

## CHAPTER THREE

### AQUATIC ECOSYSTEMS

#### 3.1. Community Structure

Classes of organisms found in aquatic ecosystems can be categorized as **plankton, nektons and benthos**

##### 3.1.1. Plankton community

- The term plankton is derived from the Greek word “planktos”, meaning “drifter” to indicate their movement which is largely dependent on water currents.
- Plankton are any drifting organisms including animals, plants or bacteria that inhabit the pelagic zone of aquatic ecosystems.
- While some forms are capable of independent movement and can swim hundreds of meters **vertically** in a single day, their **horizontal** position is primarily determined by the surrounding water currents.
- They provide a crucial source of food to larger aquatic organisms such as fish. Moreover, they are important in the biogeochemical cycles of many important chemical elements including carbon.

In a plankton community two forms can be recognized: Holoplankton and Meroplakton:

- ❖ **Holoplankton:** are plankton such as most algae, copepods, salps and jelly fish spending their entire life as plankton are termed as holoplankton.
- ❖ **Meroplankton:** are those which are planktic only for part of their lives, such as the larval stages of fish, crustaceans, starfish, etc.

Plankton abundance and distribution are strongly dependent on factors such as

- ✓ Ambient nutrients concentrations,
- ✓ Physical state of the water column, and
- ✓ Abundance of other plankton.

Local abundance varies horizontally, vertically and seasonally primarily because of the availability of light.

The term

- “**Vertical**” refers to variation at different points along the depth (i.e. from top to bottom or bottom to up) and
- “**Horizontal**” refers to variation along the length or the width of the water body.

✍ All plankton ecosystems are driven by the input of **solar energy** (except the chemosynthetic forms), confining primary production to surface waters, and to geographical regions and seasons having abundant light.

✍ A secondary variable is **nutrient availability**. For example, although large areas of the tropical and subtropical oceans have abundant light, they experience relatively low primary production because they offer limited nutrients such as nitrate, phosphate and silicate resulting from large-scale ocean circulation and water column stratification.

#### TROPHIC GROUPS OF PLANKTON

Plankton can be divided into some functional or trophic level groups.

- ⇒ **Producer plankton** are those capable of transforming inorganic nutrients (CO<sub>2</sub> and O<sub>2</sub>) into organic materials (e.g. carbohydrates) using either sunlight (photosynthetic plankton) or chemical energy (chemosynthetic plankton).
  - These are therefore the primary producers in aquatic environments, which are equivalent to the “green plants” in terrestrial ecosystems.
- ⇒ **Heterotrophic plankton** are those which are not capable of converting inorganic substances into organic substances.
  - They can be either consumer or decomposer (recyclers). These major plankton categories (i.e. autotrophic and heterotrophic) are divided into functional or trophic level groups though the determination for some plankton may not be straightforward.

- For example, although most dinoflagellates are photosynthetic producers or heterotrophic consumers, many species are mixotrophic (i.e. both photosynthetic and heterotrophic) depending upon circumstances.

The following are the major categories of plankton:

- ✂ **Phytoplankton (microscopic plants),**
- ✂ **Zooplankton (microscopic animals) and**
- ✂ **Bacterioplankton.**

## PHYTOPLANKTON

Phytoplankton (from Greek phyton, or plant) are autotrophic, prokaryotic or eukaryotic algae that live near the water surface where there is sufficient light to support photosynthesis. They are plant like photosynthetic microorganisms adapted to live freely drifting within the main water body of aquatic systems such as freshwater, marine water and estuaries. They live, wholly or partly, in the open water and are carried by the water currents.

Phytoplankton are the main primary producers and hence energy sources in the aquatic food web and equivalents of plants in terrestrial food web. They are composed of organisms from different kingdoms and size groups.

- ❖ Among the more important groups are the diatoms, cyanobacteria, dinoflagellates and coccolithophores. Some phytoplankton are prokaryotic bacteria (cyanobacteria) while others are eukaryotic algae. They don't have differentiated plant structures such as roots, stems or leaves.

Phytoplankton (algae) show diversity in size and morphology. They can occur as single cell, colonial or filamentous forms, and can be motile or non-motile. They vary in size ranging from 0.2  $\mu\text{m}$  to 1 cm and which can be categorized into various size classes based on their cell size (diameter): picoplankton (< 2  $\mu\text{m}$ ), nanoplankton (2 – 20  $\mu\text{m}$ ), microplankton (20 – 200  $\mu\text{m}$ ) and macroplankton (>200  $\mu\text{m}$ ). Phytoplankton also show taxonomic diversity and the major divisions, for example, include Chlorophyta (green algae), Cyanophyta (blue-greens), Dinophyta (dinoflagellates), Bacillariophyta (diatoms) and so on.

### SOME BENEFITS OF PHYTOPLANKTON AS:

- ✚ Primary producers in aquatic food web
- ✚ They are food source; carbon dioxide recycles and oxygen release
- ✚ **Base of food web in the aquatic ecosystems**, providing energy sources for all organisms in the system.
  - The existence of the smallest animals or consumers (e.g. zooplankton) to largest mammals (e.g. whale) living in the water is due to the phytoplankton. Half of the photosynthetic production on earth is accounted for by the phytoplankton.
- ✚ **Play an important role in the global carbon-cycle.** Through photosynthesis, they fix carbon dioxide, the main greenhouse gas, and convert to organic carbon. In this process, they can consume carbon dioxide equivalent to that taken up by land plants and thus contribute a lot to regulation of global warming. During photosynthesis, they also release a lot of oxygen, which account for about half of the total amount of oxygen produced by all plants on earth.

## FOOD AND CHEMICAL SOURCES

Several species of phytoplankton have been used as food and valuable chemical sources. The *Cyanobacterium Spirulina* (Arthrospira), for example, is well known species used as food for humans and other animals due to its best nutritional qualities and as sources of chemicals of high pharmaceutical values.

- Spirulina contains rich sources of protein, accounting for up to 70% crude protein (of dry weight) with balanced proportion of amino acids. It also contains rich sources of vitamins (e.g. beta-carotene and B12), minerals (e.g. iron), fatty-acids (e.g. gamma-linolenic acid), essential amino acids and the pigment phycoerythrin.
- Due to these facts, WHO and other world organizations consider Spirulina as the best nutrition to combat hunger and malnutrition.
- Several big business companies around the world, Earthrise Nutritionals and Cyanotech in USA, for example, are currently engaged in producing and selling Spirulina as food supplements.
- Spirulina is abundantly found in some natural soda lakes of Ethiopia such as Lake Chitu.
- There are several other phytoplankton such as *Dunaliella*, *Haematococcus*, *Chlorella*, etc., which are widely cultivated to produce various high-value compounds such as carotenoids, beta-carotene (from *Dunaliella salina*) and astaxanthin (from *Haematococcus pluvialis*) and food supplements.

## BIOFUEL PRODUCTION

Algae-based biofuel production has now received worldwide interest in developing green economy using renewable and cleaner biofuel sources. It has been confirmed that, compared to terrestrial oilseed crops such as soybean and canola, algae are capable of producing **40 times** the amount of oil for biodiesel per unit area of land under controlled conditions. As a result, many algae biofuel companies are expanding rapidly around the world.

Some examples of algal genera or species with high oil content and potential for biofuel include *Botryococcus braunii*, *Nannochloropsis*, *Hantzschia*, *Chlorella*, *Scenedesmus*, *Cyclotella*, *Nitzschia*. These and others are cultured in various cultivation systems (open ponds or bioreactors) and their biomass harvested is used to produce biofuel including biodiesel, ethanol, methane, hydrogen and other hydrocarbon fuels.

## AS INDICATORS OF ENVIRONMENTAL CHANGES

Phytoplankton are sensitive and quickly respond to changes in water quality and thus can serve as bioindicators, a particular species or community that provide information on surrounding environment.

- ⇒ Occurrence of a particular species in high abundance, a phenomenon known as a **bloom**, indicates changes in water conditions. Dominance of a specific cyanobacterial species (*Microcystis*) in freshwaters, for example, is indicative of eutrophication and increase of temperature of the water body.
- ⇒ Eutrophication is an enrichment (excessive loading) of the water body with the major algal nutrients such as phosphorus and nitrogen, mainly caused by human activities. Such blooms have disastrous effects to the ecosystems:
  - ✓ blocking of penetration of light to the bottom,
  - ✓ causing fish kill due to depletion of oxygen caused by decomposition of the collapsed bloom,
  - ✓ releasing toxins to the water column,
  - ✓ impairing recreational activities and the like.

Some species of the phytoplankton such as certain dinoflagellates and blue-green algae (cyanobacteria) can produce harmful algal blooms with powerful biotoxins, which are toxic to aquatic as well as terrestrial animals including human beings.

- The phytoplankton diatoms are also often used as bioindicators for study of environmental conditions. Several diatoms are used as indicators of contemporary ecological conditions because of their ecological preference (tolerance) to certain environmental conditions such as turbulent water, nutrients, organic pollutions, salinity, pH and heavy metals.
- Benthic diatoms are often used for assessment of water quality in rivers and many indices have been developed to use diatoms as water quality indicators. In addition, diatoms are used to obtain information on past water quality or ecological conditions (reference conditions or earlier situations

when there was insignificant anthropologic influence) from lake sediment analysis of their fossils (palaeolimnological study).

- The formation of fossils of diatoms is because of their thick silica cell wall (frustule), which is resistant to biodegradation. Lake sediment diatom analysis is used to assess problems of surface water acidification, eutrophication and climate change.
- In general, the knowledge and information from the bioindicator species is useful to monitor the aquatic environment and to prevent or reduce the problems.

### **ALGAE-BASED WASTEWATER TREATMENT (BIOREMEDIATION)**

Phytoplankton are nowadays considered useful organisms in algae-based treatment of various kinds of municipal and industrial wastewaters. Some species like *Chlamydomonas*, *Scenedesmus*, *Chlorella*, *Pondorhina*, *Euridina*, etc. are living in wastewater (sewage water) and are important bioremediation agents. They are mainly useful to clean the water by supplying oxygen to the aerobic bacteria (decomposers) through photosynthesis and consuming the nutrients (mainly CO<sub>2</sub>, nitrogen and phosphorus materials) in the wastewater. In such systems, algae also remove toxic heavy metals and reduce odor from the wastes.

In general, studying phytoplankton is one of the basic and applied scientific fields, enabling one to entertain ecological, environmental and economic issues. Presently, increased deterioration of water bodies and climate change associated with increased pressure from human activities has further made phytoplankton studies of utmost importance.


### **SIZE CLASSES OF PLANKTON**


Many planktonic organisms are microscopic and a few also comprise organisms covering wide range of sizes including large organisms. Plankton are often described in terms of size as summarized in the following table.


<b>Group</b>	<b>Size range</b>	<b>Examples</b>
Megaplankton	2×10 <sup>-2</sup> m (20+ mm)	Metazoans such as jellyfish, ctenophores, salps & pyrosomes (pelagic tunicata), cephalopoda
Macroplankton	2×10 <sup>-3</sup> →2×10 <sup>-2</sup> m (2–20 mm)	Metazoans such as pteropods, chaetognaths, euphausiacea (krill), medusae, ctenophores, salps, doliolids and pyrosomes(pelagic tunicata),cephalopoda
Mesoplankton	2×(0.2 mm-2 mm) 10 <sup>-4</sup> →2×10 <sup>-3</sup> m	Metazoans such as copepods, medusae, cladocera, ostracoda, chaetognaths, pteropods, tunicata, heteropoda
Microplankton	2×10 <sup>-5</sup> →2×10 <sup>-4</sup> m (20-200 μm)	Large eukaryotic protests, most phytoplankton, protozoa (e.g. foraminifera), ciliates, rotifera, juvenile metazoans- crustacean (e.g. copepod nauplii)

Nanoplankton	$2 \times 10^{-6} \rightarrow 2 \times 10^{-5}$ m (2-20 $\mu$ m)	Small eukaryotic protists, small diatoms, small flagellates, Pyrrophyta, cryophyte, Chlorophyta, xanthophyte
Picoplankton	$2 \times 10^{-7} \rightarrow 2 \times 10^{-6}$ m (0.2-2 $\mu$ m)	Small eukaryotic, protists, bacteria, chrysophyta
Femtoplankton	$< 2 \times 10^{-7}$ m (<0.2 $\mu$ m)	Marine viruses

## ZOOPLANKTON

 Zooplankton (from Greek zoon, which means animal), small protozoans or metazoans (e.g. crustaceans and rotifers) that feed on other plankton. Eggs and larvae of some of the larger animals such as fish, crustaceans, and annelids are included here.

 They are the initial prey item for almost all fish larvae as they switch from their yolk sacs to external feeding. Fish rely on the density and distribution of zooplankton to match that of new larvae, which can otherwise starve.

 Natural factors (e.g., current variations) and man-made factors (e.g. river dams) can strongly affect zooplankton, which can in turn strongly affect larval survival, and therefore fish breeding success.

**BACTERIOPLANKTON** are bacteria and archaea which play an important role in remineralizing organic material down the water column.

