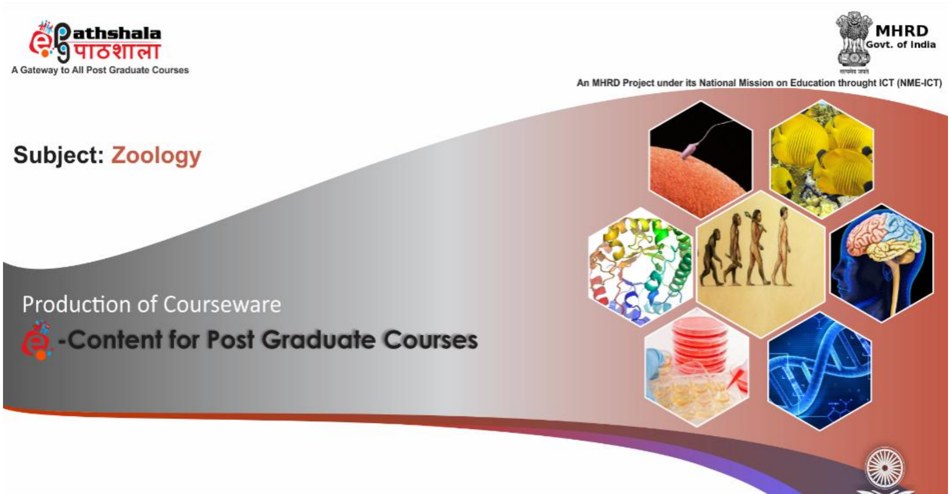

Paper : 12 Principles of Ecology

Module : 22 Types of Ecosystems: Aquatic Ecosystem-Fresh Water Ecosystem: Part 2

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Description of Module	
Subject Name	ZOOLOGY
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Keywords	Lentic, lotic, community, lake, temperate lake, zone, eutrophy, Langmuir circulation

Contents

1. Learning Objectives

After the end of this module you will be able to

1. Understand the concept of fresh water ecosystem.
2. Understand the characteristics of the Lentic ecosystems.
3. Know the communities of lentic ecosystems and their ecological adaptations.
4. Know properties of Lake Ecosystems and their types.
5. Understand the major changes that are causing the threats to freshwaters ecosystems.

2. Introduction

Freshwater ecology can be interpreted as interrelationship between freshwater organism and their natural environments. Fresh water streams (springs, rivulets, creeks, brooks, etc.) and rivers trend over their course from being narrow, shallow and relatively rapid to increasingly broad, deep and slow moving. The degree of each feature depends upon the vertical drop over its length. This shift in movement of the water is reflected in the substrate, which trends from being rocky and without sediment to deep sediments found in the deltas at the mouth of some great rivers like Mississippi.

Lentic ecosystems (pools, ponds, swamps, bogs lakes, etc.) vary considerably in physical, chemical and biological characteristics. In general, they have different zonation, unlike the rapid and the pool zones of the lotic system with different specialized lentic community.

3.The Lentic Aquatic System

Lentic aquatic bodies contain stagnant waters. These are formed usually in large or small depressions formed on earth's surface where water is trapped and has no exit flow. Ponds, lakes, swamps etc. are few such water bodies. Therefore, the lentic systems are closed systems i.e. most of the aquatic forms that enter these systems rarely get out. They have to persist, decay and decompose within the lentic body. In due course of time, they change into swamps or marshy wetlands and finally into dry lands.

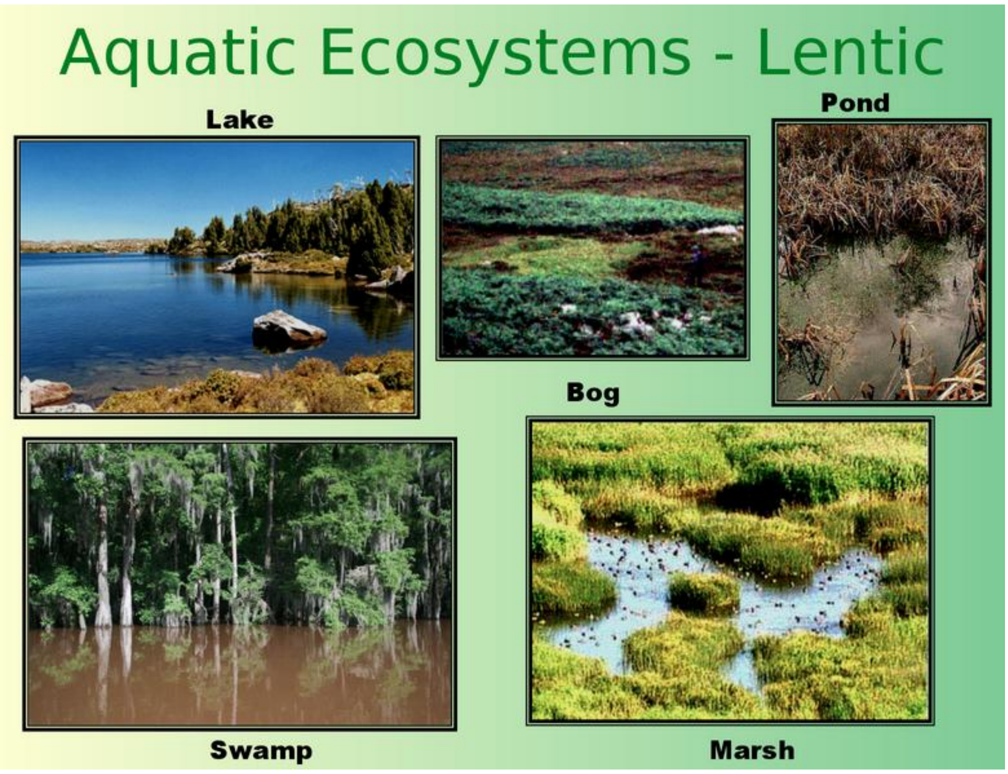


Fig.1: Examples of Lentic ecosystem

3.1. Zonation in Lentic Systems

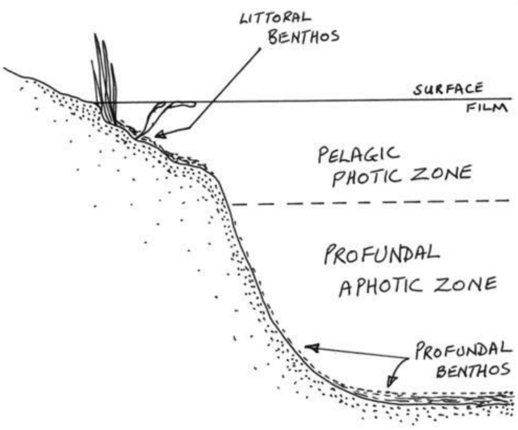


Fig.2: Zonation in Lentic water body

The bodies like ponds and lakes have three zones:

1. ***Littoral Zone***: It is the shallow water region in which the light penetrates till the bottom. Due to the availability of plenty of sunlight, this zone is marked typically by the presence of rooted plants. This may not be true in 'managed' or 'man-made ponds or lakes'.

2. ***Limnetic Zone***: It is the open water zone to the depth of effective light penetration called the *compensation level*. The compensation level is that depth at which the rate of photosynthesis becomes equal to the rate of respiration. In general, this level will be at the depth at which light intensity is about 1 per cent of full sunlight intensity. The community in this zone is composed only of planktons and the nektons and sometimes neustons. This zone is absent in small, shallow ponds. The total illuminated stratum including the littoral and the limnetic zone is termed as *Eutrophic zone.*

3. ***Profundal Zone:*** This is the deep bottom zone which is beyond the depth of effective light penetration. This zone is often absent in ponds.

