CHAPTER I
INTRODUCTION

Chapter objectives

Up on the accomplishing of this chapter students will be able

To identify The meaning of the term Ecology

To know the different branches of Ecology

To identify relation of ecology with other disciplines

No micro-organism, plant or animal species including man is an isolated organism living in a void. Each of them is surrounded by a host of physical conditions that can be measured in terms of chemical composition, texture, pressure, temperature, and humidity, as well as being surrounded by a host of other living organisms which can be described in such terms as microbes. plants. animals, rood, parasites. and enemies. Studies of the inter-relationships of organisms with their physical and biotic environments are termed environmental biology or ecology. These words are very much in the public consciousness today as we become aware of some of past and current ecologic malpractices. It is important for everyone to know and appreciate the principles of this aspect of biology so that he can fonn an intelligent opinion regarding topics such as insecticides, detergents, mercury pollution, sewage disposal, power dams, urbanization and their effects on mankind, on human civilization, and on the world we live in.

The term ecology *(oekologie)* is derived from two Greek words *oikos- means* 'house' or 'place to live' *and-logos* means 'a discussion or study'. Literally, ecology is the study of organisms 'at home', in their native environment. The term first of all introduced by REITBR in 1868, but because the German biologist ERNIT HAECKEL first of all fully defined this term and he made an extensive use or this term in his writings, therefore, usually he is falsly credited or the coinage of the term ecology

DEFINITION OF ECOLOGY

The traditional definition of ecology is *'the study of an organism and its environment',* however different ecologists have defined it variously. ERNST HAECKEL(1869) defined ecology as, *the total relation of the animal. to both its organic and" its inorganic environment.* In 1936, TAYLOR defined ecology as *"the science of all the relations of all organisms to all their environments."* CHARLES_ELTON (1947) in his pioneering book *Animal Ecology* defined ecology as *'scientific natural history.* Although this definition does point out the origin of many of our ecological problems, yet it is much broad and vague like Haeckelian definition of ecology. ALLE*E et al.*, (1949), in their definition of ecology, clearly emphasizes the all-encompassing character of this field of study. According to them Ecology may be defined broadly as *"the science of the interrelation between* living *organisms and their environment, including both the plrysical and biotic environments, and emphasizing interspecies as well intraspecies relations*. Though, F. J. VERNBBRG and W. B. VERNBERO (1970) are completely agreed with ALLEE *et al* definition, vet there are certain ecologists which are not satisfied with this definition and have provided their own definitions of ecology. For instance, ANOREWARTHA (1961) defined ecology as *'the scientific study of the distribution and abundance of organisms.'* G.A. PETRIDES (1968) has defined ecology as *'the study* *of environmental interactions which control the welfare of living things, regulating their distribution, abundance, production and evolution."* EUGENB OOUM (1971) has defined ecology as the cc *structure and function of nature," C.l.* KREBS (1972) has shown his satisfaction over the definition of OOUM for its emphasizing the form and function idea that permeates biology, but, he considered it vague. He, however, proposed the modified version of ANOREWARTHA'S definition of ecology, according to which *"ecology is the scientific study of the interactions that determine the distribution and abundance of organisms."* According to M.E. CLARK (1973) *"Ecology, the science of the environment, is a study of ecosystems, or the totality of the reciprocal interactions between living organisms and their physical surroundings."* Two Indian authors ANANTHAKRISHNAN and VISWANATHAN (1976)' have defined ecology as *'the study of the ways by which individual organisms, populations of species and communitiesof populations respond to diverse environmental pressures, i.e . physical and biotic pressures,'* This definition merely is the modified version of the definition of ecology which has been originally proposed by T. LEWIS and L. R. TAYLOR (1967) in their book, *Introduction to Experimental Ecology.* According to LEWIS and TAYLOR *l Ecology is the study of the way in which individual organisms, populations of-same species and communities of populations respond to these changes.'* Lastly to avoid this ecological jargon we can rely upon the simple definition of ecology which has been provided by CHARLES H. SOUTHWICK (1976). According to him *ecology is the scientific study of the relationships of living organisms with each other and with their environments.* Thus, it is the science of biological interactions among individuals, populations, and communities. Ecology is also the science of ecosystems-the interrelations of biotic components with their non-living environments.

BRANCHES OF ECOLOGY

The science of ecology often is divided into autecology and Synecology. Autecology deals with the study of the individual organism or an individual species. In it, life' histories and behaviour as a means of an adaptation to the environment are usually emphasized. Synecology deals with the study of groups of organisms which are associated together as a unit *(i.e.,* community). Thus, if a study is made of the relation of a white oak tree (or of white oak trees in general) to the environment, the work would be autecological in nature. If the study concerned the forest in which the white oak lives, the approach would be synecological (ODUM, 1971). While autecology is experimental and inductive, the synecology is philosophical and deductive (SMITH, 1974).

Synecology is often further subdivided into aquatic and terrestrial ecology. The aquatic ecology includes freshwater ecology;!eustuarine ecology and marine ecology. -Terrestrial ecology, subdivided further into such areas as forest ecology, grasslaod ecology, crop land ecology and desert ecology, is concerned with terrestrial ecosystems-their microclimate, soil chemistry, nutrient and hydrological cycle and productivity.

Further, demecology is that branch of ecology which 'deals with the ecology of populations. Early ecologists have recognized two major subdivisions of ecology in relation to plants and animals; plant ecology and 'animal ecology. But when it was found that in the ecosystems plants and animals are very closely associated and interrelated,
then, both of these major subdivisions of ecology into plant ecology and animal ecology became vague. Besides these major subdivisions the ecology has been classified in the following branches according to the level of orgauization, kind of environments or habitats and taxonomic position:

1. Habitat ecology: It deals with the study of different habitats of the biosphere. According to the kind of habitat, ecology is subdivided into Marine Ecology, Freshwater Ecology, and Terrestrial Ecology. The terrestrial ecology too is further subdivided into Forest Ecology, Cropland Ecology, Grassland Ecology, *etc.*, according to the kind of study of its different biomes.

2. Ecosystem ecology: It deals with the analysis of ecosystern from structural and functional point of view including the interrelationship of physical (abiotic) and biological (biotic) components of environment.

3 - Conservation ecology: It deals with methods of proper management of natural resources like land, water, forests, sea, mines, etc., for the benefit of human beings.

4. Production ecology: It is the modern subdivision of ecology which deals with the gross and net production of different ecosystems like freshwater, sea water, agriculture, horticulture, etc. and tries to do proper management of these ecosystems so that maximum yield can be get from them

5. Radiation ecology: It deals with the study of gross effects of radiations and radioactive substances over the environment and living organisms.

6. Taxonomic ecology: It is concerned with the ecology of different taxonomic groups and eventually includes following sub- divisions of ecology-plant ecology, insect ecology, invertebrate ecology, vertebrate ecology microbial ecology and so on.

7. Human ecology: It deals with the study of man with his, environment.

8. Space ecology: It is a modern subdivision of ecology which remains concerned with the development of partially or completely regenerating ecosystems for supporting life of man during. long space flights or during extended exploration of extra-terrestrial environments.

9. Systems ecology: The systems ecology is the most modem branch of ecology which is concerned with the analysis and understanding of the function and structure of ecosystem by the use of applied mathematics such as advanced statistical techniques, mathematical models and computer science.

RELATIONSHIP OF ECOLOGY WITH OTHER DISCIPLINES

Modern ecology is a multidisciplinary science which depends on a variety of disciplines like Physics, chemistry, mathematics, statistics, meterology, climatology, geology, geography, economics, sociology, agriculture science, forestry, horticulture, genetics, pbysiology, etc. All these disciplines have helped in the better understanding of many ecological principles.

For instance, meterological and climatological data for certain geographic localities allow for a more suitable interpretation of results. A basic knowledge of forestry can. be, invaluable for a forest-ecologist to understand forest type distribution, floristic composition and prevalent environmental factors. Likewise,. statistical data helps in interpreting the reasons for activity, population increases, migrations, probability of ecological events occurring in a particular area, sampling techniques and reliability of results, Palaeontology (geology) provides information -about the ancestral organisms and environmental situations prevalent in past. Evolution and genetics are utilized to interpret the reason for, organic changes when linked with environmental conditions establishment of new populations and species, environmental effects on genetics populations and species, environmental effects on genetic populations and so on. Such interdisciplinary approaches to ecology, consequently have given rise to following subdivisions of ecology:

1. Ecological genetics: An ecologist recognised a. kind of genetic plasticity in the case of every organisms. In any environment only those organisms that are favoured by the environment survive. The branch of ecology dealing with genetics in relation to ecology is called ecological genetics.

2. Pa1aeoecology: It deals with the movements of biotic elements based on palaentological evidence, which provide information about ancestral organisms and environmental conditions existing in the past.

3. Ecophyslology: The factors of environment have a direct bearing on the functional aspects of organisms. The ecophysiology ,deals with the survival of populations as a result of functional adjustments or organisms with different ecological conditions of the ecosystem.

4. Chemical ecology: It deals with the adaptations of animals or preferences of particular organisms like insects to particular chemical substances. ,

5. Pedology: 'It is a branch of terrestrial ecology and it deals with the study of *soil,* in particular their acidity, alkalinity, humus content, mineral contents, soil type, etc., and their influence on the organisms. , ' ,' ..

6. Ecogeography: It deals with the study of the role' of the environment in animal distribution. It is related with biogeography which is concerned with the structural and functional relations of living organisms in space, which form the immediate environment of the individuals as well as populations. Ecefloras and ecofaunas are the lowest units of which a biogeographic flora or fauna is made up of. '.

7. Ecological energetics: It deals with energy conservation and its flow in the organisms' within the, ecosystem. In its thermodynamics has its significant contribution.

Because of its far-flung involvements with so many fields, ecology is often regarded as a generality rather than a speciality. Visualizing .this fact, an ecologist, A. MACFADYEN(1957) wrote in his book Animal Ecology: Aims and Methods= The ecologist is something of a chartered libertine. He roams at will over the legitimate .preserves of the plant and animal biologist. the taxonomist, the physiologist, the ,behaviourist, the meterologist , the geologist, the physicist, the chemist and even the sociologist; he poaches from 011 these and from other established and respected disciplines. It is indeed a major problem for the ecologist in his own interest, to set bounds 10 his divagations. -'

Importance of Animal ecology

Applied animal ecology is a framework for the application of knowledge about ecosystems so that actions can be taken to create a better balance and harmony between people, animal (living organism) and nature in order to reduce some unwanted impact on living things and their habitats.

Scope: - In situ and ex situ conservation systems

With respect to scope, it is intended that this course should contain a body of knowledge about the use of ecological theory and principles to solve problems associated with the intensive human use of the environment and its resources. It is beyond our capacity to return Earth to a primeval state, but what we can do is build a technological 'ark' to retain as much ecological integrity as possible. To achieve this, many aspects of ecology have to be applied to manage conservation systems where the maintenance, restoration, and creation of diverse and healthy ecosystems are principal objectives.

Some conservation systems may be broadly classified as in situ operations. These include:

protection of rare species and habitats;

restoration of industrial wasteland and the mitigative creation of new ecosystems;

using wetland ecosystems for treating wastewater;

environmental valuation in relation to the needs for conservation and development to go hand in hand;

integration of sustainable ecosystems with commercial enterprises, such as agriculture and nature tourism;

Study of the ecology of human diseases in relation to their control.

Other kinds of conservation systems are classified as ex situ. These include operations in zoos, botanical gardens, museums, and germ plasm stores. The objectives are to provide breeding populations of plants and animals for reintroductions, and maintain a classified biodiversity inventory of specimens and genetic resources.

CHAPTER TWO
ECOSYSTEM STRUCTURE

Chapter objectives

Up on the accomplishing of this chapter students will be able

- ✓ *To identify different ecosystem structure*
- ✓ *To know Structure of Biotic Components of an Ecosystem*
- ✓ *To identify Structure of Abiotic Components of an ecosystem*
- ✓ *To explain Energy flow and Nutrient cycle*
- ✓ *To define Food chain and Food Web*

2.1. Introduction to Ecosystem Structure

In ecology, an ecosystem is a naturally occurring assemblage of organisms such as plant, animal and other organisms also referred to as a biotic community or biocoenosis, living together in their physical environment (or biotope), functioning as a loose interacting unit.

The term ecosystem first appeared in publication by the British ecologist Arthur Tansley in 1935.

An ecosystem consists of the community of organisms plus the associated physical environment. For instance in a rangeland ecosystem it is the combination of domestic and wild animal, different species of plants and some nonliving things in an area. The prefix 'eco' indicates environment and 'system' refers to a complex of coordinated units. An ecosystem is a dynamic and complex whole, interacting as an ecological unit. Some consider this the basic unit in ecology. It is a structured functional unit in equilibrium characterized by energy and material flows between its constituent elements.

The size of an ecosystem can vary widely. It may be as big as a whole forest, or as small as a little pond. Different ecosystems are often separated by geographical barriers, like deserts, mountains or oceans, or are isolated otherwise, like lakes or rivers. As these borders are never rigid, ecosystems tend to blend into each other. As a result, the whole earth can be seen as a single ecosystem, or a lake can be divided into several ecosystems depending on the scale used

Ecosystem ecology is the study of the movement of energy and matter through ecosystems. It is one of the fundamental disciplines of ecology. Ecosystem ecology operates at a scale above that of communities but it is defined more by subject matter than by scale. The ecosystem is an energy processing system whose components have evolved together over long period of time. The structure of an ecosystem is related to energy flow and material cycling through and within the system. The more complex the structure, the lesser it needs energy to maintain itself. The organisms in an ecosystem are usually well balanced with each other and their environment. This balance is achieved through various types of symbiosis, such as predation, parasitism, mutualism, commensalism, competition, and amensalism. Introduction of new elements into an ecosystem, whether it is living or non-living tend to have a disruptive effect. In some cases, this can lead to ecological collapse and the death of many native species. The abstract notion of ecological health attempts to measure the vigor and recovery capacity of an ecosystem. Although every ecosystem is different from one another, whether it is aquatic or terrestrial is made up of two major components: the *biotic* and the *abiotic*. The *biotic* component refers to the community, all interacting groups of organisms living in an area. The *abiotic* part, on the other hand, embraces the non-living or the physical environment with which the organisms do interact with. If we take some Lake in the country, as an example of a closed aquatic ecosystem, we find the following major components and units that interact to each other to make the whole integrated ecosystem.

