PREFACE

In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. *core, generic, discipline specific elective, ability and skill enhancement* for graduate students of all programmes at Honours level. This brings in the semester pattern which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade “A”.

UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme.

Self Learning Material (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs.

I wish the venture a grand success.

Professor (Dr.) Subha Sankar Sarkar
Vice-Chancellor

Netaji Subhas Open University

Under Graduate Degree Programme

Choice Based Credit System (CBCS)

Subject : Honours in Zoology (HZO)

Course : Aquatic Biology (Theory)

Course Code : GE-ZO-21

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Unit - 1 ❑ Aquatic Biomes

Structure

1.0 Objectives

By studying this unit, students will be able to understand about the following—

- Aquatic biomes and its types.
- Different types of freshwater and wetland ecosystem.
- Intertidal zones and its zonation.
- General features of estuaries and its attributes.
- Marine benthic zone and marine pelagic zone.

1.1 Introduction

In life sciences, plant and animal communities are studied separately, which obscures the concept of wholeness of the community that limits our understanding on ecosystem functions. In fact, plants and animals are closely associated with each other, and growth and distribution of animals are strongly dependent on plants and vegetation. This results in a more inclusive classification, which embraces several plant communities but includes all animal life associated with them; this classification is called a biome. The word biome is formed from two Greek words : bios = life and oma = group or mass. Therefore, it is as a biological unit which is a type of vegetation, climate, soil and altitude of that specific place. The term biome is a synonym for biotic community (Möbius, 1877) opined that A biome is, therefore, a collection of plants and animals that have common characteristics for the environment they exist in. Clements and Shelford (1939), the biome is the "biotic community of geographical extent characterized by distinctiveness in the life forms of the important climax species". In other words, biomes are broader term than habitat which has distinct biological communities formed in response to a shared physical climate.

1.2 Aquatic biome

Aquatic biome refers to as a major biotic community characterized by the dominant forms of plant and the dominating aquatic environment. Aquatic biome is the largest biome in the world covering around 70% of the Earth.

1.3 Types of aquatic biome

Aquatic biomes have been classified into five different types. These are as follows—

1. **Freshwater biome :** Freshwater biomes are communities of animals and plants found in regions with water characterized by less than 1% salt concentration. Types of freshwater biomes include lakes, rivers, ponds, streams and some wetlands. Freshwater regions can be found on every single continent that covers about $^{1}/_{5}$ th area of the world. Freshwater biomes are the largest communities of freshwater microscopic bacteria, algae,

phytoplankton, zooplankton, invertebrates, vertebrates including fish. Freshwater biome is the resource of food and water to human.

2. **Freshwater wetland biome :** A wetland is a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem. Freshwater wetlands are ecosystems that are affected by the permanent or temporary rising of a body of water and it's overflowing onto normally dry land. It plays an important role in the regulation of water flow, water quality to whole catchment areas. Wetland supports a great diversity of plants and animals especially the migratory birds, and provides refuge for fauna during droughts. *Cattails* and *Sedges* are common plants that grow up from the soil, through the water. All types of amphibians like frogs, toads, salamanders etc. are found in wetlands. The marsh, bog, fen, swamp, mire, slough, and prairie pothole are different types of freshwater wetlands.

3. **Brackish water or estuarine biome :** Estuary biomes are normally located along coasts, where freshwater rivers meet saltwater oceans. During high tides, salt water flows into the estuary. Likewise, freshwater flows down the rivers and creeks and mixes with the saltwater changed the physico-chemical characteristics of water. Estuary can be surrounded by swamps, coral reefs, and beaches. Estuary biome temperatures vary with seasons, which have also affects the health of the biome. Plants that grow in estuary biome must be adapted to tolerate (i) fluctuating salinity levels; (ii) varying exposure to wind and sunlight; (iii) strong currents and storm waves; (iv) low levels of oxygen in muddy soils. The plants that are found in estuary biomes include Eelgrass, Gumweed, Saltgrass, Red algae, Sea lettuce etc.

4. **Marine biome :** The marine biome is the region of the earth characterized by the presence of salt water. Although salinity of ocean varies largely from place to place, the average value may be around 35 ppt (parts per thousand).

   The marine biome is the largest biome of the Earth that includes all the oceans like, Pacific Ocean, Atlantic Ocean, Indian Ocean and Arctic Ocean. The water temperature of the marine biome may be warmer or colder depending on location. Oceans near the equator will have a higher temperature than those near the poles.

Marine biome is divided into the pelagic or photic zone and benthic or abyssal zone. Aquatic organisms are adapted to live in different vertical profiles of the ocean.

The marine biome is the home to a vast array of living organisms ranging from microscopic algae and bacteria, and number of invertebrate animals, such as jelly fish, octopus, echinoderms, cray fish, etc. Marine biome animals include a vast array of fish species, including mackerel, butterfish, spiny dogfish, squid, monkfish and others. Many birds, such as shore birds, gulls, terns and wading birds, call the marine ecosystem their home. Coral reefs are home to some of the largest diversity of marine species anywhere on the planet. Most of the bottom dwelling marine animals are provided with bioluminescent organs that are used for vision in the darkness and helps to capture prey.

Marine biome plays a crucial role in the global carbon cycle and hydrological cycle. The hydrologic cycle is largely influenced by the vast oceans via precipitation and evaporation. It influences the terrestrial climate, rainfall through circulation of air through waves and currents.

Kelp forests are underwater ecosystems formed in shallow water by the dense growth of several different species known as kelps. Though they look like plants, kelp are large brown algae that live in cool, relatively shallow waters close to the shore. They grow in dense groupings much like a forest on land. Kelp forests can be seen along much of the west coast of North America.

5. **Coral reef biome :** Coral reef biome is another classic example of marine biome. Corals are marine colonial polyp characterized by a calcareous skeleton. Coral reefs are formed due to the accumulation and compaction of the skeletons of these lime secreting organisms. It is found in the clear tropical ocean entirely between latitudes 30°N and 25°S. It is the most diverse ecosystems on the planet and also considered the medicine cabinets of the 21st century because several medicines are developed to treat cancer, arthritis, human bacterial infections, Alzheimer’s disease, heart disease, viruses, and other diseases. Hence, it is very necessary to protect the coral bleaching which is happening due to environmental degradation.

1.4 Freshwater ecosystems

Freshwater ecosystems are a subset of Earth's aquatic ecosystem that includes lakes, ponds, rivers, streams, springs, bogs and wetlands. Different physico-chemical and biological factors such as, temperature, light, turbidity, salinity, nutrients, vegetation etc. influence the freshwater habitats. Freshwater ecosystems have undergone substantial transformations over time, which have had an impact over various characteristics of the ecosystems. All the freshwater ecosystems indeed exhibit self sufficient, self-regulating system. The components of freshwater ecosystem are as follows :

1. **Abiotic components :** The chief abiotic components are heat, light, pH value of water, and the basic inorganic and organic components, such as water itself, carbon dioxide gas, oxygen gas, calcium, nitrogen, phosphates, amino acids, humic acids etc. Some proportions of nutrients are in solution state but most of them are present as stored in particulate matter as well as in living organisms.

2. **Biotic components :** The various organisms that constitute the biotic components are as follows :

   (A) Producers : These are autotrophic, green plants and some photosynthetic bacteria. The producers fix radiant energy and with the help of minerals derived from the water and mud, they manufacture complex organic substances as carbohydrate, proteins, lipids etc. Producers are of two types- (i) Macrophytes : These are mainly rooted larger plants which include partly or completely submerged, floating and emergent hydrophytes. The common plants are the species of *Trapa, Typha, Sagittaria, Nymphaea, Chara, Hydrilla, Vallisneria* etc. (ii) Phytoplanktons : These are minute, floating or suspended lower plants. Majority of them are filamentous algae as *Zygnema, Ulothrix, Spirogyra, Cladophora and Oedogonium.*

   (B) Comsumers : They are the heterotrophs which depend for their nutrition on the organic food manufactured by producers, the green plants. Most of the consumers are herbivores, a few as insects and some large fish are carnivores feeding on herbivores. The consumers have been divided into primary consumers, secondary consumers and tertiary consumers according to their feeding habit.

(C) Decomposers : They are also known as microconsumers, since they absorb only a fraction of the decomposed organic matter. They bring about the decomposition of complex dead organic matter of both-producers (plants) as well as the macroconsumers (animals) to simple forms. Thus, they play an important role in the return of mineral elements again to the medium of freshwater ecosystem. These include a variety of heterotrophic microbes that are osmotrophs. *Aspergillus, Cladosporium*, *Pythium*, *Rhizopus*, *Fusarium* are most common decomposers.

1.5 Lake ecosystem

Lakes are bodies of standing fresh water that may support emergent vegetation at their edges or over their entire area. Lakes may be shallow or deep, permanent or temporary. Lakes lack any direct exchange with an ocean. Lakes of all types share many ecological and biogeochemical processes and their study falls within the discipline of ‘limnology’.

Lake ecosystems provide a considerable quantity of ‘goods and services’ such as drinking water, waste removal, fisheries, agricultural irrigation, industrial activity, and recreation for the benefit of humans. Many organisms also depend on freshwater for survival. For these reasons lakes are important ecosystems. Lake ecosystem (Fig-1) are influenced by their watersheds, the geological, chemical and biological processes that occur on the land and uphill streams. A lake and its watershed are often considered to be a single ecosystem (Likens, 1985). Another factor that influences the composition of lake ecosystems is the degree to which light penetrates the water. The zone in which light penetrates sufficiently to support photosynthesis is known as the photic zone. The zone in which too little light penetrates to support photosynthesis is known as the aphotic (or profundal) zone.

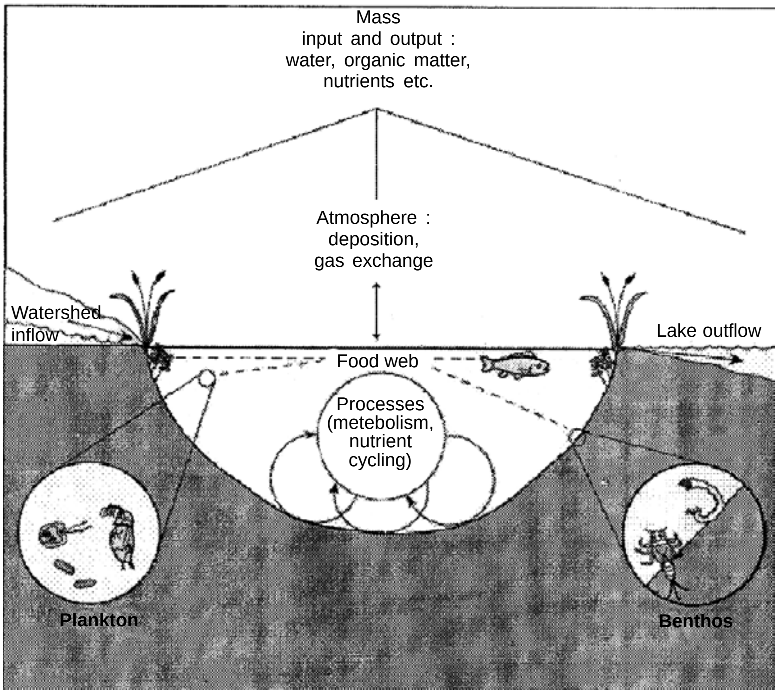


Fig-1 : A representation of ideal lake ecosystem

Lakes are divided into three different "zones" which are usually determined by depth and distance from the shoreline (Fig-2).

The topmost zone near the shore of a lake is the ***littoral zone***. This zone is the warmest since it is shallow and can absorb more of the Sun's heat. It sustains a fairly diverse community, including several species of algae (like diatoms), rooted and floating aquatic plants, grazing snails, clams, insects, crustaceans, fishes and amphibians. In the case of the insects, such as dragonflies and midges, only the egg and larvae stages are found in this zone. The vegetation and animals living in the littoral zone are food for other creatures such as turtles, snakes, and ducks.

The near-surface open water surrounded by the littoral zone is the ***limnetic zone***. The limnetic zone is well-lighted and is dominated by phytoplankton and zooplankton which are small organisms that play a crucial role in the food chain. A variety of freshwater fish also occupy this zone.

Plankton have short life spans-when they die, they fall into the deep-water part of the lake/pond, the ***profundal zone***. This zone is much colder and denser than the other two. Little light penetrates all the way through limnetic zone into the profundal zone. Heterotrophic fauna that thrive on dead organisms and use oxygen for cellular respiration are present in this zone.

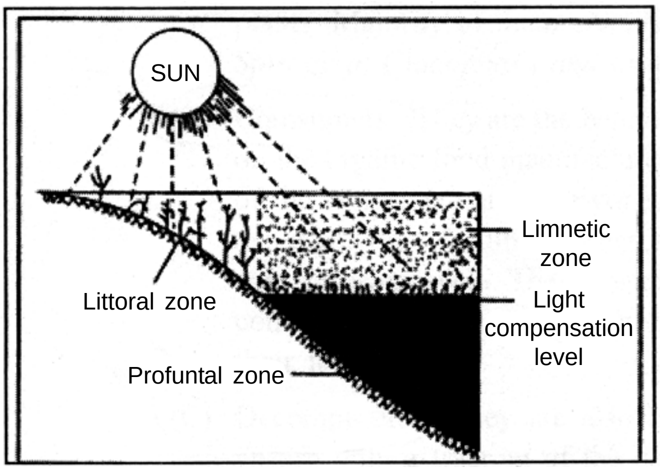


Fig-2 : Three major zones of a freshwater lake

1.5.1 Important abiotic factors in lake ecosystem

A lake ecosystem or lacustrain ecosystem includes biotic components (plants, animals and microorganisms) and non living abiotic components (physical and chemical factors) and their interactions. Lake ecosystems are diverse, ranging from a small, temporary rainwater pool a few inches deep to a larger one like Baikal lake, which has a maximum depth of 1642 m^2 (Hansson, 2005). The main difference between pools/ponds and lakes is that ponds and pools being shallow have their entire bottom surfaces exposed to light, while lakes are deep and do not. In addition, some deep lakes mostly in temperate countries become seasonally stratified.

1. **Light :** The main energy source of lentic (standing water) systems is light which drive the process of photosynthesis. Depending upon the light received, the entire lake can be divided into the surface photic zone and the bottom layer, the aphotic regions.

2. **Temperature :** Temperature is another important parameter to lake ecosystem. Water can be heated by direct radiation from the sun at the surface and conduction to or from the air and surrounding substrate. The special density distribution due to water temperature leads to thermal stratification in lakes, where a relatively stable, warm layer is found near the surface and colder layers in deep waters. In between there is a layer with a rapid water temperature decrease. It is called the metalimnion. Shallow ponds do not have thermal stratification, instead they show a continuous temperature

gradient from warmer waters at the surface to cooler waters at the bottom. In addition, temperature fluctuations can vary greatly in these systems, both diurnally and seasonally.

3. **Wind :** In exposed systems, wind can create turbulent, spiral-formed surface currents called Langmuir circulations. It is the interaction between horizontal surface currents and surface gravity waves. The visible result of these rotations, can be seen in any lake, are the surface foam lines that run parallel to the wind direction. The degree of nutrient circulation is system specific, as it depends upon such factors as wind strength and duration, as well as lake or pool depth and productivity concern.

1.5.2 Primary producers in lake

Different groups of algae, including phytoplankton, periphyton and nanoplankton, are the primary photosynthetic organisms in lakes. In addition, aquatic plants also contribute to primary production. Aquatic plants can be grouped according to their habitat distribution in lakes such as : (i) emergent : rooted in the substrate, but with leaves and flowers extending into the air. There are many species of emergent plants, among them, the reed (*Phragmites*), *Cyperus papyrus*, *Typha* sp. are important; (ii) floating-leaved : rooted in the substrate, but with floating leaves. Common-floating leaved macrophytes are water lilies (family-Nymphaeaceae), pondweeds (family-Potmogetonaceae); (iii) submerged : growing beneath the surface. Examples include stands of *Equisetum fluviatile*, *Hippuris vulgaris*, yellow flag (*Iris pseudacorus*), *Typha* etc. ; (iv) free-floating macrophytes : not rooted in the substrate, and floating on the surface. Free-floating macrophytes can occur anywhere on the system's surface. Examples include *Pistia* spp. commonly called water lettuce, water cabbage or Nile cabbage.

1.5.3 Macroconsumer organisms

The macroconsumer organisms in lake ecosystem include zooplanktons, zoobenthos, insect larvae, crustaceans, fishes, etc. A large number of zooplankton and zoobenthos are found in the water column and surface sediment of the lake respectively. In addition, a variety of macroconsumers including insect larvae and fish are also found in lake. Like phytoplankton, these species have developed mechanisms that keep them from sinking to deeper waters, including drag-inducing body forms, and the active flicking of appendages (such as, antennae or spines). As for example the zooplankton, *Daphnia* sp. make daily vertical migrations in the water column by passively sinking to the darker lower depths during the day, and actively moving towards the surface during the night. The invertebrates, like crustaceans (e.g., crabs, crayfish, shrimp), mollusks (e.g., clams and snails) and numerous types of insects that inhabit the benthic zone are numerically dominated by small species, and are species-rich compared to the zooplankton of the open water.

1.5.4 Fish and other vertebrates

Fish is one of the important sentinel organisms inhabiting in the lake. Fish have a range of tolerance to physiological conditions and that can be used to quantify the tolerance level of a particular fish. Other vertebrate taxa like amphibians (e.g., salamanders and frogs), reptiles (e.g., snake, turtles and alligators) and a large number of waterfowl species inhabit lentic systems as well. Most of these vertebrates spend part of their time in terrestrial habitats, and thus, are not directly affected by abiotic factors in the lake or pond. Many fish species are important both as consumers and as prey species to the larger vertebrates.

1.5.5 Decomposers

The major decomposers are bacteria and fungi. Decomposers may even become food themselves when they are attached to a piece of detritus that is eaten. Examples of decomposers include organisms like bacteria, mushrooms, mold, worms, springtails etc. Many decomposers need oxygen to survive and without it there is little or no decomposition. Oxygen is needed for decomposers to respire, to enable them to grow and multiply. Some decomposers can survive without oxygen, getting their energy by anaerobic respiration.

1.6 Wetland ecosystem

A wetland is a distinct ecosystem that is flooded by water, either permanently or seasonally, where oxygen-free processes prevail. Wetlands are also considered the most biologically diverse of all ecosystems, serving as home to a wide range of plant and animal life. The primary factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation and aquatic plants, adapted to the unique hydric soil. Wetlands perform a number of functions, including water purification, water storage, processing of carbon and other nutrients, stabilization of shorelines, and support of plants and animals. For these reasons, they are often called as the kidney of the city. Despite the diversity of wetland types, all wetlands share some common features. To be considered a wetland, an area must have :

- hydrology that results in wet or flooded soils ;
- soils that are dominated by anaerobic process ; and
- biota, particularly rooted vascular plants, that are adopted to life in flooded, anaerobic environments.

Wetlands are distributed worldwide. They may be with freshwater, brackish water or salt water. The main wetland types are swamp, marsh, bog and fen. There are different sub-types of wetlands which include mangrove forest, pocosin (a wetland bog with sandy peat soil) floodplains, vernal pool, sink and many others. Wetlands can be tidal (inundated by tides) or non-tidal. The largest wetlands include the Amazon river basin, the west Siberian plain, the Sundarbans in Ganges-Brahmaputra delta. Constructed wetlands are used to treat municipal and industrial wastewater as well as storm water runoff. They may also play a role in water sensitive urban design.

To save the wetlands various discussions were made among the scientists throughout the Globe. In this context the Ramsar Convention on Wetlands was held as International importance especially as waterfowl habitat and sustainable use of wetlands. It is also known as the Convention on Wetlands. It is named after the city of Ramsar in Iran, where the convention was signed in 1971. 2nd February is considered as World Wetlands Day, marking the convention's adoption on 2 February 1971. This convension defines wet lands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of maine water the depth of which at low tides does not exceed six meters". There are 2414 Wetlands of International importance under Ramsar treaty spreading over 254,540,512 hactor of lands across the globe. The treaty came into force on February 01, 1982 in India. By 2019, India had 42 Ramsar sites. The following is the map of Ramsar sites in India (Fig-3).