3.2. Characteristics of Lentic Ecosystem

The physico-chemical environment in a lentic aquatic system is remarkable due to absence of flow of water. Some important features of a lentic water body of water are summarized below:

(a) *Stability in the physicochemical characteristics of water quality*: Most of the water in the lentic system derives from surface runoffs, rains or from underground water sources. These sources undergo very little change in their compositions over the years. Therefore, the quality of water in lentic systems remains virtually unchanged for long duration of time.

(b) *Impact of Seasonal change*: The productivity of a lentic body is influenced by its positive correlation with the seasonal changes in physicochemical characteristics of water. The seasonal fluctuation of the water quality greatly affects the composition of the living community. During the periods of bright sunshine, a rich growth of phytoplankton is observed which is also associated with a remarkable decline in the concentration of many plant nutrients.

(c) *Impact of area Vs volume of water on assessment of productivity*: In the assessment of the productivity of a lentic water body, the total surface area of the water body is more important than volume of water or the depth of the water body. The total stretch of the littoral and limnetic zones determines the productivity. Even the profundal zones are nutrient rich in some lentic bodies, productivity is hardly affected due to lack of enough sunshine.

(d) *Lentic systems are closed systems*: Since there is no outlet for the water body, substances with persistent nature, products of decomposition and mineralization of the organic matter as well as the degraded or semi degraded products of pollutants that are discharged in these aquatic bodies, persist in the system. This has a significant impact on the biotic communities.

(e) *Thermal and nutritional Stratification:* The phenomenon of stratification, also known as vertical donation, is one of the most important features of a lentic water body. This is observed in lakes and ponds which usually have deeper static waters having a depth of more than 6 to 8 meters. Stratification results in different layers of a lentic water having different temperature, oxygen content and the nutrient status. Stratification develops mainly due to following reasons:

i. *Seasonal change*: The typical seasonal cycle results in the thermal stratification. During summers the top waters become warmer than the bottom waters, as a result, only the warm top layer circulates, and it does not mix with the more viscous cold water, creating a zone with a steep temperature gradient in between called the *thermocline.* The details of the same will be discussed later.

ii. *Light*: Sunlight illuminates only the upper layers i.e., the limnetic zone, where active photosynthesis and growth takes place. This results in generation of plenty of oxygen and also rapid consumption of nutrients. On the other hand, the benthic and the profundal and benthic zones are dark and deprived of primary productivity. Some amount of atmospheric oxygen also dissolves into the upper surface water, making the upper zone rich in oxygen and poor in nutrition while the bottom zone rich in nutrition but poor in dissolved oxygen content.

iii. *Decomposition and mineralization of organic matter*: Nutrient is abundant near the bottom strata from where they diffuse towards the upper strata. Decomposition of dead organisms, mineralization of organic matter and regeneration of nutrients occur actively in the profundal and benthic zones. On the other hand, the consumption of the same is comparatively less than the surface. These zone are oxygen deficient, therefore products of anaerobic microbial activities also accumulate in these zones.

iv. *Atmospheric temperature and air circulation*: 95% of heat is received or lost by the aquatic body through its upper surface which is in contact with atmospheric air. Therefore, the temperature of the surface layer is directly influenced by atmospheric temperatures and also the presence or absence of air circulation. Since the deeper layers are insulated from all sides, they do not undergo any rapid change in temperature. This also affects the density of water.

v. *Density gradient of water*: When lighter or less dense layer of water is placed on heavier or denser waters, thermal stratification develops. Water has its maximum density at 4°C. Above 4°C warmer, it is lighter like every liquid but at temperature below 4°C, the situation is exactly opposite to other liquids since warmer waters are heavier than cooler ones.

The conditions under which stratification develops in a static water body are:

1. When the water body having temperatures below 4°C is subjected to cooling.

2. When the water body having temperatures above 4°C is subjected to heating.

In both the cases, the surface layer becomes lighter than the layer of water underneath. The lighter water tends to stay at the top and prevents free circulation and the mixing of different layers of water. The imaginary line that demarcates the two zones having different temperatures is termed as the thermocline. The zone above thermocline is known as *epilimnion* and the zone below this line are known as *hypolimnion*.

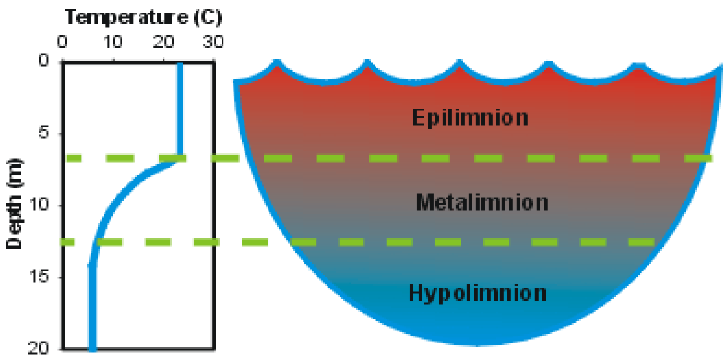


Fig.3: Stratification in lentic system

Complete mixing of water occurs:

1. When a water body having temperature above 4°C cools up to 4°C.

2. When a water body having temperature below 4°C is heated up to 4°C.

Under both these conditions the upper layers of water become heavier. They sink down and the lighter water comes up to replace the heavier layer. Thus thorough mixing of different layers of water shall occur.

Stratification is an importance process in temperate regions where temperatures falls below 0°C. As a result of thermal stratification, cooler water stays at the surface of the water body and ice formation starts from top moving downwards. Therefore, the aquatic life continues safely under the sheet of ice.

The temperatures rarely go below 4°C in sub-topical and tropical regions. In these regions, it is very hot during the day resulting in stratification. At night, cooling causes sinking of the nutrient-deficient but oxygen-rich top layer of water and at the same time the nutrient-rich but oxygen-deficient layer comes up to replace the upper layer. This diurnal circulation of oxygen and nutrients is responsible for high productivity of such water bodies.

3.3. Lentic Community

3.3.1. Communities of the littoral zone

Producers: Two types of producers are present in the littoral zone:

a. Rooted or benthic plants

These are generally spermatophytes, the seeded plants. These plants form concentric zones within the littoral zone, one group replacing another as the depth of the water changes, either in space or in time. A representative arrangement proceeding from shallow to deeper water is described as follows:

(i) Zone of emergent vegetation: These include the rooted plants with principal photosynthetic surfaces projecting above the water. Thus, carbon dioxide for food manufacture is obtained from beneath the water surface. These plants obtain nutrients from the deep anaerobic sediments and thus act as a useful "nutrient pump" for the ecosystem.

Eg. Cattails of *Typha*, are dominant producers. Bulrushes (*Scirpus)*, arrowheads (*Sagittaria*), bur reeds (*Eleocharis*), pickerelweeds (*Pontederia*), etc are few other examples of this zone. These plants along with the plants of the moist shore form an important link between water and land environments. They are used for food and shelter by amphibious animals and provide a convenient means of entry and exit into the water for aquatic insects which spend part of their lives in water and part on land.