Biotic Component (includes the different animal, plant and microbe communities)		**Abiotic component** (includes all the physical and chemical factors)
– Phytoplankton (floating photosynthetic organisms such as algae and bluegreens – Zooplankton (floating invertebrates and microbes) – Macrophytes (rooted aquatic plants) – Weed bed fauna (decomposer invertebrates) – Aquatic insects (e.g., dragonfly, beetles) – Microscopic organisms (like bacteria, blue-greens, and pathogens) – Fishes and amphibians – Reptiles such as alligators and lizards – Mammals such as hippos and otter – Aquatic birds (including fish predators, scavengers, insect eaters, herbivores, filter feeders and many others)	Interaction	– Suspended solid particles – Salinity and pH – Light intensity of the water – Dissolved nutrient – Dissolved gases – Water temperature – Water movement (wave motion) The mud and the rock

In an agricultural ecosystem especially in a range land, which is a managed ecosystem, we find also a number of plant and animal communities interacting to each other. For example, crops interact with different weeds, pollinators, parasites, pathogens, pests, earthworms, soil microbes, herbivores, shading trees, and many other organisms. Some studies show that a square meter of organic soil from a temperate agricultural land may contain more than 1000 species of organism with population densities in the order of $106/m^2$ for nematodes, $105/m^2$ for micro arthropods and $104/m^2$ for other invertebrates groups (Swift and Anderson, 1993). A gram of soil may contain over a thousand fungal hyphae and up to a million or more individual bacterial colonies. These communities are useful in nitrogen fixing and nutrient cycling. Those groups of organisms form the biotic component of the ecosystem. On the other hand, the physical and chemical characteristics of the soil such as its texture, color, pH, nutrient level, temperature, speed and direction of wind, moisture, light and a number of other factors form the abiotic component of the ecosystem

Structure of Biotic Components of an Ecosystem

There are various ways of interactions between organisms in an ecosystem. The clearly observed form of interaction is revealed in their energy and food source in the ecosystem. Organisms in any kind of ecosystem could be generally classified or structured into two broad categories based on their ability to synthesize their organic molecules: *autotrophy* and *heterotrophy*. The following diagram(next Figure) shows how the biotic component of an ecosystem is structured in terms of the trophy. Each organism has its own specific role in the ecosystem.

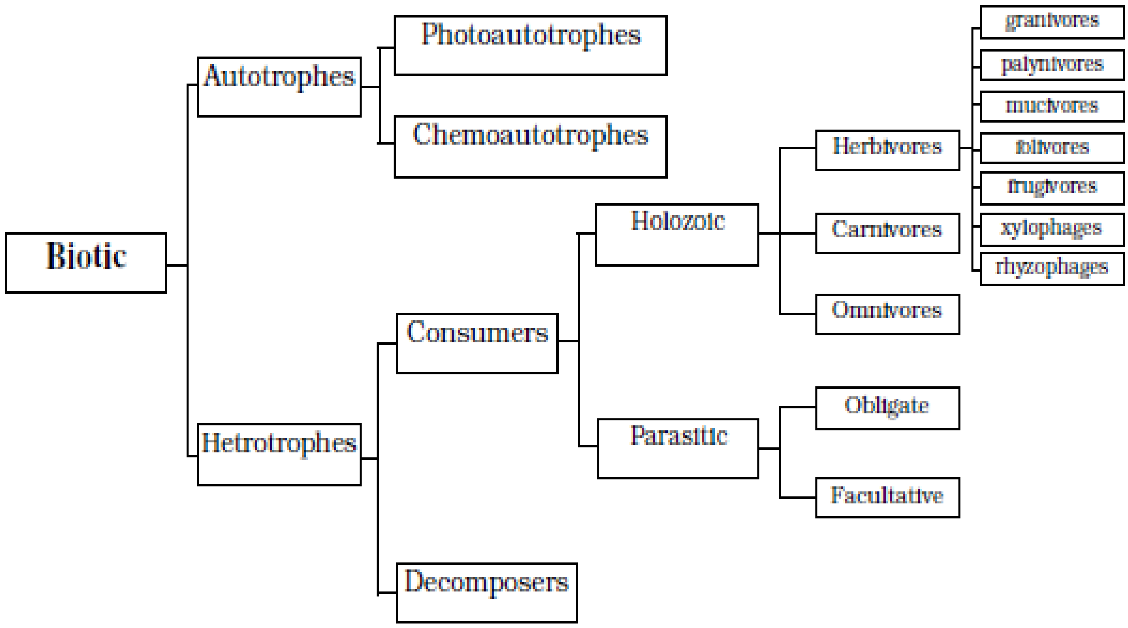


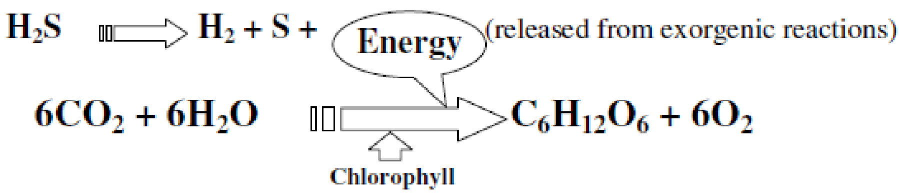
Figure: A diagrams showing the tropic structuring of in an ecosystem

Autotrophs

These organisms are also called primary producers. The group includes all organisms in an ecosystem that can synthesize and store their own chemical energy in the form of organic molecules from inorganic raw materials. Based on the energy source for synthesis and the biochemical pathway of the anabolic process, they are further classified in to two groups:

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + 6O_2$$

Chemo-autotrophs: This group of organisms uses energy that is generated from reductionoxidation reaction of some chemicals involving the electron transfer mechanism. The biochemical pathway is called *Chemosynthesis*. Recently, scientists have discovered microbes living deep in the darkest and coldest part of the sea on the ocean floor. In these areas lava erupts into the ocean and eventually forms hydrothermal vents. The vents pump out hot seawater loaded with minerals. Microbes living here do not depend on plants or the sun at all to live, but generate their energy by oxidizing reduced chemicals in the vent column and build their cell material from CO_2. In fact, the reactions that they use to make cell material from CO_2 are identical to those used by photoautotrophs Sulfur bacteria, for example, can synthesize their own food using the energy released from the oxidation of hydrogen sulphide (H_2S) as shown in the diagram below. However, the group shares very insignificant contribution to most ecosystems.



Heterotrophs

This category includes all organisms other than autotrophs that cannot synthesize their own food. They are, therefore, dependent on primary producers for organic food. Two broad categories are identified under this group: ***consumers*** **and** ***decomposers*.**

Consumers: Consumers are organisms that derive their nutrient from primary producers. Two kinds of nutrition are known: *holozoic* and *parasitic*

***Holozoic Nutrition*: -** This is a kind of nutrition upon which the organisms feeds relatively larger piece of organic matter (plant or animal) by killing.

Herbivores: - Herbivores are those animals that feed on plant materials. In some ecosystems animals have highly specialized feeding habits. The group can be further classified into various sub-groups, such as folivores (grazers or browsers which are specialize on feeding leaves, frugivores, which eat mainly fruit; and nectarivores, which feed on nectar. Among herbivorous insects and other arthropods, the level of feeding specialization can be far more fine-tuned; including seed-eaters (granivores), pollen-eaters (palynivores), plant fluid-feeders (mucivores), and those specialized to feed on wood (xylophages) or roots (rhizophages). In other animals, however, the degree of specialization is not so advanced. Many fruit and leaf-eating animals also eat other parts of plants, notably roots and seeds. The diets of some herbivorous animals also vary with the seasons, especially in the temperate zones, where different plant foods are most available at different times of the year. Mammals such as cattle, sheep and goats, gazelles, elephant and giraffes; reptiles such as tortoise; birds like parrots and doves; and some insects like locusts and grasshoppers are under this category.

***Carnivores*: -** Carnivores are animals or sometimes insectivore plants that feed on herbivores or another carnivore (animal prey). The carnivore could be predator that kills a living animal or scavenger that eats on carcasses (dead animals). For example, mammals like lions, hyena, tiger, dogs, cats and foxes; reptiles like crocodile; Fish like sharks; birds like vultures and eagle, and some insects like dragonfly and preying mantis are under this group.

***Omnivores*:-** This includes those animals that feed on both plants and animals. They are generalistic feeders that have no special feeding preference. Examples include humans, pig and many other apes.

Parasitic Nutrition:- This is a kind of nutrition by which the parasite derives its organic food from a living host. They are usually much smaller in size than the host. The group includes a number of protozoa, parasitic insects, and none chlorophylous plants. There are different forms of parasitism:

Endoparasites versus Ectoparasites: The former are those organisms that dwell in side the body of the host, while the latter dwell on the external body of the host.

Facultative Versus Obligatory parasites: The former groups are those parasites that can shift their mode of nutrition to saprophytic (decomposer) if their host is dead. This group of parasite is highly virulent that may kill their hosts and decompose the dead organic matter. Obligatory parasites, on the other hand, are completely parasitic that totally depend on a living host, as the result of which, they usually never kill their hosts.

Decomposers (Saprophytic Nutrition):

These are organisms that feed on fallen leaves, twigs, and other dead organic materials including remains of plans and animals. This group includes most of the bacteria and mushrooms that degrade complex dead organic matter of all categories into simple inorganic compounds, and restore minerals to the environment. Some soil invertebrates also fall in to this category, and have strong mutualistic relations with microorganisms to aid in the breakdown of cellulose and lignin. Digestion could be either intracellular (inside the body) by absorbing small pieces of organic matter in the form of solution, or extra-cellular by secreting enzymes on the food material and absorbing the digested food particles.

Structure of Abiotic Components of an ecosystem

The abiotic component of an ecosystem is made up of all the substances, factors and forces in the habitat that affect the organism. The abiotic environment is the result of the interactions among the energy, inorganic minerals, gases, dead organic matter and a number of other factors and forces. As the result of this interaction, the environment is always in the state of continuous change or flux.

The abiotic component of an ecosystem, hence, could be generally categorized in to the following components:

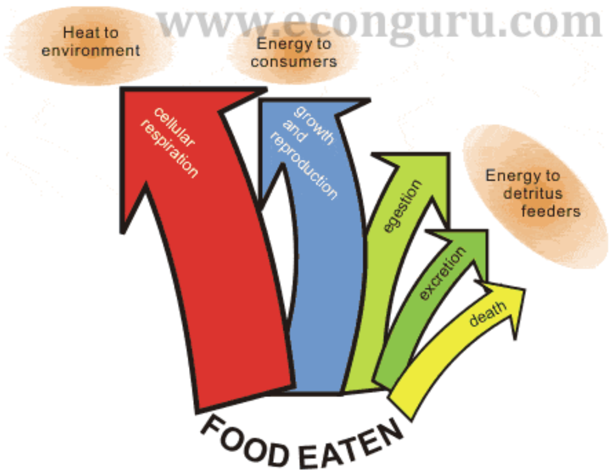
- ***Lithosphere***: all the solid mineral matter including the soil and rocks;
- ***Hydrosphere***: all the water bodies (in the ocean, lakes, rivers) and its physico-chemical characteristics;
- ***Atmosphere***: all the gaseous mixture in the air;
- ***Radiant solar energy***: the electromagnetic radiation (including visible light) coming from the sun and stars; and
- Position and movement of the earth, the moon and other extraterrestrial bodies, and their gravitational force.

Energy flow and Nutrient cycle

Trophic Structure and the Food Chain

Most important relationships between living organisms and their environment are ultimately controlled by the amount of energy reaching the earth from the sun, beside the water and nutrients they require for their metabolism and growth.

Everything needs energy for motion, living things are no exceptions. Sun is the ultimate source of energy for every ecosystem. The energy flow of an ecosystem starts the moment photosynthesizes capture sun light and transform it into a stock of organic compound like glucose that stores heat and energy for later use, and ends until the energy is used up or released into the surroundings in metabolic processes. In between them, energy transfers from one organism to another at the aid of food webs, each of the organisms receiving only a small percentage of the total energy carried in the one being consumed, because of all the processes indicated in this diagram:



tropic structures of animals

Only a very small proportion of energy that the earth receives from the sun is trapped by green plants and converted into a biochemical form. For example, a study indicates that maize can utilize only about 1.6% of available solar energy that hits the surface of its leaf (Brewer, 1994). It is estimated that the most efficient ecosystems are rarely able to trap more than 3% of this energy. A certain amount of energy is egested in faeces or excreted in urine and sweat. Of the assimilated energy, a portion is utilized in cellular respiration and thereafter becomes heat. The remaining portion of energy is converted into increased body weight or additional offspring which is radiated back to the atmosphere or other objects in the form of heat.

