increase in available nutrients promotes plant growth, favouring certain species over others and forcing a change in species composition. In aquatic environments, enhanced growth of plugging aquatic vegetation or phytoplankton disrupts normal functioning of the ecosystem, causing a variety of problems. Eutrophic conditions decrease the resource value of rivers, lakes and estuaries such that recreation, fishing, hunting and aesthetic enjoyment are hindered. Health related problems can occur where eutrophic conditions interfere with drinking water treatment.

Eutrophication was recognized as a pollution problem in European and North American lakes and reservoirs in the middle of the 20th century. Since then, it has become more widespread and surveys indicated that 54% of lakes in Asia are eutrophic; in Europe, 53%; in North America 48%; in South America, 41% and in Africa, 28%.

Causes of Eutrophication

Eutrophication can be a natural process in lakes, occurring as they age through geological time. Also, estuaries tend to be naturally eutrophic because land-derived nutrients are

concentrated where run-off enters the marine environment in a confined sea-passage and mixing of relatively high nutrient fresh water with low nutrient marine water occurs.

However, human activities can enhance the rate at which nutrients enter ecosystems. Runoff from agriculture and development, pollution from septic systems and sewers and other human-related activities increase the flux of both inorganic nutrients and organic substances into terrestrial, aquatic and coastal marine ecosystems. Elevated atmospheric compounds of nitrogen can increase soil nitrogen availability.

Chemical forms of nitrogen are most often of concern with regard to eutrophication because plants have high nitrogen requirements; addition of nitrogen compounds stimulate plant growth. Nitrogen is not readily available in soil because N_2 , a gaseous form of nitrogen, is highly stable and basically unavailable to higher plants. Terrestrial ecosystems rely on microbial nitrogen fixation to convert N_2 into other chemical forms e.g., nitrate. However, there is a limit to how much additional nitrogen can be utilized. Ecosystems with nitrogen inputs in excess of plant nutritional requirements are referred to as nitrogen-saturated. Over-saturated terrestrial ecosystems contribute both inorganic and organic nitrogen to freshwater, coastal and marine eutrophication, where nitrogen is also typically a limiting nutrient. However, in marine environments, phosphorous may be limiting because it is leached from the soil at a much slower rate than nitrates, which are highly soluble.

Impacts of Eutrophication

Innumerable impacts can arise where primary production is enhanced. Three of the impacts are quite prominent viz., decreased biodiversity, changes in species composition and dominance and toxicity effects.

Decreased Biodiversity

When a body of water experiences an increase in nutrients, primary producers acquire the benefits first. This means that species such as algae experience a population increase. Algal blooms tend to disturb the ecosystem by limiting sunlight to bottom dwelling organisms and by causing wide fluctuations in the amount of dissolved oxygen in the water. Oxygen is required by all respiring microorganisms, plants and animals in an aquatic environment and it is replenished in daylight by photosynthesizing plants and algae. Under eutrophic conditions, dissolved oxygen greatly increases during the day, but is alternately greatly reduced after dark by the respiring dense algal population and by microorganisms that feed on the increasing mass of dead algae. When dissolved oxygen levels decline to hypoxic levels, fish and other marine animals suffocate. As a result, creatures such as fish, shrimp, and especially immobile bottom dwellers die off. In extreme cases, anaerobic conditions occur, promoting growth of anaerobic bacteria such as sporulating clostridia that produce toxins deadly to birds and mammals. Zones where this occurs are known as dead zones.

New Species Invasion

Eutrophication may cause competitive release by making abundant a normally limiting nutrient. This process causes shifts in the species composition of ecosystems. For instance, an increase in nitrogen might allow new, competitive species to invade and out-compete original inhabitant species. This has been shown to occur in New England salt marshes and rivers in India.

Toxicity

Some algal blooms, otherwise called nuisance algae or harmful algal blooms are toxic to plants and animals. Toxic compounds produced by the algae can make their way up the food chain, resulting in animal mortality. Freshwater algal blooms can pose a threat to livestock. Due to death of such algae there is release of neurotoxins and hepatotoxins which can kill animals and may pose a threat to humans.

An example of algal toxins working their way into humans is the case of shellfish poisoning . The toxins created during algal blooms are taken up by shellfish, leading to these human foods acquiring the toxicity and poisoning humans. Examples include paralytic, neurotoxic and diarrhoetic shellfish poisoning. Other marine animals can be vectors for such toxins, as in the case of ciguatera where it is typically a predator fish that accumulates the toxins and then poisons humans.

There are also toxic effects caused directly by nitrogen. When this nutrient is leached into groundwater, drinking water can be affected because concentrations of nitrogen are not filtered out. Nitrate (NO_3) has been shown to be toxic to human babies. This is because bacteria can live in their digestive tract that convert nitrate to nitrite (NO_2). Nitrite reacts with hemoglobin to form methemoglobin, a form that does not carry oxygen. The baby essentially suffocates as its body receives inadequate oxygen.