(ii) Zone of rooted plants with floating leaves: Water lilies (*Nymphaea*) are the predominant types in this zone in the eastern half of the United States, but other plants such as water shield (*Brasenia)* are also found in many water bodies. This zone is similar to the zone of emergent vegetation. However, the horizontal photosynthetic surfaces effectively reduce the light penetration into water. The undersurfaces of the lily pads provide convenient resting places and substrate for egg deposition by animals.

(iii) *Zone of submergent vegetation*: This zone includes rooted or fixed submerged plants. The leaves of these plants are thin and finely divided and adapted for exchange of nutrients with the water. The pond weeds or *Potamogetonaceae* are the usual dominant species of this zone. Coontail (*Ceratophyllum*), water milfoils (*Myriophyllum*), waterweed (*Elodea or Anacharis)*, naiads (*Najas*), and wild celery (*Vallisneria*) are some important submerged plants of United States.

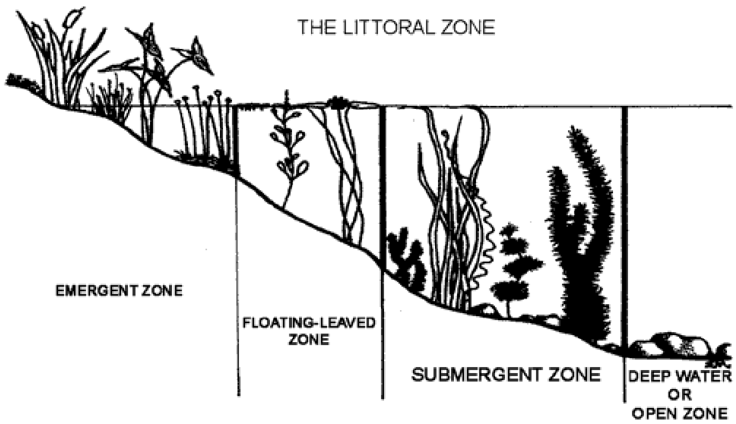


Fig.4: Producers of littoral zone

b. Floating or phytoplankton:

These include the green algae. The non-rooted producers of the littoral zone comprise numerous species of algae. Many species are found floating throughout the littoral as well as the limnetic zone. Some species of algae, bound or associated with the rooted plants, are typically found in the littoral zone. Some major types of algae found are:

Diatoms (*Bacillariaceae*): These are box like silica shells and have yellow or brown pigment in the chromatophores masking the green chlorophyll. These are good indicators of water quality.

Green algae (*Chlorophyta*): These include single celled forms such as desmids, filamentous forms either floating or attached. In these organisms, chlorophyll is not masked by other pigment; hence their population has a bright green appearance.

Blue-green algae (*Cyanophyta*): These are single celled or colonial algae with diffuse chlorophyll masked by blue-green pigment. They are of great ecological significance because their biomass increases immensely in polluted ponds and lakes. They are able to fix gaseous nitrogen into nitrates.

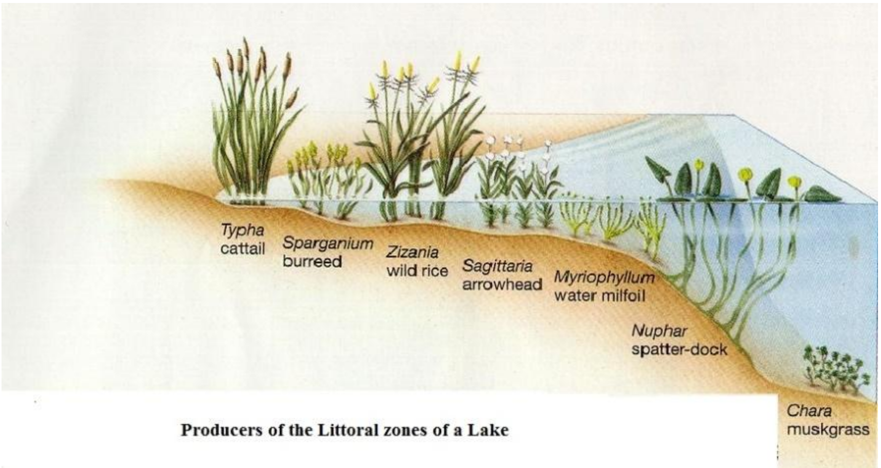


Fig.5: Producers of littoral zone

Consumers: Littoral zone is the home for many varieties of consumers.

Algal growth or greater primary productivity is associated with abundance of food for organisms that feed on algae. Algae eaters are mostly invertebrates, such as micro-crustaceans, insect larvae and molluscs. Many small fish, including the young of larger species and minnows, also feed on algae and other plants. However, all algae are not edible for these creatures; some species have structures that make them more difficult to consume for the small animals.

Periphyton, exhibit a zonation paralleling that of the rooted plants, but many species occur more or less throughout the littoral zone. Among animals, vertical zonation is more prominent rather than horizontal zonation. Some common examples are: Pond snails, damsel fly nymphs, climbing dragon fly nymphs, rotifers, flatworms, bryozoan, and midge larvae. Snails feed on plants or Aufwuchs, whereas midge larvae obtain food from detritus. Dragon and damsel fly are carnivorous.

Another group of animals can also be observed resting on the bottom or beneath the silt or plant debris. Few examples are, sprawling Odonata nymph, crayfish, isopods and certain mayfly nymphs. Clams, true worms (annelida), snails and chironomids and other dipteran larvae live in minute burrows.

Nektons of littoral zones show great diversity and are present in large numbers. Beetles and various adult hemipterans, some dipteran larvae, remain suspended in water, often near the surface.

Amphibious vertebrates, such as frogs, salamanders, turtles and water snakes are most exclusive members of littoral zone community. Tadpoles of the frogs and toads are important primary consumers, feeding on algae and other plant material, whereas adults move to a higher tropic level.

Pond fishes move freely across the various zones but most of the species spend a large part of their life in the littoral zone, they breed and reproduce in this zone. Sunfish belonging to Centrarchidae family is a predominant genus of pond. *Gambusia* fishes are abundant in the ponds of southern United States.

Zoolplanktons of this zone are different form the limnetic zone consisting of heavier, less buoyant crustacean, which cling to the plants or rest on the bottom. They are large, weak-swimming species of Cladocera (water fleas) and some species of *Daphnia* and *Simocephalus*.

Littoral neustons consist of:

(i) Wriggling beetles (family Gyrinidae), commonly known as fishermen's "lucky bugs". They are unique in presence of special eye which is divided in two parts, one half for seeing and the other half for underwater vision.

(ii) Large water striders (family Gerridae).

(iii) Small broad shouldered water striders (family Veliidae).

3.3.2. Communities of Limnetic Zone

Producers

Phytoplankton producers of the open water zone consist of algae and algae like green flagellates, chiefly the dinoflagellates, Euglenidae and Volvocidae. Most of the limnetic forms are microscopic and hence they are not visible.

Phytoplankton may exceed the rooted plants in primary productivity per unit area. The phytoplankton of Northern temperate lakes show marked seasonal variation in population density. Very high density appears quickly but is short lived is known as '*algal bloom*' or *phytoplankton 'pulses'*.

The lakes of Northern United States show large *spring bloom* in early spring and a smaller pulse in autumn. During winter due to low water temperatures and reduced light conditions the number of phytoplankton organisms increase rapidly since nutrients are not limiting for the moment. When the nutrients are exhausted after sometime, the bloom disappears.