Forms of Energy in the Ecosystem/ Biological Production

Living organisms may use energy in two basic forms; either radiant or fixed energy. *Radiant energy* is electromagnetic radiation, such as solar light. For example, green plants use this energy to synthesize glucose molecule. *Fixed energy*, on the other hand, is the chemical energy stored within the carbon bonds of organic molecules, such as glucose. This energy is then released through either aerobic or anaerobic respiration to yield ATP (Adenosine Tri-phosphate), that is stored in the tissue and utilized for different biochemical activities, when oxidized in to ADP and AMP. The process of storing or producing fixed energy by organisms is referred to biological production. There are two kinds of biological productions: Primary production and Secondary production.

Primary Production

This is the form of fixed energy accumulated by autotrophs by converting the radiant energy. The total amount of fixed energy incorporated into the bodies of photosynthetic organisms is known as the gross primary production (GPP). Primary productivity, on the other hand, is the rate at which energy is incorporated into the body of plants at a given time, usually for most ecosystems, it is measured per year.

The rate of GPP in an ecosystem could be estimated using different techniques such as infrared gas analysis or radioisotope method. The infrared gas analysis technique measures the amount of CO_2 absorbed (or O_2 produced) by the plant in the process of photosynthesis by using infrared gas analyzer. The analyzer measures the gas entering and leaving an airtight enclosure of a known area or volume that is constructed of a light-transmitting substance, in which a plant leaf or branch is placed. In the CO_2 assimilation technique, for example, it is assumed that any CO_2 absorbed from the leaves is the result of photosynthesis. However, this simply measures the net amount of CO_2 absorbed by the plant, because, at the same time, a substantial amount is also produced as a byproduct of respiration. Therefore, a comparable study is required using a light tight (non-transparent) container where, no photosynthesis will take place, but respiration will. The amount of CO_2 released from this chamber in a given periods, or at a periodic intervals, will be a measure of the amount and rate of respiratory activity. Therefore, the amount of the gas measured from the two chambers, will be added to approximate the gross primary production of the system.

Factors affecting the rate of primary production

Primary production in terrestrial ecosystems is influenced by various factors such as temperature, precipitation, and nutrient availability, length of growing season, animal utilization and fire. For example, tropical rain forests are the most productive ecosystems unlike deserts, tundra and open sea ecosystems. In equatorial regions, where the temperature is high throughout the year, and there is good water supply, it is suitable for the plant growth. Therefore, the primary productivity is very high as compared to other ecosystems. On the other hand, annual primary production is low in lower-latitude and middle-latitude deserts, where growth is limited due to the lack of moisture. At higher latitudes, around the polar region, more moisture is generally available. However, due to low temperature for most of the year, annual primary production is low. In aquatic systems, primary production is largely limited by the availability of light, nutrient and water temperature. Primary productivity strongly affects species richness and food-web structure of ecological communities. Coral reefs are the most productive ecosystems in the aquatic biomes.

Annual net production is a convenient basis for comparing various ecosystems. It may range from zero (in desert ecosystems) to 5000gm/m2 (in highly productive ecosystems like tropical rain forest). More than 60% of the terrestrial primary production occurs in the tropics. However, on average, only about 30% of the GPP is available as NPP in Tropical Rain Forests when compared to 40% in temperate forests. This difference is in part due to the faster rate of respiration than photosynthesis in higher temperature.

Secondary Production

Once it has been fixed by autotrophs, energy may travel in an ecosystem through the consumption of dead or living organic material. On decomposition, complex organic molecules may be broken down again into inorganic forms, allowing them to be taken up once again by autotrophs. This inorganic energy may also move from one ecosystem to another through a variety of processes. These include animal migration or harvesting, plant harvesting or seed dispersal, leaching and erosion. The total amount of energy stored at consumer level is called *secondary production*. The total energy assimilated in the tissue of the consumer, which is equivalent to GPP in Primary producers, is called *Assimilation energy*. The net amount of energy, which is equivalent to NPP in Primary producers, left from maintenance and respiration is called *Production energy*. This energy is stored in the form of the production of new tissue, fat deposit, growth and production of new individuals. This is available for the next trophic level, when consumed.

Food chain and Food Web

A food chain is a simple food relationship between organisms. It is a link (chain) of organisms, one supplying food for the next. Like many simple models, the idea of a food chain only provides an abstract idea of the way energy flows through an ecological community. A food chain cannot really exist as a single series of connections, isolated from any others. A model describing the relationship between organisms in many different food chains is called a food web. The food web demonstrates the complex patterns of energy flow in an ecosystem. It is believed that the more complex a food web is, the more resistant it is to outside interference. There are two kinds of food chain:

Photosynthesis is only the beginning of a chain of energy conversions. There are many types of animals that will eat the products of the photosynthesis process. Examples are deer eating shrub leaves, rabbits eating carrots, or worms eating grass. When these animals eat these plant products…energy and organic compounds are transferred from the plants to the animals. These animals are in turn eaten by other animals, again transferring energy and organic compounds from one animal to another. Examples would be lions eating deer, foxes eating rabbits, or birds eating worms

The organisms within the system can be categorized depending upon their part in the process:

- **Producers** are organisms that convert inorganic compounds into organic compounds. They convert light energy into stored chemical energy. "They are called **producers** because all of the species of the ecosystem depend on them."
- **Consumers** depend upon other organisms for their source of energy.
  - **Primary consumers:** consumers that get their energy directly from producers. Primary consumers include cows and rabbits.
  - **Secondary consumers:** consumers that get their energy directly from primary consumers. Secondary consumers include fish and hawks.
  - **Tertiary consumers:** consumers that get their energy directly from secondary consumers. Tertiary consumers include wolves and hawks.

Since many organisms have more than one type of energy source, they can be classified in more than one category. For instance, when a field mouse eats seeds, it can be labeled a primary consumer. However, when the mouse eats insects, it is acting as a secondary consumer.

Before we are going to see the other important part of this chapter fist it is a must to see what exist between different organisms.

Under different Ecological Pyramids we could find different type organism according to their productivity those includes:-

Autotrophs - Organisms with an ecosystem that produce their own food

- Primary producers within an ecosystem
- Make the energy available for ALL organisms
- Photoautotrophs - Absorb light energy to convert CO2 and H2O into glucose
- Chemoautotrophs - Break down inorganic chemicals for energy to convert

Heterotrophs - Organisms that get energy requirements by consuming other organisms. Called

Consumers

- **Herbivore** - Consumer that eats only other autotrophs
  - Cow, Rabbit, Grasshopper
- **Carnivore** - Consumer that preys on other heterotrophs
  - Wolves, Lions, LynxCO_2 into organic compounds

- **Omnivore** - Consumer that feeds on both Producers and other consumers

Humans, bear, mocking birds

Detritivores - Consumers that feed on pieces of dead organic matter

Earthworm, insects at the bottom of ponds

Decomposers - Breakdown dead organic material to make nutrients available for producers to reuse . Bacteria, fungi

Grazing Food Chain

This is a model that describes the general flow of energy in communities. For most ecosystems, this model of food chain begins with the fixation of light, water and carbon dioxide by photosynthetic autotrophs (primary producers). Primary producers include green plants, photosynthetic bacteria and protists. Primary consumers (such as ants, termites, sheep and other herbivores) form the second link in the grazing food chain, when they gain energy by consuming the primary producers. The third link in the grazing food chain are the primary carnivores (or secondary consumers), such as foxes, cats and spiders, which kill and consume the primary consumers. A further step is the secondary carnivores (or tertiary consumers), which feed on primary carnivores; and the chain goes the same way. Decomposers (detritivores) usually retain the last level in the food chain decomposing all dead organic matter, but are sometimes themselves consumed by some of the organisms they digest.

Detritus Food Chain

This type of food chain begins with decomposing organisms (detrivors). The food chain differs from the grazing food chain in several fundamental ways. Organisms in such a food chain are, in the first place, physically smaller. Also, the functional roles of the different organisms do not fall neatly into various categories as in the grazing food chain. Thirdly, detritivores live in habitats rich in scattered food particles. As a result of this, detritivores are generally less motile than herbivores or carnivores. The members of this food chain include a large number species from different kingdoms or classes, such as algae, bacteria, slime moulds, fungi, protozoa, animals and plants. These detritivores consume organic waste; shed tissues and dead bodies of organisms. They tend to be rather active, decomposing large amounts of organic waste into inorganic nutrients. The rate of decomposition in the detritus food chain is controlled by a number of factors. In most terrestrial systems, temperature, soil, oxygen and moisture content prove to be the primary variables controlling the rate of decomposition.

A **food chain** is useful for beginning a discussion of energy flow in an ecosystem, but it's a very small part of a much larger picture. The nice, straight line from is only one possible way energy can transfer. Within an ecosystem, there are many, many more possible combinations. We can attempt to illustrate these combinations using a **food web**.

This is a *model* of energy transfer, and that's an important distinction. We use **food chains** and **food webs** to help students understand how energy flows in an ecosystem, but we don't want them to think that the system is limited to the diagrams we present. For the sake of clarity, **food webs** are commonly limited to *several* interrelated organisms; *all* the possible relationships are not illustrated, because the diagram then would be very difficult to interpret.

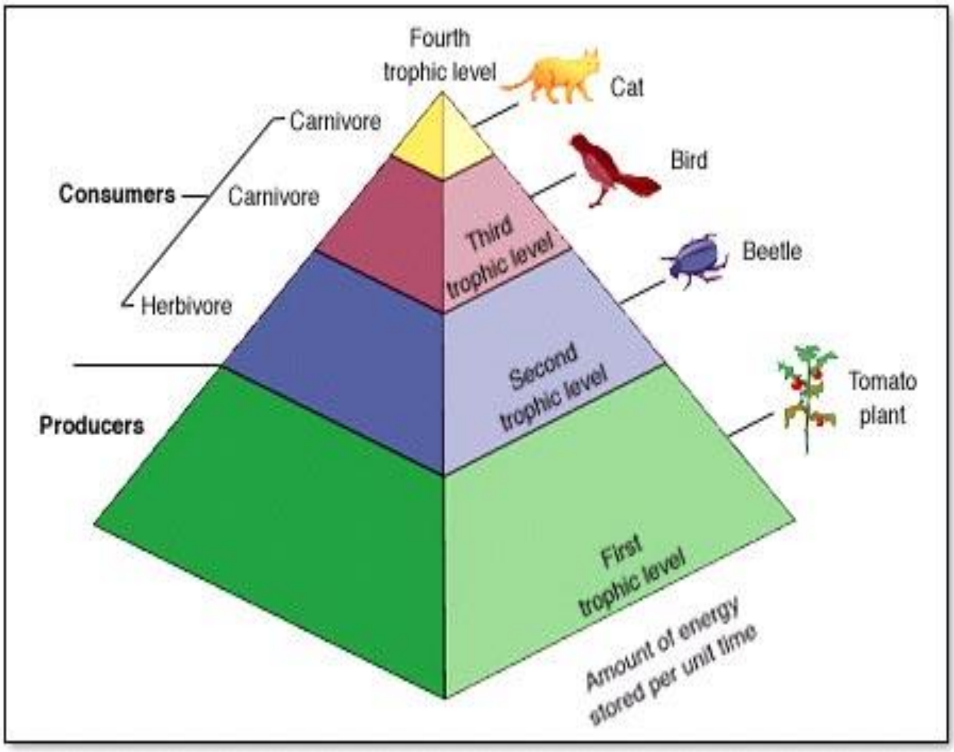
Trophic Level

It is the level of each of the different organism in the food chain. Each trophic level is defined by the number of steps through which energy passes in order to reach the organisms in the food chain. Despite enormous differences between different communities, most have only 3 to 5 trophic levels. The reason is the fact that energy is lost between each level and the amount is gradually diminished.

However, highly stable ecosystems, for example in tropical rain forests, may have up to 9 trophic levels. In a grazing food chain producers retain the 1st TL, herbivores the 2nd, primary carnivores the 3rd, secondary carnivore the 4th TL, and the like.

Ecological Pyramids

Food chains are morphological systems of energy flow in an ecosystem. However, the energy flow within a system may be described in more quantitative terms using ecological pyramids. When energy flows and accumulates in the body of organisms at any trophic level in a certain food chain, it is revealed either in terms of increase in biomass (weight), calories (energy) or numbers (new individuals born). If we measure in quantities and draw the relative number, biomass or calories of each organism at each trophic level in the specific food chain, we get a pyramid-shaped diagram, broader at the base and narrower at its apex. This implies that the amount of energy stored at each trophic level gradually decline in the process of transfer from the lower trophic level, at the base (e.g. Primary producers) to the highest trophic lever, at the apex (e.g. Snakes). This kind of diagrammatic expression helps to demonstrate the relative amount of energy fixed and transferred in the process of food chain at each trophic level. However, in certain circumstances, the shape of the ecological pyramid might be distorted somewhere, and might not have exactly a pyramid shape, hence, we call this kind of pyramid, an inverted pyramid.



Ecological pyramid

Nutrient (Biochemical) cycle in an ecosystem

The existence of the living world depends up on the flow of energy and the circulation of materials through the ecosystem. For example domestic animals to survive and provide different product required by human being in the presence of enough biomass growth plants which comes true in the normal nutrients cycle in range land ecosystem. Nutrients required by life exist in mineral form in Earth's crust. All the essential nutrients flow from none living to living and back to the non-living parts of the ecosystem in a more or less circular path. This is termed as the *biogeochemical cycle* ("*bio*" implies living; "*geo"* implies water, rocks and soil; and "*chemical"* implies the processes involved).

In ecology, a biogeochemical cycle is a circuit or pathway by which a chemical element or molecule moves through both biotic ("bio-") and abiotic ("geo-") compartments of an ecosystem. In effect, the element is recycled, although in some such cycles there may be places (called "sinks") where the element is accumulated or held for a long period of time. Biogeochemical cycles always involve equilibrium states: a balance in the cycling of the element between compartments. However, overall balance may involve compartments distributed on a global scale.