### 3.3.2. Nekton and Benthic communities


- **Nektons** are organisms such as fish that can swim against the water current and control their position. They represent as secondary productivity in aquatic ecosystems.
- **Benthos** are those organisms inhabiting the bottom of the aquatic habitat.

## FUNCTIONAL FEEDING GROUPS

### AUTOTROPHIC GROUPS

Autotrophic organisms are producers that generate organic compounds from inorganic materials. These are largely phytoplankton (algae) that use solar or chemical energy to generate biomass from carbon dioxide.

Eg. **Photosynthetic organisms** are the major autotrophs in aquatic ecosystems whereas **chemosynthetic organisms** (e.g. some bacteria both photosynthetic or chemosynthetic) are largely benthic in aquatic ecosystems and aquatic rooted plants such as weeds contribute to aquatic primary production.

 **HETEROTROPHIC GROUPS:** These organisms derive their organic nutrient need from autotrophic organisms either as consumers or decomposers. Consumers are largely zooplankton and nektons such as fish whereas decomposers include some bacteria.

### 3.2. Autochthonous and Allochthonous Inputs

- ❖ **Autochthonous inputs** refer to the organic production within the water body as a function of the primary producers such as phytoplankton. This is the major source of organic supply to the life in the aquatic habitats.
- ❖ **Allochthonous input** refers to organic materials (such as leaves, branches and dead bodies) washed into the system. These inputs provide an important food source, especially where dense vegetation along the shore blocks out sunlight or high turbidity prevents light penetration.

### 3.1. HABITAT ZONATION'S

#### 3.1.1. Zonation in Freshwater Ecosystems

Deep lakes are often divided into some horizontal and vertical distinct zones.

❖ **Littoral zone** is shallow, well-lighted, warm water close to shore. It is usually rooted and floating plants flourish, but in some lakes aquatic plants (macrophytes) may be completely lacking, such as in circular, cone-shaped crater lakes. This is usually because of poor catchment or steep littoral.

**Its characterized by:**

- ✚ presence of rooted and floating vegetation,
- ✚ a diverse attached algae community, and
- ✚ a very diverse animal fauna including suspension feeders (e.g. clams),
- ✚ herbivorous grazers (e.g. snails), and
- ✚ herbivorous and carnivorous insects, crustaceans, fishes, amphibians, some reptiles, waterfowl, and mammals.

❖ **Photic (euphotic) zone** is the upper layer in the limnetic zone where light is sufficient enough for the rate of photosynthesis and to exceed the rate of respiration.

❖ **Aphotic (dark) zone** is the lower zone that receives little or no light, due to the absorption of light attenuation in the upper water column, and no photosynthesis occurs.

❖ **Limnetic zone** is the open, well-lighted waters away from the shore occupied by phytoplankton (algae and cyanobacteria) which are photosynthetic, zooplankton, higher animals and produces food and oxygen that supports most of lake's consumers.

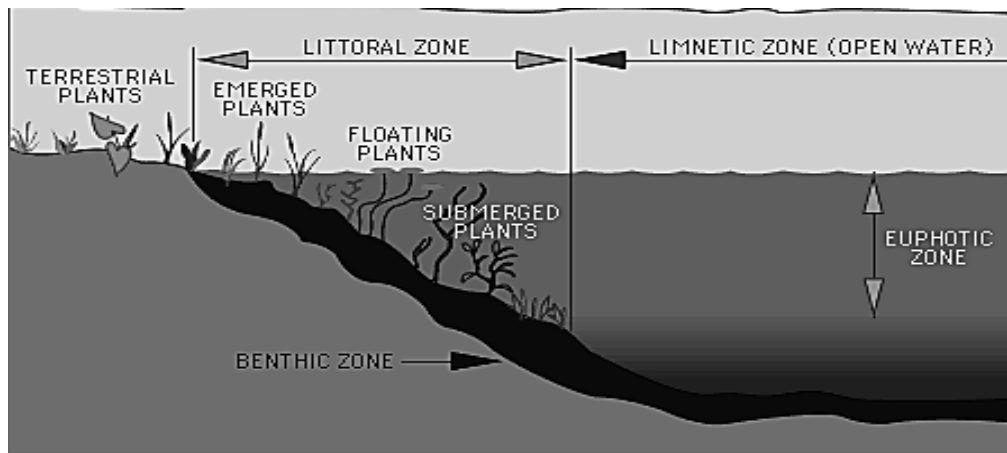
- This zone could be small or large, depending on the surface area of the lake.
- Zooplankton (rotifers and small crustaceans) that grazes on phytoplankton, and small fish that feed on the zooplankton.
- Occasionally large fish, turtles, snakes, and piscivorous birds are also seen in this zone.

❖ **Profundal zone** is the deep, aphotic zone lying beneath the limnetic zone where water temperature is usually cold.

- This is an area of decomposition where detritus is broken down; thus, oxygen is low and mineral nutrients are usually plentiful due to cellular respiration of decomposers.
- Waters of the profundal zone usually do not mix with surface waters because of density differences related to temperature. Mixing of these layers usually occurs twice each year in temperate lakes and ponds; this results in oxygen entering the profundal zone and nutrients being cycled into the limnetic zone.

❖ **Benthic zone** is the bottom of the lake and is inhabited by organisms that can tolerate cool temperatures and low oxygen levels.

- The food source is **detritus** which animals feed on in different ways. Diversity of animals and plants is low in this zone, but the abundance and biomass of a few species could be very high. Insect larva and some oligochaetes are abundant here.



**Fig.3.1.** The different zones in a lake

### 3.1.2. Zonation in Marine Ecosystems

There are several zones in the ocean based on

- ✎ depth of water,
- ✎ degree of light penetration,
- ✎ distance from shore and open water versus bottom area.

The marine ecosystems can be divided into various **horizontal and vertical** zones such as intertidal (littoral), neritic, oceanic, etc.

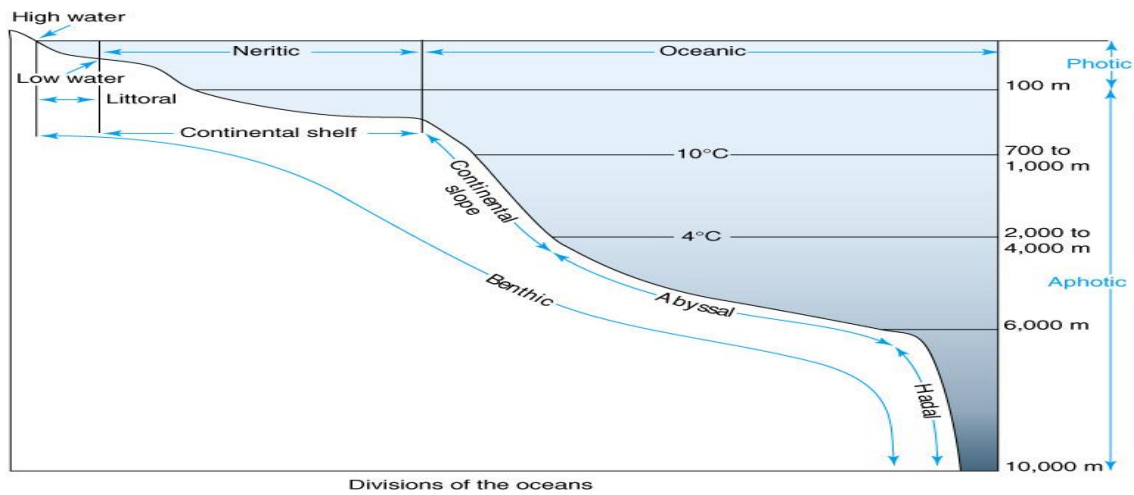
**Zonation** in marine communities include 5 general zones

1. **Intertidal zone:** is where land meets water. This zone is alternately submerged and exposed twice daily due to tides.
  - Animal and plant communities are subjected to huge daily variations in availability of saltwater and temperature.
  - Organisms are subject to mechanical forces of wave action because the habitat can be rocky or sandy.
  - Organisms have adaptations that enable them to survive periodic exposure to the air and wave action.
  - Examples for this zone include mangrove swamps, seagrasses, coral reefs and sandy beaches. These habitats all come with their unique challenges and are inhabited by a wide variety of organisms and some of these regions are quite productive.
  - Due to extensive human habitation in this zone, the biota is often destroyed by pollution, sedimentation and human activity.
  - These include
    - ✓ Mangrove,
    - ✓ Sea grass,
    - ✓ Coral reefs and
    - ✓ Rocky inter tidal zones.

- ✚ **Mangrove** is a marine habitat comprised of a number of salt-tolerant (halophytic) plant species, of which there are more than 12 families and 50 species worldwide.
  - ✚ Mangrove plants have a tangle of roots which are often exposed above water, leading to the nickname “walking trees.”
  - ✚ The roots of mangrove plants are adapted to filter salt water, and their leaves can excrete salt, allowing them to survive where other land plants cannot. Mangroves are important marine habitats providing food, shelter and nursery areas for fish, birds, crustaceans and other marine life.
  - ✚ **Seagrass** is a flowering plant (angiosperm) that lives in a marine or brackish environment. There are about 50 species of true seagrasses worldwide. Seagrasses are found in protected coastal waters such as bays, lagoons, and estuaries and in both temperate and tropical regions.
  - ✚ Seagrasses attach to the ocean bottom by thick roots and rhizomes, horizontal stems with shoots pointing upward and roots pointing downward.
  - ✚ Larger animals such as manatees and sea turtles feed on animals that live in the seagrass beds.
  - ✚ **Coral reefs** are marine habitats formed by hundreds of coral species found in the world’s oceans in littoral. There are **two types of corals**: hard corals and soft corals.
  - ✚ Only hard corals build reefs. While the majority of coral reefs are found in tropical and sub-tropical water within the latitudes of 30 degrees north and 30 degrees south, there are also deep-water corals in colder regions.
  - ✚ Coral reefs are complex ecosystems supporting a wide array of marine species. The largest and most well-known example of a tropical reef is the Great Barrier Reef in Australia.
- ✚ **Rocky intertidal zones** are vertically stratified and inhabited by organisms that possess structural adaptations that allow them to remain attached in this harsh environment.
  - ✚ The uppermost zone is submerged only by the highest tides and is occupied by relatively few species of algae, grazing mollusks, and suspension-feeding barnacles; these organisms have various adaptations to prevent dehydration.
  - ✚ The middle zone is exposed at low tide and submerged at high tide; many species of algae, sponges, sea anemone, barnacles, mussels, and other invertebrates are found in this area.
  - ✚ The diversity is greater here due to the longer time spans this area is submerged. Tide pools are often found in the middle zone.
  - ✚ These are depressions which are covered during high tide and remain as pools during low tide; tidepool organisms face dramatic salinity increases as water evaporates at low tide. The low intertidal zone is exposed only during the lowest tides and shows the greatest diversity of invertebrates, fishes and seaweeds.
- 2. The Neritic zone** extends beyond intertidal and includes shallow regions over the continental shelves.
- ❖ In warm tropical waters, this region contains coral reefs dominated by structure of coral itself. Coral reefs are formed by diverse group of cnidarians that secrete hard external skeletons made of calcium carbonate and are assisted in the process by photosynthetic symbionts living in the body wall (called zooxanthellae and zoochlorellae).
  - ❖ Primary productivity here depends on planktonic algae growing as deep as the light can reach. The neritic zone is very productive because currents and waves constantly and renew nutrients light penetrates to ocean floor allowing photosynthesis. But this zone is easily degraded by pollution, development and high-water temperatures.



3. **The oceanic pelagic zone** extends past continental shelves, can be very deep, is the open water and includes most of the ocean's water.
- ❖ This zone is constantly mixed by ocean currents and because there is no place to sit on, tiny floating plants and animals called plankton live in the lighted area (photic zone) here. Nutrient concentrations are generally lower than in coastal areas.
  - ❖ In this zone despite its diversity of life, primary productivity is much limited to the depths that light can reach.
  - ❖ The producers are planktonic algae that support secondary and higher consumers (e.g., fish) in the nekton. Besides plankton, this zone is home for a great variety of free-swimming animals (fish, large squid, sea turtles, marine mammals).
4. **The benthic zone** consists of the ocean bottom below neritic and oceanic pelagic zones (deep sea) includes the deepest, darkest, coldest parts of the ocean. In this zone are found unique habitats namely the **hydrothermal vents** that remained unknown until about 30 years ago, when they were discovered in the submersible Alvin.
- ❖ Hydrothermal vents are found at an average depth of about 7,000 feet and are essentially underwater geysers created as a result of cracks in the ocean floor due to the movement of plate tectonics. Ocean water enters these cracks, is heated up by the Earth's magma, and then released through the hydrothermal vents, along with minerals such as hydrogen sulfide.
  - ❖ The water coming out of the vents can reach incredible temperatures of up to 750 degrees F. Despite their threatening description, hundreds of species of marine life thrive in this habitat.
  - ❖ The main food source are the dead organic matter and nutrients "rain" down from above in form of detritus. The communities consist of bacteria, fungi, seaweed and filamentous algae, numerous invertebrates, and fish.
5. **The abyssal zone** is the deepest part of the ocean below 4 km and is **home of** deep benthic communities. Organisms here are adapted to continuous cold, high pressure (hydrostatic), low to no light (aphotic) and low nutrients.
- ❖ Despite these stresses, deep-sea also *hydrothermal vents* of volcanic origin are found here and some bacteria which can metabolize simple molecules such as  $H_2S$ ,  $CO_2$  are found here. These producers are called *chemoautotrophs*.
  - ❖ The abyssal zone is the bottom of the ocean basins which is relatively unvarying region largely inhabited by sparse populations of bottom-dwelling organisms that make up the benthos. T
  - ❖ here are consumers and decomposers which depend on the organic matter drifting down from the upper portions of the sea.