When nutrients again begin to accumulate, nitrogen-fixing blue-green algae (like *Anabaena)* are often are responsible for *autumn blooms*. These organisms increase rapidly despite a reduction of dissolved nitrogen until phosphorus, low temperature or some other factor becomes limiting and stop the population growth.

Consumers

Few species of zooplanktons are present in the limnetic zone but their number is fairly large. Copepods, cladocerans and rotifers are important groups, but their species is different from that of the littoral zone. Long antennae or calanoid copepods, such as *Diaptomus* are found in this zone. Middle antennae forms like *Cyclops* are more abundant in smaller water bodies. Many crustaceans are 'strainers', filtering bacteria, detrital particles and phytoplankton by means of combs of setae on their thoracic appendages. They graze on the plants.

Zooplankton blooms are generally seen soon after phytoplanktonic blooms as they are dependent on the plant community. Some organisms use dissolved organic matter for food but most of the zooplanktons use the particulate food as their main energy source.

Nektons consist of fishes. The species are same as that of the littoral zone in case of ponds, but in case of larger lakes, the limnetic zones have some unique species of fishes. Most of the fishes feed on large free swimming animals while few species such as gizzard shads, *Dorosoma* and *Signalosa* have strainers and they are plankton feeders.

3.3.3. Communities of Profundal Zone

Since there is no light, the amphibians of the profundal zone depend on the limnetic and littoral zone for basic food materials. The profundal zone provides 'rejuvenated' nutrients which are carried by currents and swimming animals to the other zones.

The major community of this zone comprises of bacteria and fungi, which are abundant in the water-mud interphase where organic matter accumulates.

There three groups of consumers in this zone:

a. Blood worms or the hemoglobin containing chironomid larvae and annelids

b. Small clams of Sphaeriidae family, and

c. 'Phantom larvae' or *Chaoborus (Corethra)*

Blood worms and the clams are the benthic forms while the phantom larvae are the plankton form that move up to the limnetic zone during night and down to the bottom during the day. The population of red annelid worms increases in domestic sewage polluted water. All members of the profundal zone are adapted to withstand periods of low oxygen concentration, whereas most of the bacteria are anaerobic.

4. Lake Ecosystem

Lakes are the perfect habitats for studying the ecosystem dynamics which shows the distinct biological, physical and chemical processes.

Though lakes contain only 0.01% of all the water on the earth's surface, they contain 98% of the total fresh water on the land surface. Water sheds from land influence the lake ecosystem, therefore, the biological, chemical and geological processes occurring on the land and the streams lying uphill influence the characteristic of the lake ecosystem. Deposition of detritus, movement of chemicals and many organisms is unidirectional in the direction of watershed to the lake, whereas the migration of some fishes can happen upstream and many aquatic insects can disperse on land. For this reason a lake and its watershed are sometimes considered as a single ecosystem forming a flow-through system (Likens,1985).

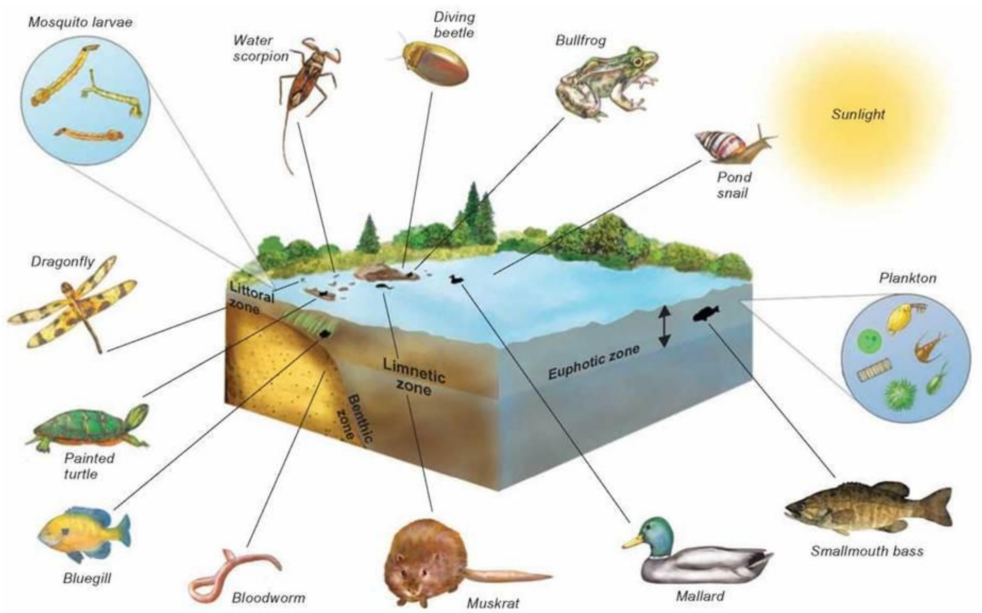


Fig.6: Lake Ecosystem

4.1. Thermal Properties of Lake

In warm weather the surface of a lake is heated and it becomes less dense and remains at surface, floating on the denser cold water beneath. The surface continues to gain heat while the bottom water remains cold. If this heating continues for some critical period of days in absence of strong winds, a marked difference in the temperature develops between the top and the bottom water. In the lakes of north temperature belt the temperature difference between surface and deep water can be as much as 10 to 15^0C.

The two layers '*epilimnion*' and the '*hypolimnion*' are separated by the '*thermocline*'. Sometimes the thermocline is referred as '*metalimnion*' and treated as separate compartment in its own right.

The hypolimnion is cold and is entirely cut off from air by an immovable lid of warm water with which it does not mix. It cannot obtain oxygen from the air and depends on the reserves of dissolved oxygen or oxygen from the deep-water photosynthesis. However, it is in continuous contact with the bottom mud and which is potentially the largest nutrient reserve.

On the other hand, the warmer epilimnion floats on the surface and is in permanent contact with air and therefore it has a continuous supply of oxygen. Since water in this layer is in close contact to the light, it receives most of the oxygen from photosynthesis. The epilimnion layer of water is in contact with the mud only at the lake margins, providing a lesser contact with potential nutrient reserves than the hypolimnion.

In freezing weather lakes are stratified differently. Since water is densest at 4^0C and freezes at 0^0C, deep water at 4^0C may be warmest with temperature gradient from there to the surface. The surface is then covered with ice (solid phase), effectively separating the entire lake from its oxygen supply.

4.2. Seasonal Cycle in Temperate Lake

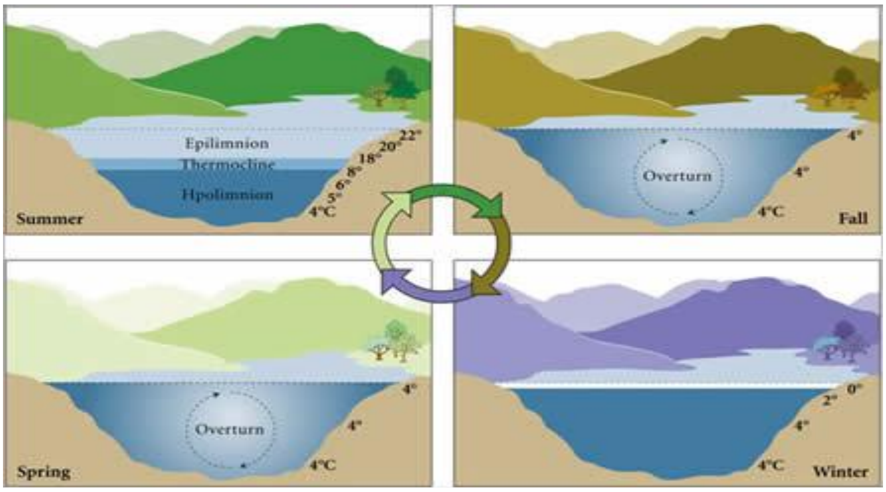


Fig.7: Annual mixing pattern in young lakes

In seasonal climates with cold winters and hot summers, lakes have corresponding seasonal histories of stratification. In winters they are stratified with ice floating over warmer water. This ends when the ice melts and strong winds completely mix the waters of the lake. This process is known as '*spring-overturn'*. In early summer the lake goes into its second period of stratification with a warm epilimnion floating over the cold hypolimnion and the thermocline in between. Surface cooling and the strong winds at the end of the summer mix the water once again. This mixing is referred as the '*fall overturn'*.