Main Important Nutrients in an Ecosystem

Plants have nutritional requirements in order to accumulate energy and grow, develop and complete their life cycle. The supply of nutrients to the plants should be balanced, ensuring not to over or under-fertilize. There are about 16 most important elements in an ecosystem that are crucially important for the plant growth. These nutrients are classified into different categories based on the amount of requirement to plants.

Types of Nutrient Cycling

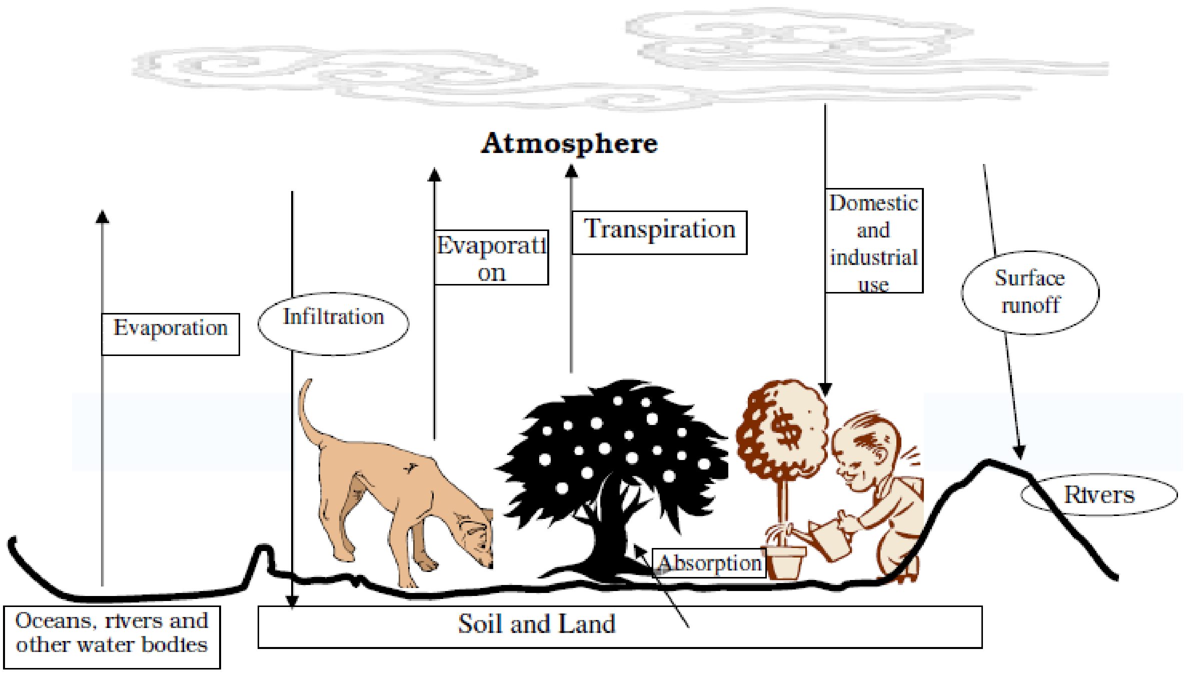
There are two basic types of biogeochemical cycles in an ecosystem: *Gaseous* and *sedimentary* cycles.

a. *Gaseous (atmospheric) cycle*: In this kind of cycling, the main reservoirs of elements are the atmosphere and oceans. Examples of those element cycling in the gaseous or atmospheric cycle include the following:
   - Hydrological cycle
   - Carbon cycle
   - Oxygen cycle
   - Nitrogen cycle

b. *Sedimentary (edaphic) cycle*: In this kind of cycling, the main reservoirs of elements are the soil and rocks. Examples include:
   - Sulfur cycle
   - Phosphorus cycle
   - Nitrogen cycle

Hydrological/ Water Cycle

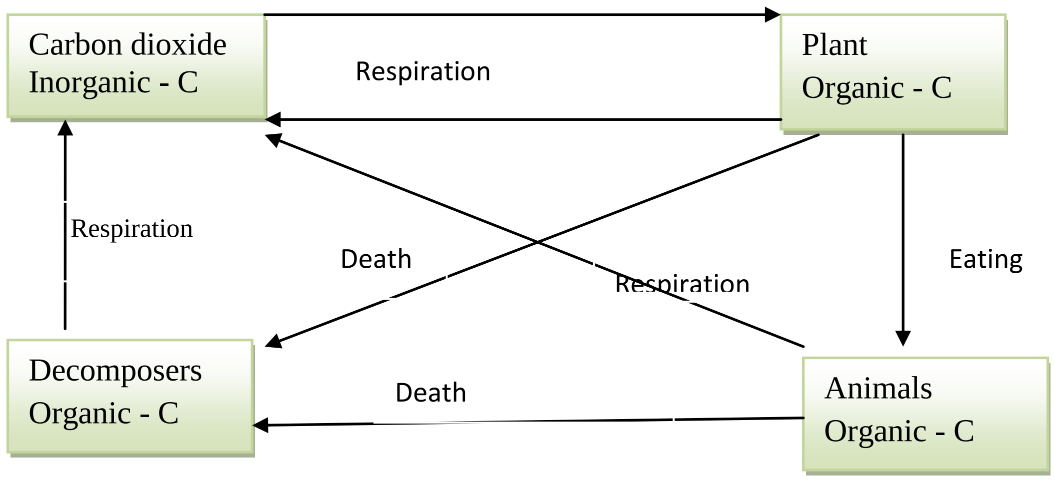
Solar energy is the driving force behind the water cycle. The heating of the atmosphere and its role in evaporation provide the basic mechanism of the cycle. Water evaporates from the water bodies, soil, and the tissue of plants and animals and is held in the atmosphere. Water vapor in the atmosphere when condensed, it falls in the form of rain as droplets or in the form of ice crystals. The precipitation that reaches the soil runs off to the surface water bodies (rivers, lakes and streams) or gets into the ground by infiltration. The rate of infiltration is influenced by the nature of the soil, the landform (slope) and the characteristic of the vegetation. The water that is retained by the soil is absorbed by the plants and used for different physiological activities such as cooling, photosynthesis, and transportation of elements. Animals also drink and use the surface and ground water. They also get a considerable amount of water while consuming other plants and animals. The water in the tissue of organisms and the soil, again, evaporates and returns back to the atmosphere or oceans, the reservoirs. The cycle continues the same way. See the following diagram



Water cycle in a territorial ecosystem

Carbon cycle

Carbon is pulled from the air by autotrophs during photosynthesis and converted to food. It is returned to the atmosphere by the cellular respiration of organisms. The other way it can be added to the ecosystem is that when organisms die and their remains settle into sediment. This source of carbon is stored deep in the ground for millions of years as fossil fuels (coal, oil, natural gas) and also as sedimentary rock. Oceans are also a reservoir for carbon because they absorb carbon from cellular respiration as well as other carbon-containing compounds from atmosphere, terrestrial runoff, undersea volcanoes, and detritus of marine organisms.



Carbon cycle in an ecosystem

Impacts to Carbon Cycle

Mining of fossil fuels removes carbon from underground reservoirs in which they usually remain for millions of years. Burning of fossil fuels puts this carbon back into the atmosphere (from which it has been removed for many years) and contributes to global warming.

Cutting down forests and burning fields not only releases carbon from the affected vegetation but also removes photosynthesizes that take carbon out of the atmosphere. This and the other condition reduce the products of plant in a given ecosystem which result if shortage of feed for domestic and wild animals.

The Nitrogen cycle

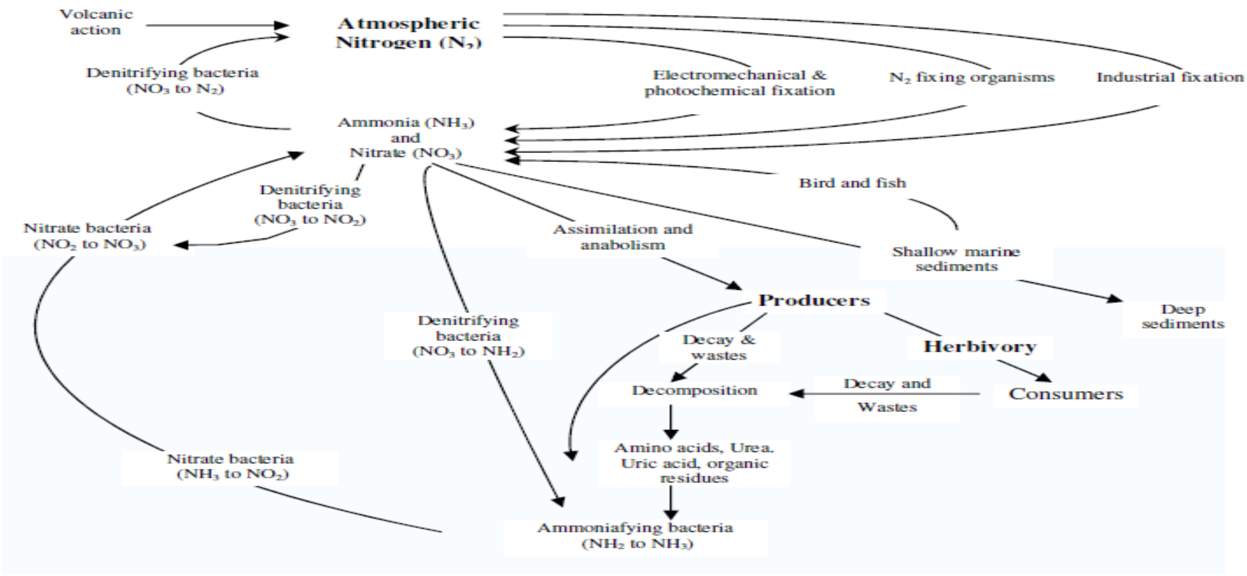
About 78 percent of the air is composed of nitrogen. Nitrogen is essential for many biological processes. All nitrogen obtained by animals can be traced to the consumption of plants at some stage of the food chain. However, the molecular form of nitrogen is not usable by plants. They get the usable nitrogen from the soil by absorption by their roots in the form of either *nitrate* ions or *ammonia*.

There are different mechanisms to fix atmospheric nitrogen and convert into a more chemically reactive form:

a. ***Biological fixation*****:** some bacteria (associated with certain leguminous plants) and certain bluegreen algae (also known as *cyanobacteria*) are symbiotic microbes able to fix nitrogen and assimilate it as organic nitrogen. It contributes much of nitrogen fixation. Some studies estimated that the annual average amount of biological fixation of nitrogen is about 54 million metric ton per year (Kormondy, 1996). Bacteria and blue green algae fix 100-200kg of Nitrogen per hectare, annually.

b. ***Lightening*****:** the formation of NO from N_2 and O_2 due to photons and lightning are important in the process of nitrogen fixation. However, it contributes little for terrestrial or aquatic nitrogen turnover. Lighting produces 8.9 kg of Nitrogen per hectare annually where 2/3 is in the form of NH3 and 1/3 in the form of HNO. The average amount of nitrate formed by electrochemical and photochemical fixation is in the order of 7.6 million metric tones per year (Kormondy, 1996).

c. *Combustion of gasoline and fossil fuel*: A fossil fuel has different impurities of nitrogen gas. The combustion of fuel by automobile engines and thermal power plants transfers elemental nitrogen gas into oxides of nitrogen (NO_x).



Nitrogen cycle in terrestrial and aquatic ecosystem

In the process of biological fixation, ammonia is produced in the soil by nitrogen fixation organisms which can produce the enzyme *nitrogenase. Nitrogenase* combines gaseous nitrogen with hydrogen to produce ammonia. Some nitrogen-fixing bacteria, such as Rhizobium, live in the root nodules of legume plants (such as peas or beans). Here they form a symbiotic relationship with the plant, producing ammonia in exchange for carbohydrates. Nutrient-poor soils can be planted with legumes to enrich them with nitrogen.

Another source of ammonia is the decomposition of dead organic matter by saprophytic bacteria called *decomposers*, which produce *ammonium* ions (NH_4^+). In well-oxygenated soil, these are then oxygenated first by a group of bacteria such as *Nitrosomonas europea* into *nitrites* (NO_2^-); and then by *Nitrobacter* into *nitrates* (NO_3^-). This conversion of ammonia into nitrates is called *nitrification*.

CHAPTER THREE
ANIMAL POPULATION ECOLOGY

Chapter objectives

At the end of this course students will be able
To define animal population ecology
To identify types of population growth
To identify and explain Population characteristics
To understand factors that limit and regulate population growth

Definition of population

Population is a group of organisms belonging to the same species occupying a particular space at a particular time. Individual members of a population are interbreeding and live in a particular place, in the same time and interact to one another as a society. A particular group of organisms, according to this definition, should fulfill the following points if it needs to be considered a population:

- ✓ Members must belong to the same kind of species
- ✓ all the members must occupy the same place,
- ✓ members must live in the same time and
- ✓ Members must interact to one another.

Biologists have for some time recognized that the most important level of organization of a species is its population, because at this level the gene pool is most coherent. Population is the basic unit of a community. Population ecology, hence, deals with the distribution and abundance of a population and the factors governing them.

Socializations in a Population

The degree of socialization or interaction between members of a population ranges from the most solitary animals like humming bird to the most complex interaction in social insects such as termites and honeybees. A society is a more complex interaction between members of a population. In a hive of honeybee or a mound of termites, millions of insects live in a very perfect coordination. They have complex division of labor and communication. Most of primates such as Chimpanzees and Gorillas are also highly social mammals. In those highly social animals (called Eusocials) rearing of youngs is in cooperative. The colony is also permanent by which offspring remain cooperative to the parents.