**Fig. 3.2.** Major zones in the oceans (note vertical and horizontal distribution)

### 3.4. AQUATIC ECOLOGY

#### 3.4.1. Abiotic Components

Abiotic factors such as temperature, precipitation, and light influence the distribution of organisms. The patchiness of the global biosphere illustrates how the different physical environments produce a mosaic of habitats.

#### 3.4.2. Functional Feeding Groups

##### Autotrophic Groups

- ✚ Autotrophic organisms are producers that generate organic compounds from inorganic materials. These are largely phytoplankton (algae) that use solar or chemical energy to generate biomass from carbon dioxide.
- ✚ Photosynthetic organisms are the major autotrophs in aquatic ecosystems whereas chemosynthetic organisms (e.g. some bacteria) are largely benthic in aquatic ecosystems.
- ✚ Aquatic rooted plants such as weeds and also some bacteria (photosynthetic and chemosynthetic bacteria) also contribute to aquatic primary production.

##### Heterotrophic Groups

- ✚ Heterotrophic organisms derive their organic nutrient need from autotrophic organisms either as consumers or decomposers. Consumers are largely zooplankton and nektons such as fish whereas decomposers include some bacteria.
- ✚ Primary production in the pelagic zone of the oceans is the result of photosynthetic activity of phytoplankton.
- ✚ Zooplankton graze on smaller phytoplankton. Phagoplankton are another form of heterotrophic forms of plankton assimilate dissolved organic material from the water.
- ✚ The oceanic food web is largely plankton-based whereas in freshwaters (e.g. some lakes, rivers and streams) food web weeds are also important bases in addition to phytoplankton.

✚ Zooplankton and phagoplankton are, in turn, consumed by small invertebrates and fish.

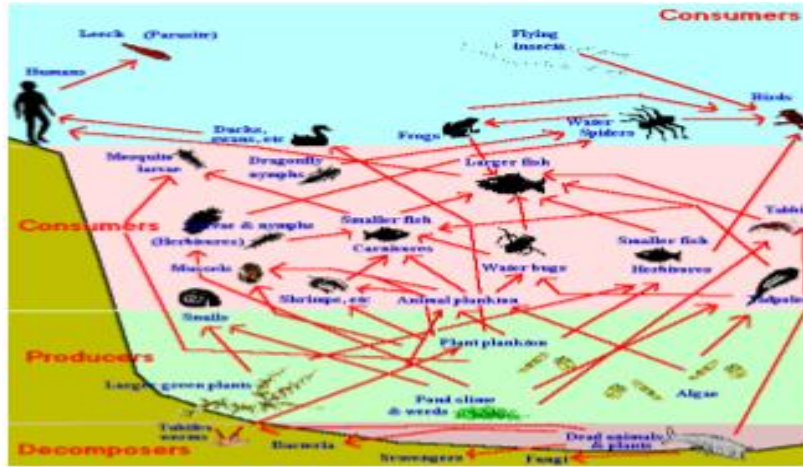


Fig. 3.3 General Representation of Aquatic food web

### 3.5. Catchments/Drainage Basins

✂ Catchment (also known as drainage basin) is an area of land where water drains down into water bodies such as river, lake, wetland, seas and oceans.

✂ Catchment characteristics (also known as catchment factors) are important factors that affect various aspects of the water body located in the basin.

i. **Catchment geomorphology** (rock or soil type) influences the water quality characteristics, such as the nutrients, total suspended solids (TSS) and conductivity, of the water body (river or lake) located in the basin.

✂ For instance, if the soil of the catchment is a lime stone, electrical conductivity of the aquatic ecosystem increases because of the dissolution of carbonate minerals

ii. **Catchment size** is also important in determining the characteristics of the water bodies located in the catchment area.

✂ Catchment size helps determine the amount of water reaching the river, as the larger the catchment the greater the potential for flooding. Moreover, the bigger the catchment means relatively there will be more contact with soil before water reaches the lake.

✂ Catchments are thus important elements to consider in ecology because as water flows over the ground it can pick up nutrients, sediment, and pollutants that can affect the ecological processes along the way as well as in the receiving water source.

iii. **Catchment topography and shape:-**


✂ Determine the speed of run off to the river. Run off from mountainous areas reach the river faster than from flat or gently sloping areas and a long thin catchment will take longer to drain than a circular catchment.

✂ The catchment soil type determines the amount of water that reaches the river. Sandy soils are very free draining and rainfall on sandy soil is likely to be absorbed by the ground.

✂ However, soils containing clay can be almost impermeable and therefore rainfall on clay soils will run off and contribute to flood volumes.

✂ Catchment vegetation cover is important in reducing surface run off into the water body from the catchment area and thus contributes to good water quality of the water body.

✂ Type of catchment land use can affect the receiving water body in many ways. They contribute to the volume of water reaching the river.

 More over human practices such as farming, cattle grazing, and industries of various types all can contribute to some sort of pollutants that can reach the water body.

## Chapter 4: Water Pollution

### 4.1. What is Water Pollution?

- ✚ Various definitions exist water pollution. Some, for instance, define water pollution as: “the introduction by man, directly or indirectly, of substances or energy into the aquatic environments resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to aquatic activities, including fishing, impairment of water quality with respect to its use in agriculture, and often economic uses”.
- ✚ Others define water pollution as a “state resulting when substances are released into a body of water, where they become dissolved or suspended in the water or deposited on the bottom, accumulating to the extent that they overwhelm its capacity to absorb, break down, or recycle them, and thus interfering with the functioning of aquatic ecosystems”.
- ✚ Given the various ways of defining water pollution, it, however, refers to the contamination of both the surface water and groundwater.
- ✚ Surface water resources are more vulnerable to pollution. Moreover, factors that lead to surface water pollution may not lead to groundwater pollution and vice versa. Also the management of groundwater pollution is more difficult.

### 4.2. Sources of Water Pollution

- ❖ Water pollution can occur due to natural or anthropogenic (i.e. human induced) factors. Natural factors such as dissolution of rocks and evaporation lead to increased salinity and introduction of heavy metals such as Pb, Hg, Cd and As.
- ❖ The high fluoride content in drinking water leads to conditions such as dental and bone fluorosis whereas the heavy metals are toxic both to human and the environment in various ways.
- ❖ Industrialization and agricultural activities amalgamated with an alarmingly increasing human population are among the anthropogenic factors that significantly contribute to water pollution. According to the World Population Prospects (2008) the current (2010 G.C.) human population is estimated to be nearly 7 billion, which is projected to reach 9 billion by 2050.
- ❖ At present water pollution is becoming such a serious problem in that every continent, from the tropics to the once-pristine polar regions, is getting contaminated.
- ❖ The human induced water pollution comes from a number of different sources. If the pollution is from **a single source**, such as an oil spill or a factory discharging its waste through a pipe into a water body, it is called point-source pollution.
- ❖ On the other hand, if the pollution is caused from **many sources**, it is called nonpoint-source (diffuse) pollution.
- ❖ Point-source pollution often affects the area immediately around the source. For example, when a tanker accident occurs, the oil spill is concentrated around the tanker itself.
- ❖ This is, however, less likely to happen with nonpoint source pollution since the pollutants enter the environment from many different places.
- ❖ Sometimes pollutions, such as nuclear or radioactive waste, may affect the environment hundreds of miles away from the source; this is called trans boundary pollution.

### 4.3. Types of Water Pollutions and the Contaminants

- ❖ A particular pollution source usually produces a mix of water pollutants. For instance, a waste originating from industries could consist of chemicals such as heavy metals, oils, microorganisms, etc.
- ❖ Moreover, a given pollutant could come from more than one type of pollution sources. However, for the sake of simplicity we categorize types of water pollutions and the major contaminants as presented below.

### **1. Domestic and Industrial Pollution**

- ❖ Domestic activities such as washing and toilet flushing, and industrial activities such as manufacturing processes in industries produce a wastewater that contains waste products collectively known as sewage.
- ❖ Sewage is thus a water-carried waste, in either solution or suspension, that is intended to flow away from a community.
- ❖ Wastewater is largely pure water and is characterized by its volume or rate of flow, its physical condition, its chemical constituents, and the bacteriological organisms that it contains.
- ❖ Sewage practically contains various types of substances including the pharmaceutical drugs, papers, plastics, and other wastes humans flush down their toilets and factories.
- ❖ Moreover, it often carries harmful micro-organisms such as viruses and bacteria into the environment causing health problems such as hepatitis, typhoid, and cholera.
- ❖ Sewage especially from industries may also contain chemicals such as heavy metals including lead and mercury that are harmful to the health of many animals, including humans.
- ❖ Heavy metals draw attention in that their concentration increases high up in food chain, a condition known as bioaccumulation or bioamplification. The effect of heavy metals is thus highly pronounced at higher trophic levels such as in human being.
- ❖ If suitably treated and used in moderate quantities, sewage can be a fertilizer: it returns important nutrients to the environment, such as nitrogen and phosphorus, which plants and animals need for growth. The trouble is, sewage is often released in much greater quantities than the natural environment can cope with. Untreated sewage can contaminate the environment and cause diseases such as diarrhea.
- ❖ Sewage management or disposal is a major problem in developing countries as access to sanitary conditions and clean water in these areas is scarce.
- ❖ Sewage in developed countries is carried away from the home quickly and hygienically through sewage pipes to be treated in water treatment plants and ultimately disposed into the aquatic environments. However, the dumping of sewage into seas and oceans still remains a serious environmental problem especially in developed countries.

### **2. Agricultural Pollution**

- ❖ Agricultural activities cause the pollution of water through the addition of pesticides, herbicides and nutrients with surface run-offs as described below.

#### **Pesticides and Herbicides**

- ❖ Pesticides and herbicides are chemicals that are used in farming to control insects, weeds and fungi. These chemicals enter water bodies with run-offs causing poisoning of aquatic life such as fish. Subsequently, birds, humans and other animals may be poisoned if they eat infected fish.
- ❖ The high concern with these chemicals is that, similar to the heavy metals, tend to bioaccumulate in nature.

#### **Nutrients**

- ❖ Chemical fertilizers used by farmers add nutrients such as nitrogen (in the form of nitrates) and phosphorus (in the form of phosphates) to the soil which when run-off into nearby lakes, rivers, or oceans cause an increase in nutrient levels of the water bodies.

- ❖ Nutrients are basically essential for plant growth and development. However, the excessively high nutrient enrichment of the water bodies causes a massive increase in the growth or bloom of algae or plankton, leading to a condition known as **eutrophication**. Eutrophication can be a problem to the aquatic habitats in various ways.
- ✚ The bloom of algae may also block sunlight from photosynthetic aquatic plants found at lower depth. Sunlight blocking also has an effect on visual dependent predators living at relatively lower depths.
- ✚ It is important to bear in mind, however, that eutrophication is basically a natural process that can develop because of the vertical mixing of the water bodies (which upwells nutrients from the bottom) and with the ageing of the water bodies, often leading to high aquatic productivity including high fish production. It becomes catastrophic when accelerated because of the human induced activities.

### 3. Oil Pollution

- ❖ Oil pollution is caused by oil spills from tankers, shipping, dumping from factories and surface run-offs. However, the latter three factors account for the larger proportion of oil pollution.
- ❖ Oil spills cause a localised problem but can be catastrophic to local aquatic wildlife such as fish and aquatic birds. Oil cannot dissolve in water and thus forms a thick layer in the water.
- ❖ It consequently suffocates fish, gets caught in the feathers of marine birds stopping them from flying and blocks light from photosynthetic aquatic plants.

### 4. Atmospheric Deposition

- ❖ Atmospheric deposition is the pollution of water caused by air. Anthropogenic activities such as coal mining and smelting of ores (e.g. sulfide) cause the pollution of air with products that would subsequently lead to the formation of acids such as sulfuric acids, carbonic acids and nitric acids as shown in the chemical reaction below.
- ❖ These acids will reach into the aquatic environments with the rain, called acid rain.



- ❖ It is important to note that human activities can also cause direct acidification such as through addition of battery acid in to water bodies. Acidification of aquatic environments has a sterilizing effect on water as fishes become too weak to survive, and lose their capacity to reproduce normally.
- ### 6. Thermal Pollution
- ❖ This is an increase in water temperature as a result of discharge of hot effluents from sources such as factories and power plants into the water bodies especially into the rivers or naturally caused by global warming.
  - ❖ Global warming is a process where the average global temperature increases due to the greenhouse effect. The burning of fossil fuel releases greenhouse gasses, such as carbon dioxide, into the atmosphere causing heat from the sun to get 'trapped' in the earth's atmosphere and consequently the global temperature rises.
  - ❖ An increase in water temperature can result in the death of many aquatic organisms and disrupt many aquatic habitats. For example, it can cause bleaching of coral reefs around the world. Coral reef bleaching is when the coral expels the microorganisms of which it is dependent on.