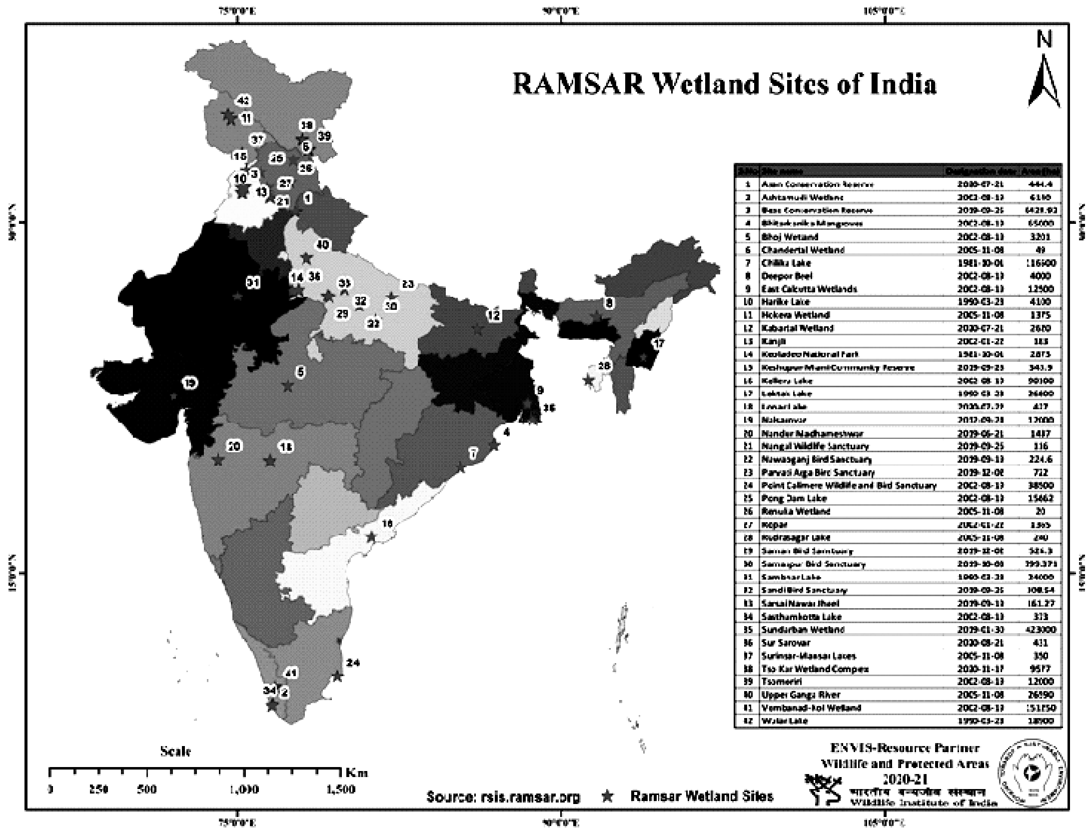


Fig-3 : Ramsar Wetland Sites of India (Source : http://www.wiienvis.nic.in/Database/ramsar_wetland_sites_8224.aspx)

In wetlands, high levels of nutrients and light support a large biomass of photosynthetic organisms. Most common plant life includes floating pond lilies, cypress, tamarack, blue spruce etc. Wetland supports diverse communities of invertebrate and vertebrate animals that burrow in the sediment, crawl or perch on plants, or swim or wade in standing water. Primary consumer from crustaceans, molluscs and aquatic insect larvae to muskrats, geese, and deer rely on abundance of algee, plants and detritus for food. Wetlands also support a variety of carnivores including dragon flies, otters, alligators and osprey.

1.7 Stream ecosystem

A stream is a body of water with surface water flowing within the bed and banks of a channel. As such, river ecosystems are prime examples of lotic ecosystems. *Lotic* refers to flowing water, from the Latin lotus, meaning washed. Lotic waters range from springs only a few centimeters wide to few kilometers in width particularly major rivers. Lotic ecosystems can be contrasted with lentic ecosystems, which are still water or standing water bodies such as lakes, ponds, and wetlands.

The flow of a stream is controlled by three inputs, surface water, subsurface water and groundwater. The surface and subsurface water are highly variable between periods of rainfall. Groundwater, on the other hand, has a relatively constant input and is controlled more by long-term patterns of precipitation.

Depending on its location or certain characteristics, a stream may be referred to by a variety of local or regional names. Long large streams are usually called rivers. Streams are important as conduits in the water cycle, instruments in groundwater recharge, and corridors for fish and wildlife migration. The biological habitat in the immediate vicinity of a stream is called a riparine zone. Streams play an important corridor role in connecting fragmented habitats and thus in conserving biodiversity.

1.8 River ecosystem

In general, rivers are the largest types of stream, moving large amounts of water from higher to lower elevations. River ecosystems are flowing waters that drain the landscape, and include the biotic (living) interactions amongst plants, animals and micro-organisms, as well as abiotic (nonliving) physical and chemical interactions of its many parts. River ecosystems are part of larger watersheds networks or catchments, where smaller headwater streams drain into mid-size streams, which progressively drain into larger river networks. Some of the characteristic features that make rivers unique among aquatic habitats are as follows :

(i) Flow of water is unidirectional;

(ii) There is a state of continuous physical change;

(iii) The level of oxygen is high and not liming unless it is heavily polluted.

(iv) There is a high degree of spatial and temporal heterogeneity at all scales (microhabitats);

(v) Variability of physico-chemical parameters across the river length is high forming a gradient;

(vi) Primary productivity is low;

(vii) Detritus feeding bottom animals are abundant;

(viii) The biota is specialized to live with flow conditions.

The physico-chemical and biological characteristics of a river or stream change during the journey from the source to mouth. The source features cooler temperature that it is at the mouth. The water is also clear, has higher oxygen levels and freshwater fish such as trout and heterotrophs can be found there. Towards the middle part of stream/river, the wide increase, numerous aquatic green plants and algae can be found. Toward the mouth of the river/stream since there is less light, there is less diversity of flora, and because of lower oxygen levels, fish that require less oxygen (catfish) can be found.

1.9 Estuary

1.9.1 Introduction

The word “estuary” is derived from the Latin word aestuarium meaning tidal inlet of the sea, which in itself is derived from the term aestus, meaning tide. An estuary is a dynamic ecosystem having a connection to the open sea through which the sea water enters with the rhythm of the tides. The seawater entering the estuary is diluted by the fresh water flowing from rivers and streams. The pattern of dilution varies between different estuaries and depends on the volume of freshwater, the tidal range, and the extent of evaporation of the water in the estuary.

1.9.2 Definition

There are many definitions proposed to describe an estuary. A more comprehensive definition of an estuary is “a semi-enclosed body of water connected to the sea as far as the tidal limit or the salt intrusion limit and receiving freshwater runoff; however the freshwater inflow may not be perennial, the connection to the sea may be closed for part of the year and tidal influence may be negligible” (Wolanski, 2007).

1.9.3 Important physico-chemical characteristics of estuary

The most important variable characteristics of estuary water are the concentration of dissolved oxygen, salinity and sediment load. There is extreme spatial variability in salinity, with a range of near-zero at the tidal limit of tributary rivers to 3.4% at the estuary mouth. At any one point, the salinity will vary considerably over time and seasons, making it a harsh environment for organisms. Sediment often settles in intertidal mudflats which are extremely difficult to colonize, thus vegetation based habitat is not established. Sediment can also clog feeding and respiratory structures of species, and special adaptations exist within mudflat species to cope with this problem. Dissolved oxygen variation can cause problems for life forms. Nutrient-rich sediment from man-made sources can promote primary production life cycles, perhaps leading to eventual decay removing the dissolved oxygen from the water; thus hypoxic and anoxic zones can develop (Kaiser et al, 2005).

Phytoplanktons are key primary producers in estuaries. They move with the water bodies and can be flushed in and out with the tides. Their productivity is largely dependent upon the turbidity of the water. The main phytoplankton present is diatoms and dinoflagellates, which are abundant in the sediment. It is important to remember that a primary source of food for many organisms on estuaries, including bacteria, is detritus from the settlement of the sedimentation

1.9.4 Examples of estuaries

The following are different estuaries lying in different continents of the world.

Sl. No.	Continents	Estuaries
1.	Africa	• Orange River Estuary • Lake St Lucia Estuary
2.	Asia	• Yenisei Gulf Estuary • Han River Estuary • Meghna River Estuary
3.	Europe	• Golden Horn • Severn Estuary • Thames Estuary
4.	North America	• East River • Great Bay • San Francisco Bay
5.	Oceania	• Spencer Gulf • Gippsland lakes • Port Jackson (Sydney Harbour)
6.	South America	• Rio de la Plata • Amazon River

A few important estuaries in India are - (i) Thane Creek : Thane Creek is an estuary that separates the city of Mumbai from the Indian Mainland; (ii) Kayamkulam Estuary : The Kayamkulam estuary is the famous Kayamkulam Lake located between Panmana and Karthikapally in Kollam; (iii) Zuari River Estuary : The Zuari river is one of the prominent rivers in Goa. The Zuari river along with the Mandovi river joins the Arabian Sea near Marmugoa; (iv) Baga Creek : The Baga creek is a tidal inlet that joins the Arabian Sea at Baga (Goa).

1.9.5 Classification of estuary

Estuary can be classified as following four types :

1. **Drowned river valleys :** Drowned river valleys are also known as coastal plain estuaries. In places where the sea level is rising relative to the land, sea water progressively penetrates into river valleys and the topography of the estuary remains similar to that of a river valley. This is the most common type of estuary in temperate climates. An example of drowned river valleys is Severn Estuary in UK.

2. **Lagoon-type or bar-built :** Bar-built estuaries are found in a place where the deposition of sediment has kept pace with rising sea levels so that the estuaries are shallow and separated from the sea by sand spits or barrier islands. They are relatively common in tropical and subtropical locations. Example : Galveston Bay, Albemarle – Pamlico sound.

3. **Fjord-type :** Fjords were formed where pleistocene glaciers deepened and widened existing river valleys, so that they become U-shaped in cross-sections. At their mouths there are typically rocks, bars or silts of glacial deposits, which have the effects of modifying the estuarine circulation.

   Fjord-type estuaries can be found along the coasts of Alaska, the Puget region of western Washington State, New Zealand, and Norway.

4. **Tectonically produced :** These estuaries are formed by subsidence or land cut off from the ocean by land movement associated with faulting, volcanoes, and landslides. Inundation from ecstatic sea-level rise during the Holocene Epoch has also contributed to the formation of these estuaries. There are only a small number of tectonically produced estuaries.

   Example : San Francisco Bay, which was formed by the crustal movements of the San Andreas fault system causing the inundation of the lower reaches of the Sacramento and San Joaquine rivers.

1.9.6 Estuarine organisms

Estuaries are tough environments where organisms in estuaries are subject to tremendous osmotic stress. Organisms adapted to fresh water have relatively low salt concentrations in their body fluids. When immersed in salt water, the greater osmatic potential of sea water sucks water out of them until their tissues become saltier. Some organisms can regulate their osmotic state using powerful kidneys to excrete salt or water as needed to maintain osmotic homeostasis. The anadromous salmonid fishs are an example.

1.9.7 Importance of estuarine ecosystem

The following are the importance of estuarine ecosystem.

(i) Important in hydrological cycles.

(ii) Sediments supplies to ocean.

(iii) Habitat for a large variety of life.

(iv) Highly productive among aquatic systems.

(v) Food resources of socio-economic relevance.

1.10 Intertidal zone

Intertidal zone are traditional coastal regions located between the high and low tide marks. The intertidal zone, also known as the foreshore or seashore, is the area that is above water level at low tide and underwater at high tide (in other words, the area within the tidal range). This area can include several types of habitats with various species of life, such as sea stars, sea urchins, and many species of coral. Sometimes it is referred to as the littoral zone, although that can be defined as a wider region.

Organisms in the intertidal zone are adapted to an environment of harsh extremes. The intertidal zone is also home to several species from different phyla, such as, porifera, annelida, coelentareta, mollusca, arthropoda etc. Water is available regularly with the tides, but varies from fresh with rain to highly saline and dry salt, with drying between tidal inundations. With the intertidal zone's high exposure to sunlight, the temperature can range from very hot with full sunshine to near freezing in colder climates. Some microclimates in the littoral zone are moderated by local features and larger plants such as mangroves. Adaptation in the littoral zone allows the use of nutrients supplied in high volume on a regular basis from the sea, which is actively moved to the zone by tides. Edges of habitats, in this case land and sea, are themselves often significant ecologies, and the littoral zone is a prime example.

1.10.1 Ecology

The intertidal region is an important model system for the study of ecology, especially on wave-swept rocky shores. The region contains a high diversity of species, and the zonation created by the tides causes species ranges to be compressed into very narrow bands. This makes it relatively simple to study species across their entire cross-shore range, something that can be extremely difficult in, for instance, terrestrial habitats that can stretch thousands of kilometres.

The burrowing invertebrates, such as insects, spiders, sea urchins, crustaceans, clams and worms that make up large portions of sandy beach ecosystems are known to travel relatively great distances in cross-shore directions as beaches change on the order of days, semilunar cycles, seasons, or years.

Since the intertidal zone is alternately covered by the sea and exposed to the air, organisms living in this environment must have adaptions for both wet and dry conditions. Hazards include being smashed or carried away by rough waves, exposure to dangerously high temperatures, and desiccation. Typical inhabitants of the intertidal rocky shore include urchins, sea anemones, barnacles, chitons, crabs, isopods, mussels, starfish, and many marine gastropod molluscs such as limpets and whelks.

1.10.2 Zonation of intertial zone

The four zones in intertidal zone include from the highest to the lowest is splash zone, high zone, mid zone and low zone (Fig-4).

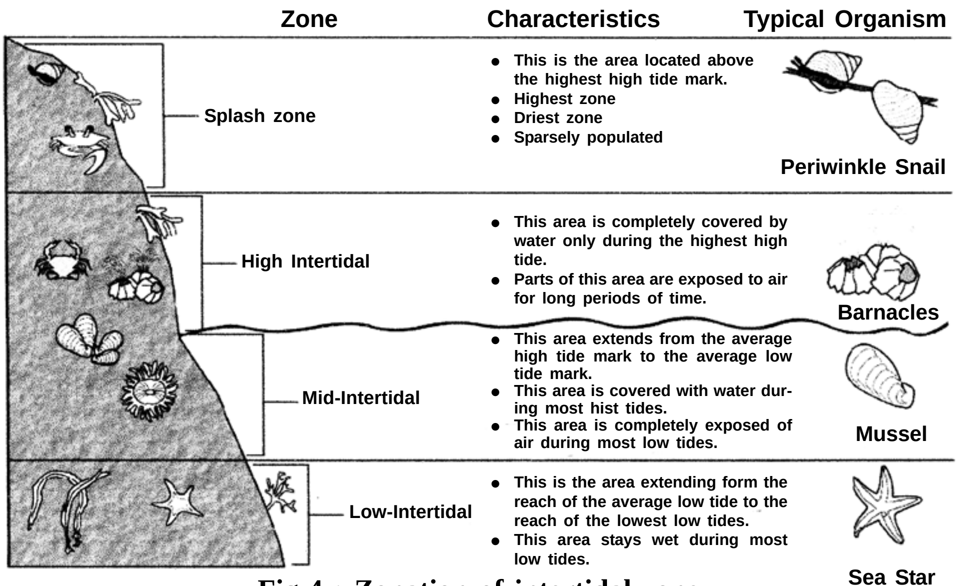


Fig-4 : Zonation of intertidal zone

(i) The Splash Zone :

The Splash zone is the area above the high tide water line and mainly depends on sea spray and mist from waves and freshwater runoff from rain and streams for water coverage. This relatively dry area is sparsely populated. Few organisms can withstand the extreme fluctuations in moisture, temperature and salinity found in this zone.

The characteristics species of the splash zone are the Little Acorn Barnacles (*Cthamalus dalli*), Sea Lettuce (*Ulva sp.*) and the Periwinkle Snail (*Littorina sp.*). All species are adapted to withstand long periods of exposure.

(ii) The High Zone :

The High zone is the area of intertidal that is completely covered with water in high tides. Parts of this region are exposed to the air for long periods as the tides recede. The inhabitants of this area are study individuals and can remain wet even if they are exposed to the sun and wind. The organisms in this area have also developed attachment devices such as muscular feet, suction cups, byssal threads, or holdfasts to help them resist the force of the waves.

The zone is characterized by the large Acorn Barnacle (*Balanus glandula*), Limpets, Chitons and two species or rockweed *Selvetia compressa and Hesperophycus harveyanus*.

(iii) The Mid Zone :

The mid-intertidal zone is the area between the average high tide and low tide mark. This region is covered by water during most high tides, but it is exposed to the air during most low tides. This environment supports a more highly populated and diverse group of organisms, than either the splash zone or high intertidal zone. In order to overcome space and competition problems, organisms that live here have developed specialized niches within the community.

The highly recognizable intertidal species found here are the Seastar (*Pisaster sp*), the Mussel (*Mytilus californianus*) and the Gooseneck Barnacle (*Pollicipes polymerus*). The Mussel beds provide the characteristic band for this zone.

(iv) The Low Zone :

The low intertidal zone is the area between the average low tide level and the lowest low tide level that can be found in both the intertidal and sub-tidal habitats. This area stays moist during most low tides making it an iedal home for many kinds of organisms. This zone also has lots of food as nutrients are circulated in near-shore waters. Many plankton are found within this habitat, and grazers enjoy the rich abundance of algae available. Large fleshy brown algae begin to appear in this zone.

Other common algal species are the Feather Boa (*Egregia menziesii*) and the Sea Plam (*Eisenia arborea*). This zone acts as a better shelter and gives more portection from desiccation than the other intertidal zone.

1.10.3 Adaptive features of intertidal zone animals

1. Hardy organisms with the capacity to withstand the pounding waves and extremes in temperature, salinity and water availability are found in this zone.
2. Barnacles has a tough, protective covering made of chitin. During their juvenile, or larval stages, barnacles swim freely about in the water column searching for a place to live. Once they find a place to settle, they produce a glue from their head. They use this glue to attach themselves to the substrate which protects them from being tossed about by incoming waves. They use their feathery legs called cirri provided with sensory organs to locate plankton and filter food from the water.
3. Mussels live close together. Once settled, they secrete fibrous byssal threads from a gland in their foot which are used to help the mussel adhere to the rocks. They eat by filtering small particles of organic matter from the seawater. They close their shells tightly to keep in moisture while the tide is out or to protect themselves from predators such as the sea star.
4. Sea anemones have a cylindrical body and a central mouth surrounded by tentacles containing stinging cells called nematocysts that are used to stun prey such as small fish. In sexual reproduction, fertilized eggs are released in the water column and in asexual reproduction, anemones create clones

that can form large colonies where intruders are not welcome. To prevent drying out, anemones can turn their tentacles inward and shrink or move to a moist location using a special foot called a pedal.

5. The sea star (*Pisaster ochraceus*) is an echinoderm. They use their water vasular system to operate their tube feet. In this system, water enters and exists the sea star through an opening on its back. This opening is called the madreporite. Sea stars protect themselves with the help of a tough integument or outer covering that keeps them from drying out. They can also regenerate lost arms, so they can continue their predatory life stlye.