Very large temperate lakes like Lake Eric in North America, can be mixed by strong force winds even in summer, so these lakes sometimes have alternate periods of 'mixis'. But most temperate lakes remain stratified throughout the summer.

4.3. Biological Oxygen Demand

In stratified lakes, there is a differential oxygen supply to the epilimnion and the hypolimnion. In fertile lakes, nearly all the photosynthesis takes place in the epilimnion, which receives oxygen throughout the summer while the hypolimnion does not.

Since the organisms present in the hypolimnion need to respire, the demand for oxygen continues in the hypolimnion even when the supplies are cut-off. Respiration for the decomposers is of most importance because the dead matter from the surface regions of epilimnion falls into the hypolimnion which forms the food for the decomposers. Therefore the *biological oxygen demand (BOD*) is met by the oxygen reserves of the water.

For a highly fertile lake, the BOD exceeds the oxygen reserves and the hypolimnion becomes oxygen deprived in late summer. Fishes of the deep and cold bottom waters like trout suffocate in the anoxic hypolimnion and only surface living fish species are able to survive. When the lake is infertile, some photosynthesis is carried out in the depths. Since little dead matter falls to the bottom, the BOD is low and the hypolimnion never becomes anoxic. Fish like trout thrive in these lakes, spending much time in cold water of the hypolimnion and making only brief foraging excursions to the warm epilimnion for food.

4.4. Eutrophy and Oligotrophy

Limnologists, refer the fertile lakes as '*Eutrophic lakes'* and the infertile lakes as '*Oligotrophic lakes'.* The fertility of the lakes is set by concentration of the dissolved nutrients. The concentration of the nutrients can change with the seasons, depending on the intensity and duration of stratification and also the free oxygen available near the bottom mud. These properties in turn depend on the physical parameters like temperature and the depth of the lake. Oligotrophy or eutrophy of a lake is determined by various factors that control the concentration of the nutrients in the open water where the plants live.

a. Nutrient Cycling

Nutrients enter the lake by rapid descent to mud. The fate of the nutrient reaching the mud depends on the *'redox potential'* of the mud i.e. whether the mud is in contact with oxidized water or reduced water.

The solubility of the important nutrients like iron and phosphorus is critically dependent on whether they are oxidized or not. Ferrous iron salts are easily soluble but ferric iron compounds (e.g. rust) precipitate from solutions. Iron deposited at the bottom of the oligotrophic lake with excess of available oxygen in the hypolimnion lies in its ferric state, fixed and insoluble. On the other hand, iron deposited at the bottom of eutrophic lake having anoxic hypolimnion, is in ferrous state and is easily dissolved into the bottom water.

Nutrient cycle in Oligotrophic lake: Nutrients entering from watersheds are taken up by the plants, which are then passed through the food chains or back to the water through herbivory and death. During this cycle, a rapid attribution of nutrients takes place as corpses and debris fall into the dark depths of the lake. In oligotrophic lakes, the nutrition stays at the oxidized bottom mud.

Nutrient cycle in Eutrophic lake: Nutrient inputs are large enough in fertile lake. Nutrients enter from the watershed, are cycled, and fall down to the depths as in the oligotrophic lakes. But the falling particles are numerous and are often referred as '*brown snow'* of corpses and debris. BOD is high, the hypolimnion is reduced, and the surface mud is reduced also. Accordingly, nutrients are rapidly re-dissolved so that the hypolimnion becomes charged with nutrients.

Throughout the summer period of stratification, dissolved nutrients collect in the hypolimninion of eutrophic lakes, to be mixed back into the rest of the lake at fall overturn. Thus fertile lakes have a nutrient retrieval and feedback mechanism, which is absent in oligotrophic lakes.

b. Lake Depth and Temperature

Temperature influences the fertility of lake. If a lake is cold, a high nutrient load can still fail to make it eutrophic and a relatively high influx of nutrients from the watershed merely results in rapid deposition of those same nutrients to oxic mud under and oxygen rich hypolimnion.

Deep and narrow lakes have large volumes of water in hypolimnion, compared to the wide shallow basins. A large volume of water implies a large oxygen reserve in the hypolimnion all summer, even though the surface waters are fertile, the deep lakes can retain the properties of oligotrophic lakes despite significant nutrient loadings from watershed. On the other hand, the broad and shallow lakes having small volume of water in the hypolimnion can easily function as a eutrophic lake.

Oligotrophic Vs Eutrophic lakes

Oligotrophic Lake	**Eutrophic Lake**
Concentration of dissolved nutrients is low.	Concentration of dissolved nutrients is high.
Water appears transparent or blue.	Water is turbid, opaque and green or brown.
Algal blooms at the surface are not visible.	There are dense algal blooms in the surface water with the possibility of floating mats of algae; dense shade cast by plankton of the surface water prevents the photosynthesis in the lower part of the water column.
Productivity is low	Productivity is high; community respiration and BOD is high.
Deep water retains oxygen at all seasons.	Deep water may become anoxic in summers.
Accumulation of nutrients in the hypolimnion during summer is low	Hypolimnion is enriched with nutrients in summer.
Sediment at mud-water interface is oxidized at all season.	Sediment at mud-water interface may be reduced in summer and settling nutrients may be re-dissolved.
Injection of nutrients to the surface water at fall overturn is low.	There is a strong fertilizing effect at fall overturn when the nutrient rich water is brought to the surface.
There is some plant production throughout the water column and on the water column and the mud surface.	No productivity is seen in the lower surface due to algal bloom during summer.

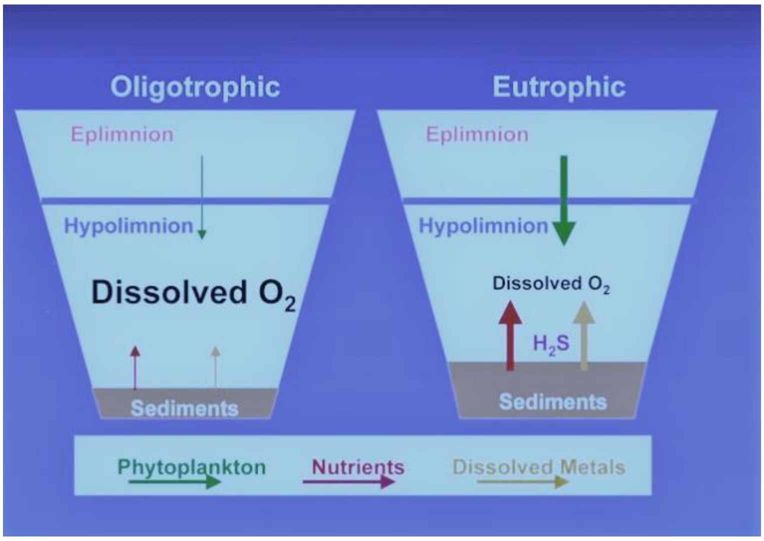


Fig.8: Oligotrophic Lake Vs Eutropic Lake

4.5. Langmuir Circulation and the Descent of the Thermocline

Within the epilimnion there is no change of temperature with the depth. Therefore, mixing currents must penetrate from the surface to the thermocline. These currents determine the depth of the thermocline and they force it deeper as a season progresses.