### 6. Suspended Matter Pollution

- ❖ Suspended matter in water bodies basically consists of clay, silt, sand, organic compounds, plankton and other microscopic organisms.
- ❖ Such particles vary in size from approximately 10 nm in diameter to 0.1 mm in diameter, although it is usually accepted that suspended matter is the fraction that will not pass through a pore diameter size of 0.45 μm filter.

- ❖ Suspended matter often originates from surface of the catchment area, eroded from river banks, lake or ocean shores and re suspended from the bed of the water body. Suspended matter can be detrimental to the aquatic environments in various ways. For instance,
  - ❖ Suspended matter may be responsible for transporting pollutants such as heavy metals.
  - ❖ The suspended matter causes the water to become cloudy limiting the depth of sunlight penetration. This hampers aquatic photosynthesis which in turn can disrupt the functioning of the whole aquatic ecosystem.
  - ❖ The suspended particles can cause siltation at the bottom which is harmful to the benthic aquatic life.
  - ❖ Toxic chemicals suspended in water can be harmful to the development and survival of aquatic life.
  - ❖ When land is cleared of forests, it not only destroys the habitat, but also it can affect the area in other ways. The cleared land becomes exposed, without roots of plants to hold on to the soil, wind and rain will move large amounts of soil from the ground into water bodies, polluting the water.

## **7. Radioactive wastes pollution**

- ❖ The radioactive (nuclear) wastes largely originate from developed countries and carried around the world when dumped into the sea. The following are some of the major sources of nuclear (radioactive) wastes:
  - ❖ Nuclear-fuel reprocessing plants such as in northern Europe (England & France) are the biggest sources of man-made nuclear wastes in the surrounding ocean. Radioactive wastes from these plants have been reported to pollute the downstream countries such as Norway and Ireland. Reports also indicate that traces of radioactive pollution have been found as far away as Greenland.
  - ❖ Mining and refining of uranium and thorium are also causes of marine nuclear wastes.
  - ❖ Radioactive wastes are also produced in the nuclear fuel cycle which is used in many industrial, medical and scientific processes.
  - ❖ Nuclear wastes can have serious detrimental effects on aquatic habitats especially the marine habitats which are the main targets. They can cause cancer and other diseases at lower concentrations and death at higher concentrations. Nuclear wastes can also be threat to the groundwater when injected deep into the earth as an alternative way of dumping them.

## **8. Alien (exotic) species**

- ❖ Most of the time our perception of water pollution involves things like sewage, toxic metals, or oil spill etc However, the introduction of alien species into a given water body can cause a serious problem both on the organisms naturally living in that water body and the aquatic habitats.
- ❖ Alien species (sometimes known as invasive species) are animals or plants from one region that have been introduced into a different ecosystem where they do not belong.
- ❖ Outside their normal environment, they have no natural predators so they rapidly run wild, crowding out the usual animals or plants that thrive there.
- ❖ Alien invaders can cause economic loss when they affect the aquatic habitat or its biota. A fish known as common carp has been introduced to some of the Ethiopian waters but are generally described invasive in most of the countries.

## **9. Forests and Water Quality**

- ❖ Forests make a significant contribution to maintaining high water quality in watersheds by preventing soil erosion.
- ❖ Forests are more effective than other types of land cover in preventing erosion as roots, undergrowth and forest litter trap sediment.

- ❖ Especially on slopes, trees play a key role in preventing landslides and downward soil movements, lessening the impact of raindrops with their lower canopy leaves.
- ❖ Pollution from diffuse sources i.e. non-point source pollution, such as industrial and agricultural activities, can be reduced by maintaining forests in riparian zones along watercourses.
- ❖ In contrast, deforestation increases the flow of surface water and transports sediment to streams, silting them up and affecting water quality downstream.
- ❖ Forests can protect watersheds from pollution, caused by chemicals from agriculture and industry, or heavy concentrations of organic matter, which cause eutrophication.

## Chapter 5: Water Quality Assessment

### 5.1. Water Quality

- ❖ Owing to the complexity of factors determining water quality and the purpose of water quality requirement, it can be difficult to give simple definitions for water quality.
- ❖ Nevertheless, water quality can be defined as “a measure of the condition of water in terms of one or more of its physical, chemical and biological characteristics relative to the intended use”.
- ❖ Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, use of water bodies as a heat sink, and overuse.
- ❖ It is most frequently measured by reference to a set of guidelines and standards against which compliance can be assessed as described below in section 5.2.
- ❖ Water quality requirement is generally applicable in various purposes, such as drinking water supply, industrial use, agricultural (irrigation) use, swimming, boating, and aquatic life and fisheries.

### 5.2. Water Quality Assessment Parameters

- ✚ Water quality assessment refers to the overall processes of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect health of the aquatic system itself.
- ✚ There exist a large number and complex factors that determine water quality, giving us large choice of variables used to describe water quality in quantitative terms.
- ✚ The appropriate choice of variables for any water quality assessment depends on the objectives of the assessment.
- ✚ Broadly water quality assessments can be divided in to two categories: **use-oriented and impact oriented**. Use-oriented assessments test whether water quality is satisfactory for specific purposes, such as drinking water supply, industrial use, agricultural (irrigation) use and aquatic life and fisheries.
- ✚ Many waters use have specific requirements with respect to physical, chemical or biological factors. Thus, the quality of water required for a prescribed water use is often defined by guidelines (recommended concentrations) or standards (mandatory concentrations) or maximum allowable concentrations of the contaminants.
- ✚ The World health organization (2008) of the United Nations (UN) has guidelines and standards for various water uses though the concentrations for some variables could vary from country to country.
- ✚ Variables of water quality can also be selected in relation to pollutant sources such as sewage and municipal wastewater, agricultural activities, industrial effluents and emissions, atmospheric sources, etc.
- ✚ Basically, a continuous measurement of water quality parameters is important but in practice this is impossible for financial, technical and logistic limitations.



- ✚ Thus, discrete samples because such samples that constitute only a minute fraction of the whole body of water under investigation should be used, and because they are only representative of conditions at the particular time of sampling the interpretation of data arising from such samples requires great care.
- ✚ Generally, factors used in water quality assessment can be categorized as **physico-chemical and biological factors**.

### 5.2.1. Physico-chemical Parameters

- ❖ Some of the physico-chemical parameters such as temperature, pH, dissolved oxygen, conductivity, water turbidity or transparency can be made simply on site in direct contact with the water source in question.
- ❖ These are measured using portable water test kits. If portable meter kits are not available, it is also possible to measure some parameters such as dissolved oxygen and conductivity using lab procedures.
- ❖ Others such as total biochemical oxygen demand (BOD) suspended solids (TSS), total dissolved solids (TDS), nutrients such as phosphates, nitrates, nitrites and ammonia, and metallic and non-metallic elements are necessarily measured in a laboratory setting. Below only some of the physico-chemical parameters used in the assessment of water quality are discussed.

#### 1. Turbidity

- ✚ Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended material in water.
- ✚ It can be measured by using a device known as **turbidimeter**. This instrument measures the amount of scattered light in a water sample, and in general scattering intensity increases with particle concentration.
- ✚ The preferred unit to express turbidity is the nephelometric turbidity unit (NTU). The turbidity of a water in-situ (i.e. on site) can also be indirectly inferred from measurements of water transparency.

#### 2. Water Transparency

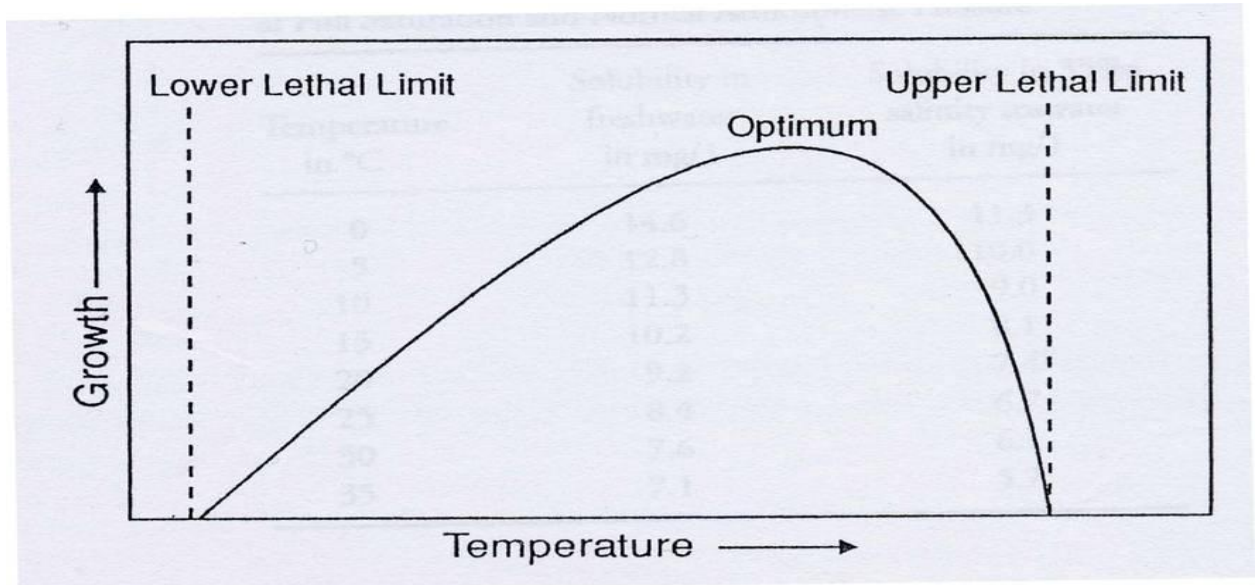
- ✚ Water transparency is measured using a **secchi disk**. Secchi disk is a circular disc of usually 20-30 cm in diameter and often painted with black and white sectors. However, the disc diameter does not affect the measurement of water transparency.
- ✚ Water transparency is measured by lowering a secchi disk on a calibrated cable into the water until it just disappears and then retrieved until it reappears.
- ✚ The depth at which it reappears during retrieval is recorded as a depth of water transparency or secchi depth. Transparency is primarily used as an estimation of primary productivity or phytoplankton biomass.



Fig 6.1. (a) A secchi disc with its cable (b) A secchi disc lowered into water body

### 3. Temperature

- ✚ Aquatic organisms are cold-blooded animals. They can modify their body temperature to the environment in normal condition.
- ✚ Each species has a characteristic **temperature range** of optimal feeding, metabolism, growth with **upper and lower lethal limits**.



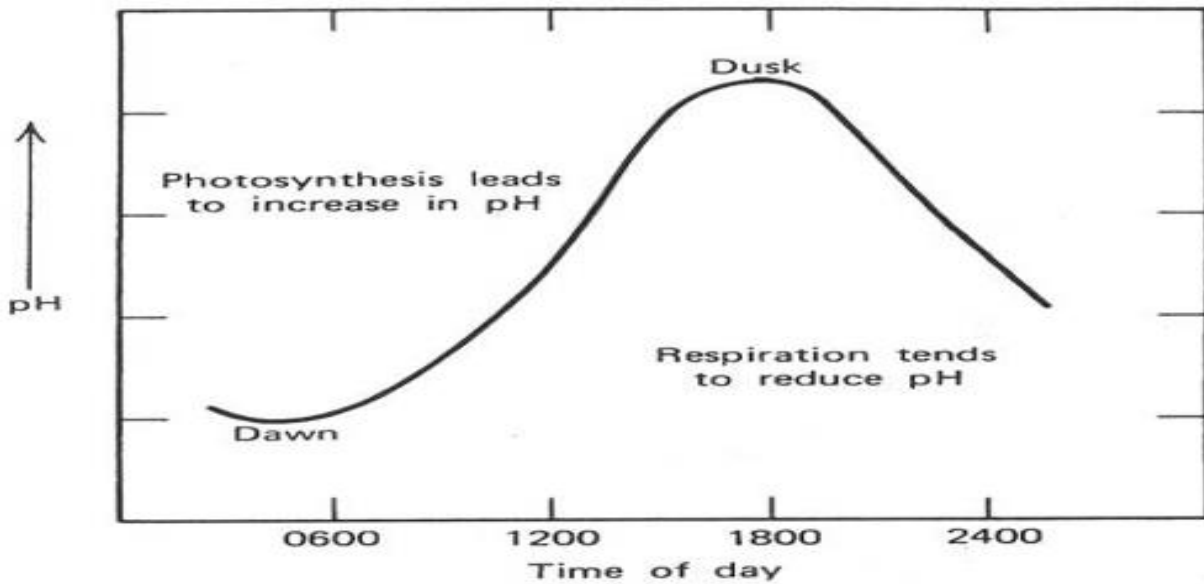
- ✚ Temperature is an important parameter in natural surface water systems.
- ✚ Temperature of surface waters governs to a large extent the biological species present and their rates of activity.
- ✚ Temperature has an effect on most chemical reactions that occur in natural water systems. Temperature also has a pronounced effect on the solubility of gasses in water.
- ✚ An increase in water temperature favours the conversion of ammonium ion ( $\text{NH}_4^+$ ) into ammonia ( $\text{NH}_3$ ) which is toxic to the aquatic life including fish. Temperature is often measured by a digital temperature meter.