1.11 Marine benthic zone

1.11.1 Introduction

The benthic zone is the ecological region at the lowest level of water body such as an ocean, lake or stream, including the sediment surface and some sub-surface layers. The benthic region of the ocean begins at the shore line (intertidal or littoral zone) and extends downward along the surface of the continental shelf out to sea. The continental shelf is a gently sloping benthic region that extends away from the land mass. At the continental shelf edge, usually about 200 metres (660 ft) deep, the gradient greatly increases and is known as the continental slope. The continental slope drops down to the deep sea floor. The deep-sea floor is called the abyssal plain and is usually about 4,000 metres (13,000 ft) deep. The ocean floor is not all flat but has submarine ridges and deep ocean trenches known as the hadal zone. Depending on the water-body, the benthic zone may include areas that are only a few inches below water, such as a stream or shallow pond; at the other end of the spectrum, benthos of the deep ocean includes the bottom levels of the oceanic abyssal zone.

1.11.2 Benthic organisms

Organisms living in this zone are called benthos which include microorganisms (e.g., bacteria and fungi) as well as larger invertebrates, such as crustacean and polychetes. Organisms here generally live in close relationship with the substrate and many are permanently attached to the bottom. The benthic boundary layer, which includes the bottom layer of water and the uppermost layer of sediment directly influenced by the overlying water, is an integral part of the benthic zone, as it greatly influences the biological activity that takes place there.

Benthos are the organisms that live in the benthic zone, and are different from those elsewhere in the water column. Many have adapted to live on the substrate (bottom). In their habitats they can be considered as dominant creatures, but they are often a source of prey for Carcharhinidae such as the lemon shark (Dugan et al, 2013). Many organisms adapted to deep-water pressure cannot survive in the upper parts of the water column because the pressure difference can be very significant (approximately one atmosphere for each 10 meters of water depth).

Because light does not penetrate very deep into ocean-water, the energy source for the benthic ecosystem is often organic matter from overlying water column that drifts down to the depths. This dead and decaying matter sustains the benthic food chain; most organisms in the benthic zone are scavengers or detritivores. Some microorganisms use chemosynthesis to produce biomass.

Benthic organisms can be divided into two categories based on whether they make their home on the ocean floor or a few centimeters into the ocean floor. Those living on the surface of the ocean floor are known as epifauna (e.g. feather stars, sand dollars, sand crabs, mussels). Those who live burrowed into the ocean floor are known as infauna (e.g., Eastern oyster, European Green Crab, commpn cockle, Soft shell clam). Extremophiles, including piezophiles, which thrive in high pressures, may also live there.

1.11.3 Classification of benthos

From the nutritional point of view, the benthos can be categorized into primary producers (algae, aquatic plants) living on the bottom as "phytobenthos" and "zoobenthos" that consume phytopenthos and protozoa. The term epibenthos is used for those organisms living on top of the sediment and hyperbenthos for those living just above the sediment.

Benthos also can be categorized according to size :

- Macrobenthos, size greater than one mm.
- Meiobenthos, size less than one mm but greater than 32 µm (µm is a thousandth of a millimeter).
- Microbenthos, size less than 32 µm.

1.11.4 Benthos habitats

The benthic zone is the lowest level of a marine or fresh water system and includes the sediment surface, the water just above it, a same sub-surface layers. The benthic zone starts at the shore and extends down along the bottom of the lake or ocean giving rise to following zone —

(i) Littoral or intertidal zone : area betwen high and low tide.

(ii) Sublittoral zone : from low tide to shelf break, *i.e.*, continental shelf.

(iii) Bathyal zone : Shelf break to 2000 m.

(iv) Abyssal zone : from 2000 to 6000 m.

(v) Hadal zone : Sea floor deeper than 6000 m.

Because of the depths it can reach, the benthic zone is often characterised by low sunlight and low temperature, but may drop to 2 – 3° C at the most extreme depth of abyssal zone.

The lower zones are in deep, pressurized areas of the ocean. Human impacts have occurred at all ocean depths, but are most significant on shallow continental shelf and slope habitats. Many benthic organisms have retained their historic evolutionary characteristics. Some organisms are significantly larger than their relatives living in shallower zones, largely because of higher oxygen concentration in deep water.

1.12 Marine pelagic zone

1.12.1 Introduction

The pelagic zone is that region of lake, river or ocean that is not associated with the shore or the bottom. Pelagic zone is the ecological realm that includes the entire ocean water column. Of all the inhabited Earth environments, the pelagic zone has the largest volume, 1,370,000,000 cubic kilometres (330,000,000 cubic miles), and the greatest vertical range, 11,000 metres (36,000 feet). Although, the pelagic zone is nutrient poor, but pelagic life is found throughout the water column, although the numbers of individuals and species decrease with increasing depth. The regional and vertical distributions of pelagic life are governed by the abundance of nutrients and dissolved oxygen; the presence or absence of sunlight, water temperature, salinity, and pressure; and the presence of continental or submarine topographic barriers.

1.12.2 Classification of pelagic zone

The pelagic zone is divided into the following sub-zones based on the penetration of light (Fig-5).

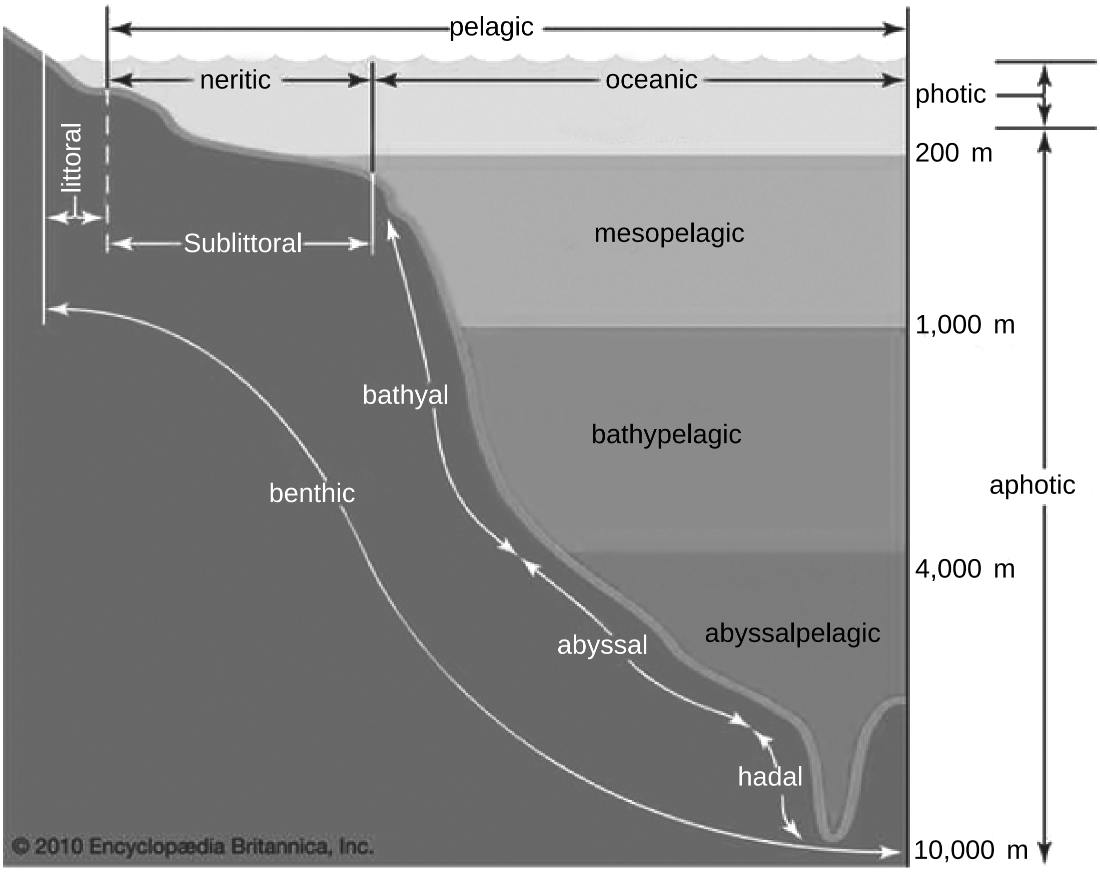


Fig-5 : Zonation of the ocean

1. Epipelagic Zone :

(i) This zone stretches from the surface to a depth of less than 200 metres.

(ii) It is the surface zone where sufficient light penetrates for photosynthesis.

(iii) This region is dominated by phytoplankton, diatoms, and dinoflagellates.

(iv) Large fishes such as tunas and sharks are found in this zone. That is why the smaller animals come up to this zone only at night to stay away from the large predators around.

2. Mesopelagic Zone :

(i) This zone extends from 200-1,000 metres below the epipelagic zone.

(ii) This is known as the twilight zone.

(iii) Although some light reaches the region, it is not sufficient for photosynthesis.

(iv) Some animals found in this zone have large eyes to make the best use of limited light.

(v) The oxygen concentration is also very low in this zone.

(vi) The organisms such as squids, nautilus shells, swordfish, etc. have the capacity to survive in this zone.

3. Bathypelagic zone :

(i) This is known as the dark zone where no light can reach.

(ii) This zone extends from 1,000 to 4,000 metres below the continental slope.

(iii) This is the zone of high pressure. The organisms with special features to withstand such high pressures can survive in this zone. For example, the fishes found here lack the swim bladder.

(iv) The organisms stay here to conserve energy.

(v) The fishes exhibiting bioluminescence are prominent in this zone.

(vi) The temperature in this zone stays between 2 – 4° C.

(vii) Giant squids and sperm whales are found in this zone.

4. Abyssopelagic zone :

(i) This zone extends from 4,000- 6,000 metres and is the region where the continental slope levels off.

(ii) It comprises of more than 30% of the bottom ocean.

(iii) The organism remains here are colourless and blind.

5. Hadopelagic zone :

(i) This zone extends from 6,000-11,000 metres.

(ii) Very few species are observed in this zone, as this is the aphotic zone with no light penetration.

(iii) Food availability is very low here.

(iv) Many organisms are found here to live in hydrothermal vents.

1.12.3 Pelagic zone animals

The organisms in the pelagic zone range from the tiny planktons to large mammals like whales. The biotic components of pelagic zone consist of phytoplankton, zooplankton and macroconsumers and decompsers. Invertebrates like jellyfish, squids, octopus and krill are also found in the pelagic zone. Large ocean vertebrates such as crustaceans, sharks, bluefin tuna, and sea turtles live or migrate through the pelagic zone. Seabirds such as shearwaters, petrels and gannets can be found above the pelagic zone.

Coral reefs are discussed in the Unit–3 part of the sutdy material

1.13 Summary

- Aquatic biomes refers to as a major biotic community characterized by the dominant forms of plants and the dominating aquatic environment.
- Freshwater ecosystems are of two main components—abiotic and biotic components.
- Lakes are bodies of standing freshwater that may support emergent vegetation at their edges or over their entire area.
- Wetland is a distinct ecosystem that is flooded by water, either permanently or seasonally, where oxygen-free processes prevail.
- A stream is a body of water with surface water flowing within the bed and banks of a channel.
- Estuary is a semi-enclosed body of water connected to the sea.
- Intertidal zone are traditional coastal regions located between the high and low tide marks.

1.14 Questions

(i) What is aquatic biome?

(ii) Write a short note on marine biome.

(iii) What are the primary producers in lake?

(iv) Differentiate between stream and river ecosystem.

(v) Classify pelagic zone with characteristics.

(vi) Write a few examples of pelagic zone animals.

(vii) What is kelp forest?

(viii) Write a short note on Ramsar Convention.

1.15 Suggested Readings

1. Hansson, CLA (2005). The Biology of Lakes and Ponds. Oxford University Press, Oxford. p. 285.
2. Brown, AL (1987). Freshwater Ecology. Heinimann Educational Books, London. p. 163. .
3. McLusky, DS and Elliott, M (2004). The Estuarine Ecosystem : Ecology, Threats and Management. New York : Oxford University Press. ISBN : 978-0-19-852508-0
4. Wolanski, E. (2007). Estuarine Ecohydrology. Amsterdam : Elsevier. ISBN : 978-0-444-53066-0
5. Kaiser et al. (2005). Marine Ecology. Processes, Systems and Impacts. New York : Oxford University Press. ISBN : 978-0199249756
6. What is the intertidal zone? World Atlas. Retrieved on 17. 09. 2019.
7. Dugan, JE, Hubbard, DM and Quigley, BJ (2013). "Beyond beach width : Steps toward identifying and integrating ecological envelopes with geomorphic features and datums for sandy beach ecosystems". Geomorphology. 199: 95–105.
8. Wetzel, RG (2001). Limnology : Lake and River Ecosystems, 3rd edn. Academic Press, San Diego. pp. 635–637.
9. Fenchel, T, King, G and Blackburn, TH (2012). Bacterial Biogeochemistry :

The Ecophysiology of Mineral Cycling, 3rd edn. Academic Press, London. pp. 121–122.

10. “What are Benthos?” Baybenthos.versar.com. 2006-01-23. Retrieved on 2019-11-24.

11. Bright, M (2000). The private life of sharks: the truth behind the myth. Mechanicsburg, Pennsylvania: Stackpole Books. ISBN : 0-8117-2875-7

12. Epifaunal-Definition and more from the free Merriam-webster dictionary.Merriam-webster.com. Retrieved on 24-11-2020

13. Infauna- Definition and more from the free Merriam-webster dictionary. Merriam-webster.com. Retrieved on 24-11-2020

14. Harris, PT and Baker, EK (2012). “GEOHAB Atlas of seafloor geomorphic features and benthic habitats – synthesis and lessons learned”, in : Harris, P. T.; Baker, E. K. (eds.), Seafloor Geomorphology as Benthic Habitat : GeoHab Atlas of seafloor geomorphic features and benthic habitats. Elsevier, Amsterdam, pp. 871-890.

15. Harris, PT and Baker, EK (2012). Seafloor Geomorphology as Benthic Habitat : GeoHab Atlas of seafloor geomorphic features and benthic habitats. Elsevier, Amsterdam, p. 947.

16. Harris, PT (2012). “Anthropogenic threats to benthic habitats”, in: Harris, P. T.; Baker, E. K. (eds.), Seafloor Geomorphology as Benthic Habitat : GeoHab Atlas of seafloor geomorphic features and benthic habitats. Elsevier, Amsterdam, pp. 39-60.

17. Royal Belgian Institute of Natural Sciences, news item March, 2005 September 28, 2011, at the Wayback Machine.

18. Ecology and Environment (2002-03) by P. D. Sharma, Pub : Rastogi publication, Meerut-250 002.

19. Fish and Fisheries (1991) by V. G. Jhingran, Pub : Hindustan Publishing Corporation (India), Delhi.

20. Study Material (Post Graduate Zoology), Paper-2A, Netaji Subhas Open University (2006), Pub : The Registrar, NSOU.

21. Study Material (Post Graduate Zoology), Paper-3A, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.

22. Study Material (Post Graduate Zoology), Paper-8B, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.

23. Biology of Animals (Volume-II) by Ganguly B, Sinha A and Adhikari S (1987). Pub : New Central Book Agency.

24. Environmental Biology (Principles of Ecology) by Verma PS and Agarwal VK (1993). Pub : S. Chand & Company Ltd., New Delhi-110055.

Unit - 2 ❑ Freshwater biology of lakes

Structure

2.0 Objectives

By studying this unit, students will be able to understand about the following—

- Lake and its characteristics.
- To know about lake ecosystem.
- Nitrogen, phosphorus and sulpher cycle.
- Stream and adaptive modification of hill steam fishes.

2.1 Introduction

Lake is a large body of natural water collected in a depression. On our Earth, a body of water is considered as lake when it is inland, not part of the ocean, is larger and deeper than a pond. It differs from a pond/ tank due to its larger size, depth and related ecological factors. The presence of a lake, in any region, greatly influences the life of the people living adjacent to it. Lakes are helpful in controlling weather and local climate. In some places, lakes are good sources for water supply for drinking. In terms of area, one-third of the world's standing water is represented by lakes. Streams of watershed are the feeding sources to lakes. India has a vast resource of lakes which are exploited for the development of fisheries and tourism. Fisheries of lakes are called lacustrine fisheries. Every lake is characterized by-

(a) Its basin, which is the depression holding the water;

(b) Its maximum depth of water;

(c) Its volume of water;

(d) Its surface area;

(e) Rate of inflow and outflow of water;

(f) Quality of water;

(g) Total dissolved load of nutrients and sediments;

(h) Biotic species and their density.

2.2 Definition of lake

Lakes are defined as naturally formed hollow depressions on the surface of the earth, which get filled with water. Ponds, in contrast are man made water bodies. According to Forel (1892), lakes are a body of standing water occupying a basin and lacking continuity with sea. Welch (1952) regards all large bodies of standing water as lakes, in contrast to ponds which are small shallow bodies of quite standing water.

Lake Baikal is the world's largest freshwater lake in terms of volume, while the Caspian sea (salty water) is the world's largest lake say surface area.

2.3 Origin of lakes

In geological terms lakes are ephemeral. They originate as a product of geological processes and terminate as a result of evaporation caused by changes in hydrological balance, or by in filling caused by sedmentation.

There are various ways by which lake has been formed.

1. **Tectonic basins :** These are of two types

   A. **New land lakes :** This types of lakes are formed by uplifting of marine sediments. These lakes are often large and shallow. Ex- Lake Okeechobee, Florida.

B. **Structural basins :** Lake in a down faulted depression or uplifting forms of a dam or uplifting around entire basin or by local depression due to earthquakes. Ex- Baikal lake, Pyramid lake (Nevada), Lake Victoria, East Africa.

2. **Lakes associated with volcanic activity :** Lakes formed due to collapsed or exploded volcanoes and surrounded by rim of lava. Sometimes lava or ash dams form a stream or collapsed lava flow cavern. Ex- Tagus Lake (Galapagos), Lake Kivu (Central Africa).

3. **Lakes formed by landslides :** Landslides obstruct valleys forming natural dams and thereby formed lakes. Ex-Quake Lake, Yellowstone; most of the Kumaun lakes in Uttar Pradesh (India).

4. **Lakes formed by wind :** In arid regions, the movement of fine, loose materials such as, clay and sand particles may result in the formation of lake basins. The deposition of soil particles may happen to block an existing stream, thus giving rise to a dammed lake. Ex-Pan lake, Sambhar lake in Rajasthan (India).

5. **Lakes formed by rivers :**

   A. **Plunge pools :** This includes basins of old waterfalls in now dry river systems. Ex-Falls lake.

   B. **Oxbow lakes :** Bends in river that becomes isolated. These lakes are shallow and oddly shaped. Ex-Delta lake.

   C. **Floodplain or varzea lakes :** Formed due to depressions in the flood plain area. Some are due to sediments deposited across mouths of inflowing streams.

6. **Lakes formed by glaciers and ice :**

   A. **Existing glaciers or ice :** Pockets of meltwater on the surface or below glaciers. In this form, lakes are situated at the front of a receding glacier. Ex-Permafrost lakes (Cryogenic lakes).

   B. **Past glaciers :** Glacially deepened valley or fault adjoining the sea. They may be isolated from the sea or may be dammed. Ex- Finger lakes (Lake Mendota, WI).

7. **Solution lakes :** Formed by dissolution of soluble rock (often limestone) by percolating water. The formulae is : $CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^-$. Areas with numerous solution lakes are known as "Karst topography". Ex-Lake Ohrid, Yugoslavia.

8. **Lakes associated with shorelines :** These lakes are formed at the shores of oceans and they are large lakes.

   A. **deltaic lakes :** Sedimentation as river currents slowed down when they enter a large lake or the ocean. They may isolate lakes on deltas.

   B. **coastal lake :** Movement of sand in spits and bars may enclose basins.

9. **Biogenic lakes :** These lakes are mainly human made lakes. They are mainly the reservoirs with dams over 15 m high, 0.1 km^3 surface area and 10% volume of natural lakes.

2.4 Classification of lake

Classification helps us to understand and visualize the relationships and also helps us to communicate. The simplest classification is based on the dimension of a lake, whether a lake is small, big or very large. The following are the classification of lakes based on water quality and trophic level of water.

