CHAPTER 13

CLO 7. The student will be able to state the factors that influence the primary productivity in the oceans and illustrate how it affects the biomass of living forms in the ocean realm. (Biological oceanography)

LIFE IN THE OCEAN

- We now turn to "life in the ocean" after having covered some of the major features of the marine environment.

1. BEING ALIVE

1.1 Matter (The Building Blocks)

- **Matter –** Substance with measurable mass (quantity or weight of matter) and volume (space occupied by matter)
- Matter appears in three phases or states: solid, liquid or gas
- All matter is composed of "**atoms**" which are in turn chemically bonded together to form "**molecules**" (and "**compounds**")
- There are 118 or so known elements (atoms of a specific nature that cannot be broken into simpler substances by chemical means) (See **"periodical table – Appendix 7, p. 557"**)

The Ingredients of Life

- The process of life involves an intricate series of interactions among an immense variety of chemicals.
- All Earth's organisms are composed of about 23 of the 107 known chemical elements.
- Four of these – **carbon (C)**, **hydrogen (H)**, **oxygen (O)**, and **nitrogen (N)** – make up 99% of the mass of all living things, with 9 additional elements (**macronutrients**) comprising nearly all the remainder.
- Water --- is the base of all; the medium in which all other molecules dissolve and interact --- (most organisms are made of 2/3 water; up to 95% in case of jellyfish)
- These elements (atoms) combine in living things to form classes of biological chemicals **(organic compounds)** common to all life. Organic compounds are high-energy molecules.
- The main categories of these organic compounds are:
  - **Carbohydrates** (Contains: C,H, O – in proportions $C_nH_{2n}O_n$ – includes the sugars, starch, cellulose, chitin)
  - **Proteins** (made from amino acids –contain nitrogen (N) as well as C,H, O --- muscles, enzymes, hormones)
  - **Lipids** (contains – C,H, and O – but the proportions are different i.e. with little O -- fats, oils, waxes…)
  - **Nucleic acids** (built of nucleotides --- simple sugar joined to the molecules that contain phosphorus (P) and nitrogen (N). --- DNA (Deoxyribonucleic acid—the primary molecule of heredity; and ATP – the molecule of energy)

What is life?

Living organisms are defined by the following:

- **Made of cells**
- **Grow**
- **metabolize** (all the chemical reactions that take place in an organism) – to maintain themselves (internal environment)
- **react to the external environment** (by the use of their senses)
- **reproduce** -- to perpetuate their kind, and to pass their characteristics on to their offspring (**Heredity**)
- **Level of organization (Hierarchy)** – cells; tissue; organs; organ systems
- **use energy** (ability to do work) --- to do these various activities i.e. metabolize, growth, reproduce, maintain themselves, and react to the external environment…

The Basic Structure of Life:

- The molecules in living things are organized into structural and functional units that work in a coordinated way.
  - **Cell –** Is the basic structural unit of life
  - All organisms are made of one (**unicellular**) or more cells (**multicellular**)

Levels of Organization

- A cell is a self-contained unit that can carry out all the functions necessary for life.
- One-celled organisms are called **unicellular**
- Most organisms are **multicellular** – they have more than one cell
  - The multicellular organisms can have cells becoming specialized for particular jobs – the extent of this specialization and organization is referred to as the levels of organization. (cellular, tissue, or organ level)

Organization Within the Body

- **Cell level**- each cell is essentially an independent, self-sufficient unit; the simplest organization level
- **Tissue level** - A group of cells specialized for one function \
  - muscle tissues, nervous tissues…
- **Organ level** - A group of tissues specialized for a specific function.\
  - heart, stomach, lungs…
- **Organ system level** - Different organs act together to form systems
  - nervous, digestive, circulatory, and reproductive systems...