### 4. pH

- ✚ **pH** is the way of expressing the hydrogen ion activity as a measure of acidity of the water. At a given temperature the intensity of the acidic character of a solution is indicated by **pH** as:  $\text{pH} = -\log [\text{H}^+]$ .
- ✚ **pH** scale is usually represented as ranging from 0 to 14, with **pH 7** at 25°C representing absolute neutrality, less than 7 represents acidity and greater than 7 represents basicity.

#### water pH fluctuation over 24-hr period

- ✚ pH diurnal fluctuation pattern that is associated with the intensity of photosynthesis. This is because carbon dioxide is required for photosynthesis and accumulates through nighttime respiration.



- ✚ pH of the aquatic habitats could vary on a daily basis. During the day time (when concentration of CO<sub>2</sub> is relatively less due to more photosynthesis) pH may rise and during night time (when CO<sub>2</sub> concentration is relatively high due to less photosynthesis) it may fall beyond the optimal level and that, in turn, can increase the concentration of the toxic ammonia (NH<sub>3</sub>).
- ✚ Water pH is measured on site using digital pH meters.
- ✚ Water conductivity depends on the presence of ions or salts, their concentration and mobility, and temperature. It is measured using conductivity meter on site and expressed as μmhos/cm or μS/cm. Conductivity is measured as an estimate of dissolved charged atoms or molecules. It is thus used to estimate the total dissolved solids TDS (in mg/L) by multiplying it by a certain conversion factor. Pure water often has less conductivity than polluted water.

## 6. Nitrogen

- ✚ Nitrogen is an essential nutrient for algal growth. Nitrogen in water bodies can be measured in the form of nitrogen containing compounds such as ammonia (NH<sub>3</sub>), nitrate (NO<sub>3</sub><sup>-</sup>) and nitrite (NO<sub>2</sub><sup>-</sup>) following standard laboratory procedures.
- ✚ It is expressed as μg/L or mg/L. In the presence of oxygen, ammonia can be converted by microorganisms known as nitrosomonas to **nitrite**, which in turn is oxidized by nitrobacter to **nitrates** as shown below.



## 7. Phosphate

- ✚ Phosphorus, together with nitrogen is an essential nutrient for algal growth, and when in excess it is one of the leading causes of eutrophication.
- ✚ The primary sources of phosphorus in natural systems include waste water treatment facilities, runoff of fertilizer from agricultural operations, detergents and some natural sources. It is expressed as μg/L or mg/L.
- ✚ Orthophosphates and polyphosphates are the most common forms of inorganic phosphorus found in natural waters.
- ✚ Orthophosphates contain a single phosphorus molecule, and common orthophosphates include trisodium phosphate (Na<sub>3</sub>PO<sub>4</sub>), disodium phosphate (Na<sub>2</sub>HPO<sub>4</sub>), monosodium phosphate

( $\text{NaH}_2\text{PO}_4$ ), and diammonium phosphate ( $(\text{NH}_4)_2\text{HPO}_4$ ). Polyphosphates contain multiple phosphorus molecules, and examples include sodium hexametaphosphate ( $\text{Na}_3(\text{PO}_3)_6$ ), sodium tripolyphosphate ( $\text{Na}_5\text{P}_3\text{O}_{10}$ ), and tetra sodium pyrophosphate ( $\text{Na}_4\text{P}_2\text{O}_7$ ).

- ✚ These are measured using standard laboratory procedures to give a measure of phosphorus in water.

## 8. Dissolved Oxygen (DO)

- ✚ Natural levels of dissolved oxygen in surface waters range from 7 mg/L to 14 mg/L, depending on temperature, salt concentration, and the amount of biodegradable organic matter.
- ✚ When organic pollution is present, for example, due to a combined sewer overflow, microorganisms in the water utilize the available oxygen to convert the organic material to cell mass and carbon dioxide. As a result, the dissolved oxygen concentration can drop to levels significantly below 7 mg/L.
- ✚ Dissolved oxygen in the natural waters can be measured directly on site using appropriate digital oxygen meter or in the lab using titration methods such as Winkler method.

## 9. Biochemical oxygen demand (BOD)

- ✚ This is measuring the amount of organic pollution in terms of the amount of oxygen required by microorganisms to biologically degrade organic wastes.
- ✚ Complete stabilization of a waste by microorganisms requires too long incubation period; therefore, the 5-day period has been accepted as a standard.
- ✚ The 5-day BOD (known as BOD<sub>5</sub>) is the total amount of oxygen consumed by microorganisms during the first 5 days of biodegradation.
- ✚ Samples are incubated at 20°C in darkness to prevent algae from adding oxygen to the air tight bottle. The BOD of the water is given by an expression:
  - ✓  $\text{BOD} = \text{DO}_{t0} - \text{DO}_{t5}$  where  $\text{DO}_{t0}$  is the amount of dissolved oxygen (mg/L) of the water at time  $t = 0$  and  $\text{DO}_{t5}$  is the amount of dissolved oxygen (mg/L) of the water after 5 days.
  - ✓ The amount of dissolved oxygen during the initial ( $\text{DO}_{t0}$ ) and dissolved oxygen after 5-days incubation ( $\text{DO}_{t5}$ ) are measured following standard laboratory procedures.

## 10. Chemical oxygen demand (COD).

- ✚ The Chemical Oxygen Demand (COD) is the amount of oxygen needed to chemically oxidize organic wastes in the water under investigation.
- ✚ In the COD test, a strong chemical oxidizing agent is used to oxidize the organics.
- ✚ The primary advantage of COD over BOD is that it is relatively fast, taking 2 to 3 hours, whereas BOD requires 5 days to complete.
- ✚ Another difference in the test methods is that BOD is a biochemical process as measured by the ability of microbes to degrade the organics, whereas COD is purely a chemical process.

### 5.2.2. Biological Parameters

- ✚ Aquatic organisms have preferred habitat requirements with respect to the physical, chemical and biological conditions.
- ✚ Variations in one or more of these conditions can result in reduction in species numbers or a change in species dominance or total loss of sensitive species by death or migration.
- ✚ This can be employed to measure water quality of aquatic habitats in one of the two main approaches: methods based on 'indicator' organisms and methods based on community structure.

- ✚ An indicator organism is a species selected for its tolerance or more frequently for its susceptibility to various types of pollutions or its effects.
- ✚ The various groups of organisms used as indicators of water quality include bacteria, algae, macro invertebrates, protozoa, macrophytes and fish.
- ✚ However, the use of each group of organisms has advantages and limitations. In streams, rivers, and lakes, the diversity of fish and insect species provides a good measure of water quality.
- ✚ Various biotic scores or biotic indices (biotic indexes) are used in order to determine whether the measurement of a certain group of organisms indicate pollution or in order to determine the water quality of the sampled water body.
- ✚ In this course, however, only three biological measurements namely bacteriological, algal (chlorophyll a) and benthic macro invertebrates will be presented and discussed with their specific biotic scores or indices.

### 1. Bacteriological Analysis

- ✚ This is a microbiological analytical procedure of analyzing water to identify the type or estimate the number of bacteria present in the water sample in the study of water quality.
- ✚ Bacteriological analysis of water can have two targets: analysis for the indicator organisms or analysis for the pathogens that might cause concern.
- ✚ Indicator bacteria include non-specific coliforms such as *Escherichia coli* and *Pseudomonas aeruginosa* that are very commonly found in the human or animal gut and which, if detected, may suggest the presence of sewage.
- ✚ Indicator bacteria are used because even when one is infected with more pathogenic bacteria, more indicator bacteria are excreted than the pathogens.
- ✚ It is thus logical to deduce that if indicator bacteria levels are low, then pathogen levels will be very much lower or absent, and conversely.
- ✚ When indicator organisms' levels exceed specific sets, analysis for pathogens may be undertaken using specific culture methods or molecular biology.
- ✚ Bacteriological analysis of water is usually performed using culture, biochemical and sometimes optical methods. Some of the various methods that can be applied in the bacteriological water quality analysis include plate count, multiple tube method, ATP testing, membrane filtration and pour plates. In plate count method bacteria grow in colony on a nutrient medium so that the colony becomes visible to the naked eye and the number of colonies on a plate can be counted.
- ✚ A culture medium is a substance containing nutrients in which bacteria or other microorganisms or tissues are cultivated for scientific purposes. Typical media used in bacteriological water quality analysis include Plate count agar for a general count or MacConkey agar to count gram-negative bacteria such as *Escherichia coli* (E.coli).

### 2. Chlorophyll a Analysis

- ✚ Chlorophyll a is the most abundant and important pigment which generally constitutes 2 to 5% of the dry weight of an algal cell.
- ✚ Thus, chlorophyll a is often measured to give an approximate indication of total phytoplankton biomass thus the trophic (productivity) status of the water body that could be caused due to nutrient enrichment such as nitrates and phosphates.
- ✚ The higher the chlorophyll concentration is the higher the abundance of the phytoplankton, and conversely.

- ✚ Chlorophyll a sample are collected and transported to laboratory in black or translucent bags. It is processed immediately up on arrival in the laboratory following standard procedures (e.g. Clesceriet *al.*, 1998).
- ✚ At the end of laboratory procedures, the amount of chlorophyll a is measured using various methods. However, a method known as spectrophotometry is much commonly used.
- ✚ In this method the amount of light absorbance by chlorophyll a solution is measured using an instrument known as spectrophotometer. Finally, the absorbance values are converted into the chlorophyll a concentrations using standard formula: Chlorophyll a =  $(26.73(663a-665b)V2)/(V1)(L)$  mgm-3

Where, V1 = Volume of sample (m3)

V2 = Volume of extract (L)

L = Light path length of cuvette (cm)

The value 26.7 = the absorbance correction. (Bartram and Balance, 1996).

- ❖ The trophic status of a water body is estimated from chlorophyll a concentrations in reference to standard trophic classification schemes.

### 3. Benthic Macro invertebrates

- ✚ Benthic macro invertebrates are various groups of invertebrates including flatworms (e.g. planaria), mollusks (e.g. snail) and mainly insects (e.g. caddisflies, dragonflies, etc) that inhabit the floor of the aquatic habitats.
- ✚ These organisms have differing tolerance to water pollution impacts. Some are easily susceptible or sensitive to water pollution, some are partly sensitive and others are tolerant of water pollution impacts.
- ✚ In assessing any impact of pollution in a given water body using macroinvertebrates one has to collect the organisms following standard field procedures.
- ✚ A kick net or dip net is often used to collect the macroinvertebrates. After collection the macroinvertebrates are sorted usually in the field and then transported to laboratory preserved in 70 % alcohol for identification (using identification keys e.g. Bouchard, 2004) and enumeration.
- ✚ Different biological indexes and scores of macroinvertebrates are used to interpret the macroinvertebrate data into water quality.
- ✚ Two biological indices namely EPT index and the Chandler biotic index and one scoring system known as the Biological monitoring working party (BMWP).

### 5.2.3. Sampling of Surface Waters

#### 5.2.3.1. Designing Sampling Programs

- ✚ In designing water quality sampling programs various factors should be taken in to account. For instance, factors such as sampling techniques, the timing and frequency of timing, procedures related to sample collection, transport and analysis should be considered.
- ✚ Ecological methods of water quality assessments can use a wide range of sampling techniques. These include:
- ✚ Qualitative technique-e.g. selection of macrophytes by hand

- ✚ Semi-quantitative technique-e.g. selection of benthic organisms using a standardized hand net technique
- ✚ Fully quantitative technique-e.g. using bottle samples for plankton or grab samples for benthic organisms.
- ✚ Sampling of parameters, such as macroinvertebrates, is preferable during dry season in tropical climate such as Ethiopia as this timing gives representative samples of the organisms.
- ✚ The water sampling field work checklist should include the following important elements among others:
  - ✓ Sampling materials
  - ✓ Documentation materials
  - ✓ On-site test materials
  - ✓ Safety materials
  - ✓ Transport materials
  - ✓ Calibration of meters and other equipment.

### 5.2.3.2. Safety in the Field

During water sampling personnel (i.e. people working the sampling) may encounter a wide range of hazards. For example:

- ✚ Access to the sampling stations may involve dangerous landscape
- ✚ The water to be sampled may be highly contaminated with various pollutants
- ✚ The possibility of slipping and injury while wading in streams to take water samples, etc.