(A) Classification based on water quality : Based on water quality lakes are broadly classified into three main categories : fresh water lake, salt water lake and brackish water lake.

1. **Freshwater lake :** Fresh water lakes are comprises of naturally occurring water with low amounts of dissolved salts. The following are the examples of fresh water lakes.

   (i) **Kolleru lake :** Located in Andhra Pradesh. Total area covered is 90000 hactor. The lake is faced with the problem of inflow of effluents, siltation and infestation of water hyacinth.

   (ii) **The Hussain sagar lake :** This is one of the largest man-made lake in Asia, located in the heart of Hyderabad, contributing to its immense beauty. It is a sprawling artificial lake that holds water perennially. It was built during the region of Ibrahim Qutub Shah in 1562, on the tributary of the river Musi.

2. **Brackishwater lake :** Brackishwater lakes are comprises of water having salinity between freshwater and seawater. The following are the examples of brackishwater lakes.

   (i) Chilka lake : Chilka lake is situated in the Ganjam district of Orissa with a water spread area of 906 sq. km. The water area increases during monsoon to about 1165 sq. km. The lake is connected to the Bay of Bengal by a long outer channel through a single mouth while on the other side it receives several branches of Mahanadi river system. It is a shallow lake, the maximum depth being 3 meters in the south western region, 2.5 metre in the central region and 1.5 metre in the north west.

   (ii) Pulicat lake : This lake is distributed over two states. The major part is located in the Nellore district of Andhra Pradesh while the rest part is located in the Chingleput distrct of Tamilnadu, where it is connected to the Bay of Bengal to the Pulicat village. Two seasonal rivulets Rayrla Vagu and Kalangi drain in the Pulicat lake. The tidal influence from the Bay of Bengal is restricted upto 16 km from the mouth of the lake with the Bay of Bengal.

3. **Saline water lake :** A highly concentrated solution of salt in water is found in saline water lake. The following are the few examples of saline water lake.

   (i) Sambher lake : Located in the arid zone of Rajasthan, the sambhar lake is one of the largest inland saline lakes in India. Salt extraction is one of the major activities in the wetland.

   (ii) Pangon Tso : One of the most spectacular lakes in Ladakh is the Pangon Tso, which lies across the Changla Pass from Leh. At an altitude of almost 4,500 meters, the Pangon Tso is only 8 km wide at its broadest point, but is an amazing 134 km long. The Pangong is considered to be the longest lake in Ladakh. It is a saltwater lake formed in much the same way as the Tso Morari lake during Ice Age.

(B) Classification based trophic levels : Trophic level states a water body's ability to support plants, fish, and wildlife. The richness in nutrient level is called as productivity. It is the basis for the trophic concept of classification. Based on the productivity, this type of lakes are classified into following eight categories:

(a) Oligotrophic lakes : Oligotrophic lakes are characterized by the following features :

(i) Very low concentrations of nutrients required for plant growth.

(ii) Low productivity.

(iii) Small populations of phytoplankton, zooplankton, attached algae, macrophytes (aquatic weeds), bacteria, and fish.

(iv) Very little consumption of oxygen.

(v) Good water clarity (a deep Secchi disk reading, averaging about 10 meters or 33 feet).

(vi) Low chlorophyll readings (average about 1.7 mg/m^3).

(vii) Sandy or rocky bottom.

(b) Mesotrophic lake : The mesotrophic lake is intermediate in most characteristics between the oligotrophic and eutrophic stages. Mesotrophic lakes are characterized by the following features-

(i) Production of the plankton is intermediate, so some organic sediment accumulating and some loss of oxygen in the lower waters.

(ii) The oxygen may not be entirely depleted except near the bottom (the relative depth of the lake has a bearing on this characteristics).

(c) Eutrophic lake : These are in contrast to the oligotrophic lakes having the following characteristics.

(i) Rich in plant nutrients.

(ii) Productivity is high.

(iii) Produce high numbers of phytoplankton (suspended algae).

(iv) Poor Secchi disk readings (average about 2.5 meters or 8.0 feet).

(v) High numbers of zooplankton and minnows and other small fish that feed on the zooplankton.

(vi) Contain considerable amount of organic sediments.

(vii) Depletion of oxygen from the lower depths of these lakes.

(viii) Chlorophyll concentrations averaging about 14 mg /m^3 or higher.

(ix) Phosphorus concentration averages something over 80 mg /m^3.

(d) Dystrophic lakes : The dystrophic lakes are developed from the accumulation of organic matter derived from outside the lake. In this case, the watershed is often forested and there is an input of organic acids (e.g. humic acids) from the breakdown of leaves and evergreen needles. This is followed by a series of processes resulting in a lake having low in pH in water acidic and often has moderately colored (yellow/brown) water. These lakes are poor in plankton production and have sparse fish populations largely because of the acid conditions and have low nutrient concentrations.

(e) Acidotrophic lakes : Acidotrophic lakes show low production with low phosphorus and nitrogen, but pH < 5.5.

(f) Alkalitrophic lakes : Alkalitrophic lakes show high production with high calcium.

(g) Argillotrophic lakes : Argillotrophic lakes show low production with high clay turbidity.

(h) Siderotrophic lakes : Siderotrophic lakes show low production with high iron.

2.5 Problems in lake

Most of the lakes in India are degraded, depleted and contaminated mainly by human activities : The main causes are :

(i) Inflow of domestic sewage.

(ii) Agricultural run-off.

(iii) Discharge of industrial effluents.

(iv) Over fishing.

(v) Introduction of exotic species and habitat degradation from population growth.

(vi) Expansion of cities.

As more water is withdrawn for human use and more of it is returned to lakes and rivers as badly polluted, there is less water available to maintain vital freshwater ecosystems.

2.6 Lake ecosystem

2.6.1 Introduction

Pond and lake ecosystems are a prime example of lentic ecosystems. Lentic refers to stationary or relatively still water, from the Latin word *lentus*, which means sluggish. Like all other aquatic ecosystem, a lake ecosystem includes both the biotic and abiotic components. The biotic components include living plants, animals and micro-organisms. On the other hand the abiotic components include physical and chemical interactions of non-living components.

2.6.2 Ecology of lakes

The freshwater lake habitats are vertically stratified into five distinct zones depending upon the intensity of light, temperature and absorption of light, which are as follows —

1. **Littoral Zone :** The shallow water zone with rooted vegetation near the shore that contains the oxygen riched circulating layer of warm water. In a deep water lake it is extended upto 10 mitre depth.

2. **Sub littoral zone :** It extends from the littoral zone to non circulating poor oxygenated cold water zone. It extends upto 10 mitre depth.

3. **Limnetic zone :** The open deep water zone upto the depth of 50 mitre. Light penetrates to entire depth and active photosynthesis occurs all along the depth.

4. **Profundal zone :** This zone situated beneath the limnetic zone with no penetration of light.

5. **Abyssal zone :** In very deep lake the sub-littoral zone is extended to dark bottom of the lake and is called as abyssal zone.

2.6.3 Biotic communities in lake

Biotic communities in lakes determined the productivity of the water bodies. Biotic communities are constituted by :

(i) **Plankton :** Small animals and plants that have limited power of locomotion and remain at the mercy of the waves and currents of water. Plankton of plant origins are called phytoplankton (*Votox sp.*) and those of animal origin are called zooplankton (*Dhapnia sp.*).

(ii) **Nekton :** The swimming animals are called nekton and are represented mostly by the fish in ponds and lakes.

(iii) **Neuston :** The animals clinging on the surface of water are called neuston. Some aquatic insects and protozoans constitute these groups of animals.

(iv) **Benthos :** Organisms living at the bottom of the ponds and the lakes are called benthos. The worms, molluscs, nematods etc. from important benthic community in a pond or lake.

2.6.4 Lake organisms

Animals : The animals mainly lives in the lakes are small and large fishes, amphibians, turtles, larger zooplankton and insects. The important characteristics of these animals and zooplanktons are that they may move where they chose.

Floating animals and plants : These animals move where the water takes them. Some of them are living things (plankton) and some are dead staff (detritus). Among the living things, the important organisms are zooplankton, phytoplankton and bacterio-plankton. The detritus are internal (produced within lake) or external (washed in from watershed) in nature.

Benthos : The organisms live on the lake bottom. They are mainly aquatic insects, molluscs (clams, snails and other invertebrates) worms, crayfish etc. There are also some higher plants (macrophytes), attached algae (periphyton), sewage sludge and aufwuchs (mixture of algae, fungi and bacteria).

2.7 Lake morphometry

2.7.1 Introduction

Morphometrics (Greek morphe means “shape” and metria means “measurement”) or morphometry refers to the quantitative analysis of form, a concept that encompasses size and shape. Morphometric analyses are commonly performed on organisms, and are useful in analyzing their fossil record. Morphometrics can be used to quantify a trait of evolutionary significance, and by detecting changes in the shape, deduce something of their ontogeny, function or evolutionary relationships. A major objective of morphometrics is to statistically test hypotheses about the factors that affect shape.

2.7.2 Morphometry of lakes

Morphometry is the measurement of external form or shape of a selected water body. It is that branch of limnology which deals with the measurement of significant morphological features of any basin which included water mass is known as morphometry.

Traditional methods for calculating lake morphometry metrics have relied upon the use of paper bathymetry maps, planimeters, or simple heuristics. In addition, detailed bathymetry is a requirement for the calculation of most lake morphometry metrics, but is generally only available for a relatively small number of lakes. Studying lake morphometry can also help us appreciate lakes for what they are and manage them with more realistic expectations.

2.8 Physico-chemical characteristics of lake

The physico-chemical parameters of water play a significant role in lake ecosystem. The diversity of flora and fauna depend upon the optimum physical condition of water. The following is a brief discussion about the physico-chemical characteristics of lake.

Depth : Depth of a lake has an important bearing on the physical and chemical qualities of water. In shallow lakes, sunlight penetrates upto the bottom, warms up the water and facilitates increase in productivity. While depth greater than 5 mitre it is considered congenial from the point of view of biological productivity of a lake.

Light : Sunlight determines the maximum depth of the littoral zone, the depth of the lake where enough light reaches to allow plants and algae to grow. That depth is called the compensation point, generally at about 1% of incident light. If nutrients are available, sunlight can support algae across the surface of a lake.

Temperature : A temperature increase of only a few degrees does not only cause an increase in the temperature of large water masses such as oceans, seas, lakes and ponds but it also causes hydrological events that cause a change in the physical and chemical characteristics of water.

Thermal stratification : Thermal saratification is influenced chiefly by seasonal variation. Strong thermal stratification is formed in the summer months which prevent or slow the exchange of water in the epilimnion. The upper stratum, which usually has the highest dissolved concentration and is characterised by a temperature gradient of less than 1°C per metre of depth is the epilimnion and hypolimnion. It induces water quality deterioration in the bottom because of anoxia in the hypolimnion. The lowest streatum of water characterised by a tempeature gradient of less than 1°C per metre of depth in the hypolimnion.

Turbidity : In water bodies such as lakes, rivers and reservoirs, high turbidity levels can reduce the amount of light reaching lower depths, which can inhibit growth of submerged aquatic plants and consequently affect species which are dependent on them, such as fish and shellfish.

Dissolved solids : In water bodies like lake or rivers, higher levels of total dissolved solids often harm aquatic species. The total dissolved solids changes the mineral content of the water, which is important to survival of many animals. Dissolved salt can dehydrate the skin of aquatic animals, which can be fatal.

Carbonate and bicarbonate : Calcium carbonate is a dietary supplement used when the amount of calcium taken in the diet is not enough. Calcium is needed by the body for healthy bones, muscles, nervous system, and heart. Alkaline lake is, typically with a pH value between 9 and 12. They are characterized by high concentrations of carbonate salts (typically sodium carbonate and related salt complexes), giving rise to their alkalinity. In addition, many alkaline lakes also contain high concentrations of sodium chloride and other dissolved salts, making them saline or hypersaline lakes as well. The resulting hypersaline and highly alkaline lakes are considered some of the most extreme aquatic environments on the lake.

Phosphorus : Phosphorus is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes.

Nitrate : Basically, any excess nitrate in the water is a source of fertilizer for aquatic plants and algae. If there is an excess level of nitrates, plants and algae will grow excessively.

Oxygen : Dissolved oxygen levels in water below 5.0 mg/l put aquatic life under stress. Thus lower the concentration, the greater the stress in faunal density. Oxygen levels that remain below 1-2 mg/l for a few hours can result in large fish kills. Thus optimum dissolved oxygen is required in any lake to sustain good aquatic environment.

Carbon dioxide : Carbon dioxide is found in water as a dissolved gas. It can dissolve in water 200 times more easily than oxygen. Aquatic plants depend on carbon dioxide for life and growth, just as fish depend on oxygen. Plants use carbon dioxide during the process of photosynthesis.

2.9 Nutrient cycle in lakes

2.9.1 Phosphorus cycle

Phosphorus is an essential nutrient for plants and animals as well as it is considered as limiting nutrient for aquatic organisms. Phosphorus does enter the atmosphere in very small amounts when the dust is dissolved in rainwater and sea spray but remains mostly on land and in rock and soil minerals. Eighty percent of the mined phosphorus is used to make fertilizers. Phosphates from fertilizers, sewage and detergents can cause pollution in lakes and streams. Over-enrichment of phosphate in both fresh and inshore marine waters can lead to massive algal blooms. In fresh water, the death and decay of these blooms leads to eutrophication.

The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere and biosphere. As phosphorus and phosphorus-based compounds are usually solids at the typical ranges of temperature and pressure found on Earth, thus unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movement of phosphorus. This is to mention that the phosphorus cycle should be viewed from whole Earth system and then specifically focused on the cycle in terrestrial and aquatic systems (Fig-1).

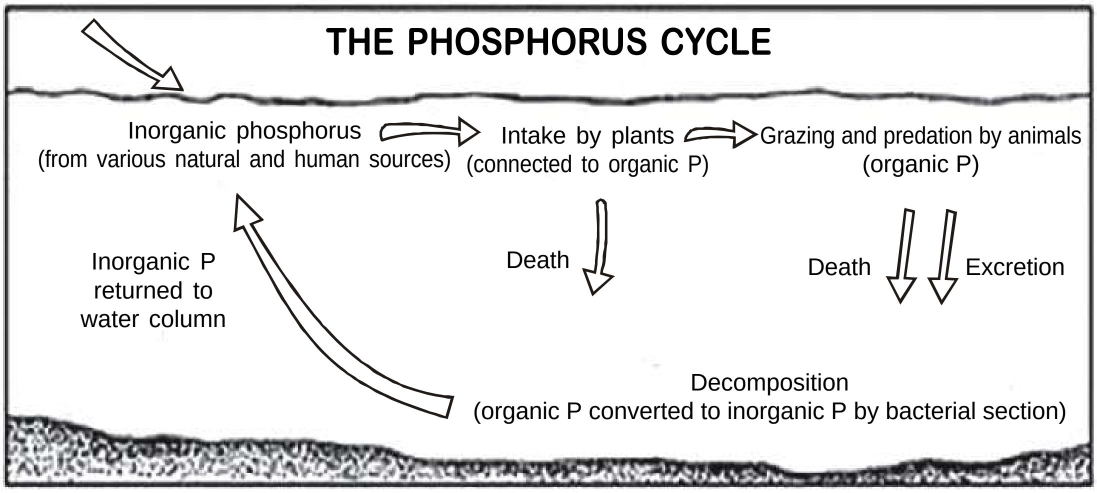


Fig-1 : The aquatic phosphorus cycle

Major pools of phosphorus in aquatic systems

There are four major pools of phosphorus in freshwater ecosystems: dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), particulate organic phosphorus (POP), and particulate inorganic phosphorus (PIP). Dissolved material is defined as substances that pass through a 0.45 µm filter. DIP consists mainly of orthophosphate (PO_4^{3-}) and polyphosphate, while DOP consists of DNA and phosphoproteins. Particulate matter are the substances that get caught on a 0.45 µm filter and do not pass through. POP consists of both living and dead organisms, while PIP mainly consists ofhydroxyapatite, $Ca_5(PO_4)_3OH$.

Phosphorus cycling

Phosphates move quickly through plants and animals; however, the processes that move them through the soil or ocean are very slow, making the phosphorus cycle overall one of the slowest biogeochemical cycles.

The global phosphorus cycle includes four major processes :

(i) tectonic uplift and exposure of phosphorus-bearing rocks such as apatite to surface weathering;

(ii) physical erosion, and chemical and biological weathering of phosphorus-bearing rocks to provide dissolved and particulate phosphorus to soils, lakes and rivers;

(iii) riverine and subsurface transportation of phosphorus to various lakes and run-off to the ocean;

(iv) sedimentation of particulate phosphorus (e.g., phosphorus associated with organic matter and oxide/carbonate minerals) and eventually burial in marine sediments (this process can also occur in lakes and rivers).

Soil phosphorus is usually transported to rivers and lakes and can then either be buried in lake sediments or transported to the ocean via river runoff. Atmospheric phosphorus deposition is another important marine phosphorus source to the ocean. In surface seawater, dissolved inorganic phosphorus, mainly orthophosphate (PO_4^{3-}), is assimilated by phytoplankton and transformed into organic phosphorus compounds. Phytoplankton cell lysis releases cellular dissolved inorganic and organic phosphorus to the surrounding environment. Some of the organic phosphorus compounds can be hydrolyzed by enzymes synthesized by bacteria and phytoplankton and subsequently assimilated. The vast majority of phosphorus is remineralized within the water column, and approximately 1% of associated phosphorus carried to the deep sea by the falling particles is removed from the ocean reservoir by burial in sediments. A series of diagenetic processes act to enrich sediment pore water phosphorus concentrations, resulting in an appreciable benthic return flux of phosphorus to overlying bottom waters. These processes include-

(i) microbial respiration of organic matter in sediments;

(ii) microbial reduction and dissolution of iron and manganese (oxyhydro) oxides with subsequent release of associated phosphorus, which connects the phosphorus cycle to the iron cycle;

(iii) abiotic reduction of iron (oxyhydro) oxides by hydrogen sulfide and liberation of iron-associated phosphorus.

(iv) phosphate associated with calcium carbonate; and

(v) transformation of iron oxide-bound phosphorus to vivianite play critical roles in phosphorus burial in marine sediments.

These processes are similar to phosphorus cycling in lakes and rivers (Fig-2).

Although orthophosphate (PO_4^{3-}), the dominant inorganic P species in nature, is oxidation state (P^{5+}), certain microorganisms can use phosphonate and phosphite (P^{3+} oxidation state) as a P source by oxidizing it to orthophosphate. Recently, rapid production and release of reduced phosphorus compounds has provided new clues about the role of reduced P as a missing link in oceanic phosphorus.

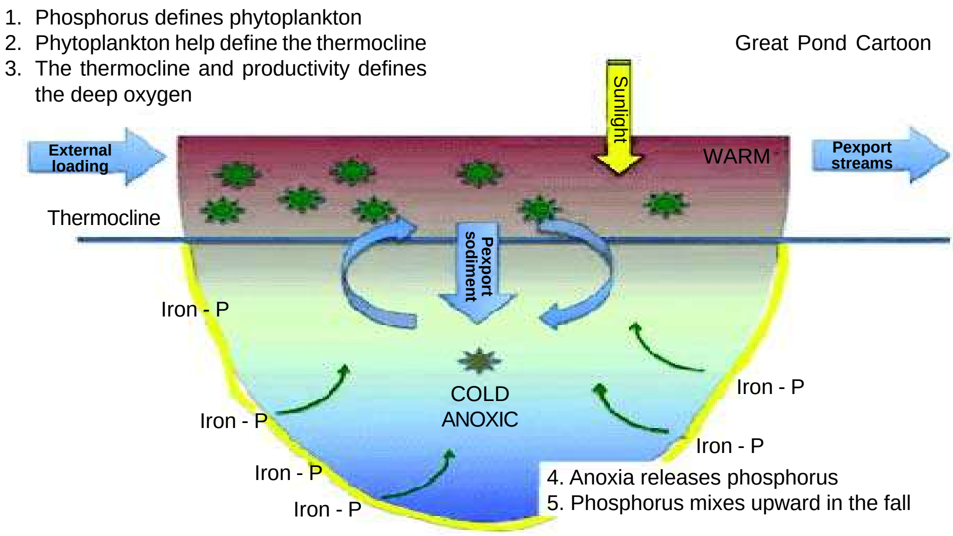


Fig-2 : Phosphorus cycle in a lake

2.9.2 Sulpher cycle

Sulpher is a versatile element, importantly linked to numerous fundamental biotic and abiotic geochemical reactions and cycling processes within the Earth's geosphere, biosphere, hydrosphere and atomosphere. The sulfur cycle is the collection of processes by which sulfer moves between rocks, waterways and living systems. Such biogeochemical cycles are important in geology because they affect many minerals. Biochemical cycles are also important for life because sulfur is an essential element, being a constituent of many proteins and cofactors, and sulfur compounds can be used as oxidants or reductants in microbial respiration. The global sulpher cycle involves the transformations of sulfur species through different oxidation states, which play an important role in both geological and biological processes.