Langmuir circulation is an important generator of these currents. It was first discovered by Langmuir in the sea in the year 1938. Debris, particularly the torn-up remains of seaweeds from the rocky shores, floats in rows on the sea surface. These rows are parallel to the direction of the wind. According to Langmuir, the water current moves at the right angles of the wind and nudge the debris into rows. He suggested the following pattern of circulation:

- The wind tends to push the surface water along in the direction in which it was going, but this moving water has to be replaced.
- Part of the replacement is done by the water from behind, but some of it is replaced by the water coming from below.
- Therefore, the horizontal current of water is also accompanied by a vertical ascending current.

- At the same time, the water moving upward (upwelling) is replaced by the water that sinks (downwelling).

- This results in a system of up and down circular cells which is associated with the horizontal movement of water.

- When such system develops in a three dimensional water body, a series of helical circulation cells is formed, which is known as Langmuir circulation.

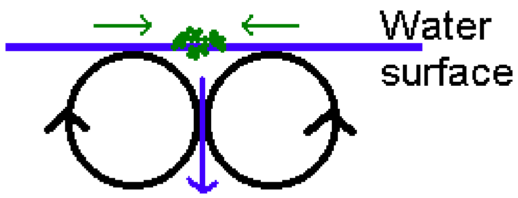


Fig.9: Formation of Circular currents associated with horizontal current

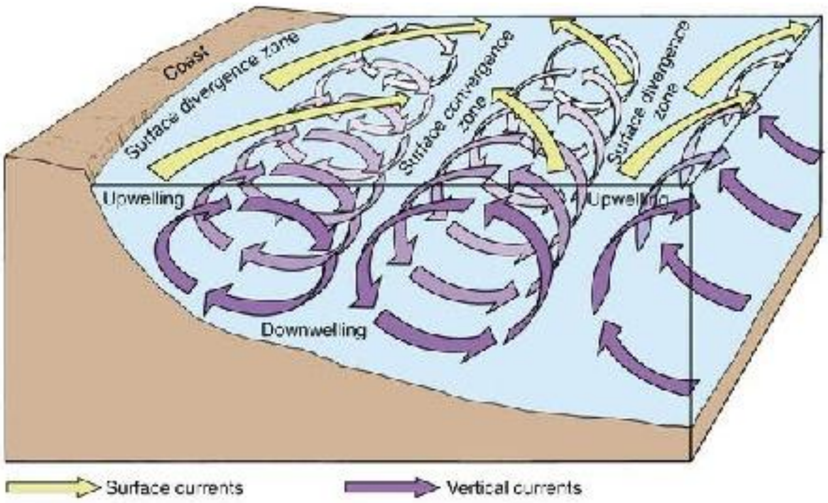


Fig.10: Langmuir circulation cells

The system of helical cells postulated by Langmuir, explain the lines of seaweeds, because these would collect where the horizontal water vectors met. Langmuir tested his hypothesis in larger lakes. He examined the current systems directly by using dies or natural density floats to plot the paths of the currents and their velocities. Downward currents where the cells merge were as high as 4 cm per sec, and the corresponding upward currents where the cells parted were as high as 1.5 cm per second.

Fig.11: Zone of convergence between the adjacent Langmuir circulation cells

The downward currents were found by Langmuir to extend to depths of up to 7 meters. This mechanism, accounts for the mixing of the waters of the epilimnion. When the wind blows strongly, the Langmuir circulation cells are set up in the surface water of lakes and they mix the warmed surface water with a thin layer lying immediately underneath. Because the underlying water is denser, the mixing process is resisted. But as the season progresses, a repeated pressure are exerted on the metalimnion by the descending currents of the Langmuir cells and the thermocline is driven down.

Thermal Stratification in Tropical Lakes

Tropical lakes with high surface temperatures (20^0C to 30^0C) exhibit weak gradients and little seasonal changes in temperature at any depth. Water density differences resulting from even slight thermal gradient, however, may produce a stable stratification on a more or less year-round basis. General circulation is irregular, occurring mostly in cooler seasons. Very deep tropical lakes tend to remain only partly mixed.

The hypolimnion in a lowland tropical lake is nearly always without oxygen. Oxygen deficits can be pronounced even in the epilimnion. This is partly due to high productivity because of high temperature and partly due to biological decomposition of the large inputs of organic matter from productive tropical ecosystems on the banks.

A typical jungle lake is therefore turbid, murky and opaque with high biological activity. These lakes may be overturned by exceptional storms or being flooded by cold rain or groundwater. Such lakes are known as '*oligomictic lakes'*. They may be stratified for weeks or months before there is a short lived episode of mixing.

In the high elevated tropical lakes, like in the equatorial Andes Mountains, cool climate exists without seasons but have alternation of 12 hours of day and 12 hours of night. Surface heating during day is partly counterbalanced by surface cooling at night. Therefore, the temperature gradient is slight with low temperature range where the density changes are least. The turnover frequency of such lakes is measured in hours and they are known as '*polymictic lakes*'.

4.6. Types of Lakes

Lakes across the world can be classified in various categories on different basis.

Classification on the basis of primary productivity:

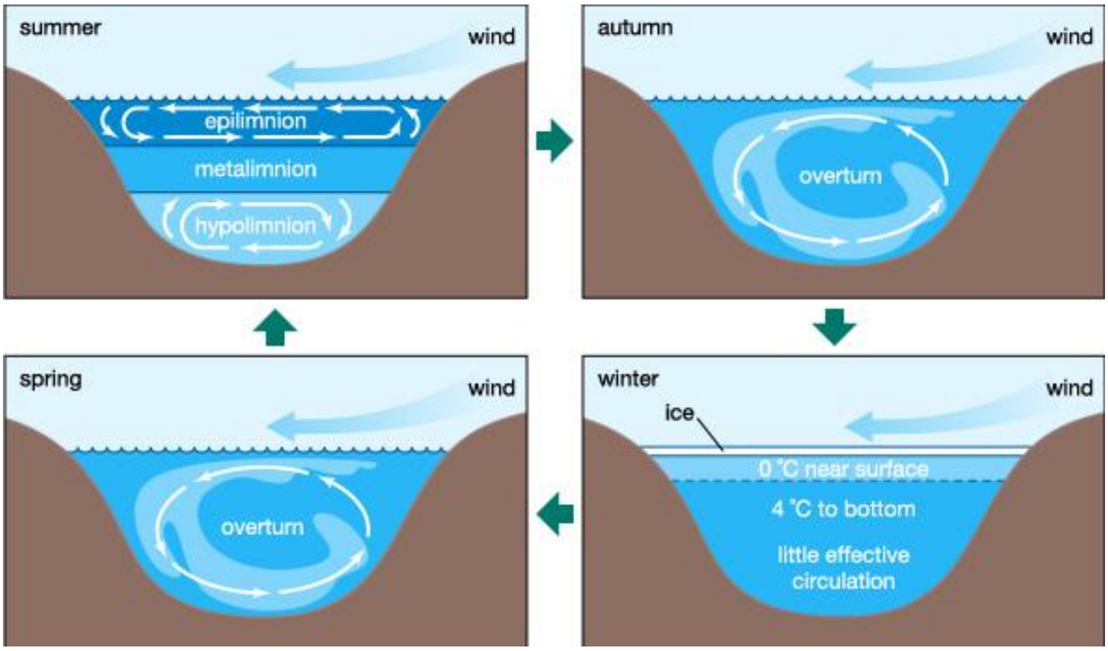
a. *Oligotrophic lakes:* These are deep with hypolimnion larger than epilimnion and have low primary productivity. Littoral plants are scarce and plankton density is low, although the number of species may be large; algal/planktonic bloom is rare, hypolimnion is not subjected to oxygen depletion; hence stenothermal. These lakes are considered as geologically young lakes. Cold water fishes are limited and characteristic to the hypolimnion. E.g., Great Lakes and Finger Lakes of New York.