Thus, while leaving for field work to take water samples one should have and obey the following safety practices:

- ✚ Consistent use of suitable protective clothing such as rubber gloves to protect against contaminants.
- ✚ Training on the awareness of potential hazards and how to deal with them such as on water safety and first-aid.
- ✚ Having a first aid kit carried at all times

### 5.2.3.3. Hydrological Measurements

- During water quality sampling hydrological measurements should be taken since they are essential for the interpretation of water quality data. This is because variations in hydrological conditions have important effects on water quality.
- Hydrological factors such as discharge (i.e. the volume of water passing through a cross section of river in a unit time, m<sup>3</sup>/second), the velocity of water flow (m/second), turbulence, water depth, rainfall, wind, erosion, etc are some of the factors that need to be recorded during water sampling.

### 5.2.3.4. Types of Samples taken from Surface Waters

- Two different types of samples can be taken from rivers, lakes and similar surface waters. These are Grab samples and Composite samples.
- Grab samples are the simplest type taken at a selected site, time and depth. These are also known as “spot” or “snap” samples. Composite samples, also known as integrated samples, are made of several different parts of samples. The following are examples of composite samples:
  - ✚ Depth-integrated sample: combining samples taken at various depths
  - ✚ Area-integrated sample: combining samples taken at various sites

- ✚ Time-integrated sample: combining samples taken at different times
- ✚ The type of composite sample to be taken is determined by the objective of sampling. Generally, in water quality sampling programs, standard guidelines (e.g. Bartram and Balance, 1996) should be followed in collecting samples for physio-chemical and biological parameters

## Chapter 6: Aquatic Resources

### 6.1 Fish and Fisheries

- Fishery (fisheries) is a business or an activity of fishing. It comes in two forms namely capture fishery and aquaculture.
- Capture fishery is the practice of catching fish from natural water bodies using various techniques for commercial or recreational purpose.
- Aquaculture is, however, the growing or farming of fish (or other beneficial aquatic organisms) in the natural or artificial water bodies mainly for food or commercial purpose.
- The term fish is often used to refer to the aquatic vertebrates with fins as appendages and gills as respiratory structures. These are specifically known as finfish. In fishery the term fish is also used to include aquatic invertebrates such as mollusks (e.g. squid and oyster) and crustaceans (e.g. lobster and crab) that are consumed by humans for protein supply. These are specifically known as shellfish.



Fig 7.1 (a) Squid (mollusk) (b) Lobster (crustacean) (c) Crab (crustacean)

Shellfish are almost entirely marine forms whereas finfish inhabit both the freshwater and marine habitats. The taxonomic hierarchy of finfish can be represented as shown below:

- ✚ Kingdom: Animalia
- ✚ Phylum: Chordata
- ✚ Subphylum: Vertebrata
  - Fish: there are six classes of fish
    - Class: Ostracoderms
    - Class: Cyclostomata
    - Class: Placodermi
    - Class: Acanthodi
    - Class: Chondrichthyes (cartilaginous fish)
    - Class: Osteichthyes (bony fish)

#### 1. The jawless (agnathan) fish

- These are primitive fishes that lack jaws and are thus also known as agnathan fish.
- They lack the paired fins and have notochord instead of vertebral column. They are largely extinct (e.g. ostracoderms) and some are extant (cyclostomes).



- Cyclostomes have suctorial circular or round mouth and include two living groups: Lampreys and Hagfishes. The Lampreys are blood sucking (parasitic, usually on other fish), both marine and freshwater forms. The hagfishes are scavengers usually inhabiting marine habitats.

### **Ostracoderms**

- They are small, jawless creatures collectively called ostracoderms (ostrakon, shell; +derm, -skin) which belong to the agnatha division of the vertebrates.
- These earliest jawless fishes lacked paired fins that later fishes found so important for stability. This class contains the following group of fishes.

#### **Order- Heterostracans (Pteraspida): -**

- Is one group of the earliest known ostracoderms. They had a wide and dorsal region covered by a carapace.
- A heavy exoskeleton is present in many early craniate. The plates and scales are formed by a combination of superficial denticles and underlying bone.
- The denticles are like teeth and are composed of the hard tissue, dentine. The lateral line sense organs lay in pits opening by pores between the ridges of dentine.
- There are no movable paired fins. The mouth was partly surrounded by long plates. In some of the later heterostracans the mouth was a tube at the very front end. These animals mostly had paired eyes and also a median pineal eye. They had paired nasal sacs. There were only two semicircular canals.

#### **Osteostraci (Cephalaspidiforms):**

- Coexisting with the heterostracans throughout much of the Devonian period were the osteostracans (osteo, bone; ostrakon, shell).
- These are fossil agnathas that show even more similarity to the modern cyclostomes than the heterostracans.
- The osteostracans improved the efficiency of their benthic life by evolving paired pectoral fins that increased the control of swimming.
- This ensured well-directed forward movement. The jawless mouth is toothless. Other distinctive features included a sensory lateral line system, paired eyes with complex eye muscle patterns and inner ear with only two semicircular canals.
- An upturned tail was heterocercal, covered with heavy bony scales.

#### **This class is extinct but had the following characteristics:**

- ✚ Small fish-like animals (only few centimeters long)
- ✚ Bottom dwellers, poor swimmers
- ✚ Rudimentary fins and bony armor
- ✚ No lower jaw
- ✚ No teeth
- ✚ Filter feeders or deposit feeders
- ✚ Marine

#### **Cyclostomes (Living agnathans) (lampreys and hagfishes)**

- ❖ The class cyclostomata derived its name by having around or circular mouth and include two living groups: Lampreys and Hagfishes.
- ❖ The Lampreys are blood sucking (parasitic, usually on other fish), both marine and freshwater forms. The hagfishes are scavengers usually inhabiting marine habitats.

#### **The class is characterized by the following features:**

- ✚ Eel-like in structure

- ✚ They have rows of horny teeth that move in circular
  - ✚ The mouth cannot close and always open such that water constantly cycles through it.
  - ✚ They are Prey (parasitize on fishes)
  - ✚ Lack exoskeleton/scales
  - ✚ Notochord persists in adults
- ❖ The Cyclostomes are very unique among vertebrates because of their semi-parasitic nature.
  - ❖ The lampreys with the exception of some small fresh-water forms attach themselves to other fishes using their sarratorial mouth and then rasp off the flesh by means of the horny teeth carried by the highly-developed tongue.

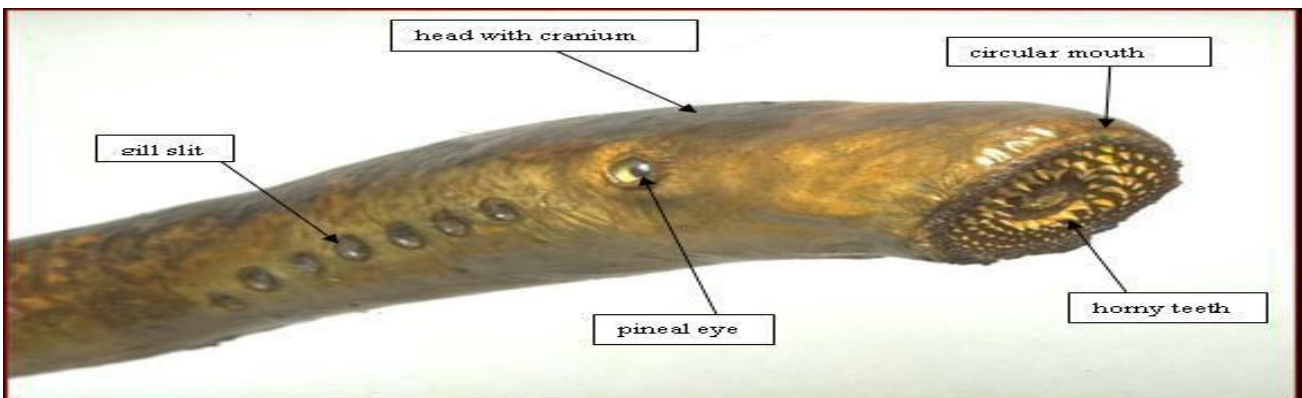
The class Cyclostomata consists of two orders:

1. **Order Petromyzontia (or Hyperoartii)**
2. **Order Myxinoidea (or Hyperotreti).**

**1. Order: Petromyzontia(or Hyperoartii).e.g.lampreys-/Petromyzonmarinus/.**

The Petromyzontes are characterized by:

- ❖ Soft body without scales
- ❖ Pineal (cone-like) eye
- ❖ Endo skeleton made of cartilage and notochord
- ❖ Seven gill pouches open directly to exterior
- ❖ Circular sucking mouth used in parasitizing other fishes
- ❖ Lack paired fins but have finray
- ❖ Single dorsal nasal open in gontopof the head
- ❖ Cartilaginous braincase
- ❖ Ammocoetes larva which metamorphoses to adult



**Figure6.3A** cyclostome-sea lamprey

**Order: Myxinoidea(Hyperotreti)**

The hagfishes are characterized by:

- ⇒ Circular mouth fitted with rasping tongue surrounded by short tentacle.
- ⇒ Gill pouches joined to a common external opening one it her side
- ⇒ Gasal opening at the tip of the snout rather than on top of the head as in the lampreys
- ⇒ Exclusively marine
- ⇒ Elongate(eel-like)body
- ⇒ Scale less body
- ⇒ Many mucous glands present for anti-predator defence
- ⇒ Unsupported fin ray

Hagfish

## 2. The Jawed vertebrates(Gnathostomata) Fish.

- ❖ This includes the rest of the four fish classes (Placodermi, Acanthodi, Chondrichthyes and Osteichthyes).
- ❖ Placodermi and Acanthodi are extinct whereas chondrichthyes and osteichthyes are extant groups. These are fish with jaws and are thus also known as gnathostomatan fish.
- ❖ In contrast to the agnathan fish, these possess paired fins. Fishes of the extinct class Placodermi were the first vertebrates to develop jaws and paired fins.
- ❖ A branch of Placodermi probably gave rise to the two main modern classes of fish: the cartilaginous and bony fish.

### 2.1 Class Placodermi

- ❖ Class Placodermi includes the earliest gnathostomes except for the acanthodians. They were mostly bottom living animals, dorsoventrally flattened and somewhat like modern rays.
- ❖ Many lived on invertebrate or by shoveling mud, like their agnathan ancestors. Most lived in the sea, but some in freshwater.
- ❖ There were paired pectoral and pelvic fins and often large pectoral spines attached to the trunk plate. The male had pelvic claspers and reproduction was presumably like that of sharks.
- ❖ This feature is one of them as reasons for considering that the placoderms were related to the ancestors of the chondrichthyes.

#### 2.1.1 Characteristics of members class Placodermi

- ✚ Appear in the Early Silurian and extinct by end of the Devonian
- ✚ Predatory
- ✚ The sister taxon to all other jawed vertebrates(Eugnathostomata)
- ✚ Unique jaw musculature with the muscle's median to the palate quadrates (the upper jaw elements).
- ✚ Upper jaws were attached tightly to the cranium or head shield, which limited the mobility of the jaws
- ✚ No teeth that resemble those of other jawed vertebrates
- ✚ Only some individuals within a species had pelvic appendages, which indicate they were male and that the species had internal fertilization
- ✚ The head region was covered with thick dermal bone.
- ✚ Some form had a moveable joint between the plates where the neck would be, which allowed the jaws to be opened very wide.

### 2.2 Class Acanthodians

- ❖ The acanthodians, found in freshwater deposits extending from the Ordovician to the Permian but chiefly in the Devonian, are the oldest known gnathostomes. They were small fishes with a fusiform body, heterocercal tail and one or two dorsal fins.
- ❖ The lateral fins consisted of a series of pairs, often as many as seven in all, down the sides of the body. The fins were all supported by the large spines.