Sources of Nutrients

In order to ascertain how to prevent eutrophication from occurring, specific sources that contribute to nutrient loading must be identified. There are two common sources of nutrients and organic matter viz., point and non-point sources.

Point Sources

Point sources are directly attributable to one influence. In point sources the nutrient waste travels directly from source to water. e.g., factories that have waste discharge pipes directly leading into a water body would be classified as a point source. Point sources are relatively easy to regulate.

Nonpoint Sources

Non-point source pollution is that which comes from ill-defined and diffuse sources. These sources are difficult to regulate and usually vary spatially and temporally. It has been shown that nitrogen transport is correlated with various indices of human activity in watersheds including the amount of development. Agriculture and development are activities that contribute most to nutrient loading. The non-point sources are troublesome due to following reasons:

Retention in Soil

Nutrients from human activities tend to accumulate in soils and remain there for years. It has been shown that the amount of phosphorous lost to surface waters increases linearly with the amount of phosphorous in the soil. Thus much of the nutrient loading in soil eventually makes its way to water. Nitrogen similarly has a turnover time of decades or more.

Runoff to Surface Water and Leaching to Groundwater

Nutrients from human activities tend to travel from land to either surface or ground water. Nitrogen in particular is removed through storm rains, sewage pipes and other forms of surface runoff.

Nutrient losses in runoff and leachate are often associated with agriculture. Modern agriculture often involves the application of nutrients onto fields in order to enhance production. However, farmers frequently apply more nutrients than are taken up by crops or pastures. Regulations aimed at decreasing nutrient exports from agriculture are typically far less stringent than those placed on sewage treatment plants and other point source polluters.

Atmospheric Deposition

Nitrogen is released into the air because of ammonia volatilization and nitrous oxide production. The combustion of fossil fuels is a large human-initiated contributor to atmospheric nitrogen. Atmospheric deposition can also affect nutrient concentration in water, especially in highly industrialised regions.

Other Causes

The bright green water in the Potomac River estuary is result of a dense bloom of cyanobacteria. Any factor that causes increased nutrient concentration can potentially lead to eutrophication. In modelling eutrophication, the rate of water renewal plays a critical role. Stagnant water allows to collect more nutrients than bodies with replenished water supplies. It has also been shown that the drying of wetlands causes an increase in nutrient concentration and subsequent eutrophication explodes.

Prevention and Reversal of Eutrophication

Eutrophication poses a problem not only to ecosystems, but to human as well. Reducing eutrophication should be a key concern when considering future policy and a sustainable solution for everyone including farmers seems feasible. While eutrophication does pose problems humans should be aware that natural runoff is common in ecosystems and should thus not reverse nutrient concentrations beyond normal levels.

Effectiveness

Cleanup measures have been mostly, but not completely, successful. Finnish phosphorous removal measures started in the mid 1970s and have targeted rivers and lakes polluted by industrial and municipal discharges. These efforts, which involved removal of phosphorous, have had 90% removal efficiency. Still some targeted point sources did not show a decrease in runoff despite reduction efforts.

Minimising Nonpoint Pollution

Non-point pollution is the most difficult source of nutrients to manage. The literature suggests that when these sources are controlled, eutrophication decreases. The following steps are recommended to minimise the amount of pollution that can enter aquatic ecosystems from ambiguous sources.

Riparian Buffer Zones

Studies show that intercepting non-point pollution between the source and the water is a successful mean of prevention. Riparian buffer zones have been created near waterways in an attempt to filter pollutants; sediment and nutrients are deposited here instead of in water. Creating buffer zones near farms and roads is another possible way to prevent nutrients from travelling too far. Still studies have shown that the effects of atmospheric nitrogen pollution can reach far past the buffer zone. This suggests that the most effective means of prevention is from the primary source.

Prevention Policy

Laws regulating the discharge and treatment of sewage have led to dramatic nutrient reductions to surrounding ecosystems, but it is generally agreed that a policy regulating agricultural use of fertilizer and animal waste must be imposed. In Japan the amount of nitrogen produced by livestock is adequate to serve the fertilizer needs for the agriculture industry. Thus, it is not unreasonable to command livestock owners to clean up animal waste which when left stagnant will leach into ground water.

Nitrogen Testing and Modeling

Soil nitrogen testing (N-Testing) is a technique that helps farmers to optimise the amount of fertilizer applied to crops. By testing fields with this method, farmers saw a decrease in fertilizer application costs, a decrease in nitrogen lost to surrounding sources, or both. By testing the soil and modelling the bare minimum amount of fertilizer needed, farmers acquire economic benefits while the environment remains clean.

Natural State of Algal Blooms

Although the intensity, frequency and extent of algal blooms have tended to increase in response to human activity and human-induced eutrophication, algal blooms are a naturally-occurring phenomenon. The rise and fall of algae populations, as with the population of other living things, is a feature of healthy ecosystem. Rectification actions aimed at abating eutrophication and algal blooms are usually desirable, but the focus of intervention should not necessarily be aimed at eliminating blooms, but towards creating a sustainable balance that maintains or improves ecosystem health.