Steps of the sulfur cycle are :

- Mineralization of organic sulfer into inorganic forms, such as hydrogen sulfide (H_2S), elemental sulfur, as well as sulfide minerals.
- Oxidation of hydrogen sulfide, sulfide, and elemental sulfur (S) to sulfate (SO_4^{2-}).
- Reduction of sulfate to sulfide.
- Incorporation of sulfide into organic compounds (including metal-containing derivatives).

The important factor controlling the rate of sulphate reduction in lakes is the concentration of sulphate and an enhanced input may stimulate reduction, substantially altering the cycling of elements such as carbon, nitrogen, phosphorus and iron in lakes. Information on the impact of enhanced sulphate concentration is, however, sparse and the modern phenomenon of a raised atmospheric concentration in acid rain and the discharge of wastewater with a high concentration underlines the importance of understanding sulphur cycling in lakes (Fig-3).

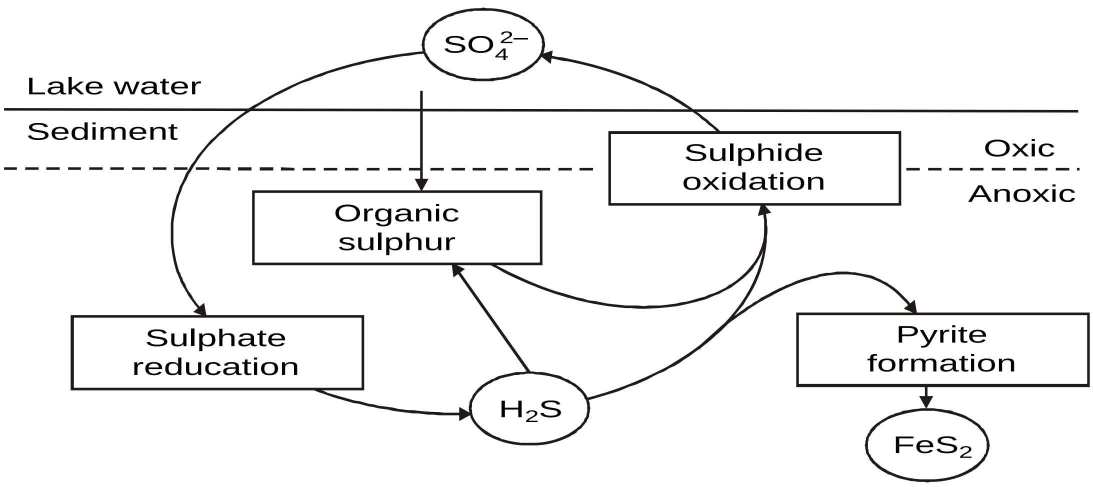


Fig-3 : Schematic presentation of the sulphur cycle in freshwater sediments (modified from Jørgensen, 1988).

Many lakes have changed from oligotrophy to meso- or eu-trophic conditions during the past decades because of nutrient loading from wastewater and fertilizers. The formation and precipitation of insoluble iron sulphide compounds reduces the binding of phosphate iron oxides and a release of phosphate from the sediments may enhance the eutrophic status of lakes. There is, however, a general lack of understanding of the interactions between sulphur cycling and eutrophication.

2.9.3 Nitrogen cycle

Introduction

Nitrogen is one of the primary nutrients critical for the survival of all living organisms. It is a necessary component of many biomolecules, including proteins, DNA and chlorophyll. Nitrogen Cycle is a biogeochemical process which transforms the inert nitrogen present in the atmosphere to a more usable form for living organisms. The nitrogen gas exists in both organic and inorganic forms. Organic nitrogen exists in living organisms, and they get passed through the food chain by the consumption of other living organisms. Inorganic forms of nitrogen are found in abundance in the atmosphere. This nitrogen is made available to plants by symbiotic bacteria which can convert the inert nitrogen into a usable form – such as nitrites and nitrates. Nitrogen undergoes various types of transformation to maintain a balance in the ecosystem. Furthermore, this process extends to various biomes, with the marine nitrogen cycle being one of the most complicated biogeochemical cycles.

Steps of nitrogen cycle

Process of Nitrogen Cycle consists of the following steps : (i) Nitrogen fixation; (ii) Ammonification (iii) Nitrification; (iv) Denitrification (v) Assimilation; These processes take place in several stages and are explained below:

(i) Nitrogen fixation

It is the initial step of the nitrogen cycle. Here, Atmospheric nitrogen (N_2) which is primarily available in an inert form, is converted into the usable form ammonia (NH_3). The entire process of Nitrogen fixation is completed by symbiotic bacteria which is known as *Diazotrophs*. *Azotobacter* and *Rhizobium* also have a major role in this process. These bacteria consist of a nitrogenase enzyme which has the capability to combine gaseous nitrogen with hydrogen to form ammonia.

Nitrogen fixation can occur either by the atmospheric fixation- which involves lightening or industrial fixation by manufacturing ammonia under high temperature and pressure condition. This can also be fixed through man-made processes, primarily industrial processes that create ammonia and nitrogen-rich fertilizers.

The reaction involved in the process of nitrogen fixation is as follows :

$$N_2 + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$$

(ii) Nitrification

In this process, the ammonia is converted into nitrate by the presence of bacteria in the soil. Nitrites are formed by the oxidation of Ammonia with the help of *Nitrosomonas* bacterium species. Later, the produced nitrites are converted into nitrates by *Nitrobacter*. This conversion is very important as ammonia gas is toxic for plants.

The reaction involved in the process of nitrification is as follows :

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

(iii) Assimilation

Primary producers – plants take in the nitrogen compounds from the soil with the help of their roots, which are available in the form of ammonia, nitrite ions, nitrate ions or ammonium ions and are used in the formation of the plant and animal proteins. This way, it enters the food web when the primary consumers eat the plants.

(iv) Ammonification

When plants or animals die, the nitrogen present in the organic matter is released back into the soil. The decomposers, namely, bacteria or fungi present in the soil, convert the organic matter back into ammonium. This process of decomposition produces ammonia, which is further used for other biological processes.

(v) Denitrification

Denitrification is the process in which the nitrogen compounds makes its way back into the atmosphere by converting nitrate (NO_3^-) into gaseous nitrogen (N). This process of the nitrogen cycle is the final stage and occurs in the absence of oxygen. Denitrification is carried out by the denitrifying bacterial species- *Clostridium* and *Pseudomonas*, which will process nitrate to gain oxygen and gives out free nitrogen gas as a byproduct.

The reaction involved in denitrification process is an follows :

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO + N_2O \longrightarrow N_2$$

$$2NO_3^- + 10e^- + 12H^+ \longrightarrow N_2 + 6H_2O$$

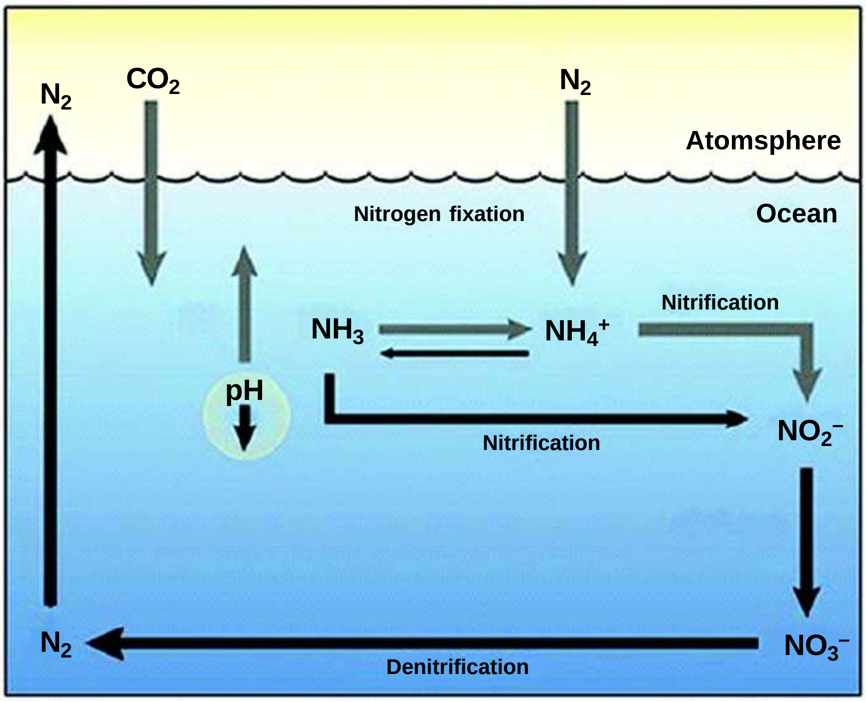


Fig-4 : Marine nitrogen cycle under future ocean acidification

Much of the nitrogen applied to agricultural and urban areas ultimately enters rivers and nearshore coastal system leading to anoxia (no oxygen) or hypoxia (low oxygen) altered biodiversity, changes in food web structure, and general habitat degradation. One common consequence of increased nitrogen is an increase in harmful algal blooms (Howalth, 2008). Additionally, increases in nitrogen in aquatic systems can lead to increased acidification in freshwater ecosystems.

Importance of Nitrogen Cycle

Importance of the nitrogen cycle is as follows :

1. Helps plants to synthesise chlorophyll from the nitrogen compounds.
2. Helps in converting inert nitrogen gas into a usable form for the plants through the biochemical process.
3. In the process of ammonification, the bacteria help in decomposing the animal and plant matter, which indirectly helps to clean up the environment.
4. Nitrates and nitrites are released into the soil, which helps in enriching the soil with necessary nutrients required for cultivation.

5. Nitrogen is an integral component of the cell and it forms many crucial compounds and important biomolecules.

2.10 Streams : Different stages of stream development

2.10.1 Introduction

When excess water from rain, snowmelt, or near surface groundwater accumulates on the ground surface and begins to run downhill, streams are created. Moving waters differ in the three major aspects from lakes and ponds :

(i) current is a controlling and limiting factor;

(ii) land water interchange is great because of small size and depth of moving water systems as compared with lakes;

(iii) oxygen is almost always in abundant supply except when there is pollution. Temperature extremes tend to be greater than in standing water. Besides these, the most distinctive features of moving water ecosystems are those related to their motion, i.e., the rate of flow and the stream velocity.

2.10.2 Stages of stream development

There are three stages of stream development : (i) young streams, (ii) mature streams, and (iii) old streams.

(i) Young stream : The characteristics of young stream are as follows-

- Flows very rapidly.
- Usually located on a steep valley that has steep sides.
- May have whitewater rapids and waterfalls.

(ii) Mature stream : The characteristics of mature stream are as follows-

- Flow less swiftly than a young stream.
- Located in a valley.
- Water in it’s shallow areas is slowed down by friction caused at the bottom of a river.
- Formation of meanders (due to increased in width, the stream begins to shift its course in a series of bends or turns called meanders).

(iii) Old stream : The characteristics of old stream are as follows-

- Flows slowly.
- Located on a broad flat floodplain that is carved.
- In can only carry smaller sized sediments like silt.
- Leads to a fan-shaped deposite extending out to sea called a delta.
- Dut to the larger size of meanders ox-bow lakes are often seen.

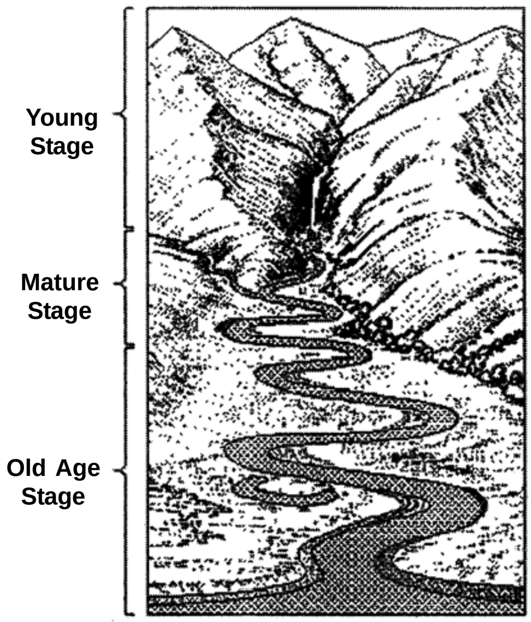


Fig-5 : Stages of stream development

2.11 Adaptation of hill stream fishes

2.11.1 Introduction

A number of fishes have migrated from sluggish waters of the lower streams to colonize in the torrential waters of the upper streams. These migrations were chiefly in search of food and the shelter from the predators. Hill stream fishes upon reaching the new habitat, adapted themselves through a number of structural modifications with the particular environment.

2.11.2 Example of few hill stream fishes

The important fishes of the hill streams belong to several genera of three families of order cypriniformes as listed below :

Sl. No.	Family	Scientific names of hill stream fishes
1.	Cyprinidae	*Barelius, Barbus* (Tor), *Garra, Labeo*
2.	Siluri	*Erethistes, Glyptothorax, Laguvia*
3.	Cobitidae	*Botia, Nemacheilus*

2.11.3 Environmental conditions of the hill stream

The following environmental conditions persist in the hill streams that influence the fishes to thrive in the particular habitat.

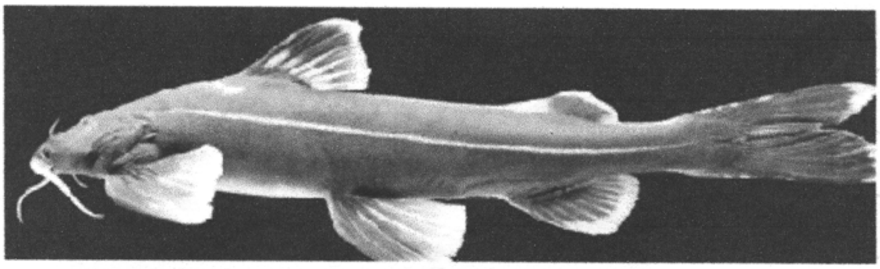
1. **Strength of water currents :** It appears to be the primary factor in the evolution of hill stream fishes. The water moves predominantly in one direction on the hills, causing both, the lesser stability of bottom materials as well as the erosion. Fishes living in hill streams have, therefore, to develop adhesive organs to avoid being swept away with the water currents.
2. **Light intensity :** The sun rays in hill streams penetrate deep into the water because it is shallow and very clear owing to absence of suspended particles. Fishes, therefore, have to adopt either to withstand the intense light or to shelter themselves under the rocks or stones. The small sized fishes can hide themselves below rocks and stones.
3. **Dissolved oxygen :** The water is well aerated with plenty of oxygen due to rapid rate of flow of water. Abundance of O_2 is, therefore, a favourable condition to fishes inhabiting the torrential streams.
4. **Temperature :** The temperature of hill streams fluctuates rapidly but remains more or less constant from surface to the bottom. The water is generally cooler but get heated by sun.
5. **Availability of food :** Good amount of food is available in the hill streams but is in the form of algae covering stones and rocks, as any other type of vegetation cannot grow due to rapid flow of water. Fishes, therefore, have to largely depend upon the algal filaments. In certain regions the microbes and the insect larva may also become available to the fishes.

2.11.4 Adaptive modification in hill stream fishes

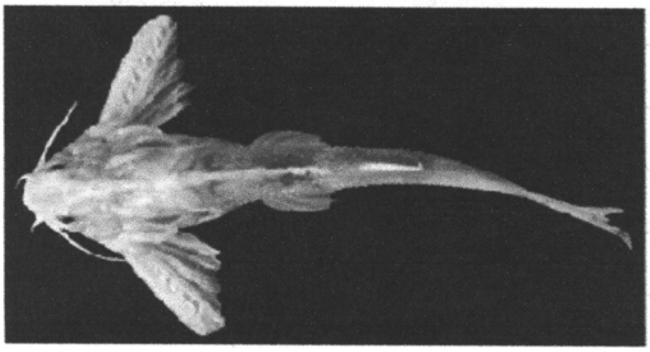
1. Shape :

Hill stream fishes usually have greatly flattened head and body in contrast to cylindrical bodies of fishes found in tanks and lakes. In highly specialized species of *Balitora*, *Glyptosternum*, *Glyptothorax* and *Pseudoechensis*, the body becomes leaf like.

The dorsal surface of hill stream fishes is mostly arched while the ventral surface flattened. Fishes living in the streams in which the water flow is not very fast have almost cylindrical bodies as *Crossocheilus latia*. The head of hill stream fishes is generally small and semi-circular.



(a)



(b)

Fig-6 : Body shape of hill stream of (a) *Glyptothorax* ; (b) *Erethistes*

2. Size :

Hill streams fishes are generally small in size, having short and thicker bodies and semicircular heads. Their small size permits them to hide under the rocks and stones during the intense sunlight and prevents them from being crushed between the rolling stones in flood.

3. Scales and bony armour :

The scales and bony armour in hill stream fishes are poorly developed. It is because that they remain free from the danger of predators. Absence of scales from the ventral side also makes the ventral surface smooth for attachment on the rocky bottom. In some species the scales are present on the dorsal and lateral surfaces of body, but become greatly reduced or absent on the ventral surface. Scales are very minute and embedded in the skin in *Schizothorax* and *Nemacheilus*.

4. Mouth :

The mouth of hill stream fishes is crescentic or semi-circular in shape. The jaws are strong. In some species like *Schizothorax*, the jaws are covered by a strong horny covering which helps the fish in scraping algal material from stones for feeding.

5. Lips :

The lips in most of the hill stream fishes are modified to form suckers of diverse types. They are used for scooping mud as well as for clinging on stones. In *Homaloptera*, the lips are modified so as to form a sucker with the help of mouth. In *Nemacheilus*, the lips are divided in the middle and are swollen, so that they form a ring-like sucker when pulled outwards. In *Glyptosternum* and *Glyptothorax*, the lips are reflected and spread around the mouth so as to form a broad sucker for attachment.

Fig-7 : Different types of lips, barbells and adhesive devices of hill stream fishes

6. Barbels :

Barbels in the hill stream fishes are specialized, greatly reduced being short and stumpy as in *Balitora*. In *Glyptothorax* and *Pseudoecheneis*, the barbels are short, but thick and fleshy at the base.

7. Eyes :

The eyes in the hill stream fishes are generally small in size and are pushed towards the upper surface of the head where they lie close to each other. The small size of eyes is regarded as a protective measure against the intense sunlight, while their dorsal shift is an obvious adaptation to let free the ventral surface for attachment. This is seen in most of the hill stream fishes like *Balitora, Glyptothorax, Pseudoecheneis* and *Glyptosternum*.

8. Fins :

The fins in the hill stream fishes are used as organs of locomotion as well as for attachment. To perform dual function various modifications in the structure of fins persist, which are as follows :

(a) Paired fins :

In some hill stream fishes both the pectoral and pelvic fins are set low on the body to provide greater friction against the rocks and stones (viz.; *Garra*). In *Astroblepus chotae*, paired fin forms a sucker, which together with a suctorial mouth is used alternately to enable the fish to climb over the vertical rocks of water fall.