#### 2.2.1 Characteristics of Acanthodians

The sister taxon to the Osteichthyes

- ✚ Earliest jawed fishes in the fossil record dating from the Early Silurian, but disappeared by the Early Permian.
- ✚ Had stout spines anterior to the dorsal, anal, and many paired fins
- ✚ Teeth lacked enamel
- ✚ Few enlarged scales, though some lacked scales.
- ✚ Three semicircular canals

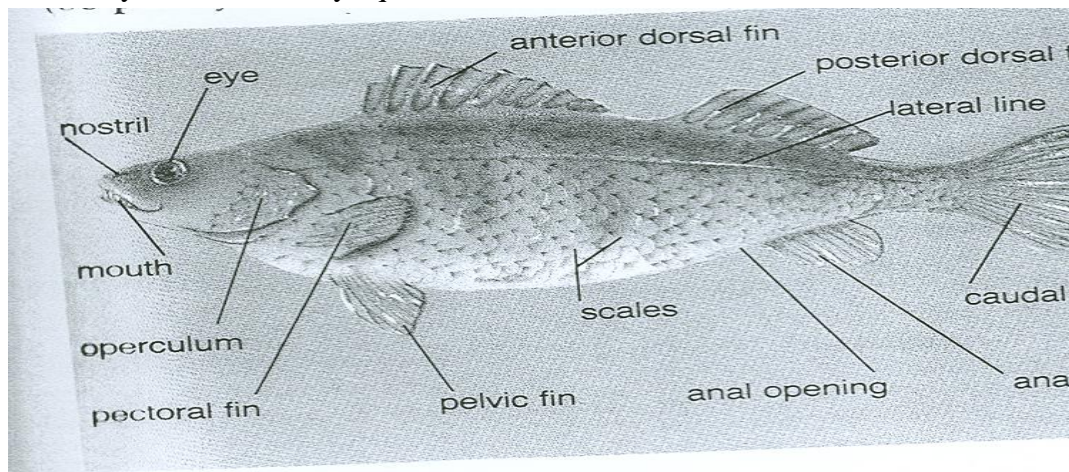
✚ Cranium composed of cartilage

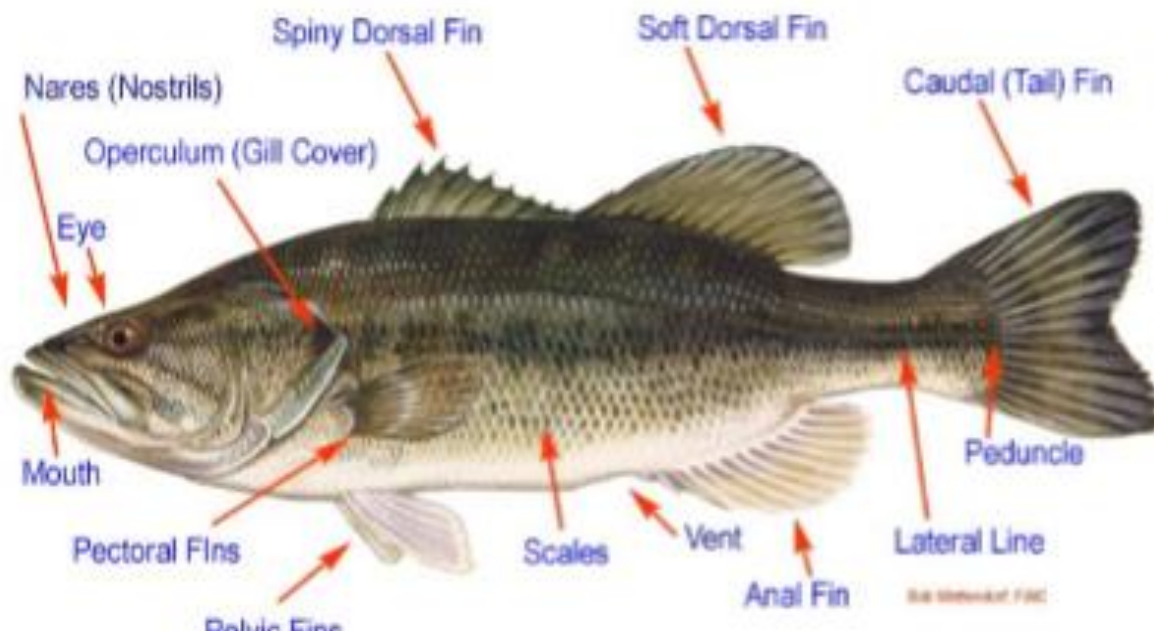
### 2.3. The Cartilaginous Fish

- ❖ The cartilaginous fishes include 2 major subgroups namely the elasmobranches (such as sharks, rays, skates) and the **holocephalans** (such as chimaeras or ratfish).
- ❖ The cartilaginous fish are distinguished from the bony fish by their cartilage endoskeleton, lack of swim bladders, lack of a gill covering (operculum) and possession of teeth-like placoid scales.
- ❖ The cartilaginous fish have a rough or a sand paper quality as a result of their teeth-like placoid scales. They are almost exclusively marine in distribution.

### 2.4. The Bony Fish

- ❖ Bony fishes are distinguished from other living fishes by their possession of bony skeletons and a swim bladder which functions as a float or, in a few fishes, as a lung.
- ❖ They also possess a bony gill cover known as operculum. The bony fishes are divided into two major subgroups: **sarcopterygian** and **actinopterygian** bony fishes.
- ❖ The Sarcopterygian bony fishes include the fleshy finned fish with a central bone supporting the fins. It is further subdivided into two subgroups: Dipnoi (Lungfishes) and Crossopterygii (e.g. Coelacanth).
- ❖ The dipnoi (lungfish) can breathe using lung for a brief period of time. The lungfish are mainly freshwater forms in the areas they occur. Examples include *Lepidosiren* (American lungfish), *Protopterus* (African lungfish) and *Neoceratodus* (Australian lung fish).
- ❖ The coelacanth, one group of crossopterygians, are mainly marine deep-sea forms. *Latimeria chalumnae* is the living fossil (i.e. the only living form) of coelacanth that occurs in Africa in Comoro Archipelago.
- ❖ Actinopterygian bony fishes are ray finned fish in which a fin consists of a skin supported by horny rays. The paired fins are closely located as opposed to that of the sarcopterygians.
- ❖ They are the most highly successful and diverse of all the fishes and include over 95% of all living fish species predominating both in fresh and marine waters. They represent an advanced adaptation of the bony fishes to strictly aquatic conditions.





(Fig. a.) External anatomy of a bony fish, Yellow perch and (Fig. b) External anatomy of a typical actinopterygian bony fish showing the various types of fins.

- ❖ Actinopterygian bony fishes are further subdivided into three groups: Chondrostei, Holostei (Neopterygii) and Teleostei. Chondrostei and Holostei have soft rayed fins that are supported by cartilaginous or soft rays; whereas teleostei have spiny rayed fins that are supported by bony (strong) spines.
- ❖ Examples of Chondrostei include Sturgeons, Bichirs, Paddlefishes and Spoonfishes. Holostei (Neopterygii) includes Bowfin, Garpikes, Gars, and Garfishes. Teleostei are the most advanced and the most numerous groups of actinopterygian fishes comprising about **23, 000 species** out of the 24, 000 fish species.
- ❖ These are fish that are important as food and thus important in fishery.
- ❖ The following are the representative orders of teleosts:
  - ✓ Anguilliformes (Anguillids) e.g. Eel (snake like appearance)
  - ✓ Clupeiformes (Clupeids) e.g. Herring and Anchovies
  - ✓ Salmoniformes (Salmonids) e.g. Salmon, Trout, Whitefishes, Pikes and Grayling
  - ✓ Cypriniformes (Cyprinids/Ostariophysi)- Minnows, Carps, Catfishes
  - ✓ Perciformes e.g. Perches, Wrasses, Dolphins, Hake, Mackerel, Tuna

## 6.2. The Ethiopian Fish and Fisheries

### 6.2.1. The Classification of Ethiopian Fish

- ❖ The Ethiopian fish fauna are the bony fishes and freshwater forms, the majority of them belonging to **teleosts**. The Ethiopian fish fauna consists of **153 indigenous** and **10 exotic species**.
- ❖ It is important to bear in mind, however, that the diversity and abundance of Ethiopian fish fauna is not complete and further works are still underway.
- ❖ The Ethiopian indigenous freshwater fauna is a mixture of **three different forms**:
  - Nilo-sudanic forms,
  - East African high land forms and
  - Endemic forms.
- ❖ **The Nilo-Sudanic forms** are those fishes related to West African fishes and include genera such as Alestes, Bagrus, Citharinus, Hydrocynus, Hyperopisus, Labeo, Mormyrus etc.
  - The similarity is assumed due to past connections of the Nile to Central and West African river systems.

- These are the dominant forms in terms of diversity and are represented by a large number of species found in the Omo-Gibe, Baro-Akobo, Tekeze and Abay drainage basins but particularly predominate the Nile basin (Baro-Akobo, Tekeze and Abay).
- However, some elements of these forms also occur in the Southern Rift Valley Lakes (Lakes Abaya and Chamo), and the Shebelle-Ghenale basins. However, Nilotic fishes are almost entirely absent from the Awash and northern rift valley lakes

❖ **The East African highland forms** are those related to fishes of eastern and southern Africa and include genera such as *Labeobarbus*, *Clarias*, *Garra*, *Oreochromis*, and *Varicorhinus*. These are found in the northern Rift Valley lakes (e.g. Lakes Awassa, Ziwai, Langano), the highland lakes (e.g. Tana and Hayq), and associated river systems, and the Awash drainage basin.

❖ **The Endemic forms** are very few comprising of about 38 species and 2 subspecies. Examples include a few genera such as *Danakilia*, *Nemacheilus*, and *Gara* (Lakes Abaya and Chamo), *Barbus* (Lakes Tana and Chamo), etc. Exotic fish introduced to Ethiopian water bodies include fish such as carp in Koka and Fincha dams.

**The economically important families of Ethiopian fish include the following:**

### 1. Family Cichlidae (Cichlids)

❖ This family is known to include **three species of tilapias in Ethiopia**. These are *Oreochromis niloticus*, *T.zilli* and *T. galilaea*. *O. niloticus* is found in most Ethiopian freshwaters and commonly known as Qoroso, St. Peter fish, Chogofe, etc. *O. niloticus* is the predominant fish in most of the Ethiopian fisheries.



**Fig. 6.4** *Oreochromis niloticus* (Nile tilapia)

### 2. Family Centropomidae (Centropomids)

❖ Most members are marine and only genus *Lates* is a freshwater form both in Ethiopia and Africa. *L. niloticus* (commonly called Nile perch) is the major species of the genus and found in Ethiopian Lakes such as Chamo, Abaya, Gambella lakes and Baro River. *L. niloticus* is carnivorous on other fish and thus it not good to introduce them into other water bodies than their natural habitats.



**Fig.6.5** *Lates niloticus* (Nile perch)

### 3. Family Claridae (Clarids)

- ❖ The common example is *Clarias gariepinus* (commonly Catfish, “Ambaza”) found in L. Tana, L. Abaya and Awash River. *C. gariepinus* can be easily recognized by their elongated body and long hair like barbells around their mouth.



**Fig.6.6** *Clarias gariepinus* (Catfish, Ambaza)

### 4. Family Cyprinidae (Cyprinids)

- ❖ It includes genera such as *Barbus* (commonly in Nechasa), *Labeo* and *Carp*. *Barbus* is more common in rivers than in lakes and is much common in Lake Tana among the lakes.
- ❖ Three carp species (Common carp, grass carp and silver carp) are introduced species belonging to this family.

## Chapter 7. Water Basin Management and Monitoring

### 7.1. Basic Water Management and Monitoring Programs

- ❖ Human beings require water for many different uses including agriculture, irrigation, hydropower generation, drinking water supply, navigation, recreation and above all for healthy ecosystems.
- ❖ All these multiple-uses on water demand coordinated action and management to ensure sustainability of the water resource.
- ❖ Water is often considered as finite and economic commodity taking into account of affordability and equity criteria.
- ❖ Particularly fresh water is a finite and vulnerable resource, but essential to sustain life, development and the environment.
- ❖ Water management and development should be based on a participatory approach, involving users, planners, policy makers and all other stakeholders and users at all levels. Such management approach is known as Integrated Water Resources Management (IWRM).
- ❖ IWRM is a comprehensive, participatory planning and implementation tool which promotes the coordination for managing and developing water resources in a way that: Balances social and economic needs, and Ensures the protection and sustainability of ecosystems for future generations.
- ❖ Specifically speaking, IWRM approaches involve applying knowledge from various disciplines as well as the insights from diverse stakeholders to devise and implement efficient, equitable and sustainable solutions to water and development problems. This approach is very important especially in the management of transboundary water resources.

## 7.2. The Nile Basin Initiative (NBI)

- ❖ The Nile River is the longest river in the world and it has been providing life to the vast Nile basin for hundreds of thousands of years. Two of its major tributaries are the **White Nile** and the **Blue Nile (Abay) Rivers**.
- ❖ The major source of White Nile is **Lake Victoria** in east central Africa and the source of the Blue Nile is **Lake Tana** in Ethiopian high lands. The White Nile flows generally north through Uganda and into Sudan where it confluences with the Blue Nile (Abay) at **Khartoum** to form the Nile River proper. The Nile River continues to flow northwards into **Egypt** and ultimately into the **Mediterranean Sea**.
- ❖ The Nile River basin has an area of more than 3,349,000 km<sup>2</sup>. The Nile River is a transboundary river that generally involves ten African countries.
- ❖ Nile basin countries also known as the **riparian countries** are countries that lie in the catchment of the Nile River. These include Ethiopia, Sudan, Egypt, Kenya, Tanzania, Uganda, Rwanda, DR Congo, Burundi and Eritrea.
- ❖ Some of the countries have only a small part of their area within the basin, whilst others are virtually entirely within the Basin. Moreover, the countries contribute differently to the basin and have different needs for the water and other resources of the basin. The Nile basin within Ethiopia territory contributes about 58 % to the water of the Nile River.

### The Nile River Agreements include:

- ✓ The Nile Water Agreement of 1929 and 1959
- ✓ The Nile Basin Initiative Agreement of May 14th, 2010
- ❖ Most of the Nile basin countries have their own policy frameworks that address the use and management of their water resources including the Nile River. Let us now see some points on:  
The Nile Water Agreement of 1929 and 1959  
The Nile Basin Initiative, and  
The Nile Basin Initiative Agreement of May 14th, 2010.