b. *Eutrophic lakes*: These are shallower and have great primary productivity. Littoral vegetation is more abundant, plankton populations are denser, and 'blooms' are characteristics. Because of heavy organic content, summer stagnation may be severe enough to exclude cold water fishes. E.g., Lake Mendota

Fig.12 Eutrophic and Oligotrophic lake

Classification on the basis of the water circulation patterns:

a. *Dimictic Lakes*: Two seasonal periods of free circulation or overturns.



b. *Cold monomictic Lakes*: Water temperature is never above 4^0C (e.g. lakes of the Polar Regions); seasonal overturn in summer.

c. *Warm monomictic Lakes*: Water temperature is never below 4^0C (e.g. lakes of warm temperate or subtropical regions); one seasonal overturn in winter.

d. *Polymictic Lakes*: More or less continually circulating with only short stagnant periods. E.g. lakes of high altitude and equatorial regions.

e. *Oligomictic Lakes*: Rarely or very slowly mixed, thermally stable. E.g., Tropical lakes.

f. *Meromictic Lakes:* Permanently stratified, most commonly as a result of chemical difference in hypo and epilimnion waters. E.g. Big Soda Lake in Nevada.

Special Lakes:

a. *Dystrophic lakes*: brown water, humic and bog lakes. Generally have high concentrations of humic acid in water; bog Lake Shave peat-filled margins (where pH is usually low) and develop into peats.

b. *Deep, ancient lakes with endemic fauna*: Lake Baikal in Russia is the most famous ancient lake. It is the deepest lake in the world, was formed in the Mesozoic era. It has 384 species of arthropods 98% of which are endemic, 36 species of fishes of which 81% are endemic. This lake is also referred as "Australia of freshwater" due to its endemic fauna. However, it is now threatened by industrial pollution.

c. *Desert salt lakes*: Occurs in sedimentary drainage in arid climates where evaporation exceeds precipitation, thus resulting in salt concentration. E.g. Great Salt Lake, Utah. It contains community composed of few species which are able to tolerate high salinity. Brine shrimp (*Artemia*) are characteristic.

d. *Desert alkali lakes*: Occurs in igneous drainages in arid climates; high pH and concentration of carbonates. E.g., Pyramid Lake, Nevada.

e. *Volcanic lakes*: Acid or alkaline lakes associated with active volcanic regions and receive water from the magma. Have extreme chemical conditions and restricted biota, E.g., Some lakes in Japan and Philipines.

f. *Chemically stratified; meromictic lakes*: These are the permanently stratified lakes by the intrusion of saline water from the sediments, creating a permanent density difference between surface and bottom waters. In such lakes, the boundary between the circulating and non-circulating layer is known as '*chemocline'*. Free oxygen and aerobic organisms are absent in bottom water of such lakes. E.g., Big Soda Lake in Nevada and Hemmelsdorfer see lake in Germany

g. *Polar Lakes*: Surface temperature remains below 4^0C or rise above it for only a very brief period during ice-free summer when circulation can take place. Plankton population grows rapidly during summers, often storing fat for long winter.

Impoundments

These are the artificial lakes which are characterized by various fluctuating properties. They vary according to the region and to the nature of the drainage. Generally, they are characterized by fluctuating water levels and high turbidity. Production of benthos is often less in impoundments than in natural lakes.

The heat budget of impoundments may differ greatly from that of natural lakes, depending on the design of the dam. When water is released from the bottom, such as impoundments built on the dams designed for hydroelectric power generation, cold, nutrient rich but poor in oxygen content is exported downstream while warm water is retained in the lake. Such impoundment then becomes a heat trap and nutrient exporter whereas the natural lakes discharge from surface and therefore function as nutrient trap and heat exporters.

5. State of Freshwater Ecosystems in Present Scenario

Intensive human activity has significantly altered earth's freshwaters, with modifications that have impacted not only the physical and chemical properties but also biological features of the aquatic systems. It is well known now that the well-being of humans can be maintained only when the use of freshwater bodies is contained in certain boundaries.

5.1. Causes of Change in the properties of freshwater bodies

There are various reasons of the change in the properties of the aquatic systems. Some major causes are change in climate, alteration of water flow and direction, chemical inputs, land cover and land use alterations, aquatic invasive species and also the harvesting of the aquaculture product.

5.1.1. Climate Change

Increased temperature increases the variability of the precipitation and progressively results in rise in levels. For example, precipitation increased over land north of 30^0N since 1901 whereas decreased precipitation was observed over the land between 10^0S and 30^0N after 1970.

Increased precipitation and temperature has resulted in decreased extent of the glaciers which has increased the thawing of permafrost, local changes in the flow rate of the streams and levels of the lakes. At higher altitude, this increase results in change in the seasonality and magnitude of the water sources of rivers and lakes.

High temperature decreases the dissolved oxygen content in water affecting the respiration and processing of the organic matter and the pollutants. It also alters the niche and habitat for the organisms requiring cold water, e.g., Salmonid fish.

Rising sea level due to global warming can result in penetration of tidal water in the freshwater bodies altering their chemical properties and also deposition of silt causing decrease in light penetration.

5.1.2. Change in Water Flow

Since freshwater bodies are unevenly distributed on earth, various water management activities make attempt to counter this heterogeneity by diverting the water when in it is present in excess and also procuring for the time when it is lacking. This is done by developing irrigation channels, drainage, impoundments, groundwater pumping, levee construction, inter-basin water transfer, etc.

These manipulations along with climate change are greatly altering the water regimes of the global fresh water ecosystems. Reservoirs are having transforming effects on river, causing change in flow rate, fragmentation, and increased loss by evaporation, increased water standing time and also significant impact on the biological communities.

Over the past 20 years, dam construction has now picked up from developed to developing countries, e.g., China, India, and South America in the past 20 years.

5.1.3. Land-Use Change

Conversion of natural land into land of human use has impacted the ecosystem drastically. This is prominent for terrestrial ecosystem but alteration in the aquatic bodies is also being done especially for agricultural practices.

Agriculture uses maximum amount of freshwater and also emit maximum greenhouse gases, causes soil erosion and nutrient runoff into the freshwater bodies. It accounts for 52% CH_4 emission and 84% NO_2 emission. Heavy livestock involvement, croplands and the urban lands add excess nutrients, silt and toxic pollutants to the water bodies.