In many hill stream fishes, the outer rays of the paired fins are modified for adhesion and the number of inner rays is, therefore, increased. The outer rays of the paired fins become thick and flat and serve for adhesion, while the inner rays are directed upwards against the sides of the body and are kept in motion. Thus, the inner rays may help in respiration also.

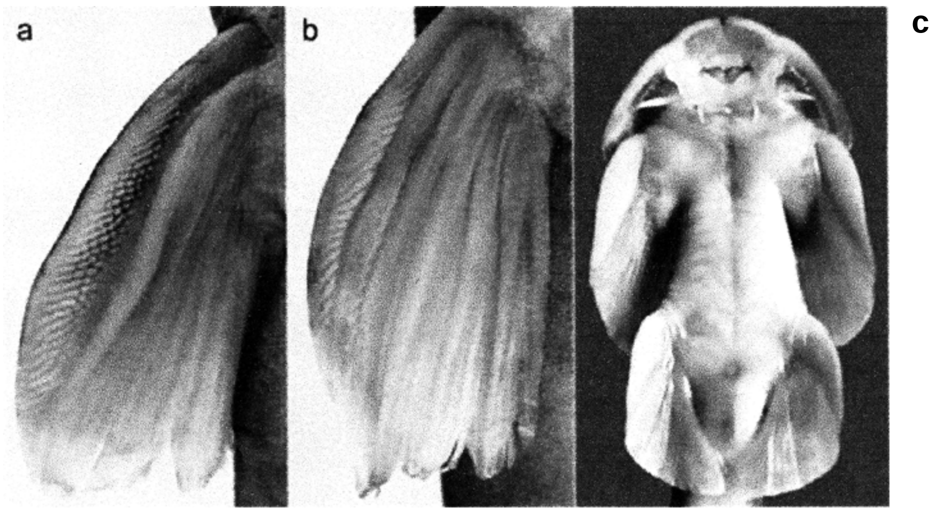


Fig-8 : Fin-rays of (a) & (b) *Glyptothorax ;* (c) *Oreoglanis*.

(b) Caudal fin and its peduncle :

Hill stream fishes usually possess a long, narrow, muscular, band shaped caudal peduncle as in *Glyptothorax striatus*, *Homaloptera* and *Balitora* etc. A long and narrow caudal peduncle appears to be an adaptation for life at high altitudes and rapid flowing water.

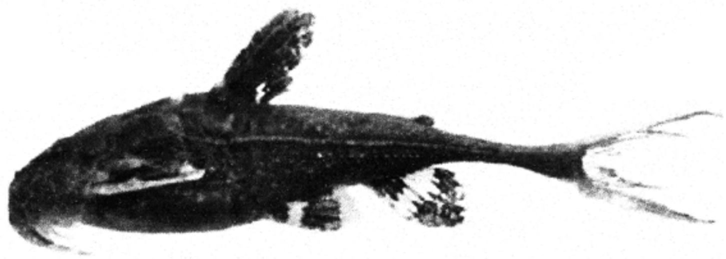


Fig-9 : Different shapes and sizes of caudal fin and caudal penduncle

9. Pectoral and pelvic girdles :

The girdles are modified in some species of the hill stream fishes, particularly in those species which are used their fins as organs of adhesion. In *Glyptothorax* and *Pseudoecheneis* various bones of the pectoral girdle are fused to provide strength. Keel-like ridges are present on the ventral surface of the inter-clavicular bone, to provide surface for attachment to their muscles.

The pelvic fins possess a special muscle besides the adductor and abductor muscles. This special muscle keeps the fin closely pressed against the rocks in resting position of the fish.

10. Breathing apparatus :

The ventral surface of gill is used for adhesion to rocks and stones, the gill slits lie on the sides and the gill chamber specialized for retaining water for a longer time. In some species of *Garra*, the gill openings are little wider, but still separated from each other with a considerable distance.

The restriction of the gill openings to the sides may effect respiration of fishes. When the fish is feeding algal slime, or is attached to rocks and stones, respiration may become difficult. However, the fishes may overcome these problems due to the following reasons-

(a) Water in the hills is well oxygenated.

(b) As the gill openings are small, the fish is able to retain water in the branchial chamber for a longer time.

(c) The inner rays of the pectoral fins are kept in constant motion and help in respiration by forcing the water in and out of the gill openings. They themselves serve for oxygenation, being supplied by numerous capillaries.

11. Air bladder :

The air bladder used chiefly as a hydrostatic organ in most fishes is much reduced or degenerate in hill stream fishes, because the buoyancy would be a disadvantage in swift currents. The bladder, if present is enclosed in a thin bony capsule.

12. Adhesive devices :

One of the major problem of hill stream fishes is to avoid being swept away in the rapid currents of mountain streams. For this, the skin is variously modified to form organs of adhesion. The *Asiatic silurids* (cat fishes), *Glyptosternum* and *Pseudoecheneis* bear a series of ridges on the ventral surface of the body. These ridges act as a frictional device in preventing the fishes from slipping in rapid water current.

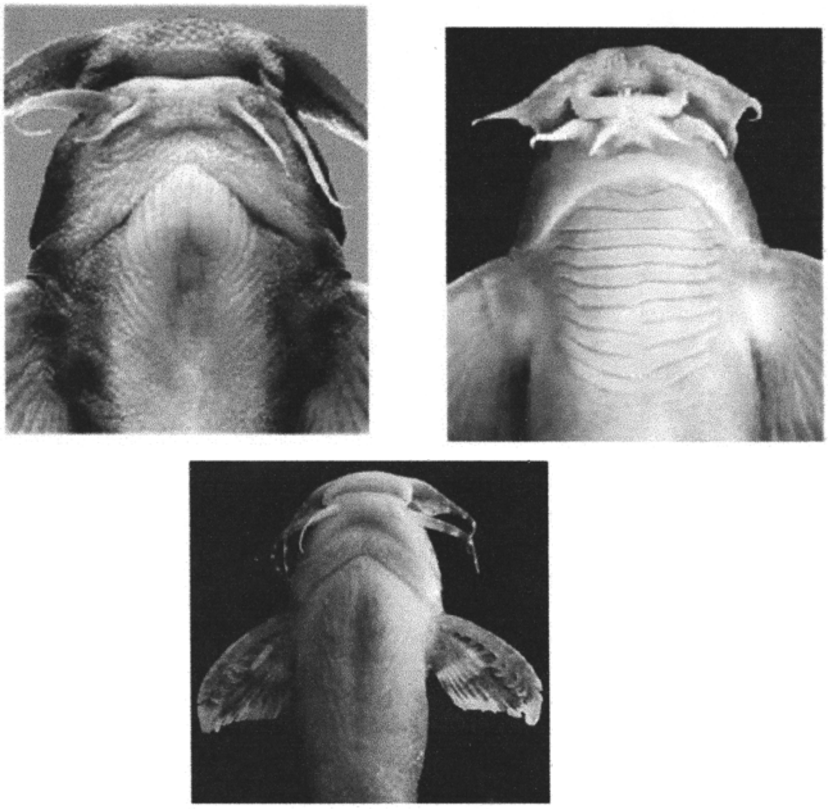


Fig-10 : Adhesive devices of (a) *Glyptothorax ;* (b) *Pseudecheneis ;* (c) *Pseudolaguvia*

In *Glyptothorax*, a well-developed U-shaped or V-shaped adhesive apparatus formed of folds of the skin is present between the bases of the pectoral fins. In *Garra*, the adhesive organ is in the form of a disc behind the mouth.

2.12 Summary

- Lake originate as a product of geological processes and terminate as a result of evaporation.
- Lake organisms includes different animals, floating animals and plants, benthos etc.
- The phosphorus cycle is a biogeochemical cycle that describes the movement of phosphorus through the lithosphere.
- Sulpher cycle play an important role in both geological and biological processes.
- Nitrogen cycle starts with the fixation of environmental nitrogen and ends with denitrification processes via several consequitive steps.
- Hill stream fishes adapted by structural modifications of different organs.

2.13 Questions

(i) Define lake. Give examples of freshwater, brackishwater and saline water lake.

(ii) Write in your own words about the origin of lake.

(iii) Write few examples of lake organisms.

(iv) State the major problems of lake.

(v) What is ox-bow lake?

(vi) Write brief note on nitrogen cycle of lake.

(vii) What do you mean by meanders?

(viii) Write the adaptive modifications of hill stream fishes.

(ix) What are different stages of stream development?

(x) What are the major pool of phosphorus in aquatic system?

2.14 Suggested Readings

1. Wetzel, RG (2001). Limnology : Lake and river ecosystems. San Diego, CA : Academic Press.
2. Voet, D and Voet, JG (2003). Biochemistry. pp. 607–608.
3. Oelkers, EH; Valsami-Jones, E and Roncal-Herrero, T. (2008). “Phosphate mineral reactivity : From global cycles to sustainable development”. Mineralogical Magazine. 72 (1): 337–340.
4. Buendía, C; Kleidon, A and Porporato, A (2010). The role of tectonic uplift, climate, and vegetation in the long term terrestrial phosphorus cycle. Biogeosciences. 7 (6) : 2025–2038.
5. Adediran, Gbotemi A; Tuyishime, JR et al (2020). Phosphorus in 2D: spatially resolved P speciation in two Swedish forest soils as influenced by apatite weathering and podzolization. Geoderma. 376 : 114-550.
6. Shen, J; Yuan, L et al (2011). Phosphorus dynamics : From soil to plant. Plant Physiology. 156 (3): 997–1005.
7. Figueroa, IA and Coates, JD (2017). Microbial phosphite oxidation and its potential role in the global phosphorus and carbon cycles. Advances in Applied Microbiology. 98 : 93–117.
8. Capone, DG and Kiene, RP (1988). Comparison of microbial dynamics in marine and freshwater sediments : Contrasts in anaerobic carbon catabolism. Limnology and Oceanography, 33: 725– 749.
9. Cook, RB and Kelly, CA (1992). Sulphur cycling and fluxes in temperate dimictic lakes. In: Sulphur Cycling on the Continents. 1992 Scope (Eds R.W. Howarth, J.W.B. Stewart & M.V. Ivanov), pp. 145–188. John Wiley & Sons Ltd, Washington.
10. Kleeberg, A (1997). Interactions between bentic phosphorus release and sulfur cycling in Lake Scharmützelsee (Germany). Water, Air and Soil Pollution, 99: 391– 399.
11. Caraco, NF; Cole, JJ and Likens, GE (1993). Sulfate control of phosphorus availability in lakes. Hydrobiologia, 253: 275– 280.

12. Ecology and Environment (2002-03) by P. D. Sharma, Pub : Rastogi publication, Meerut-250 002.
13. Fish and Fisheries (1991) by V. G. Jhingran, Pub : Hindustan Publishing Corporation (India), Delhi.
14. Study Material (Post Graduate Zoology), Paper-2A, Netaji Subhas Open University (2006), Pub : The Registrar, NSOU.
15. Study Material (Post Graduate Zoology), Paper-3A, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.
16. Study Material (Post Graduate Zoology), Paper-8B, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.
17. Biology of Animals (Volume-II) by Ganguly B, Sinha A and Adhikari S (1987). Pub : New Central Book Agency.
18. Environmental Biology (Principles of Ecology) by Verma PS and Agarwal VK (1993). Pub : S. Chand & Company Ltd., New Delhi-110055.

Unit - 3 ❑ Marine biology

Structure

3.0 Objectives

By studying this unit, students will be able to understand about the following—

- Salinity and density of marine environment.
- Continental shelf and its characteristic.
- Adaptation of dee sea organisms.
- Coral reefs, its types and importance.
- Sea weeds and its uses.

3.1 Introduction

The marine environment of seas and oceans is vast, occupying 70 percent of the earth's surface. In comparison to the total water bodies in the Earth, the volume of surface area of marine environment lighted by the sun is small. All the seas are interconnected by currents, dominated by waves, influenced by tides and characterized by saline water. Not only the seashore and banks which are the homes of many organisms but the open ocean, many hundreds of kilometers away from land, supports plant and animal communities of great diversity and complexity. In the marine environment, the most important physical factors which influence marine life are light, temperature, pressure, density, salinity, tides and currents. In this section the discussion will be emphasized on salinity and density of sea water.

3.2 Salinity

The marine animal life has specific osmoregulatory adaptation for high saline sea waters. The absence of many animal species in marine environment has been related to their inability to tolerate the high salt contents of sea water. Salinity is the saltiness or amount of salt dissolved in a body of water, called saline water. This is an important factor in determining many aspects of the chemistry of natural waters and of biological processes within it. Salinity along with temperature and pressure governs different physical characteristics like density and heat capacity of the water.

Salinity can be used as a conservative (up changing) tracer for determining the origin and mixing of water types. Zones where salinity decreases with depth are typically found occur at low latitudes and mid latitudes, between the mixed surface layer and the deep ocean are known as thermoclines.

On average, seawater in the world's oceans has a salinity of about 3.5% (35 g/l, 599 mM). This means that every kilogram (roughly one litre by volume) of seawater has approximately 35 grams of dissolved salts (predominantly sodium (Na^+) and chloride (Cl^-) ions). Seawater is denser than both fresh water and pure water (density 1.0 kg/l at 4 °C (39 °F)), because the dissolved salts increase the mass by a larger proportion than the volume. The freezing point of seawater decreases as salt concentration increases. Seawater pH is typically limited to a range between 7.5 and 8.4.

3.3 Density

The density of a material is given in units of mass per unit volume and expressed in kilograms per cubic metre in the SI system of units. In oceanography, the density of seawater has been expressed in grams per cubic centimetre. The density of seawater is a function of temperature, salinity, and pressure.

Except at high altitudes, the ocean is divided into three horizontal zones based on density :

1. **Mixed layer :** Stirring of surface water by wind produces a well mixed layer of uniforn or nearly uniform density. Thus, the ocean surface is called the mixed layer.
2. **Polycline :** Pycnocline is situated between the mixed layer and the deep

layer. Here water density increases rapidly with depth because of changes in temperature and/or salinity.

3. **Deep layer :** Below the pycnocline, there is a dark, cold layer called as deep layer which accounts for most of the oceans mass. With the deep layer, density increases gradually with depth and water moves slowly.

The density of surface seawater ranges from about 1020 to 1029 kg/m^3, depending on the temperature and salinity. At a temperature of 25 °C, salinity of 35 g/kg and 1 atm pressure, the density of seawater is 1023.6 kg/m^3. Deep in the ocean, under high pressure, seawater can reach a density of 1050 kg/m^3 or higher.

There is a relationship between the density and the depth of the water. Values associated with the change in seawater density with depth are listed in the table.

Table : Density changes with depth (seawater 35 ppt and 0° C)

Depth (m)	Pressure (decibars)	Density (g/cm^3)
0	0	1.02813
1,000	1,000	1.03285
2,000	2,000	1.03747
4,000	4,000	1.04640
6,000	6,000	1.05495
8,000	8,000	1.06315
10,000	10,000	1.07104

3.4 Continental Self

3.4.1 Introduction

A continental shelf is a portion of a continent that is submerged under an area of relatively shallow water known as a shelf sea. Under the United Nations Convention on the law of the sea, the name continental shelf was given a legal definition as the stretch of the seabed adjacent to the shores of a particular country to which it belongs. Though the continental shelf is treated as a physiographic province of the ocean, it is not part of the deep ocean basin proper, but the flooded margins of the continent.

3.4.2 Definition

In 1958 continental shelf convention used the term "continental shelf" as referring "to the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 meters or beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas" (Young, 1958).

The legal definition of a continental shelf differs significantly from the geological definition. UNCLOS states that the shelf extends to the limit of the continental margin, but no less than 200 nmi (370 km; 230 mi) and no more than 350 nmi (650 km; 400 mi) from the baseline of the sea.

3.4.3 Topography of continental shelf

The continental shelf usually ends at a point of increasing slope called the shelf break. The sea floor below the break is the continental slope. Below the slope is the continental rise, which finally merges into the deep ocean floor, the abyssal plain. The continental shelf and the slope are part of the continental margin. The shelf area is commonly subdivided into the inner continental shelf, mid continental shelf, and outer continental shelf, each with their specific geomorphology and marine biology. The following figure will give the idea about continental shelf of ocean (Fig-1). The continental shelves are covered by terrigenous sediments; that is, those derived from erosion of the continents. However, little of the sediment is from current rivers.

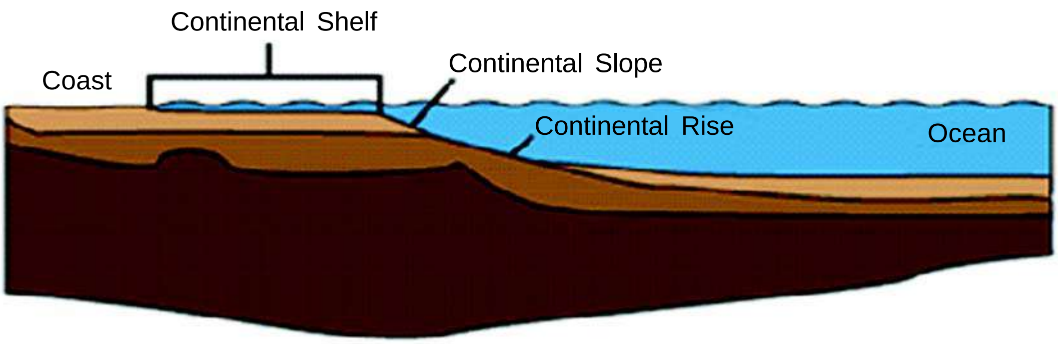


Fig-1 : Continental shelf of ocean

3.4.4 Continental shelf areas

Shelf seas refer to the ocean waters on the continental shelf. Their motion is controlled by the combined influences of the tides, wind-forcing and brackish water formed from river inflows (regions of freshwater influence). These regions can often be biologically highly productive due to mixing caused by the shallower waters and the enhanced current speeds. Despite covering only about 8% of the Earth's ocean surface area, shelf seas support 15-20% of global primary productivity. The following table will give us the idea about Continental shelf widths of different oceans.

Ocean	Active Margin Mean (km)	Active Margin Maximum (km)	Passive Margin Mean (km)	Passive Margin Maximum (km)	Total Margin Mean (km)	Total Margin Maximum (km)
Arctic Ocean	0	0	104.1 ± 1.7	389	104.1 ± 1.7	389
Indian Ocean	19 ± 0.61	175	47.6 ± 0.8	238	37 ± 0.58	238
Mediterr-anean and Black Seas	11 ± 0.29	79	38.7 ± 1.5	166	17 ± 0.44	166
North Atlantic Ocean	28 ± 1.08	259	115.7 ± 1.6	434	85 ± 1.14	434
North Pacific Ocean	39 ± 0.71	412	34.9 ± 1.2	114	39 ± 0.68	412
South Atlantic Ocean	24 ± 2.6	55	123.0 ± 2.5	453	104 ± 2.4	453
South Pacific Ocean	214 ± 2.86	357	96.1 ± 2.0	778	110 ± 1.92	778
All Oceans	31 ± 0.4	412	88.2 ± 0.7	778	57 ± 0.41	778

3.4.5 Biota of continental shelf

Continental shelves teem with life because of the sunlight available in shallow waters, in contrast to the biotic desert of the oceans' abyssal plain. The pelagic (water column) environment of the continental shelf constitutes the neritic, and the benthic (sea floor) province of the shelf is the sublittoral zone. The shelves makes up less than ten percent of the ocean, and a rough estimate suggest that only about 30% of the continental shelf sea floor receives enough sunlight to allow benthic photosynthesis. Though the shelves are usually fertile, if anoxic conditions prevail during sedimentation, the deposits may over geologic time become sources for fossil fuels.

Lobster, Dungeness, Tuna, cod, Halibut, Sole and Mackerel are found in the continental shelf. Permanent rock fixtuers are home to anemones, sponges, clams, oysters, scallops, mussels and coral. Larger animals such as whales and sea turfles can be seen in continental shelf areas as they follow migration routes.