#### 1. The Nile Water Agreement of 1929 and 1959

- ❖ This is a Nile treaty which Britain signed on behalf of its east African colonies with Sudan and Egypt. Some aspects of the treaty are: The agreement gives Egypt the right to inspect the entire length of the Nile.
  - ✓ Any projects that could threaten the volume of water reaching Egypt are forbidden.
  - ✓ Egypt has a right to use about 75 % of the water while Sudan has 11 % and the rest of the countries share 14 %.
  - ✓ The other riparian countries have to first seek permission from Egypt and Sudan before planning for any large scale development projects on the river that would affect the level and flow of the waters.
  - ✓ Egypt has the right to control, reject and veto any projects from any other nations and has the right to undertake any desired projects and developments freely without consents of other riparian countries.
- ❖ The upstream riparian countries criticize the treaty saying that it grants Egypt the lion's share of the Nile waters ignoring the rest upstream riparian countries which on the other hand are the major contributors to the Nile River. The treaty is often regarded as a colonial treaty that cannot be accepted in the era of Freedom.

#### 2. The Nile Basin Initiative (NBI):-

- ❖ The struggle for fair and equitable utilization of the Nile River continued to be a stance of most of the riparian countries.







- ❖ Accordingly, the Nile Basin Initiative was established by the riparian countries in 1999. NBI is a transitional arrangement established by the Nile Basin States at the meeting of their Council of Ministers held in Dar-es-Salaam, Tanzania, on 22<sup>nd</sup> February, 1999.
- ❖ NBI: Is responsible to foster cooperation and sustainable development of the Nile River for the benefit of the inhabitants of the riparian countries.
- ❖ Seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security.
- ❖ The NBI secretariat is based in Entebbe, Uganda and led by the Council of Ministers of Water Affairs of the Nile Basin states (Nile Council of Ministers, or NILE-COM).

### **3. The New Nile Basin Framework of 2010:-**



- ❖ For over a decade, the nine riparian countries and Eritrea as an observer have been negotiating to draft a new treaty on the usage of the Nile waters.
- ❖ All the countries agreed on the framework agreement apart from a clause which will reduce Egypt and Sudan's right to use more than 85 percentage of the water. However, Egypt and Sudan want to maintain the old status quo of them using the biggest percentage of the water as stipulated in two colonial agreements they signed with the British in 1929 and 1959.
- ❖ Ultimately the Nile Basin Initiative Agreement was signed among four Nile basin countries (Ethiopia, Rwanda, Tanzania, and Uganda) who signed the Agreement on the “Nile River Basin Cooperative Framework” in Uganda on 14th May, 2010.
- ❖ Burundi, Democratic Republic of Congo (DR Congo) and Kenya are expected to join the agreement sooner.
- ❖ The Cooperative Framework stipulates fair and equitable utilization of the Nile River basin and will remain open for one year to allow Egypt and Sudan join the rest of the countries.

### **Some of the reasons for reaching the Nile Basin Initiative Agreement on the**

“Nile River Basin Cooperative Framework” in May, 2010 include:

-  The old colonial treaty signed among Britain, Egypt and Sudan was not fair and does not entail equitable utilization of the Nile River Basin.
-  The riparian countries are now independent states and thus have equal rights as Egypt to use the Nile waters.
-  The upstream countries are in dire need of using the water to generate hydropower and irrigation following persistent drought which has hit many of the countries leaving millions of their citizens on the verge of starvation.
-  According to the framework agreement the Nile Basin Initiative will be transformed into the Nile Basin Commission which will coordinate the equitable usage of the water.

### **7.3. The Water Framework Directive**

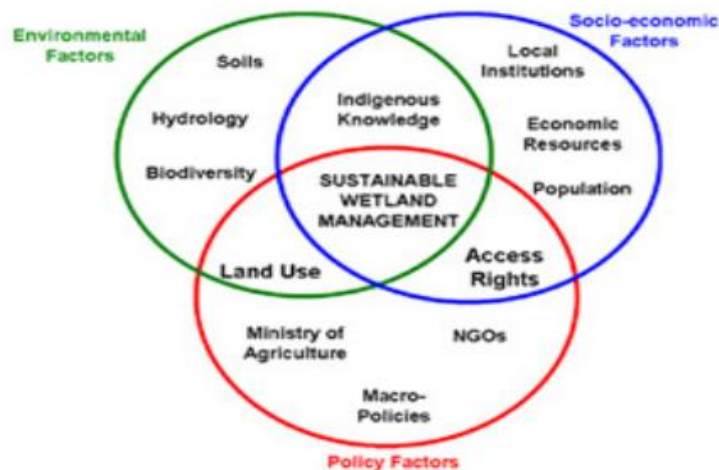
-  The Water Framework Directive is a European Union water legislation which commits European Union member states to achieve good qualitative and quantitative status of all water bodies by 2015.
-  The Directive was made on **23 October 2000** and came into force **22 December 2000**. Currently is an active legislation.

**The following are some of the important points you need to note about the Directive:**

- ✚ The Directive establishes a framework for the European Community action in the field of water policy.
- ✚ It is a framework in the sense that it prescribes steps to reach the common goal rather than adopting the more traditional limit value approach.
- ✚ The directive defines 'surface water status' as the general expression of the status of a body of surface water, determined by the poorer of its ecological status and its chemical status.
- ✚ Thus, to achieve 'good surface water status' both the ecological status and the chemical status of a surface water body need to be at least 'good'.
- ✚ Ecological status refers to the quality of the structure and functioning of aquatic ecosystems of the surface waters.
- ✚ Water is an important facet of all life and the water framework directive sets standards which ensure the safe access of this resource. The Directive aims “River Basin Management”

#### 7.4. Convention on Wetlands Management

- Wetland have integrated approaches and multifunctional, hence it deserve to use and manage our wetlands, for sustainable economy and biodiversity under treatment.



- For instance, sustainable management of wetlands requires maintaining some of the natural characteristics of wetlands while also allowing partial conversion to allow activities which can meet the economic needs of communities.
- A balance has to be struck between the environmental functioning of wetlands and their use for livelihood purposes.
- Usually sustainable management of wetlands involves minimal conversion of the wetland and limited degradation of the catchment. In the following sections we will see about the wetlands management in Ethiopia and at international level.

##### 1. Wetlands Management in Ethiopia

- Generally in Ethiopia, wetland management has been given little attention until a nongovernmental organization namely Ethio Wetlands and Natural Resources Association (**EWNRA**) initiated research in southwest Ethiopia, Illubabor zone, Oromia regional state, for the sustainable management of wetlands.

##### 2. Wetlands Management at International Level

- ⇒ **Ramsar Convention** on Wetlands Management is an international intergovernmental treaty adopted on 2 February 1971 in the Iranian city of Ramsar to address global concerns regarding wetland loss and degradation.

- ⇒ It is the first of the modern global intergovernmental treaties on the conservation and sustainable use of natural resources.
- ⇒ The Convention entered into force in 1975 and as of December 2006 has 153 Contracting Parties, or member States, in all parts of the world. Ethiopia is not among the Ramsar Convention Member State.
- ⇒ The Convention was primarily on wetlands of international importance, especially as Waterfowl (water birds) habitat.
- ⇒ Over the years, however, the Convention has broadened its scope of implementation to cover **all aspects** of wetland conservation and wise use, recognizing wetlands as ecosystems that are extremely important for biodiversity conservation and for the well-being of human communities.
- ⇒ The primary purposes of the treaty are to list wetlands of international importance and to promote their wise use, with the ultimate goal of preserving the world's wetlands.
- ⇒ Methods include restricting access to the majority portion of wetland areas, as well as educating the public to combat the misconception that wetlands are wastelands.

### **Principles of Wetland Restoration**

- To help build on the lessons of restoration projects and promote effective restoration, the Office of Wetlands, Oceans and Watersheds assembled the following list of principles that have been critical to the success of a wide range of aquatic resource restoration projects. These principles apply to different stages in the life of a restoration project - from early planning to post-implementation monitoring - and are offered here for use by a wide variety of people and organizations, ranging from Federal, State, Tribal and local agencies to outdoor recreation or conservation groups, corporations, landowners and citizens' groups.
  - These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values should not be overlooked.
- 1. Preserve and protect aquatic resources.** Existing, relatively intact ecosystems are the keystone for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems. Thus, restoration does not replace the need to protect aquatic resources in the first place. Rather, restoration is a complementary activity that, when combined with protection and preservation, can help achieve overall improvements in a greater percentage of the Nation's waters.
  - 2. Restore ecological integrity.** Restoration should re-establish in so far as possible the ecological integrity of degraded aquatic ecosystems. Ecological integrity refers to the condition of an ecosystem, particularly the structure, composition and natural processes of its biotic communities and physical environment. Restoration strives for the greatest progress toward ecological integrity achievable within the current limits of the watershed, by using designs that favor the natural processes and communities that have sustained native ecosystems through time.
  - 3. Restore natural structure.** Many aquatic resources in need of restoration have problems that originated with alteration of channel form or other physical characteristics, which in turn may have led to habitat degradation, changes in flow regimes and siltation. Stream channelization, ditching in wetlands, disconnection from adjacent ecosystems and shoreline modifications are examples of structural alterations that may need to be addressed in a restoration project. In such cases, restoring the original site physical attributes is essential to the success of other aspects of the project, such as improving water quality and bringing back native biota.
  - 4. Restore natural function.** Structure and function are closely linked in river corridors, lakes, wetlands, estuaries and other aquatic resources. Re-establishing the appropriate natural structure can bring back beneficial functions. For example, restoring the bottom elevation in a wetland can

be critical for reestablishing the hydrological regime, natural disturbance cycles and nutrient fluxes. In order to maximize the benefits of the restoration project, it is essential to identify what functions should be present and make missing or impaired functions priorities in the restoration. Verifying whether desired functions have been re-established can be a good way to determine whether the restoration project has succeeded.

5. **Work within the watershed and broader landscape context.** Restoration requires a design based on the entire watershed, not just the part of the water body that may be the most degraded site. Activities throughout the watershed can have adverse effects on the aquatic resource that is being restored. A localized restoration project may not be able to change what goes on in the whole watershed, but it can be designed to better accommodate watershed effects. New and future urban development may, for example, increase runoff volumes, stream down cutting and bank erosion, and pollutant loading. By considering the watershed context in this case, restoration planners may be able to design a project for the desired benefits of restoration, while also withstanding or even helping to remediate the effects of adjacent land uses on runoff and nonpoint pollution.
6. **Understand the natural potential of the watershed.** Establishing restoration goals for a water body requires knowledge of the historical range of conditions that existed on the site prior to degradation and what future conditions might be. This information can then be used in determining appropriate goals for the restoration project. In some cases, the extent and magnitude of changes in the watershed may constrain the ecological potential of the site. Accordingly, restoration planning should take into account any irreversible changes in the watershed that may affect the system being restored, and focus on restoring its remaining natural potential.
7. **Address ongoing causes of degradation.** Restoration efforts are likely to fail if the sources of degradation persist. Therefore, it is essential to identify the causes of degradation and eliminate or remediate ongoing stresses wherever possible. While degradation can be caused by one direct impact, such as the filling of a wetland, much degradation is caused by the cumulative effect of numerous, indirect impacts, such as changes in surface flow caused by gradual increases in the amount of impervious surfaces in the watershed. In identifying the sources of degradation, it is important to look at upstream and up-slope activities as well as at direct impacts on the immediate project site. In some situations, it may also be necessary to consider downstream modifications such as dams and channelization.
8. **Restore native species and avoid non-native species.** American natural areas are experiencing significant problems with invasive, non-native (exotic) species, to the great detriment of our native ecosystems and the benefits we've long enjoyed from them. Many invasive species outcompete natives because they are expert colonizers of disturbed areas and lack natural controls. The temporary disturbance present during restoration projects invites colonization by invasive species which, once established, can undermine restoration efforts and lead to further spread of these harmful species. Invasive, non-native species should not be used in a restoration project, and special attention should be given to avoiding the unintentional introduction of such species at the restoration site when the site is most vulnerable to invasion. In some cases, removal of non-native species may be the primary goal of the restoration project.
9. **Use natural fixes and bioengineering techniques, where possible.** Bioengineering is a method of construction combining live plants with dead plants or inorganic materials, to produce living, functioning systems to prevent erosion, control sediment and other pollutants and provide habitat. Bioengineering techniques can often be successful for erosion control and bank stabilization, flood mitigation and even water treatment. Specific projects can range from the creation of wetland systems for the treatment of storm water, to the restoration of vegetation on river banks to enhance natural decontamination of runoff before it enters the river.

**1. Monitor and adapt where changes are necessary.** Every combination of watershed characteristics, sources of stress, and restoration techniques is unique and, therefore, restoration efforts may not proceed exactly as planned. Adapting a project to at least some change or new information should be considered normal. Monitoring before and during the project is crucial for finding out whether goals are being achieved. If they are not, "mid-course" adjustments in the project should be undertaken. Post-project monitoring will help determine whether additional actions or adjustments are needed and can provide useful information for future restoration efforts. This process of monitoring and adjustment is known as adaptive management. Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.