Importance of socialization:

Animals live in a society for their advantage. Some of the benefits include:

Collective defense*:* - Animals live in a society to protect from predators either by group fighting or confusing the predator. It is also useful to immunize the weak social groups such as female and young. In Buffalo, for example, members of the society protect predators using geometrical effect in that female and young are put in the middle, and all the other are standing in a circle pointing their face to the predator for physical defense. It is also important to spot the predator and communicate easily. Organizing in a society is useful for making confusion and also mobbing against tough predators.

Improve foraging efficiency: - Groups can forage more efficiently than solitary individuals by mutual vigilance for predators' defense. Each individual in a flock can get reduced vigilant time allowing more time for foraging. In an experiment, Ostriches raise their heads at frequent intervals 3-4 times per minute to scan the presence of predators in the area while they are feeding alone. However, the frequency is reduced to less than 2 times per minute per individual while they are feeding in a group of 3 or 4. Making the society helps them to spend their time for foraging than scanning their enemy.

Social facilitation*:* - Animals learn some of the behaviors by imitating from the action of the members of the flock. This helps to save time spent for learning through trial.

Information transfer: - *Each* member can communicate to each other about food sources and other matters. E.g., the "waggle dance" in worker bees is a good example. The dance looks number "8", and the direction of the cross bar tells the direction of the food from the hive, and the length of the cross bar tells the distance from the hive.

Population growth

Population is not static, but they are in change. The number of population may change from time to time. A universal characteristic of living things is that sexually mature individuals have the ability to produce ≥1 offspring. Thus, natural populations have the ability to grow. For example, each spring, in temperate oceans and lakes around the globe, planktonic populations of diatoms and algae take advantage of the increasing availability of sunlight and abundance of nutrients. Sizes of populations fluctuate in terrestrial, as well as aquatic, environments. The capacity for population growth, even among vertebrates, is enormous, a fact that is sometimes clearly demonstrated
Perhaps the most meaningful and dramatic example of the capacity of natural populations to grow is that of our own species. Although humans are not the most numerous animal species on Earth, the proliferation of the human species is, by any accounting, a remarkable ecological event. The human population began to expand rapidly after 1600, reaching 1 billion by the early 1800s, doubling that number by 1930, and doubling again by 1975. In 1995, the global human population reached 6 billion. There are currently 6.3 billion people alive on Earth today.

A population growth is determined largely by the difference between natality and mortality. Depending on the direction of movement, migration could also affect the population density of a given locality. There are two kinds of population growth models:

a. Exponential growth models
b. Logistic growth models

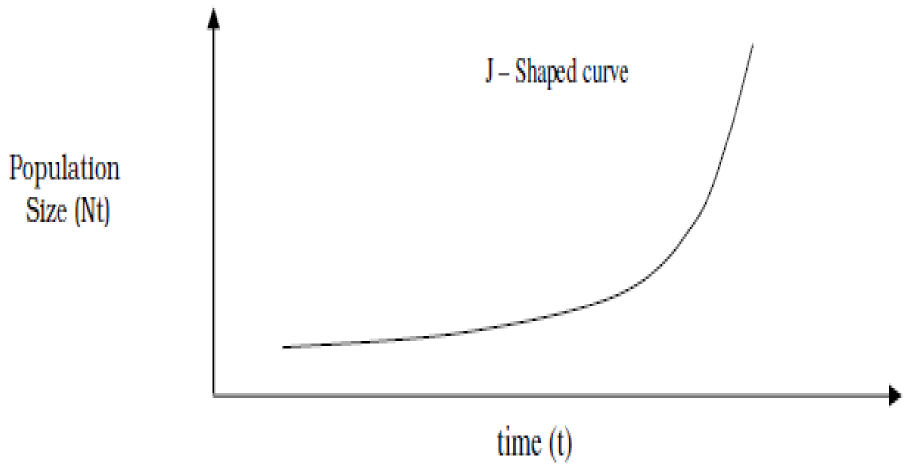
Exponential population growth model

This model assumes that if there is no environmental constraint that hiders a population growth, as a result of which the population shows ***geometric or exponential increase*** until it overshoots the ability of the environment to support it. The growth curve is J-shaped. This kind of population growth is common in new habitats where here is no shortage of resources. In this kind of growth, there is exponential relationship between time "t" and the population number at time "t". This is characteristic of r-selected species adapted to new (unstable) and resource-rich environment. A good example is binary fission in bacteria. A bacteria cell reproduces asexually by binary fission in which two identical daughter cells are reproduced from a parent cell by mitotic division. If there is good nutrient, optimum pH and favorable environment for growth, the daughter cells continue to grow and divide the same way every 20 minutes.
The following table shows the population increase of bacteria through binary fission. Suppose the initial population size is 2, and if we assume no death and migration of individuals, after 1 generation each cell divides in to two and the population size becomes 4. At the second generation, the population size grows to 8. At the 3rd generation, the size grows to 16, and 32, and so on.

Table 1The arithmetic increase of a bacterial population through binary fission

Number of Generations /time- (t)	0	1	2	3	4	5	6	7	8	9	10
Total population size (N_t)	2	4	8	16	32	64	128	256	1012	2024	4048
Relationship between N_t and "t"	$2(2^0)$	$2(2^1)$	$2(2^2)$	$2(2^3)$	$2(2^4)$	$2(2^5)$	$2(2^6)$	$2(2^7)$	$2(2^8)$	$2(2^9)$	$2(2^{10})$

From this data, if we draw a graph by putting "t" on the x-axis and Nt on the y-axis, we can see a clear "J"- shaped curve as shown in Figure 1, expressing the exponential relationship to one another.



The pattern of population growth according to the exponential growth model

The relationship between the population and the number of generations (or time) could be summarized by the following formula:

$$N_t = N_0 2^t$$

Where N_t is the total number of population after time "t", N_0 is the starting population at time 0, and "t" is the number of generation (time of reproduction).

In the above example, however, we did not consider the effect of death and migration on the population size. If we consider all the natural processes, the net natural increase, also called intrinsic rate of growth or biotic potential ("r"), would be the difference between Birth rate (N) and Death rate (M), and also rate of net migration (Immigration (I) – Emigration (E)), as given by:

r = (N-M) + (I – E) or (N+I) - (M+E)

The overall population increase using exponential model is, therefore, given by the following equation:

$$N_t = N_0 e^{rt}$$

Where "e" is the base for natural logarithm given by a constant 2.71828; "r" is the intrinsic population increase, and "t" is time or number of generations.

Example: If the existing Ethiopian livestock population (N_0) is 80 million and the birth rate (N) and death rates (M) are 45 and 15 individuals out of 1,000 populations, respectively, calculate the total population size (N_t) after 10 years.

$= 80000,000 (e^{(0.045-0.015)10})$ N_{10}

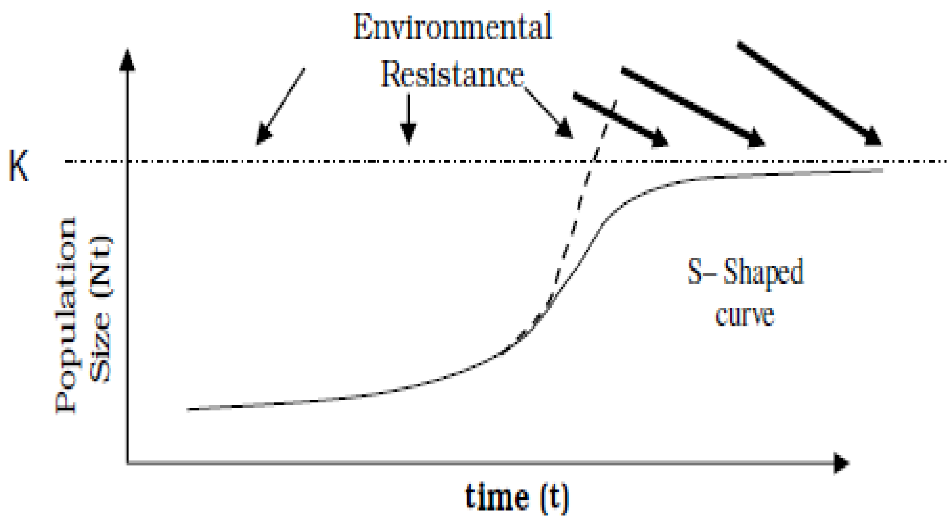
$= 8(10^7) \times 2.71828^{(0.3)}$

$= 80,000,000 (1.34985)$

$= \underline{107,988,682.8}$

Logistic growth Model

This growth model assumes that most populations cannot continue to grow exponentially because of the resistance coming from their environment that prevents from further growth. As the result, the population grows exponentially until it reaches the ***carrying capacity*** (K). However, as the population approaches to the carrying capacity, the growth is limited by the resistant factor hence the population increases arithmetically. Carrying capacity is the maximum number of individuals that a habitat could support. This kind of growth is the characteristic of k-selected species adapted to stable environment, where there is competition for resources.



The pattern of population growth according to the logistic growth model

Populations invading a new area where space and food are plenty will undergo exponential growth to begin with. But, due to different external constraints coming from the environment like shortage of space, food and other stresses, the rate of increase start to decline. The curve in the graph is called "S" or "Sigmoid"-curve as shown in the diagram on Figure 2. The rate of population increase at any time is density dependent.

Suppose an environment has a carrying capacity given by K for a particular population, the intrinsic rate of natural increase "r" is progressively reduced as population size approaches towards "K"

The available niche in the habitat, which is the inverse measure of environmental "resistance" or the "effect of crowding", is given by:

$$\frac{K - N}{N}$$

Where, "N" is the population at time "t", and "K" is the carrying capacity of the habitat. When "N" is smaller, the resistance value is nearly zero. That is there are numerous opportunities for the population. Hence, the niche is empty with out any resistance that the biotic potential (r) is fully realized. In this case, the population can grow exponentially. However, when N is higher and closer to the carrying capacity (K), the value approaches to 0; there is no available resource in the habitat to accommodate a single individual. This shows that at any ecosystem the population growth is limited by the degree of the environmental resistance. The integrated equation of logistic growth is, therefore, given by:

$$N_t = \frac{K}{1 + \left[\frac{K - N_0}{N_0}\right] X\, e^{-rt}}$$

Exercise: Suppose the current Ethiopian population (N_o) is 70 million, and the net annual intrinsic increase (r) is 3%; calculate the total population (N_t) after 1,000 year (t). Assume that the carrying capacity (k) of the land is 0 million.

Population Characteristics

A population, as a group, has unique characteristics, which can be statistical measured, and cannot be applied to individual organisms. The three basic group characteristics of a population are:

- ✓ density,
- ✓ primary population parameters, and
- ✓ Secondary population parameters

Density

It is defined as the number of individuals of a population per a given unit area. For example, 5,000 individual of cattle per a square kilo meter of range land; 300 lions per square kilometer of rangeland; or 500 browse plants per hectare of forestland. It could be also expressed in terms of a unit volume (e.g., 10 million bacteria per a cubic centimeter of water).

Density varies with time and space. Individuals in natural populations are affected by their density in some way. For example, if the population density is high, resources are shared unequally. On the other hand, if the density is very low, it reduces the chance of performing behavioral activities essential to the welfare of the population. For example, trees in crowded stands grow more slowly due to shortage of water, nutrients and sufficient light. The same way in animals, very high population density affects the population in various way such as by causing scarcity on available food resources and the access to nest site (e.g., in birds), and also aggravating the spread of disease. Having too few individuals in a population may also affect the population by reducing their chance of finding a mate.

Organism and its Environment

All living organism are constantly interacting with their environment. Animals consume plants and other animals. They digest food, absorb, nutrients, and discharge waste products. For an organism to succeed, it needs to find essential resources and supporting conditions. If the organism can survive, grow, and reproduce under a given set of environment conditions, we say it is adapted to that environment. If the environment does not offer the resources and conditions for its survival, the organism dies.

Variations in environment conditions

All organism live in a varying physical environment of temperature moisture, light, and nutrient. These factors differ from location to location – in latitude, region and locality. In addition, at any location, the physical environment varies with time- yearly seasonally and daily.

Solar radiation directly influences air temperature atmospheric moisture, and light. To a large extent, it defines the general physical environment in which organisms live. The amount of solar radiation reaching any point of Earth's surface and the resulting patterns of surface air temperature vary both spatially and temporally. Organisms at any location face both seasonal and daily variations in temperature. The variations are greatest in the temperate regions, where differences between average daily temperature in the winter and summer can be extreme.

In an ever changing physical environment, organisms must maintain a fairly constant internal environment, within narrow limits required by their cells, organs, and enzyme. For example, the human body must maintain internal temperature within a narrow range around 37°C.

An increase or decrease of only a few degrees from this value could prove fatal. Likewise, organisms must maintain certain levels of water, acidity, and salinity to mention a few factors.

Maintaining these constant conditions requires continuous exchange of energy and materials between organisms and the external environment. The organisms must consume and digest food to adjust its metabolism. Then it must excrete by-products and wastes from these chemical processes. The maintenance of conditions within the range that the organisms can tolerate is called *homeostasis*.

Range of tolerance : (Fig.1).

As the example of body temperature shows, there are limits to the range of the environment conditions over which homeostasis work. A graph illustrates this range. The X axis represents some feature of the physical environment, e,g, temperature. Axis represents the response of the organism. The response of an organism to physical environment falls along a bell-shaped curve describing performance (in this case the probability of survival).

The point along the X axis where the response of the organisms is the highest is called the optimum, the probability of survival decreases. The two point (minimum and maximum) at which the survival intercepts the X axis represent the environment conditions beyond which these two points an organism can survive, but not necessarily grow or produce. The minimum and maximum values of the environment are referred to as the *environment tolerance* of the organisms.