3.5 Adaptation of deep sea organisms

3.5.1 Introduction

Adaptation is a physiological process by which an animal adjust himself to exist in a particular environment. Structural and functional modification of living organisms occur as the environment undergoes changes. Temporary changes occur to counteract the environmental changes and it reverts back to the previous form when the environmental changes are over. This type of change is called acclimatization.

3.5.2 Physical environment of deep sea

The physical environment of deep sea has special characteristics. To cope with this environment, the animals living there undergo suitable adaptation. Five remarkable characteristics prevail in deep sea, which are-

(i) Absence of sunlight : Beyond 200 fathoms there is no sunlight.

(ii) Quiescence : Because of depth the movement of water is almost absent.

(iii) Cold temperature : In the deep sea the temperature is nearing the freezing point and the temperature remains constant.

(iv) Pressure : The pressure is high as it increases with depth.

(v) Lack of green vegetation : Total absence of light is the reason for total absence of green vegetation in the deep sea environment.

3.5.3 Adaptive changes of deep sea animals

For survival in the deep sea environment, the animals have to develop adaptive changes to cope with adverse physical condition present there. The general characteristics of deep sea animals are as follows-

(i) The deep sea organisms are weak and delicate.

(ii) The body is generally simplified.

(iii) They are either totally blind or they process powerful telescopic eyes to catch maximum amount of light.

(iv) They develop long feelers to act as tactile organs.

(v) Almost all the deep sea animals are luminescent.

(vi) Most of the deep sea fishes live on the exudes of decaying matters and so animals lose the masticatory power. There are other animals which possess powerful jaws.

(vii) Most of the animals develop wonderful devices for carrying the youngs. Other produces large number of youngs to overcome the hostile environment.

(viii) Small size is an important characteristics of deep sea living.

3.5.4 Structural modifications in deep sea animals

Almost all the phyla have representatives who lead deep sea life. The modification of the invertebrates is diverse as compare to the vertebrates. The structural modification in deep sea forms are due to peculiar physical condition of deep sea environment. Many of the crustaceans in the deep sea have the reddish colouration. They have olfactory hairs and extremely long antennae, which are used for touch. Squids have virtually no olfactory organs and therefore need well-developed eyes at all depths. Modification of the vertebrates of the deep sea have been discussed as follows-

Amongst the elasmobranch fishes, the true sharks do not exhibit deep sea characteristics excepting the luminous sharks. The silver shark, however, possess deep sea characteristics in having huge eyes, long alternated body and tail.

Amongst the teleosts, the typical deep sea form is *Cetomimus*. It has a long mouth, small teeth, very small eyes and scaleless body. However, in *Ipnops*, there are no eyes and only too large luminous organ are found on the head. Scaleless body and well developed luminescent organs are the characteristics features in Stomiatidae. In *Gastrostomus*, the body is long, slender with rows of luminous organs on the lateral side of the body and the mouth is bounded by very large jaws. The *Gadiforms* (cod like forms) have reduced mouth and dentition; the eyes are extremely large, the trunk is reduced and has a filamentous tapering tail.

The *Anglers* show typical deep sea characteristics. The paired fins are adapted for crawling on the bottom of the sea and the anterior fin rays of the dorsal fin function as a lure. In *Linophryne,* the fin rays are provided with luminous organs to compensate for the loss of eyes. In another deep sea fish, *Protostomias*, specialized light producing organs are present in roes on the lateral side of the body.

Another important feature of deep sea fishes is flatness of the body to adjust with high pressure. The body in these fishes becomes flattened and the mouth is shifted to the lateral side of the body.

3.6 Coral reef

3.6.1 Introduction

The phylum cnidaria is definitely advanced in having tissue grade of structural organization. The variety of forms which are included under this phylum are distributed throughout the world. The coral islands and the coral reefs are the secretary products of some skeleton forming cnidarians, especially the stony corals belonging to the order Madreporadia. They are composed of hard skeleton of calcium carbonate. Starting with a very simple pattern, cnadirians built up huge coral reefs or islands of various shapes and sizes.

3.6.2 Defination of coral reef

Hubbard (1997) described coral reefs as wave-resistant piles of limestone and calcarious sediments built by a thin veneer of living organisms. A coral reef is an underwater ecosystem characterized by reef-building corals. Reefs are formed of colonies of coral polyps held together by calcium carbonate. Most coral reefs are built from stony corals, whose polyps cluster in groups. Corals in course of time form coral reefs and coral islands. Formation of coral reefs needs particular environmental conditions. In general coral reefs cannot stand the tempreratur below 18° C and they show flourishing growth above 22° C. Usually the coral reefs are restricted in their vertical distribution and they donot form reef below 50 meters from the sea level.

3.6.3 Types of coral reefs

Coral reefs are usually divided into three primary types : (i) Fringing reefs; (ii) Barrier reefs; (iii) Platform reef; (iv) Atolls (Fig-2).

(i) **Fringing reefs :** A fringing reef, also called a shore reef, is directly attached to a shore, or borders with an intervening narrow, shallow channel or lagoon. Fringing reefs are initially formed on the shore at the low water level and expand seawards as they grow in size. The fringing reef is extended from the shore up to 400 metres and takes the contour of the shore. It has a reef edge, called the front where the most active coral growth occurs. Between the front and the shore there lies a more or less flat surface which is known as the reef flat. The fringing reef is largely composed of coral, sand, mud, dead coral and other debris. It is partly composed of coral colonies and other animals. Fringing reef is cut by a narrow water channel (lagoon) and the depth of the water channel is 97 to 55 metres. The fringing reefs of the Red Sea are "some of the best developed in the world" and occur along all its shores except off sandy bays

(ii) **Barrier reefs :** Barrier reefs are separated from a mainland or island shore by a deep channel or lagoon. Their lagoons can be several kilometres wide and 30 to 70 metres deep. Above all, the offshore outer reef edge formed in open water rather than next to a shoreline. It resembles the fringing coral reefs, but it follows the contour of the shore less regularly. The reef flat is separated from the shore by a lagoon of 90 to 110 metres deep. Ex- the Great Barrier Reef of the northern coast of Australia.

(iii) **Platform reef :** Platform reefs, variously called bank or table reefs, can form on the continental shelf, as well as in the open ocean. Platform reefs are found in the southern Great Barrier Reef, the Swain and Capricorn Group on the continental shelf, about 100–200 km from the coast. Some platform reefs of the northern Mascarenes are several thousand kilometres from the mainland. Unlike fringing and barrier reefs which extend only seaward, platform reefs grow in all directions. They are variable in size, ranging from a few hundred metres to many kilometres across. Their usual shape is oval to elongated. Parts of these reefs can reach the surface and form sandbanks and small islands around which may form fringing reefs. A lagoon may form in the middle of a platform reef.

(iv) **Atoll :** The atoll is more or less circular or horse shoe shaped reef and encloses a few kilometers to 64-80 kilometres across. The depth of the lagoon is 37-55 meters. The lagoon usually contains inner islands and reef.

Atolls or atoll reefs are a more or less circular or continuous barrier reef that extends all the way around a lagoon without a central island. Atolls are found in the Indian Ocean, for example, in the Maldives, the Chagos Islands, the Seychelles and around Cocos Island. The entire Maldives are reported consists of 26 atolls.

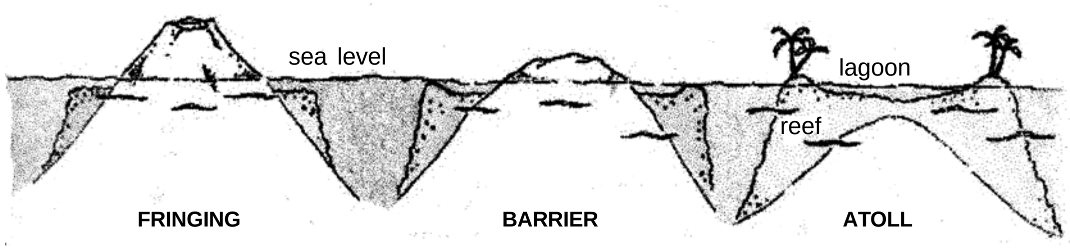


Fig-2 : Different type of coral reefs

3.6.4 Importance of coral reef ecosystem

(i) Economic : Millions of people around the globe rely on coral reefs for part of their livilihood or for part of their protein intake (Salvat, 1992). Coral reefs provide approximately $ 30 billion dollar's worth of goods and serivces to human being each year (Kittinger et. al, 2012).Coral reefs also provide other employment opportituies for people working in hotels, recreational fishing operations and other sector of tourism industry (Spalding et al., 2017).

(ii) Ecology : Coral reefs serve as important spawning and nursery sites and create habitats for a variety of different coral reef organisms. In addition, coral reefs serve as corridors through which organisms can migrate between different ecosystems such as mangrove logoons and sea grass beds. Coral reefs protect coastlines from the energy produced by currents, wave action and strom events.

3.7 Seaweed

3.7.1 Introduction

Seaweed, or macroalgae, refers to several species of macroscopic, multicellular, marine algae. The term includes some types of *Rhodophyta* (red), *Phaeophyta* (brown) and *Chlorophyta* (green) macroalgae. Seaweed species such as kelps provide essential nursery habitat for fisheries and other marine species and thus protect food sources; other species, such as planktonic algae, play a vital role in capturing carbon, producing up to 90% of Earth's oxygen. Understanding these roles offers principles for conservation and sustainable use.

3.7.2 Ecology

Two environmental requirements dominate seaweed ecology. These are seawater (or at least brackish water) and light sufficient to support photosynthesis. Another common requirement is an attachment point, although genera such as *Sargassum* and *Gracilaria* have species that float freely.

Seaweed most commonly inhabits the littoral zone (nearshore waters) and, within that zone, on rocky shores more than on sand or shingle. Seaweed occupies various ecological niches. At the surface, they are only wetted by the tops of sea spray, while some species may attach to a substrate several meters deep. In some areas, littoral seaweed colonies can extend miles out to sea. The deepest living seaweed are some species of red algae. Others have adapted to live in tidal rock pools. In this habitat, seaweed must withstand rapidly changing temperature and salinity and occasional drying.

3.7.3 Examples of sea weeds

The following table lists a very few example genera of seaweed.

Genus	Photographs of sea weeds	Colour	Remarks
Caulerpa		Green	Submerged
Fucus		Brown	In intertidal zones on rocky shores

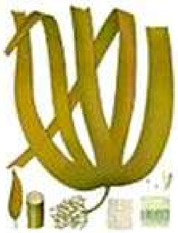
Genus	Photographs of sea weeds	Colour	Remarks
Gracilaria		Red	Cultivated for food
Laminaria		Brown	Also known as kelp, 8–30 m under water, cultivated for food
Macrocystis		Brown	Giant kelp, forming floating canopies
Porphyra		Red	Intertidal zones in temperate climate. Cultivated for food

Fig-3

3.7.4 Uses of sea weeds

Food :

Seaweed is consumed across the world, particularly in East Asia (e.g., Japan, China, Korea, Taiwan) and south east Asia. Seaweed is mixed with milk, nutmeg, cinnamon and vanilla to make *"dulce"* ("sweet"). Alginate, agar and carrageenan are gelatinous seaweed products collectively known as hydrocolloids or phycocolloids. Hydrocolloids are food additives. The food industry exploits their gelling, waterretention, emulsifying and other physical properties. Agar is used in foods such as confectionery, meat and poultry products, desserts and beverages and moulded foods. Carrageenan is used in salad dressings and sauces, dietetic foods, and as a preservative in meat and fish, dairy items and baked goods.

Medicine and herbs :

Alginates are used in wound dressings, and dental moulds. In microbiology, agar is used as a culture medium. Carrageenans, alginates and agaroses, with other macroalgal polysaccharides, have biomedicine applications. *Delisea pulchra* may interfere with bacterial colonization. Sulfated saccharides from red and green algae inhibit some DNA and RNA-enveloped viruses.

Seaweed extract is used in some diet pills. Other seaweed pills exploit the same effect as gastric banding, expanding in the stomach to make the stomach feel more full.

Bioremediation :

Seaweed (macroalgae), as opposed to phytoplankton (microalgae), is used almost universally for filtration purposes because of the need to be able to easily remove (harvest) the algae from the water, which then removes the nutrients. Marine species of *Cladophora*, *Ulva* (sea lettuce) and *Chaetomorpha* are preferred for filtration. Freshwater filtration applications commonly involve species such as *Spirogyra*.

Climate change :

"Ocean afforestation" is a proposal for farming seaweed for carbon removal. After harvesting the seaweed decomposes into biogas, (60% methane and 40% carbon dioxide) in an anaerobic digester. The methane can be used as a biofuel, while the carbon dioxide can be stored to keep it from the atmosphere. Seaweed grows quickly and takes no space on land. Afforesting (9%) of the ocean could sequester 53 billion tons of carbon dioxide annually (annual emissions are about 40 billion tons).

Other uses :

(i) Other seaweed may be used as fertilizer, compost for landscaping, or to combat beach erosion through burial in beach dunes.

(ii) Seaweed is under consideration as a potential source of bioethanol.

(iii) Seaweed is an ingredient in toothpaste, cosmetics and paints. Seaweed is used for the production of bio yarn (a textile).

(iv) Seaweeds are used as animal feeds. They have long been grazed by sheep, horses and cattle in Northern Europe. They are valued for fish production. Adding seaweed to livestock feed can substantially reduce methane emissions from cattle.

3.8 Summary

- The continental shelf is a portion of a continent that is submarged under an area of relatively shallow water known as shelf sea.
- To cope with the physical environment of deep sea the deep sea animals undergoes adabtire modification.
- Coral reefs are wave resistant piles of limestone and calcarious sediments built by a thin veneer of living organisms.
- Sea weeds refers to several species of microscopic, multicellular marine algae.

3.9 Questions

(i) What is the role of salinity and density in marine ecosystem?

(ii) What is meant by marine ecosystem ?

(iii) What is continental shelf ?

(iv) Write short note on different biota in continental shelf.

(v) What are the adaptive changes found in deep sea animals ?

(vi) Write a short note on structural modifications in deep sea animals.

(vi) What is Coral reef ?

(vii) Write different uses in sea weeds.

(viii) Write few examples of sea weeds.

3.10 Suggested Readings

1. Chester, J and Roy, T (2012). Marine Geochemistry. Blackwell Publishing. ISBN: 978-1-118-34907-6
2. Nayar, KG; Sharqawy, MH; Banchik, LD; Lienhard, V; John, H (2016). Thermophysical properties of seawater : A review and new correlations that include pressure dependence. Desalination. 390 : 1–24.
3. Harris, PT; Macmillan-Lawler, M; Rupp, J; Baker, EK (2014). Geomorphology of the oceans. Marine Geology. 352 : 4–24.
4. de Haas, H; van Weering, TC and de Stigter, H (2002). Organic carbon in shelf seas: sinks or sources, processes and products. Continental Shelf Research, 22(5) : 691-717.
5. Round, FE (1962). The Biology of the Algae. Edward Arnold Ltd.
6. Francesca, C and Claudia, S (2008). Microorganisms attack synthetic polymers in items representing our cultural heritage. Applied and Environmental Microbiology. 74 (3) : 564–569.
7. Kazlowski, B; Chiu, YH; Kazlowska, K; Pan, CL and Wu, CJ (2012). "Prevention of Japanese encephalitis virus infections by low-degree-polymerisation sulfated saccharides from Gracilariasp. and Monostroma nitidum". Food Chem. 133 (3) : 866–874.
8. Rodriguez, I (2012). Seaweed invading South Florida beaches in large numbers. South Florida Sun-Sentinel. Retrieved 2020-04-11.
9. Seaweed Power: Ireland Taps New Energy Source. alotofyada.blogspot.co.uk. 2008-06-24. Retrieved 9 April 2018.
10. https://en.wikipedia.org/wiki/Seawater
11. https://en.wikipedia.org/wiki/Continental_shelf
11. https://en.wikipedia.org/wiki/Seaweed
12. Ecology and Environment (2002-03) by P. D. Sharma, Pub: Rastogi publication, Meerut-250 002.

13. Fish and Fisheries (1991) by V. G. Jhingran, Pub : Hindustan Publishing Corporation (India), Delhi.
14. Study Material (Post Graduate Zoology), Paper-2A, Netaji Subhas Open University (2006), Pub : The Registrar, NSOU.
15. Study Material (Post Graduate Zoology), Paper-3A, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.
16. Study Material (Post Graduate Zoology), Paper-8B, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.
17. Biology of Animals (Volume-II) by Ganguly B, Sinha A and Adhikari S (1987). Pub : New Central Book Agency.
18. Environmental Biology (Principles of Ecology) by Verma PS and Agarwal VK (1993). Pub : S. Chand & Company Ltd., New Delhi-110055.

Unit - 4 ❑ Management of aquatic resources, causes of pollution

Structure

4.0 Objectives

By studying this unit, students will be able to understand about the following—

- Different type pollution.
- Eutrophication and its attributes.
- Water (prevention and control of pollution) Act, 1974.
- General features of estuaries.
- BOD, COD and their essential differences.

4.1 Introduction

Every human society, be it rural, urban, industrial and most technologically advanced society, dispose of certain kinds of by-products and waste products, which when are injected into the biosphere in quantities so great that they affect the normal functioning of ecosystems and have an adverse effect on plant, animals, and human beings are collectively called as pollutants (Smith, 1977). Sometimes the pollutants are in anthropogenic in nature. All these pollutants individually and/or collectively are responsible for pollution mainly in the air, water and sound. Based on this there are different types of pollution, such as, agricultural, industrial, sewage, thermal, nuclear, oil spills of varied nature. In a broader sense, pollution is classified into two broad categories : (i) natural pollution, which originates from natural process; and (ii) artificial pollution, which originates due to the activities of man. In this section we will discuss about the major cause of agricultural, industrial, sewage, thermal and oil spills pollution.

4.2 Definition and types of pollution

4.2.1 Definition

Pollution is an undesirable change in the physical, chemical or biological characteristics of our air, land, water that may or will harmful effect on human life or that of desirable species, our industrial processes, living conditions, and cultural assets (Odum, 1971). According to Southwick (1976) “pollution is the unfavourable alteration of our environment, largely as a result of human activities”.

4.2.2 Types of pollution

4.2.2.1 Agricultural pollution :

India is an agriculture based country. Around 67% of Indian people are dependent on agriculture and agriculture base products. Now-a-days, due to urbanization, industrialization and other agriculture based practices agricultural fields become prone to pollution in varied nature. The agricultural pollutants are mainly the chemicals used as fertilizers (both organic and inorganic) and the pesticides (biocides) used in disease control. India uses about 16 kg/ha of fertilizers (chemicals) on an average, whereas the world average is 54 kg/ha. The following is a discussion about different types of agricultural pollutants.

1. Artificial fertilizers : Modern agricultural practices rely heavily on a wide range of synthetic chemicals which include different types of fertilizers and biocides (pesticides, herbicides or weedicides etc.). These chemicals along with wastes are wasted off lands through irrigation, rainfall, drainage etc. reaching into the water bodies particularly rivers, lakes, streams etc. where they alter the physicochemical characteristics of the water and thus disturb the natural ecosystem.

2. Pesticides and biocides : Pesticides are the chemicals used for killing the plant and animal pests. It includes bactericides, fungicides, nematicides, insecticides and also the herbicides or weedicides. Since weeds (herbs) are not pests like bacteria, fungi, nematodes, insects, the spectrum of activity of these chemicals is extended beyond the pests; and thus a broader term biocide is used to include herbicide etc.

There is a wide range of chemicals used as biocides. But the most harmful are those which either do not degrade or degrade very slowly in nature. We prefer to distinguish such chemical substances as hazardous substances or toxicants. These are highly potent chemicals but enter our food chain and then begin to increase in their concentrations at successive trophic levels in the food chain. Some of the pesticides are—DDT, Aldrin, Dieldrin, Malathion, Hexachlora Benzena etc.