2. THE FLOW OF ENERGY THROUGH LIVING THINGS ALLOWS THEM TO MAINTAIN COMPLEX ORGANIZATION

- As seen above, living matter can't function without **energy**, the capacity to do work.
- Living organisms can't create new energy, but they can transform one kind of energy to a different kind. (***second law of thermodynamics***)
  - Ex: A plant can transform light energy into chemical energy; an animal can transform chemical energy into energy of movement by the muscles and can transform energy of movement into heat…

- The main source of energy for living things on Earth is the **sun**. Light energy is transformed into chemical energy and finally into heat. How is this done?

2.1 Energy can be Stored through Photosynthesis and through Chemosynthesis

- All living things use energy (defined as the capacity to do work) to make and maintain the complex chemicals necessary for life. The main source of energy for living things on Earth comes from the **sun.**

- The organisms can be divided into two broad components: **producers** and **consumers** (these also include the **decomposers**).
  - **Producers (primary producers)** – involves the synthesis of organic mateirals from inorganic substances by photosynthesis or chemosynthesis. Also named **photoautotroph** and **chemoautotrophs**.

- **Photosynthesis** --- Capacity of photoautotrophs [include seaweeds and phytoplankton (drifting microscopic plant-like cells)] to convert light energy into chemical energy and store it in the form of energy-rich molecules that can be used as fuel for consumers (heterotrophs).
  - Photosynthesis occurs only in cells that have chlorophyll and associated pigments. **(Fig. 13.11, p.378)**
  - The general formula for photosynthesis is as follow

$$\mathbf{6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6\ (\text{sugar}) + 6O_2}$$

- **Chemosynthesis –** The synthesis of organic compounds from inorganic compounds using energy stored in inorganic substances such as sulfur (hydrogen sulfide), ammonia, and hydrogen (methane; hydrogen gas). Energy is released when these substances are oxidized by certain organisms. No sunlight is required. **(Fig. 13.11, p.378)**
  - Employed by some species of bacteria and archaea
  - New discoveries permit to observe that chemosynthesis is widespread in the ocean (Hydrothermal vents; the seabed itself; and microbiological communities in extreme environments…)

2.3 Obtaining Energy by Cellular Respiration

- **Consumers –**An organism that cannot synthesize its own food but obtains food (energy) from organic matter. Also named **heterotroph**.
  - Animals that eat plants or other animals use the energy of the chemicals in the plants or animal cells for their own work. (Energy is being defined as the capacity to do work). This is why food is equivalent to energy.
  - The chemical process involved in the release of energy from organic matter is called **cellular respiration**. (The reverse of photosynthesis.)
  - The general formula for respiration is as follow

$$\mathbf{C_6H_{12}O_6\ (\text{sugar})\ [\text{organic matter}] + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}}$$

3. PRIMARY PRODUCTIVITY IS THE SYNTHESIS OF ORGANIC MATERIALS

- Autotrophs are said to "fix" carbon dioxide to make sugar and other plant materials (via photosynthesis); this is the plant's gross **productivity** (total material produced).
  - **Primary productivity -** The rate at which an ecosystem can accumulate new organic matter (through photosynthesis or chemosynthesis)
- Primary productivity is expressed in *grams of carbon bound into organic material per square meter of ocean surface per year* (g $C/m^2/yr$). **(Fig. 14.1, p.394)**

- Other than these raw materials (carbon dioxide, water, and sunlight), photoautotrophs also need "**nutrients**" including minerals, vitamins, and other substances. But the main nutrients needed by the primary producers are nitrogen and phosphorus ("fertilizers"). These are dissolved in the water and become also available when the decomposers degrade the organic matter into its inorganic constituents (includes the respective nutrients).