The figure represents the response of an organisms to a range of values for a single factor : temperature. However, organisms depend upon a wide range of environment tacters each having an optimum of tolerance. To complicate things further the factors interact. In the example of body temperature in humans, an important homeostatic response to rising body temperature is evaporative cooling or sweating. This response requires water. Therefore, water needed to survive is related to temperature. Hot conditions demand increase in water intake.

Organisms, than, are limited by a number of conditions, and often by an interaction among them. Organisms live within ranges from too much to too little the limits of tolerance. This concept, that minimum and maximum conditions limit the presence and success of an organism is called the *laws of tolerance*.

Minimum and maximum temperature tolerance define the limits of species, distribution. Although conditions close to the tolerance may be sufficient to maintain survival, growth, and reproduction, their values will be much below those that occur closer to the optimum. The nearer conditions approach the minimum and maximum tolerances of the organism, the fewer the individuals. We would expect the abundance of a decrease to increase as we move toward optimal environment conditions.

Abiotic (Physical) Factors

Climate is the combination of temperature, humidity, precipitation wind, cloudiness and other atmospheric conditions. Climate determines the availability of heat and water. It influences the amount of solar energy that plants can capture. Thus it controls the distribution and abundance of plants and animals.

Earth, immersed in sunlight, intercept solar radiation on the outher edge of its atmosphere. The intercepted energy causes thermal patterns. Coupled with Earth's rotation and movement around the sun, it generates the prevailing winds and ocean currents. These movements of air and water in turn influence the distribution of rainfall.

The conditions in which most organism live do not match the general climate. Their immediate surroundings modify the climate. Today's weather report may state that the temperature is 28℃ and the sky is clear. Nevertheless, environmental conditions will be quite different underground or on the surface, beneath vegetation or on exposed soil or on mountain slopes. Heat moisture, air movement, and light all vary greatly from one part of the landscape to another to create a whole range of localized climates. These microclimate define the conditions under which organisms live.

Light

Light is a driving force of life. Plants use visible light as an energy source to convert carbon dioxide and water to organic carbon compounds. The hours of light and dark influences the daily and seasonal activities of terrestrial and shallow water organisms.

Of the total range of solar radiation reaches Earth's atmosphere, the wave lengths making up the visible light are known as *photosynthetic active radiation*, because they include the wavelengths plants use in photosynthetic. Wavelengths shorter than the visible range are ultraviolet. Radiation with wavelengths longer than the visible range is infrared. The ozone layer in the upper atmosphere (stratosphere) absorb nearly all wavelengths, especially the violets and blues of the visible light. Molecules of atmosphere gases scatter long wavelengths.

Light intercepted by Earth is reflected, absorbed or transmitted. Of greatest ecological interests is light reaching vegetation.

Periodicity

Daily and seasonal patterns govern life's activities. Bird song signals the arrival of dawn. Butterflies, dragonflies and bees warm their wings, hawks being to circulate, and tree squirrels become active. At dusk daytime animals retire, water-lilies fold, moonflowers open, and animals of the night appear. Foxes, flying squirrels, owls, and luna moths take over niches others occupy during the day.

As seasons progress, day length changes, and activities shift. Spring brings migrant birds and initiates the reproductive cycles of many plants and animals. In fall the deciduous trees of temperate regions become dormant, insects and herbaceous plants disappear, summer birds return south, and winter birds arrive.

These rhythms are driven by the daily rotation of Earth on its axis and its 365- day revolution about the sun. through time, life has become attuned to the daily and seasonal changes in the environment. At one time biologists thought that organisms were responding only to external stimuli such as light intensity, humidity, temperature and tides. Laboratory investigations, however, have shown there is more.

Living organisms possess innate rhythms of activity

At dusk in the forests of North America, the flying squirrel emerges from a tree hole. With a leap, the squirrel sails downward in along sloping glide, maintaining itself in flight. Using its tail as a rudder and brake it makes a short upward swoop that lands it on the trunk of another tree. It emerges into the forest world with the arrival of darkness, it retires to its nest before the first light of dawn. The flying squirrel's day to day activity conform to a 24 – hour cycle. The correlation of the onset of activity with the time of sunset suggests that light has a direct or indirect regulatory effect. If the flying squirrel is brought in doors and confined under artificial conditions of night and day, it will restrict its periods of activity to darkness and its periods of inactivity to light. Whether the conditions under which the squirrel lives are 12 hours of darkness and 12 hours of light or 8 hours of darkness and 15 hours of light, the onset of activity always begins shortly after dark.

If we keep the same squirrel in a constant darkness, it still maintains its pattern of activity and inactivity from day without any external cue. Under these conditions the squirrel's activity rhythm deviates from the 24 hour periodicity defined by the diurnal cycle. Its cycle of activity and inactivity in constant darkness varies from 22 hours 58 minutes to 24 hours, 21 minutes, the average is less than 24 hours. Because the cycle length deviates from 24 hours, the squirrel gradually drifts out of phase with the external world.

Circadian rhythm

This innate rhythm of activity and inactivity covering approximately 24 hours is characteristic of all living organisms, except bacteria. Because these rhythms approximate, but seldom match, the period of Earth's rotation, they are called *circadian rhythms* (from the Latin circa. "about" and dies, "day").

circadian rhythms have a strong genetic component, transmitted from one generation to another. Temperature changes have little effect on them and they are not learned from or imprinted upon the organisms by the environment. They do not adapt to specific local or regional environmental conditions. Circadian rhythms influence not only the times of physical activity and inactivity, but also physiological processes and metabolic rates. They provide a mechanism by which organisms maintain synchrony with their environment.

Thus two daily periodicities – the external rhythm of 24 hours and the internal circadian rhythm of approximately 24 hours – influence the activities of plants and animals. If the two rhythms are to be in phase, some external cue or time cue or time –setter must adjust he internal rhythm to the environment rhythm. The most obvious time setters are temperature, light, and moisture. Of the three master time – setter in the temperate zone is light. It brings the circadian rhythm of organisms into phase with the 24 hour photoperiod of their external environment.

Biological Clock

The circadian rhythm and its sensivity to light and dark are the major mechanisms that operate the biological clock that timekeeper of physical and physiological activity in living things. In multicellular animals the clock is within the brain. To keep time, the clock has to have an internal mechanism with a natural rhythm of approximately 24 hours. Recurring environmental signals such as changes in the time of dawn and dusk, should reset it. The clock has to be able to run continuously in the absence of any environmental time-setter and the same at all temperatures Circadian rhythm fit all these criteria.

Adaptive value of circadian rhythms

One adaptive value is that the biological clock provides the organism with a time-dependent mechanism. It enables the organism to prepare for periodic changes in the environment ahead of time. For example, trees of the African savanna begin leaf growth just prior to the onset of rainy season.

circadian rhythms help organisms with physical aspects of the environment other than light or dark. For example, the transition to night is accompanied by a rise in humidity and a drop in temperature. Woodlice, centipedes, and millipedes, which lose water rapidly in dry air, spend the day in the darkness and damp under stones, logs and leaves. At dusk they emerge when humidity of the air is more favorable.

The circadian rhythms of many organisms relate to biotic aspects of their environment. Predators such as insectivorous bats must match their feeding activity rhythm of their prey. Moths and bees must seek nectar when flowers are open. Flowers must open when insects that pollinate them are flying. The circadian clock lets insect, reptiles and birds orient themselves by the position of the sun. Organisms make the most economical use of energy when they adapt to the periodicity of their environment.

Critical day lengths trigger seasonal responses

In the middle and upper latitudes of the Northern and Southern hemispheres, the daily periods of light and dark lengthen and shorten with the seasons. The activities of plants and animals are geared to the changing seasonal rhythms of night and day. Most animals and plants of temperate regions have reproductive periods that closely follow the changing day lengths of the seasons. For most birds the height of the breeding season is the lengthening days of spring for deer, the mating season is the shortening days of fall.

The signal for these responses is *critical day length*. When the duration of light (or dark) reaches a certain portion of the 24 hour day, it inhibits or promotes a photoperiodic response. critical day length varies among organisms, but it usually falls somewhere between 10 and 14 hour.

Diapauses in insets of temperate regions, is controlled by photoperiod. The time measurements in such insects is precise, usually 12 and 13 hours of light. A quarter-hours difference in the light period can determine whether an insect goes into diapause or not. The shortening days of late summer and fall forecast the coming of winter and call for diapause. The lengthening days of late winter and early spring are the signals for the insect to resume development, pupate, energy as an adult, and reproduce.

Increasing day length induces spring migratory behavior, stimulate gonadal development, and brings on reproductive cycle in birds. In mammals, photoperiod influences activity such as food storage and reproduction, too.

Seasonal changes: seasonality

In temperate zones, seasonal changes in plants and animals are clear, such as the unfolding of leaves in spring and the dropping of leaves in fall, the blooming of flowers and the ripening of seeds, and the migration of birds. In tropical regions, the dropping of leaves by some trees species and the fruiting by others mark the beginning of the dry season. Such collective biological events, recurring with the seasons, make up *seasonality*.

Seasonality in temperate and arctic regions depends on changes in light and temperature. In a broad way, Seasonal changes in temperature and light cause alternate warm and cold periods. The progression is gradual, however, and in temperate zones, seasons can be identified as early or late spring, early or late fall, and so on. Seasonality in tropical regions is keyed to rainfall. The seasonal tropics have alternate wet and dry seasons, and their onset is abrupt. The beginning of rainy season is a dependable environment cue by which plants and animals become synchronized to seasonal changes.

Seasonal activities of animals center about reproduction and availability of food. The reproductive cycle of the white – tailed deer. For example, beings in fall, and the young are born in spring when the highest quality food for lactating mother and young is available. In tropical central. America home of numerous species of fruit eating (frugivorous) bats, the reproductive periods track the seasonal production of food. The birth periods of frugivorous bats coincide with the peak period of fruiting. Young are born when both females and young will have adequate food insects and other arthropods reach their greatest biomass early in the rainy season in Costa Rican forests. At this time the insectivorous bats give birth to their young.

Photoperiodism - Models and Experimental Approaches

Focusing on photoperiodic time measurement - mostly on conceptual models and experimental designs invented to test those models. In the next installment, I will concentrate on actual physiology of photoperiodism, particularly in mammals, and then apply that to the human affliction - the Seasonal Affective Disorder (SAD, or 'Winter Blues').

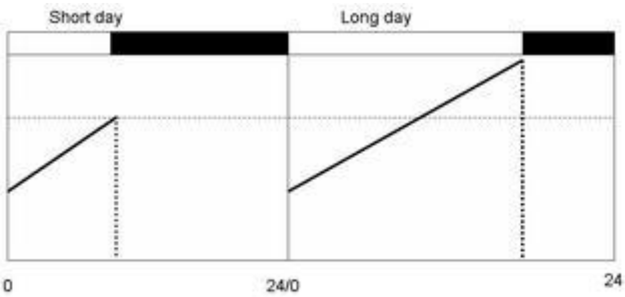
Timely prediction of seasonal periods of weather conditions, food availability or predator activity is crucial for survival of many species. Although not the only parameter, the changing length of the photoperiod ('daylength') is the most predictive environmental cue for the seasonal timing of physiology and behavior, most notably for timing of migration, hibernation and reproduction. While rising spring temperatures may vary from year to year, the gradual increase in daylength is uniform and precise. Still, some cold-blooded organisms also respond to thermoperiod (oscillations between increasing duration of warmth during the days and decreasing duration of cold temperature during the nights) and some modulate their photoperiodic response by overall temperature levels.

Models of Photoperiodism

Three main models for photoperiodic time measurement have been proposed.

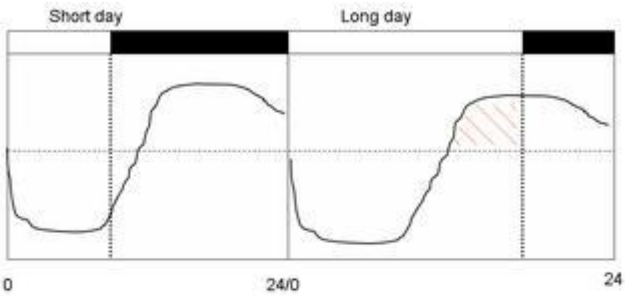
Garner and Allard, in 1920, discovered photoperiodism in plants. Soon afterwards, they and other researchers confirmed that changes in daylength, in absence of any other clues, trigger flowering in a number of plant species. Some respond to lengthening days in the spring, others to shortening days of the fall. Similar findings in insects, mammals and birds soon followed. The way these early researchers conceptualized photoperiodic response was later named the **"hourglass model"**.

The hourglass model assumes the gradual accumulation of a chemical product in the organism. A certain quantity of this chemical is necessary to trigger a physiological response (e.g., flowering in plants, or growth of gonads in mammals). The threshold is reached if the product is not first degraded. It may be degraded by dark and only accumulates during the light phase or it may accumulate during dark and be degraded by light. If the light (or the dark) is long enough threshold is reached and a physiological response, such as maturation of the reproductive system, is initiated. This model argues against the involvement of the circadian clock in the photoperiodic response because the hourglass lacks endogenous rhythmicity and must be reset or "turned over" by the light cycle each day:



The involvement of the circadian system was, however, detected in almost all species studied to date, so the hourglass mechanism is unlikely to have evolved in real organisms. However, its historical primacy, its simplicity which appeals to our sense of parsimony, and its usefulness as a hypothesis to test against, make the hourglass model an integral part of the scientific repertoire in the study of photoperiodism.