5.1.4. Changing Chemical Inputs

Chemical input in the freshwater systems is as a result of human activities in agriculture. Direct waste waters discharge from activities like mining, municipal sewage waste and industries also add chemicals to the fresh aquatic system. These activities add organic compounds, heavy metals, acids etc., to the water bodies which are toxic to the aquatic biota.

5.1.5. Aquatic Invasive Species

Intentional or unintentional introduction of biological species outside their native range affects the biological property of the aquatic systems at great length. Only few introduced species are able to self-sustain in the new environment, rest of the organisms become nuisance and harmful for the native species.

The species diversity of many of the freshwater ecosystems, are presently dominated by non-native species. e.g., the Laurentian Great Lakes have more than 180 non-native species which is rapidly increasing further.

The biological invasion has an impact on the physical chemical and the biological nature of the aquatic systems especially affecting the species biodiversity. Ross (1991) has reported that the introduction of new species has caused the reduction and elimination of native species in about 77% cases.

Non-native predatory sport fishes have become threat to endemic fishes in the western United States. Nile perch added to Lake Victoria resulted in extinction of more than hundred native haplochromine cichilids. Opossum shrimp (*Mysis relicta*) when introduced to Flathead Lake, Montana, disrupted the food web affecting the plankton, fish, bear, and eagle communities.

Spread of invasive freshwater species contributes to the biotic homogenization of freshwater ecosystems. These invasions are irreversible once established. Unlike chemical pollutants, which diminish with time, biological invasion establish and expand overtime.

5.1.6. Harvest

Fish farming is a valuable provision generated by freshwater ecosystems. Apart from fish, invertebrates (prawns, shrimps, etc.), amphibians, reptiles and birds are also harvested for local consumption, commercial use, pet trade and recreational use.

Freshwater ecosystem contributes to major global aquaculture production (approx. 68 million metric tons). This has led to overharvesting of wild fish for food, pollution, alteration in water flow and accidental biological invasions.

5.2. Impact of Change on Freshwater Bodies

The fresh waters have impact in many complex ways due the various changes described above. Change in physical features, bio-chemistry, biotic transformation, ecosystem metabolism and spread of diseases are few such impacts.

5.2.1. Physical Transformations

Construction of dam is the most conspicuous modifier of the riverine ecosystem. About 60% of the world's large river basins face alteration in their flow regime and hydrological connectivity due to construction of dams. Dams reduce the magnitude and the flow of water and stabilize the discharge pattern.

Agriculture affects the freshwaters by adding surface runoff thereby declining the stream flow.

Biogeochemistry and Nutrients

The chemical input in the water bodies result in the change in concentration of the key nutrients (N,P), organic and inorganic C, dissolved salts, sulphates and micro-pollutants. Nutrient rich runoff causes eutrophication.

SO_4, NO_3 and contaminants like mercury are introduced as atmospheric affluent. Many freshwater systems are becoming saline due to point discharge of effluents, tidal infiltration, irrigation etc. The changes in the chemical composition have major effect in the biotic community.

Biotic Transformations

About 10% of animal species and 1/3rd or the world's vertebral diversity is contributed by the freshwater ecosystem, which is about less than 1% of the earth's surface.

Direct and indirect change in the nature of the freshwater ecosystems alters its sensitive biota. Nutrient loading, sedimentation from non-point pollution sources, invasive species, altered flow regime have imperiled many freshwater taxa in North America. This in turn affects the ecosystem processes. For example, a change in the predation and competition results in alteration in habitat structure and species abundance.

Disease Occurrence and Transmission

Water is the major health determinant of human health. With altered physico-chemical and biological nature of water bodies, the risk of waterborne diseases increases in human population. This also occurs when people aggregate near water bodies due to scarcity of water.

Development of canals and irrigation system, deforestation, land use change and loss of biodiversity has resulted in increase in the number of parasites and disease vectors among human population. Resistant bacterial strains have increased significantly around aquaculture facilities. Eutrophication increases risk of infection by acting along other environmental stressors such as agrochemicals and weaken host resistance.

6. Summary

Fresh water ecosystem, unlike marine ecosystem with salt content, is most productive and diverse ecosystem ensuring wide range of utilities. Fresh water ecosystem is responsible for maintaining terrestrial ecosystem and brace marine ecosystem. Lentic ecosystem consists of stagnant water bodies with no exit flow. Due to this reason pollutants persist in the system. Physicochemical characteristics of water quality remain stable in lentic ecosystem. Productivity of this system is positively correlated with the seasonal changes. An important phenomenon of stratification is also observed in lentic bodies which results in creating different layers of water with different temperature, oxygen content and nutrient contents. When the lentic body is subjected to cooling or heating above 4^{o}C, condition of thermal stratification develops which prevents intermixing of different layers of water. Stratification plays a vital role in temperate region where temperature falls below 0^{o} C, keeping the aquatic life safely under the sheet of ice. When the ice melts, strong winds completely mix the waters of the lake and this phenomenon is known as 'spring-overturn'. Tropical lakes with high surface temperatures (20^{o}C to 30^{o}C) exhibit weak gradients and little seasonal changes in temperature at any depth. There are various communities thriving in different zones of the lentic bodies. In littoral zone communities, various types of producers are found like rooted, floating, submerged or combination of these. Similarly many varieties of consumers are also

found in littoral zone, these consumers can be algae eating crustaceans, insect larvae, small fishes, isopods, mayfly nymphs, dragon fly nymphs, pond snails, few species of beetles & hemipterans, few dipetran larvae, tadpoles, salamanders, turtles and snakes. Similarly the diversity of producers and consumers is found in limnetic zone. Algae, dinoflagellates, Euglenidae etc. constitute the phytoplanktons of the limnetic zone which may exceed the rooted plants in the primary productivity per unit area. When their number increases it causes "algal bloom" or phytoplankton's pulses. The consumers of limnetic zone consist of copepods, rotifers, *Cyclops*, crustaceans and fishes but their species is different from that of littoral zone. Profundal zone is devoid of light hence organisms of this zone are dependent on limnetic and littoral zone for food requirements. Bacteria and Fungi constitute the major community of this zone which is rich in nutrients. Consumers of this zone consist of blood worms, small clams and Phantom larvae. Lake Ecosystem consists of 98% of the total fresh water on the land. Stratification is also observed in Lake Ecosystem. The fertility of the lakes is set by concentration of the dissolved nutrients. Fertile lakes are known as 'Eutrophic lakes' and the infertile lakes as 'Oligotrophic lakes'. Algal blooms are observed on the surface of eutrophic lakes and hence their productivity and Biological Oxygen demand (BOD) is high. Phenomenon of upwelling and downwelling is also observed in a lake which helps in intermixing of warm and cold water current. A three dimensional helical circulation of water current made up of upwelling, downwelling, vertical and horizontal mixing of water forms Langmuir circulation. Lakes can be classified on the basis of primary productivity, water circulation pattern or due to special features. For healthy functioning of fresh water system, quality and quantity management of water resources is required. Climate change, biodiversity depletion, human settlements, chemical inputs, land use alterations, excessive utilization of water for agriculture and energy purposes has greatly affected the sound functioning of Freshwater Ecosystem. Sometime introduction of alien invasive species can also alter the biological property of the aquatic system and interfere with the biological chain and food web. Direct and indirect change in the nature of the freshwater ecosystems alters its sensitive biota. All these factors may become the cause of occurrence and transmission of human disease.