COMMUNITY	NET PRIMARY PRODUCTIVITY ($g\ C/m^2/yr$)
Ocean Communities	
Coral reefs	880 - 2,200
Kelp beds	400 - 1,900
Shelf plankton	90 - 270
Open ocean	1 - 180
Land Communities	
Rain forest	460 – 1,600
Temperate forest	270 – 1,140
Freshwater swamp	360 – 1,820
Cropland	45 - 1,820
ALL OCEAN	120 (average)
ALL LAND	150 (average)

(Source: Garrison, 2016, Fig. 13.1 p.394)

- The primary productivity (expressed in "g Carbon/m^2/yr" is mainly produced by:
  - **Phytoplankton (Ch.14: p.401-)---** single-celled, plantlike organisms that drift near the ocean surface (account for between 90% and 96% of the surface ocean's carbohydrate production)
  - **Seaweeds (Ch 14: p.409) ---** larger marine macrophytes (contribute 2% to 5% of the ocean's primary productivity).
  - **Marine Plants (Ch14: p.408-)** – Angiosperm are advanced vascular plants that reproduce with flowers and seeds (like most land plants).
    - **Sea grasses (Ch14: p.410)–** have leaves and stems and roots capable of extracting nutrients form the substrates.
    - **Mangroves (Ch14:p.411)**- Large, flowering plants intimately associated with the intertidal zones **(Fig. 14.18, p.411)**
  - **Chemosynthetic organisms (Ch14:p.412)–** probably account for between 2% to 5% of the total primary productivity in the water column.

3.1 Food Web disperse Energy Through Communities

- **Trophic levels –** A classification of organisms based on what they are eating or using as sources of energy and material. (A step in the flow of energy through an ecosystem.)
  - **Producers (primary producers)** – are photosynthetic or chemosynthetic organisms that make their own food from simple molecules (inorganic matter) in the environment. Also named **photoautotroph** and **chemoautotrophs**
  - **Consumers –**An organism that cannot synthesize its own food but obtains food (energy) from organic matter. Also named **heterotroph**.
- Consumers are in turn classified as follows: **(Fig. 13.13, p.379)**
  - Herbivores or primary consumers or consumers of first level – Are consumers that feed directly on the producers (animals that eat plants).
  - Carnivores I or secondary consumers or second-level consumers – Are animals that feed on herbivores (other animals)
  - Carnivore II or third-level consumers or tertiary consumers – Are animals that feed on the secondary consumers
  - And so on…
  - Top carnivores – Is the last level of the trophic levels

- **Decomposers** – Organisms that use dead organic matter as a source of energy (they are also consumers). Also named **detritivorous**.
  - Decomposers are an indispensable trophic link in the food web, since it permits the recycling of organic matter into its respective constituents that will serve as nutrients for the producers. This process is known as **nutrient regeneration**.
  - Without it, nutrients would not be recycled and made available to autotrophs, and primary production would be greatly limited.

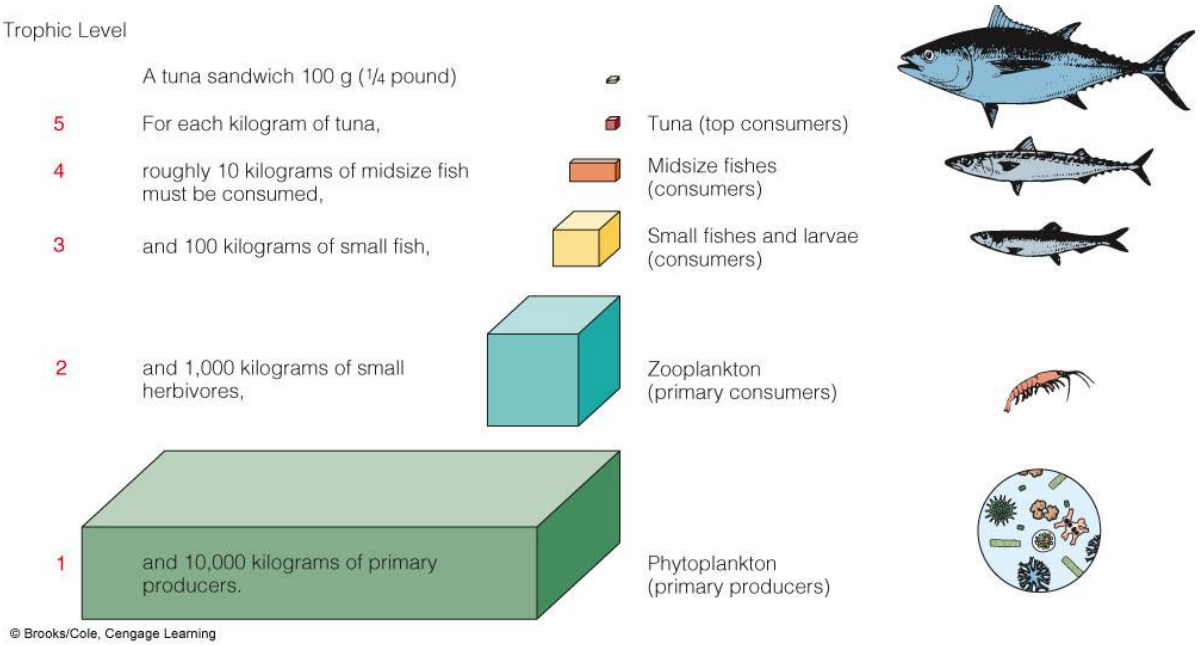
- The transfer of energy through the system usually takes place in several steps known as a **food chain**.
  - **Food chain –** A sequence of organisms that feed on one another, resulting in a flow of energy from a producer through a series of consumers. (Ex: Diatoms (producers) --- copepods (primary consumers or herbivores) --- mackerel (secondary consumers) – tuna (tertiary consumer). Each of the step of the food chain is called a "trophic level". **(Fig. 13.13, p.379)**