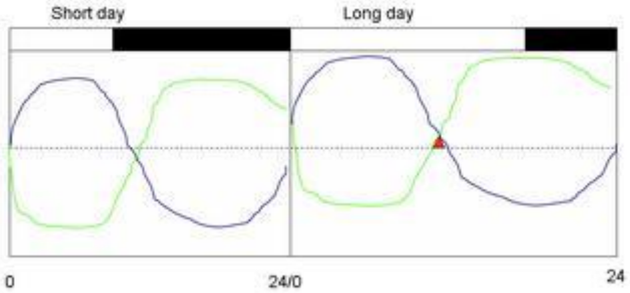
The **external coincidence model** was proposed by one of the pioneers of chronobiology, Erwin Bunning, in 1936. This model proposed the existence of a circadian rhythm of photoperiodic photosensitivity (CRPP) in which most of the night-phase is sensitive to light, while the day-phase is photoinsensitive. As the day gets longer in spring, light starts illuminating the photosensitive phase and triggers the physiological or behavioral response:



In this model light has a dual effect: it entrains the rhythm of photosensitivity and also acts as the stimulus (that is stimulates a photoperiodic response) if the light falls on a photosensitive phase of the rhythm of photoperiodic sensitivity. This model is termed an "external coincidence" model because it requires the coincidence (hatched red) of an external stimulus (light) with an internal rhythm of sensitivity to light.

This dual role of light is not necessary if one considers the **"internal coincidence" model**, proposed by Colin Pittendrigh and Dorothea Minis in 1964. In this model, the light's only role is to entrain the circadian system. At the time this model was proposed, it was becoming apparent that multicellular organisms house more than one circadian pacemaker. Each of the oscillators will behave differently under the influence of the light-dark cycles, and assume different phase-relationships with the entraining cycle.

Pittendrigh and Minis proposed that changing photoperiods may alter the internal phase-relationships between two or more rhythms, bringing them into permissive (red) or inhibitory modes. For example, secretion of a hormone has to coincide with the availability of its receptors at the target tissue, or with the absence of the enzyme that metabolizes it. In this model, therefore, light must control only the internal phase-relationships between multiple circadian rhythms:



Experimental Evidence

Several experimental protocols have been developed to test circadian involvement in the photoperiodic response. Positive results of these experiments eliminate the hourglass model, thus confirm the involvement of the circadian system in photoperiodic time measurement. It was always hoped that, in the process, these experiments would also be able to distinguish between the internal and external coincidence models.

These protocols involve the use of night-break light pulses (i.e., skeleton photoperiods, see the "Entrainment" series of posts), resonance light cycles, and non-24 hour cycles ("T-cycle experiment") of light and dark.

Skeleton photoperiods mimic the full photoperiods with the light pulses at the times of dawn and dusk only. Although the total time per day that the animal spends in light is quite small, the photoperiodic response is elicited if the night-break pulse (or the second of the two skeleton pulses) falls during the photoinductive phase of the circadian cycle.

However, in skeleton photoperiods, it is often impossible to mimic long photoperiods as the circadian system tends to entrain to the shorter of the two possible interpretations of the skeleton photoperiods. Also, there is often an additional complication of phase-shifting effects of both pulses.

Resonance cycles are light-dark regimes in which the period T (L+D) is a multiple of 12 hours (e.g., LD 6:18, LD 6:30, LD 6:42, LD 6:54, etc.). If the circadian system is involved, every other light pulse will fall onto the photosensitive phase and induce a photoperiodic response in all cycles which are odd multiples of 12 hours (e.g., LD6:18, LD 6:42), while in cycles which are even multiples of 12 hours (e.g., LD 6:30, LD 6:54) the photoperiodic response will not be seen because every light pulse falls only during the insensitive phase of the rhythm of photoperiodic photosensitivity. In resonance cycles, the long periods of darkness may theoretically counter the stimulatory effects of the rare light pulses.

In **T-cycle experiments**, the period (T) of the LD cycle is different from 24 hours and varies within the limits of entrainment. During entrainment, the phase of the pacemaker is shifted or reset each cycle by an amount (Df) equal to the difference between the free running period (t) and the period (T) of the entraining cycle (t - T = Df). The phase angle (y) between the onset of light and the onset of circadian activity will be characteristic of each T-cycle and can be calculated from the phase-response curve (PRC).

The PRC describes the phase-shifting behavior (lengths of advances or delays) of a circadian system elicited by a specific environmental perturbation (e.g., a pulse of light of defined length, intensity and wavelength) as a function of circadian timing of that perturbation. As a general rule, light pulses given around early subjective night elicit phase-delays, while those given late in the subjective night result in phase-advances.

In LD cycles of different period lengths, the phase angles between the onset of circadian activity and the onset of the light phase of the cycle will be different and predictable from the PRC. Accordingly, on some T-cycles the circadian system will be entrained in such a way that the light pulse illuminates a portion of the photoinducible phase (fi) and result in a measurable physiological photoperiodic response. If the internal coincidence model is correct, the entraining LD cycle will control the phases of different circadian outputs differently, thus changing the phase relationships between two or more circadian rhythms within the organism. Light-dark cycles of certain period lengths (T) will then bring the relevant rhythms into a phase relationship that results in the stimulation of the photoperiodically controlled physiological system.

The T-cycle protocol does not have the same difficulties in interpretation as the other two protocols. Only one light pulse per cycle is used and it has both an entraining and a potential photostimulatory effect. Utilizing different period-length cycles spanning the limits of entrainment of the organism, the light pulse can be brought into every possible phase-relationship with the circadian system. As the animals assume stable entrainment, the light pulse and the circadian system will assume a different phase-angle in each T-cycle. Presumably, in some of the cycles the light will repeatedly illuminate the photoperiodically photosensitive phase leading to the physiological response, while in other T-cycles, the light will be coincident only with the subjective day, leading to the lack of stimulation.

If an internal coincidence mechanism is operating, it is likely that the T-cycles will place the two circadian oscillators in all possible phase-relationships, leading to the stimulation in some and inhibition of response in other values of T. In theory, the two models may have different predictions as to which Ts will be inductive and which not.

So, what's the evidence?

In many organisms short days inhibit while long days stimulate various seasonal responses of physiology and behavior. Various experimental paradigms, including skeleton photoperiods and resonance cycles, demonstrated that it is not the total amount of light, but the precise temporal placing of the light that induces the photoperiodic response, giving the circadian system a role in the measurement and interpretation of daylength.

In a large number of species, including both invertebrates and vertebrates, as well as plants, these protocols have proven the involvement of the circadian system in photoperiodic time measurement, e.g., resonance cycles in male rosefinches, skeleton photoperiods in the rain quail *Coturnix coromendelica,* T-cycles and resonance cycles in golden hamsters and house finches, etc.

On the other hand, there are some organisms in which the results of all these protocols are not so conclusive. For instance, T-cycle and night-break studies in blackheaded buntings indicate the dependence of the reproductive response on the period (T) of the cycle and on the length of the light pulse within the cycle. In starlings, effects of light intensity, wavelength and pulse length can be seen even in 24 hour cycles.

Although the involvement of the circadian system has been documented in many species, it has not yet been possible to discriminate between the external and the internal coincidence mechanism for photoperiodic time measurement. So far, results of skeleton photoperiod, resonance cycle and T-cycle experiments could be interpreted equally well with both models.

Moreover, in some species it was even difficult to differentiate between the hourglass and circadian models. The vetch aphid (*Megoura viciae*) is probably the most notorious example. A mathematical model, though, was developed that succesfully describes photoperiodic responses in all of the hundreds of arthropod species that were studied over the past century. The fact that this mathematical model is consistent with all the experimental data on the vetch aphid suggests that it may also use its circadian clock to measure photoperiod, it's just that its clock's putput is of a very small amplitude.

Another species that was difficult to figure out was American chameleon (*Anolis carolinensis*). Initial studies suggested that hourglass model was operating. However, later work by Linda Hyde utilizing T-cycles showed that the circadian clock is indeed involved in photoperiodic time measurement in this species.

Finally, in Japanese quail (*Coturnix japonica*), results of skeleton photoperiods were positive, resonance cycles suggest some involvement of the clock but not the complete response, and the T-cycles were negative. This is also a species with a low-amplitude circadian system (i.e., it has a Type 0 PRC), so it is likely that clock is involved but the final demonstration is still waiting for the next creative experimenter to provide.

Temperature

Temperature has a pervasive influence on life. It affects rates of photosynthesis and energy storage in plants. It influences the need for moisture and the rates of chemical reactions in all living organisms. It is a key to climate, microclimate, and distribution of organisms.

All organisms live and live and exchange energy with a thermodynamic environment – a world of heat and cold. They absorb solar radiation, which may be direct, diffused from the sky or reflected from the ground, as well as thermal radiation from rocks. Soil, vegetation and the atmosphere. In addition, organisms produce heat during metabolic processes such as respiration and lose heat as infrared radiation. To maintain a constant body temperature, organisms must both lose heat to and gain heat from the environment.

Green plants convert a considerable amount of incoming solar radiation

To chemical energy through photosynthesis. They store this energy and pass it on to animals when consumed as food. Other radiation is converted directly to heat. Whether produced by metabolism or absorbed, excess heat must be dissipated to the environment. When the surrounding or ambient temperature is lower than the temperature of the organisms. The problem, then is for the organism to balance heat gains with heat losses to maintain a constant internal temperature.

The heat balance of an organism may be summarized by the following expression :

Heat gain (solar radiation + thermal radiation + food energy storage + conduction + convection) =

Heat loss (thermal radiation + conduction + convection + evaporation).

Physiological group of animals

Physiological animals can be divided into three group, according to the way they maintain temperature :

1. One group notably birds and mammals, relies primarily on stored energy to keep constant internal temperature independent of external temperature. This internal heat production is endothermy. These animals are ***homeotherms***. They are popularly called " *warm-blooded*".

2. A second group controls body temperature by external means. They gain heat through exposure to environmental sources and dissipate heat through conduction, convection and evaporation. This means of maintaining body temperature is *ectothermy*. They body temperature is variable. These animals are *poikilotherms* and are often called *cold-blooded*. These animals include invertebrates amphibians fish and reptiles.

3. A third group regulates body temperature by endothermy at some time and by *ectothermy* at other times. These animals are *hetertherms*.

Poikilotherms

Poikilotherms gain heat easily from the environment and lose it just as fast. Environment temperature control the rates of metabolism and activity among most Poikilotherms. Rising temperature increase the rate of enzymatic activity, which controls metabolism and respiration. For every 10℃ rise in temperature , the rate of metabolism in Poikilotherms doubles. They become activity only when the temperature is sufficiently warm. Conversely, when ambient temperatures fall, metabolic activity declines, and they become sluggish. Poikilotherms have an upper and lower thermal limit that they can tolerate. Most terrestrial Poikilotherms can maintain a relatively constant daytime body temperature by behavioral means, such as seeking sunlight or shade. Lizards and snakes, for example may vary their body temperature by no more than 4-5℃ , and amphibians by 10℃ when active.

Aquatic Poikilotherms, completely immersed, do not maintain any appreciable difference between their body temperature and the surrounding water. They are poorly insulated. Any heat produced in the muscles moves to the blood and on to the gills and skin, where heat transfers to the surrounding water by convection. Because seasonal water temperatures are relatively stable fish and aquatic invertebrates maintain a fairly constant seasonal temperature. They exhibit a low range of temperature variation in any given season.

Fish and aquatic invertebrates adjust seasonally to changing temperature by *acclimatization*. They undergo physiological changes over a period of time. Poikilotherms have an upper and lower limit of tolerance to temperature that varies with the species. If they live at the upper end of their tolerable thermal range, Poikilotherms will adjust their physiology at the expense of being able to tolerate the lower range. Similarly, during periods of cold, the animals shift to a lower temperature range that would have been lethal before. Because water temperature changes slowly through the year, aquatic Poikilotherms can make the adjustment slowly. Fish are highly sensitive to rapid change in environmental temperatures. If they are subjected to a sudderl temperature change, they will die of thermal shock.

Homeotherms

Homeothermic birds and mammals meet the thermal constraints of the environment by being endothermic. They maintain body temperature by oxidizing glucose and other energy – rich molecules. They regulate the gradient between body and air or water temperatures by seasonal changes in insulation (the type and thickness of fur, structure of feathers, and layer of fat), which Poikilotherms do not possess. They rely on evaporative cooling and on increasing or decreasing metabolic heat production. Homeothermy allows these animals to remain active regardless, of environmental temperatures, although at high energy costs.

Heterotherms

Species that sometimes regulate their body temperature and sometimes do not are called Heterotherms. At different stages of their daily and seasonal cycle or in certain situations, these animals takes on characteristics of endotherms or ectoderms. They can undergo rapid, drastic, repeated changes in body temperature.

Insects are ectothermic and Poikilotherms, yet in the adult stage most species of flying insects are heterothermic. When flying they high rates of metabolism, with heat production as great as or greater than heterotherms. Temperature is critical to flight of insects. Most cannot fly if the temperature of the thoracic muscles is below 30℃, nor can they fly if the muscle temperature is over 44℃. This constraint means that an insect has to warm up before it can take off, and it has to get rid of excess heat in flight. With wings beating up to 200 time per second insects can produce a prodigious amount of heat.

Some insects, such as butterflies and dragonflies, warm up by orienting their bodies and spreading their wings to sun. most warm up by shivering their flight muscles in the thorax. Moth and butterflies vibrate their wings to raise thoracic temperature above ambient.

Regulating body temperature

To maintain a tolerable and fairly constant temperature during active periods, terrestrial and amphibian Poikilotherms resort to behavioral means. They seek out appropriate microclimates. Insects such as butterflies, moth bees, and dragonflies bask in the sun to raise their body temperature to the levels necessary to become highly active. When become too warm, these animals seek the shade.