The Winogradsky Column

The 'Winogradsky column' beautifully illustrates the coexistence and interdependence of different ecological niches in the same habitat and it resembles, to a large extent, a natural freshwater habitat.

Surface sediment (25 g) from a freshwater pond is mixed with 0.5 g CaSO_4 and some organic material (preferably decaying vegetation). The mixture is kept in the 500 ml glass measuring cylinder and filled with freshwater. The measuring cylinder kept exposed to natural daylight at room temperature. The glass column examined visually and the samples removed from the microbiologically active zones with long Pasteur pipette and examined under microscope.

In 4-8 days' incubation the organic matter in the sediment is dissimilated by heterotrophs and the end-products of their fermentations are used by bacteria which use sulphate as an electron acceptor for anaerobic fermentation.. The *Desulfovibrio* will predominate and cause

blackening of the sediment. The resulting H₂S is subsequently utilized by sulphur bacteria of different kinds.

In the parts of the cylinder where O₂ as well as H₂S are present, *Beggiatoa* and *Thiothrix* may develop. More often, however, motile rods of the genus *Thiobacillus* (energy derived from the oxidation of H₂S) form a whitish veil at some distance above the sediment surface.

In 12-28 days' incubation, the photosynthetic purple and green bacteria develop using H₂S as the electron donor in photosynthesis and CO₂, derived from fermentation in the sediment, as the main carbon source. These phototrophs tend to stick to the wall of the vessel. The green sulphur bacteria form the lowermost layer of phototrophs in the sediment underneath the purple sulphur bacteria. They do so because, their cells are non-motile, obligately phototrophic and sulphide-dependent and the electron donor cannot be stored inside the cell in the form of elemental sulphur. The motile and sulphur storing purple bacteria may adjust themselves to the diurnal changes in sulphide concentration.

Two physical parameters greatly influence the types of microbial populations that develop viz., the wavelength of the light source and the temperature. The temperature is easier to manipulate. At temperatures above 33°C, sulphate reduction is restricted, i.e. there is a much reduced level of H₂S production and the organic end-products of the fermentative processes occurring in the sediment accumulate. Under these conditions, the purple non-sulphur bacteria *Rhodospirillum*, *Rhodopseudomonas*, (Rhodospirillaceae) develop as they can utilize organic substrates as electron donors for photosynthesis (photoheterotrophs) and tolerate micro-aerophilic conditions.

Suggested Readings

1. Bianchi, T. S., Engelhaupt, E., Westman, P., Andren, T., Rolff, C. and Elmgren, R. 2000. Cyanobacterial blooms in the Baltic Sea: Natural or human -induced? *Limnol. Oceanogr.* **45**:716-726.
2. Brock, T. D. 1966. *Principles of Microbial Ecology*, Prentice-Hall, Inc. New Jersey.
3. Campbell, R. 1977. *Microbial Ecology*, Blackwell Scientific Publications, Oxford.
4. Clayton, R. K. and Sistrom, W. R. 1978. *The photosynthetic bacteria*. Plenum Press, New York.
5. Cole, J.J., Peierls, B.L., Caraco, N.F., and Pace, M.L. 1993. Nitrogen loading of rivers as a human - driven process. pp 141-157 In *Humans as components of ecosystems* (Eds. McDonnell, M.J. and Pickett, S.T.A.). Springer-Verlag. New York, USA.
6. Horrigan, L., Lawrence, R. S. and Walker, P. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health perspectives* **110**: 445-456.
7. Kumazawa, K. 2002. Nitrogen fertilization and nitrate pollution in groundwater in Japan: Present status and measures for sustainable agriculture. *Nutrient Cycling in Agroecosystems* **63**:129-137.
8. Lynch, J. M. and Poole, N. J. 1979. *Microbial Ecology: A conceptual approach*, Blackwell Scientific Publications, Oxford..
9. *Microbial Ecology: A conceptual approach*, 1979. ed. By Lynch, J. M. and Poole, N. J., Blackwell Scientific Publications, Oxford..
10. Paerl, H.W. 1997. Coastal Eutrophication and Harmful algal blooms: Importance of Atmospheric Deposition and Groundwater as New nitrogen and other nutrient sources. *Limnol. Oceanogr.* **42**:1154-1165.
11. Raika, A., Pietilainen, O.P., Rekolainen, S., Kauppila, P., Pitkanen, H., Niemi, J., Raateland, A., and Vuorenmaa, J. 2003. Trends of phosphorous, nitrogen, and chlorophyll a concentrations in Finnish rivers and lakes in 1975-2000. *The Science of the Total Environment* **310**:47-59.
12. Shumway, S.E. 1990. A review of the effects of algal blooms on shellfish and aquaculture. *Journal of the World Aquaculture Society* **21**:65-104.
13. Smith, V.H., Tilman, G.D. and Nekola, J.C. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution* **100**:179-196.