- Most ecosystems have a number of different primary producers. Furthermore, many animals eat more than just one kind of food, and many change their diet as they get older and larger. For these reasons, trophic structure is usually a complex, interwoven **food web**.
  - **Food web –**A system of interlocking food chain.**(Fig 13.14, p.380)**

3.2 Pyramid of energy (Trophic pyramid):

- Energy cannot be recycled. Living things cannot create new energy, they can only transform one king of energy to a different kind. A plant can transform light energy into chemical energy; an animal can transform chemical energy into energy of movement (by the muscles), heat energy and so on.
- Instead of being passed on to the next higher level, much of the energy contained in a particular trophic level is used up by the activities of the organisms.
  - Energy and organic matter are also lost as waste.
- Depending on the ecosystem, between about 5% and 20% of the energy is passed from one level to the next; an average is about **10%**.
  - That means that 10,000kg of phytoplankton (primary producers) will support 1000kg of zooplankton (primary consumers – small herbivores), and 100 kg of small fish (secondary consumers), and 10 kg of mid-size fish (tertiary consumers) and finally 1 kg of tuna (top consumer). [5 different trophic levels]
  - Since there is a large amount of energy being lost at each trophic level, this suggests that a much larger number of people can be supported (fed) on a diet of bivalves (molluscs –herbivores -filter feeders) than on a diet of carnivorous fish (such as the tuna).

- The trophic structure of ecosystems can be represented by a **trophic pyramid (pyramid of energy)**, with less energy contained in each succeeding level. **(Fig. 13.13, p.379)**
  - Because there is less energy available at each level, there are also fewer individual organisms. Thus, there are fewer primary consumers (herbivores) than producers, and fewer secondary (carnivores) than primary consumers.



(Refer Garrison, 2016, Fig. 13.13, p.379)

4. ELEMENTS CYCLE BETWEEN LIVING ORGANISMS AND THEIR SURROUNDINGS

- All matter is "recyclable". The atoms and small molecules that make up the biochemicals, and thus the bodies, of organisms move between the living and nonliving realms in **biogeochemical cycles** (**nutrient regeneration)**
  - **Biogeochemical cycle (nutrient regeneration) –** Natural processes that recycle nutrients in various chemical forms from the nonliving environment to living organisms and then back to the nonliving environment.
- The elements and small molecules that form the tissues of an organism are "always on the move". They may cycle rapidly in and out of living things, or they may be trapped within the nonliving realm for a span of time. But the nature of the cycles dictates what will live where, which creatures will be successful, and ultimately, the very composition of the ocean and the atmosphere.
  - In other words, sometimes an environment has enough of a required element to sustain life; sometimes the element is in short supply.
  - The main biogeochemical cycles for life are those of :
    - Carbon **(Fig. 13.15, p.381)**
    - Nitrogen **(Fig. 13.16, p.382)**
    - Phosphorus **(---)**
    - Silicon and Iron and other trace metals (zinc, copper and manganese that are used by organisms in smaller quantities, primarily by enzymes.) **(Ch13: p.382)**

5. THE MARINE ENVIRONMENT IS CLASSIFIED IN DISTINCT ZONES

- The marine environment is divided into **zones** or areas with homogeneous physical features.