4.2.2.2 Industrial pollution :

Industrial pollution is a big issue because most pollution is caused by some industry, making it the most significant form of pollution on the planet. Most of the Indian rivers and fresh water streams are seriously polluted by industrial wastes or effluents (see table-1), which come along waste waters of different industries like petro-chemical complexes, fertilizer factories, oil refineries, pulp, paper, textiles, sugar and steel plants, tanneries, distilleries, coal washeries, synthetic material plants for drugs, fibres, rubber, plastics etc.

The industrial wastes of these industries and mills include metals (copper, zinc, lead, mercury etc.), detergents, petroleum, acids, alkalies, phenols, carbamates, alcohols, cyanide, arsenic, chlorine and many other inorganic and organic toxicants. All these chemicals of industrial wastes are toxic in nature to animals and may cause death or sublethal pathology of the liver, kidneys, reproductive systems, respiratory systems, or nervous systems in both vertebrate and invertebrate aquatic animals (Wilbur, 1969).

Chlorine which is added to water to control growth of algae and bacteria in the cooling system of power station may persist in streams to cause mortality of plankton and fish. Heavy metals like mercury, lead and cadmium has cropped up as a toxic agent of serious nature. Mercury poisoning produced a crippling and often fatal disease called Minamata disease. The toxic and pathological effects of some heavy metal industrial pollutants have been tabulated in table-2.

Table-1: Some Indian rivers and their major sources of pollution

Sl. No	River	Sources of pollution
1.	Jamuna near Delhi	DDT factory, sewage, power station
2.	Ganga at Kanpur	Jute, chemical, metal and surgical industries; tanneries, textile mills and bulk of domestic sewage of highly organic nature
3.	Gomti near Lucknow	Paper and pulp mills, sewage
4.	Damodar between Bokaro and Panchet	Fertilizers, fly ash from still plants, suspended coal particles from washeries and thermal power station
5.	Hooghly near Calcutta	Power stations, paper pulp, jute, textiles, chemical mills, paint, vernishes, metal, steel, hydrocarbonated vegetable oils, rayon, shop and polythene industries and sewage

Sl. No	River	Sources of pollution
6.	Cauvery (Tamilnadu)	Sewage, tanneries, distilleries, paper and rayon mills
7.	Godavari	Paper mills
8.	Siwan (Bihar)	Paper, sulpher, cement, suger mills
9.	Bhadra (Karnataka)	Pulp, paper and steel industries
10.	Kulu (near Mumbai)	Chemical factories, rayon mills and tanneries

Table-2 : Pathological effects of heavy metal industrial pollutants

Sl. No	Metal	Pathological effects
1.	Mercury	Abdominal pain, headache, diarrhea, hemolysis, chest pain
2.	Lead	Anemia, vomiting, loss of appetite, convulsions, damage of brain, liver and kidney
3.	Arsenic	Disturbed peripheral circulation, liver cirrhosis, hyperkeratosis, lung cancer, ulcers in gastrointestinal tract, kidney damage
4.	Cadmium	Diarrhoea, bone deformation, kidney damage, testicular atrophy, anaemia, injury of central nervous system and liver, hypertension
5.	Copper	Hypertension, uremia, sporadic fever
6.	Barium	Excessive salivation, vomiting, diarrhoea, paralysis, colic pain
7.	Zinc	Vomiting, renal damage, cramps
8.	Selenium	Damage of liver, kidney and spleen, fever, nervousness, vomiting, low blood pressure, blindness
9.	Chromium	Gastro-intestinal ulceration, disease in central nervous system, cancer
10.	Cobalt	Diarrhoea, low blood pressure, lung irritation, bone deformities, paralysis

The causes of industrial pollution are extensive but the following is a discussion about the major causes of industrial pollution.

1. **Unplanned industrial growth :** One of the important causes of industrial pollution is unplanned industrial growth because a lot of air and water pollution has occurred from companies who ignored rules or standard practices to facilitate rapid growth. Different companies are known to release significant amounts of toxic gas, making pollution an even more substantial issue from those smaller industries.

2. **Lack of effective policies :** Many industries have been able to ignore or entirely bypass pollution laws because the policies are either not valid, or not adequately enforced by pollution control boards.

3. **Using old and outdated technology :** Uses of older technologies in many industries tend to produce large amounts of waste.

4. **Use of natural resources :** Raw material is necessary for a lot of industries, which requires them to pull underground elements. One of the most common forms of leaching from natural resources is fracking for oil. When industries pull minerals, the process causes pollution in the soil and also causes oil leaks and spills that are harmful and deadly to people and animals.

5. **Improper disposal of waste :** One of the most common forms of soil and water pollution is improper disposal of wastes from the industries. This is one of the most significant causes of pollution because the effects include severe and chronic health issues and lower air quality.

4.2.2.3 Sewage pollution :

Sewage includes mostly biodegradable pollutants such as human faecal matter, animal wastes, and certain dissolved organic compounds (eg., carbohydrates, urea etc.) and inorganic salts such as nitrates and phosphates of detergents and sodium, potassium, calcium and chloride ions. Contamination of fresh waters and shallow offshore seas by sewage is a common occurrence in recent times. Domestic sewage and waste water is about 99.9 percent water and 0.02-0.04 percent solids of which proteins and carbohydrates each comprise 40-50 percent and fats 5-10 percent (Simmons, 1974). Under natural process most of the biodegradable pollutants of sewage are rapidly decomposed, but, when they accumulate in large quantities, they create problem, i.e., when their input into environment exceeds the decomposition or dispersal capacity of the latter. Now-a-days, most cities in well developed countries and some cities of developing countries like India have evolved certain engineering systems, such as, septic tanks, oxidation ponds, filter beds, waste water treatment plants and municipal sewage treatment plants for the removal of many harmful bacteria and other microbes, organic wastes and other pollutants from the sewage, before it is tipped in to rivers or sea.

4.2.2.4 Thermal pollution :

Various industrial processes may utilize water for cooling, and resultant warmed water has often been discharged into streams or lakes. Coal-oil-fired generators and atomic energy plants cause into large amount of waste heat which is carried away as hot water and cause thermal pollution or calefaction (warming). Thermal pollution produces distinct changes in aquatic biota mainly by depleting the dissolved oxygen of the water bodies and exerts a disruptive effect on aquatic ecosystem. The following are the major causes of thermal pollution.

1. **Production and manufacturing plants :** Production and manufacturing plants draw water from a nearby source to keep machines cool and then release back to the source with higher temperatures. When heated water returns to the river or ocean, the water temperature rises sharply and altered the oxygen level, which can also degrade the quality and longevity of life that lives underwater.

2. **Soil erosion :** Consistent soil erosion causes water bodies to rise, making them more exposed to sunlight and thus increased the temperature of the water bodies. The high temperature could prove fetal for aquatic biomes as it may give rise to anaerobic condition.

3. **Deforestation :** Tress and plant prevent sunlight from falling directly on lakes, ponds or rivers. When deforestation takes place, these water bodies are directly exposed to sunlight, thus absorbing more heat and raising its temperature.

4. **Runoff from paved surfaces :** Urban runoff discharged to surface waters from paved surfaces like roads and parking lots can make the water warmer. During summer, the pavement gets quite hot, which makes warm runoffs that makes the water bodies hot.

5. **Natural causes :** Natural causes like volcanoes, geothermal vents and hot springs under the oceans and seas can trigger warm lava to raise the temperature of water bodies. Lightening can also introduce a massive amount of heat into the oceans. This means that the overall temperature of water source will rise, having significant impacts on the environment.

6. **Domestic sewage :** Domestic sewage is often discharged into rivers, lakes, canals or streams without treating the waste. The temperature of municipal water sewage is normally high than receiving water. With the increase in temperature of the receiving water, the dissolved oxygen decreases, and the demand for oxygen increases, causing anaerobic conditions.

4.2.2.5 Oil spill pollution :

An oil spill is the release of a liquid petroleum hydrocarbon into the environment, especially the marine ecosystem, due to human activity, and is a form of pollution. The term oil spill is usually given to marine oil spills, where oil is released into the ocean or coastal waters, but spills may also occur on land. Oil spills may be due to releases of crude oil from tankers, offshore platforms, drilling rigs and wells, as well as spills of refined petroleum (such as gasoline, diesel) and their by-products, heavier fuels used by large ships such as bunker fuel, or the spill of any oily refuse or waste oil.

Oil spill is responsible for endangering water birds and coastal plants due to coating of oils and adversely affecting the normal activites. Oil spills penetrate into the structure of the plumage of birds and the fur of mammals, reducing its insulating ability, and making them more vulnerable to temperature fluctuations and much less buoyant in the water. Cleanup and recovery from an oil spill is difficult and depends upon many factors, including the type of oil spilled, the temperature of the water (affecting evaporation and biodegradation), and the types of shorelines and beaches involved. Spills may take weeks, months or even years to clean up.

Oil spills at sea are generally much more damaging than those on land, since they can spread for hundreds of nautical miles in a thin oil slick which can cover beaches with a thin coating of oil. These can kill seabirds, mammals, shellfish and other organisms they coat. Oil spills on land are more readily containable if a makeshift earth dam can be rapidly bulldozed around the spill site before most of the oil escapes, and land animals can avoid the oil more easily. The following table will give a general idea about oil spill pollution in different times.

Spill / Tanker	Location	Date	Tonnes of crude oil (thousands)	Barrels (thousands)	US Gallons (thousands)
Kuwaiti Oil Lakes	Kuwait	January 1991 – November 1991	3,409–6,818	25,000–50,000	1,050,000–2,100,000
Lakeview Gusher	Kern country, California, USA	March 14, 1910 – September 1911	1,200	9,000	378,000
Gulf war oil spill	Kuwait, Iraq, and the Persian Gulf off the coast of	January 19, 1991 – January 28, 1991	818–1,091	6,000–8,000	252,000–336,000
Odyssey	Nove, Scotia, Canada	November 10, 1988	132	968	40,704

4.3 Eutrophication

According to Hutchinson (1969), the eutrophication is a natural process which literally means "well nourished or enriched". Due to addition of domestic waste (sewage), phosphates, nitrates etc. from wastes or their decomposition products in water bodies, they become rich in nutrients, specially phosphates and nitrate ions. Thus with the passage of these nutrients through such organic wastes, the water bodies become highly productive or eutrophic and the phenomenon is called as eutrophication. It is a natural state in many lakes and ponds which have a rich supply of nutrients, and it also occurs as part of aging process in lakes, as nutrients accumulate through natural succession. Eutrophication becomes excessive, however, when abnormally high amounts of nutrients from sewage, fertilizer, animal wastes and detergents, enter streams and lakes, causing excessive growth of "bloom" of micro-organisms and aquatic vegetation. It must be remembered that with the addition of nutrients, there is stimulated luxuriant growth of algae in water. There is also generally a shift in algal flora, blue-green algae begin to predominate which starts forming algal blooms, floating scums or blankets of algae. Blooms of algae are generally not utilized by zooplanktons. The algal blooms compete with other aquatic plants for light for photosynthesis. Thus oxygen level is depleted within the waterbodies. Moreover, these blooms also release some toxic chemicals which kill fish, birds and other animals, thus water begins to stink. Decomposition of blooms also leads to oxygen depletion in water. Thus in a poorly oxygenated water with higher CO_2 levels, fish and other animals begin to die and clean water body turned into a stinking drain.

Although eutrophication is commonly cause by human activities, it can also be a natural process, particularly in lakes. Eutrophy occurs in many lakes in temperate grassland, for instance. Paleolimnologists now recognize that climate change, geology, and other external influences are critical in regulating the natural productivity of lakes. Some lakes also demonstrate the reverse process (meiotrophication), becoming less nutrient rich with time. The main difference between natural and anthropogenic eutrophication is that the natural process is very slow, occurring on geological time scales.

The main effects caused by eutrophication can be summarized as follows—

(i) Species diversity decreases and the dominant biota changes.

(ii) Plant and animal biomass increases.

(iii) Turbidity increases.

(iv) Rate of sedimentation increases, shortening the life span of lake.

(v) Anoxic conditions may develop.

4.4 Water (prevention and control of pollution) Act, 1974

The water (prevention and control of pollution) Act, 1974, deals with the problem of water pollution comprehensively at National level. The act was enacted under article 252(1) of the constitution, which provides power to the Union Government to legislate on matters of state list, where two or more state legislatures consent to a central law.

4.4.1 Objectives

The objectives of the act are to "prevent and control" water pollution and also maintain and restore the wholesomeness of water. It defines the term "pollution" as any contamination of water or alteration of properties of water, discharge of sewage or trade effluents or any other substances (liquid, solid or gaseous) into water (directly or indirectly) to create nuisance or injurious to life or human health, plants, animals, aquatic organisms etc. The act provides for establishing a central or state boards and joint boards for the accomplishment of the objectives of legislation.

4.4.2 Merits

1. The act provides a comprehensive scheme for the prevention and control of pollution except for the standards of the regulation of pollution but the central and state boards are given wide powers to decide their own standards and regulations for the local needs.
2. The act prohibits disposal of noxious, poisonous and polluting matter into streams or wells or onto the lands in excess of standard established by state board.
3. A person must obtain consent from the boards through an application before the establishment of any industry, operation or process which may result in disposal of sewage trade effluent into a stream. The consent by the boards will be given only after a thorough enquiry in the prescribed manner.
4. Persons who have been releasing water pollutant, without meting the consent requirements of section-25, penalties are imposed for contravention of the provisions of section 24, 25 and 26. Persons will be punished for the violation of the provisions of section 24 with imprisonment of one year and six months or which may extend.
5. The boards will take emergency measures, if the cause of pollution of well or stream is an accident or unforeseen act or event.
6. One significant and remarkable achievement of the 1988 amendment of water act is the incorporation of a provision for citizen's suit in section 49 of the act; citizens may file criminal complaints against offenders after 60 days, notice to the board.

4.4.3 Demerits

1. Definitions of some important terms like "pollutant", "discharge of pollutant", "toxic pollutant" etc. are not provided in the act.
2. This act includes a definition of stream but not an "estuary" as stream may be covered under the "river" or "sea" or "tidal waters". So, it is needed to add estuary in a suitable place.
3. The act has the provision for the establishment of central, state and joint boards but there is no adequate representation of the members of social groups and lawyers.

4. In making consent orders by state boards, there is no public participation in decision making process under the act.
5. Provisions for fixing up standards of quality and targets for eradication of pollution are absent from the act; just like public participation in fixing up these.

4.5 Biological oxygen demand (BOD)

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed (*i.e.*, demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20° C and is often used as a surrogate of the degree of organic pollution of water. BOD values are generally used as a measure of degree of water pollution and waste level. Thus, mostly BOD value is proportional to the amount of organic waste present in water. In aquatic environment, aquatic pollutants come from various sources. Excessive nutrients, such as nitrates and phosphates, commonly originate in domestic sewage, run-off from agricultural fertilizer, waste materials from animal feed lots, packing plants etc. These nutrients cause pollution primarily because they stimulate the growth of micro-organisms which often increase the BOD of the water and reduce the amount of dissolved oxygen available for fish, higher animals and other aquatic animals.

BOD analysis is similar in function to Chemical oxygen demand (COD) analysis, in that both measure the amount of organic compounds in water. However, COD analysis is less specific, since it measures everything that can be chemically oxidized, rather than just levels of biologically oxidized organic matter.

4.6 Chemical oxygen demand (COD)

Chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. It is commonly expressed in mass of oxygen consumed over volume of solution which in SI units is milligrams per litre (mg/L). A COD test can be used to easily quantify the amount of organics in water. The most common application of COD is in quantifying the amount of oxidizable pollutants found in surface water (e.g. lakes and rivers) or waste water. COD is useful in terms of water quality by providing a metric to determine the effect an effluent will have on the receiving body, much like BOD.

4.7 Essential differences between BOD and COD

❑ COD always oxidize things that the BOD cannot or will not measure; therefore, COD is always higher than the BOD. The common compounds which cause COD to be hither than BOD inculde sulfides, sulfites, thiosulfates and chlorides.

❑ The general relationship betwen BOD and COD for sewage and most human wastes is about 1 unit of BOD ≈ 0.64 – 0.68 units of COD. The relationship is not consistent and it may vary considerably for industrial waste waters.

4.8 Summary

- Pollution is an undersirable change in the physical, chemical and biological characteristics of the environment.
- Different types of pollution are found in the environment, i.e., agricultural, air, water, sound, thermal, sewage, oil spill etc.
- Eutrophication in the water occurs due to the enrichment of nutrients in the water bodies.
- COD is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured soultion.
- BOD is the amount of dissvoled oxygen needed by aerobic biological organisms to break down organic meterial present in the water bodies.

4.9 Questions

(i) Define pollution.

(ii) Write a brief note on industrial pollution.

(iii) What is sewage pollution?

(iv) What are the causes of thermal pollution?

(v) What is oil spill pollution?

(vi) What is eutrophication? State example of eutrophication.

(vii) Write the merits and demerits of water (prevention and control of pollution) Act, 1974.

(viii) Define BOD and COD.

4.10 Suggested Readings

1. "Lingering lessons of the Exxon Valdez Oil Spill". Commondreams. Org. 2004-03-22. Archived from the original on June 13, 2010.
2. NOAA Ocean Median Centre (2010-03-16). "Hindsight and Foresight, 20 years after the Exxon Valdez spill". NOAA
3. Wout, B (2015). "Crisis-induced learning and issue politicization in the EU. Public Administration. 94 (2). 381-398. doi. 10.1111/padm.12170.
4. United States Geological Survey, Campbell, Robert Wellman, ed. 1999. Iraq and Kuwait : 1972, 1990, 1991, 1997. Earthshots : Satellite images of environmental change. U.S. Geological Survey. Archived February 19, 2013, at the Wayback Machine.
5. United Nations, Updated Scientific Report on the Environmental Effects of the Conflict between Iraq and Kuwait, 8 Mar, 1993.
6. National Aeronautics and space administration, Goddard Space Flight Centre News, 1991 Kuwait Oil Fires, 21 Mar, 2003.
7. Harvey, S (2010). "California's legendary oil spill". Los Angeles Times.
8. United States Environmental Protection Agency, Report to Congress United States Gulf Environmental Technical Assistance from January 27- July 31, 1991.
9. Information Services (2010). "Data & Statistics : Academic Marine oil spillages since 1970". International Tanker owners Pollution Federation (ITOPF).
10. Walker, IR (2006). "Chironomid overview", pp. 360-366 in S. A Elias (ed). Encyclopedia of Quatemary Science, Vol.1, Elsevier.

11. Whiteside, MC (1983). "The mythical concept of eutrophication". Hydrobiologia. 103 : 107-150.

12. Callisto, M; Molozzi, J and Barbosa, JLE (2014). "Eutrophication of Lakes" in A. A. Ansari, S. S. Gill (eds.), Eutrophication : Causes, Consequences and Control, Springer Science + Business Dordrecht. doi : 10.1007/978-94-007-7814-6_5.

13. Ecology and Environment (2002-03) by P. D. Sharma, Pub : Rastogi publication, Meerut-250 002.

14. Fish and Fisheries (1991) by V. G. Jhingran, Pub : Hindustan Publishing Corporation (India), Delhi.

15. Study Material (Post Graduate Zoology), Paper-2A, Netaji Subhas Open University (2006), Pub : The Registrar, NSOU.

16. Study Material (Post Graduate Zoology), Paper-3A, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.

17. Study Material (Post Graduate Zoology), Paper-8B, Netaji Subhas Open University (2010), Pub : The Registrar, NSOU.

18. Biology of Animals (Volume-II) by Ganguly B, Sinha A and Adhikari S (1987). Pub : New Central Book Agency.

19. Environmental Biology (Principles of Ecology) by Verma PS and Agarwal VK (1993). Pub : S. Chand & Company Ltd., New Delhi-110055.

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