5.1 Classification by Light (Fig. 13.18, p.384)

- The penetration of light in the ocean is capital since it is the main source of energy for all living forms found in the ocean.
- **Photic zone–** the part which light penetrates (the sunlit top layer of the ocean)
  - **Euphotic zone—**The upper half of the photic zone, the layer in which most biological productivity occurs.
    - Extends in the tropics to a depth of approximately 200m (660ft) and in mid-latitude water down to about 70m (230 ft) to 100m (330ft).
  - **Disphotic zone –** A transition zone between the photic and the aphotic zones. This transition area has some light but not enough for photosynthesis.
    - Extends to about 600 m in mid-latitudes and 1000m in tropical zones.
- **Aphotic zone –** The permanently dark water mass below the disphotic zone. (The dark zone that extends to the bottom.)

5.2 Classification by Location (Fig. 4.33, p. 131)

- The primary division is between water (pelagic zone) and ocean bottom (benthic zone):

Pelagic zone – The entire area of the open water.

- **Neritic zone –** Near shore over the continental shelf
- **Oceanic zone –** Offshore and the deep-water, beyond the continental shelf

The Oceanic zone is further subdivided by depth into zones:

- **Epipelagic zone –** corresponds to the euphotic zone (From the surface of the ocean to generally between 100 to 200 m)
- **Mesopelagic zone** – corresponds to the disphotic zone – some light penetration but not enough for photosynthesis (It's lower boundary in the tropics is around 700m to 1000m)
- **Bathypelagic zone** – depths from 700-1000m to 2000-4000m
- **Abyssopelagic zone** – Overlying the plains of the major ocean basins (has its lower boundary at about 6000m)
- **Hadalpelagic zone** -- Is the water in the deep trenches (between 6000m and 11,000m)

Benthic zone -- Is a general term referring to organisms and zones of the sea bottom

- **Intertidal zone or littoral zone** – Is that shore area lying between the extremes of high and low tide; it represents the transitional area from marine to terrestrial conditions
- **Sublittoral or shelf zone** – Is the benthic zone underlying the neritic pelagic zone on the continental shelf; (it is illuminated and is generally populated with an abundance of organisms constituting several different communities)
- **Bathyal zone –** Is the benthic area that corresponds to the bathypelagic zone; (Is that area of bottom encompassing the continental slope and down to about 4000m)
- **Abyssal zone** – is the benthic area that corresponds to the abyssopelagic zone; (includes that broad abyssal plains of the ocean basins between 4000m and 6000m)
- **Hadal zone** – Is the benthic zone of the trenches between 6000m and 11,000m; (it corresponds to the hadalpelagic zone)

5.3 Classification by Behavior

- **Pelagic** – organisms live suspended in seawater
  - **Plankton** --- Drifting or weakly swimming organisms suspended in water. Their horizontal position is to a large extent dependent on the mass flow of water (currents) rather than on their own swimming efforts.
    - **Phytoplankton** – Plantlike, usually single-celled members of the plankton community (diatoms, dinoflagellates, silicoflagellates, coccolithophores…)
    - **Zooplankton** – Animal-like members of the plankton community (foraminiferans, radiolarians, ciliates…)
  - **Nekton** – are pelagic organisms that actively swim.
  - **Benthos** – organisms associated with the seafloor bottom
    - **Epibenthos** -- part of the overlying seafloor
    - **Endobenthos** – living buried within the seafloor sediment