Most reptiles are terrestrial and exposed to widely fluctuating temperatures. They bask in the sun to raise their body temperature. Snakes for example, heat up rapidly in the morning sun. when they reach the preferred temperature, the animals move on to their daily activities, retreating when necessary to the shade to cool. In this manner they maintain a stable body temperature during the day. Lizards raise and lower their bodies to increase or decrease the conduction of heat between themselves and the rocks or soil on which they rest. They also seek sunlight or shade or burrow into the soil to adjust their temperatures. Desert beetles locusts, and scorpions exhibit similar behavior. They raise their legs to reduce contact between their body and ground, minimizing conduction and increasing convection by exposing body surfaces to the wind. Thus body temperatures of Poikilothermo do not necessarily follow the general ambient temperature.

Endotherms also use microclimates to keep warm or cool. In the heat of a summer day, birds and mammals seek shady places. Desert mammals go underground by day and emerge at night. In winter, some mammals, such as rabbits go underground during periods of inactivity. Large mammals such as deer seek the thermal cover of conifer thickets. Mammals such as flying squirrels and birds such as penguins and quail huddle together during periods of cold, reducing individual surface area and conserving body heat.

Insulation

To regulate the exchange of heat between the body and the environment heterotherms and certain poikilotherms use some forms of insulation – a covering of fur, feathers, or body fat. For mammals, fur is a major barrier to heat flow, but its insulation value varies with thickness, which is greater on large mammals than on small ones. Small mammals are limited in the amount of fur they can carry, because thick coat could reduce their ability to move. Mammals change the thickness of their fur with season. Aquatic mammals especially of arctic regions, and arctic and antaractic birds, as penguins have a heavy layer of fat beneath the skin. Birds reduce heat lose by fluffing the feathers and drawing the feet into them, making the body a round feathered ball.

Although the major function of insulation is to keep body heat in. it also keeps heat out. In a hot environment, an animals either has to rid itself of excess body heat or prevent heat from being absorbed in the first place. One means is to reflect solar radiation from light – colored fur or feather.

Another mean is to grow a heavy coat of fur that heat does not penetrate. Large mammals of the desert, notably the camel, employ this method. The outer layers of hair absorb heat and return it to the environment.

When insulation fails, many animals resort to shivering, a form of involuntary muscular activity that increase heat production.

Evaporative cooling

Many birds and mammals, and even wasps employ evaporative cooling to reduce the body heat load. Birds and mammals lose some heat by evaporative of moisture from the skin. They accelerate evaporative cooling by sweating and panting. Only certain mammals have sweat glands, particularly horses and humans. Panting in mammals and gular fluttering in birds increase the movement of air over moist surfaces in the mouth and pharynx. Many mammals such as pigs, wallow in water and wet mud to cool down. Paper wasps maintain a rather constant temperature in their paper nests by fanning their wings. If the nest temperature becomes excessive over 35℃ wasps gather water from nearly sources, carry it to the nest, and fan their wings to speed evaporative cooling.

Moisture

An organism's water balance is closely related to its thermal balance. It is difficult to discuss one without the other, sweating, which allows the evaporation of water is one way animals reduce body heat generated metabolically during strong physical exertion. Terrestrial animals and plants could never maintain their thermal and moisture balance without the unique features of water that make life on earth possible. Water is the medium by which elements and other materials make their never-ending odyssey through the ecosystem. Without the cycling of water decomposition and nutrient cycling could not proceed, ecosystems could not function and life could not persist.

Water balance in animals

For animals the usual sources of gaining water are drinking water, water in food and metabolic water. Loss is through urine, feaces and water evaporated problem in maintaining water balance. All animals however possess a more or less universal mechanism, the excretory system, which is simple in some animals and complex in others.

Osmotic pressure moves water through cell membranes from the side of greater water concentration to the side of lesser water concentration, aquatic organisms living in fresh water have a higher salt concentration in their bodies than in the surrounding water. Their problem is to prevent uptake or to rid themselves of excess water. Protozoans accomplish that task by means of contractile vacuoles, which collect and expel wastes. Freshwater fish maintain osmotic balance by absorbing and retaining salts in special cells and producing plentiful amount of watery urine. Amphibians balance the loss of salts through the skin by aborbing ions directly from water and transporting them across the skin and gill membranes.

Terrestrial animals, such as birds and reptiles, have a salt gland and a cloaca, a common receptacle for the digestive, urinary and reproductive tracts. They absorb water from the cloaca back into the body. Mammals possess kidneys capable of producing urine with high osmotic pressure and ion concentrations.

In arid environment, animals face a severe problem of water balance. They can solve the problem in one of two ways either by evading the drought or by avoiding its effects. Animals of semiarid and desert regions may evade drought by leaving the area during dry season. That is the strategy employed by many of the large African ungulates. The spadefoot toad of the southern desert of the U.S.A aestivates below the ground and emerges when the rains return. Some invertebrates, such as flatworms which occupy ponds that dry up in summer, develop hardened cysts in which they remain for the dry period. Other aquatic or semi aquatic animals retreat deep into the soil until reach the level of groundwater. Many insects undergo diapauses.

Other animals remain active during the dry season but reduce respiratory water loss. Some small desert rodents lower the temperature of the air they breathe out. Moist air from the lungs passes over cooled nasal membranes, leaving condensed water on the walls. As the rodents inhales the warm, dry air is humidified and cooled by this water.

Some small desert mammals reduce water loss by remaining in burrows by day and emerging by night. Many desert mammals, such as camels, produce highly concentrated urine and dry feces and extract water metabolically from the food they eat. In addition, some desert mammals can tolerate a certain degree of dehydration. Desert rabbits may withstand water losses of up to 50% and camels up to 27% of their body weight.

Animals in salts environment faces problems opposite to these in fresh water. These organism have to retain their body fluids. When the concentration of salts is greater outside the body than within, organisms tend to dehydrates. Osmosis draws water out of the body into the surrounding environment. In marine and brackish environment, organisms have to inhibit the loss of water by osmosis through the body wall and prevent an accumulation of salts in the body. There are many solutions to this problem. Invertebrates get around it by possessing body fluids that have the same osmosis pressure as seawater. Marine bony fish absorb salt water into the gut. They secrete magnesium and calcium through the kidneys and pass these ions off as a partially crystalline paste. Fish excrete sodium and chloride, major, ions in seawater, by pumping the ions across special membranes in the gills. This pumping process is one type of active transport. Salts move across a concentration gradient at a cost of metabolic energy. Sharks retain a sufficient amount of urea to maintain a slightly higher concentration of salt in the body than in surrounding seawater. Birds of the open sea can consume seawater because they possess special salt-secreting glands located on the surface of the cranium. Gulls and other seabirds excrete from these glands fluids in excess of 5% salt.

In marine mammals the kidney is the main route for the elimination of salt. Porpoises have highly developed kidneys to eliminate salt loads rapidly. In marine mammals the urine has a greater osmotic pressure (ion concentration) than blood and seawater, their physiology is poorly understood.

Populations

After studying the relationship of individual organisms to their physical environment, this part will turn to the biotic environment. How the individual interacts with others of its own species, and with competitors, predators, parasites, diseases, and mutualisms are the subjects of this part.

Properties of Populations

A population is group of potentially interbreeding and interacting individuals of the same species living in the same place at the same time. It is reproductively isolated from other such groups.

Population have unique features. They have an age structure, density, and distribution in time and space. They exhibit a birthrate, a death rate and a growth rate. They respond in their own ways to competition, to predation, and to other pressures. Individuals that make up a population affect one another in various ways. The relationship of one population with another influence the structure and function of whole ecosystems.

Density

Two outstanding attributes of a population are density and dispersion. Individuals in natural populations are affected by density. Trees in crowded stands may grow more slowly, and some may succumb to a lack of water, nutrients, and light, unequally shared. Scarce food may be denied to smaller or less aggressive mammals in a populations. Some birds may deny others access to nest sites when not enough sites exist to meet the demand. Having too few individuals in a population may reduce the chances of finding a mate or inhibit behavior essential to the welfare of the population. Low population density may raise an individual's risk of succumbing to predation. Affecting the welfare of individuals in all these ways, density in part controls a population's birth rates, death rates, and growth.

However important it may be, density is difficult to define and to determine. *Density* can be characterized as the number of individuals per unit of spaces, as so many per square kilometer, per hectare, or per square meter. That measure is *crude density*. The trouble with this measure is that individuals do not occupy all the space within a unit, because not all of it is suitable habitat. A biologists might estimate the number of deer living in a square kilometer. The deer, however, might avoid half the area, because human habitation, land use, and lack of cover and food.

No matter how uniform a habitat may appear is usually patchy, because of micro differences in light, moisture, temperature, exposure, or other physical conditions, or because of the lack of sites available for colonization. Each organism occupies only these areas that can meet its requirements.

Dispersion

How organism are dispersed over space has an important bearing on density. Individuals of population may be distributed *randomly*, *uniformly* or in *clumps*. Individuals are distributed *randomly* if the position of each is independent of the other's. some invertebrates of the forest floor, particularly spiders may be spaced at random.

By contrast, individuals distributed *uniformly* are more or less evenly spaced. In the animals world, uniform dispersion usually results from some form of competition, such *territoriality*.

The most common dispersion type is *clumped* dispersion, in scattered groups. Clumping results from responses to habitat differences, daily and seasonal weather changes, reproductive patterns, and social behavior. There are various degrees and types of clumping. Group may be randomly or non randomly distributed over an area. Aggregation may range from small groups to a single centralized group. If environmental conditions encourage it, populations may be concentrated in long bands or strips along some features of the landscape, such as a river, leaving the rest of the area unoccupied.

Age structure

Population has age structure. Because reproduction is restricted to certain age classes and mortality is most prominent in others, the ratio of the age groups bears on how quickly or slowly populations grow.

Population divide into three ecological period : prereprouductive reprouductive, and postreprouductive. The length of each period depends largely on the life history of organisms. Among annual species the length of the prereprouductive period has little influence on the rate of population growth. In longer lived animals, the length of the prereprouductive period has a pronounced effect on the population's rate of growth. Organisms with a short prereprouductive period often increase rapidly, with a short span between generations. Organisms with a long prereprouductive periods, such as elephant and whales, increase slowly and have a long span between generations.

The age structure of a population is the ratio of the various age classes to each other at a given time. Age pyramids (see figure 20) compare the sizes of age groups to help us visualize age structure. As the population changes with time, the number of individuals in each age class changes, and so do the ratios, a large number of young, which expands the base of the pyramid, characterizes a growing population. This large class of young eventually moves up into the reproductive age classes. A high proportion of individuals moving into the older age classes characterizes a declining population. With fewer young, fewer individuals will enter the reproductive age classes, further depressing the population. In this way age structure changes over time.

Life history Patterns

Reproductive is the major drive of all living organisms. The role of the reproductive drive is to transmit genetic characteristics from one generation to another. The ability of an organisms to accomplish that successfully is termed its *fitness*. Fitness is equated with the ability of an organisms to leave behind reproducing offspring. Individuals that leave behind the most reproducing offspring are supposedly the fitness. Achieving fitness involves, among other things, fecundity and survivorship, physiological adaptations, modes of reproduction age at reproduction, number of eggs or young produced, parental care, size, and time to maturity. How organisms achieve fitness becomes the organism's Life history Pattern.

Reproduction

Reproduction falls into two categories : *asexual* and *sexual*. *Asexual* reproduction creates new individuals genetically the same as the parent. The one – called *Paramecium* reproduces by dividing in two. Hydra reproduce by budding. Aphids produce eggs by normal cell division or mitosis that develop into female adults without fertilization. A process called *parthenogenesis*. However, organisms that rely heavily on asexual reproduction revert on occasion to sexual reproduction. Hydras at some time in their life cycle produce eggs and sperms. At the end of summer aphid resort to sexual reproduction to make males.

sexual reproduction : is common in multicellular organisms. Two individuals produce haploid gametes: egg and sperm, that combine to form a diploid cell or zygote. This halving and recombination of genes allow the gene pool to mix, producing genetic variability among offspring.

Some individuals possess male and female organs. They are *hermaphroditic.*

Mating strategies

The behavioral mechanisms and social organization involved in obtaining a mate make up a mating system.

Monogamy is the formation of a pair bond between one male and one female. It is most prevalent among birds and rare among mammals, except several carnivores, such as foxes and few herbivores, such as beavers and muskrat.

Monogamy occurs mostly among species in which cooperation by both parents is needed to rear young successfully. Nearly 90 percent of all species of birds are seasonally monogamous, because in most birds the young are helpless at hatching and need food, warmth and protection. The avain mother is no better suited to provide these needs than the father. Instead of seeking other mates, the male can increase his fitness more by continuing his investment in the young. Without him, the young carrying his genes may not survive. Among mammals, the situation is different. The females lactate, providing food for the young. Male often can contribute little or nothing to the survival of the young, so it is to their advantage to male with as many female as possible. Among the exceptions are foxes and wolves, which the male provides the female and young and defends the territory. Both male and female regurgitate food for the weaning young.

Monogamy, however, has another side. Among some 100 species of

Monogamous birds, the female or male may "cheat" by engaging in extra-pair copulation while maintaining the reproductive relationship with the primary male caring for the young.

Polygamy is the acquisition by an individual of two or more mates, non of which is mated to other individuals. It can involve one male and several females or one female and several males. A pair bond exists between the individuals and each mate. When one member of the pair is freed from parental duty, partly or wholly, it can devote more time and energy to competition for more mates and resources.

The number of the opposite sex an individual can possess depends upon the degree of synchrony in sexual receptivity. For example, if females in the population are sexual active for only a brief period, as with the white – tailed deer, the number of male can possess is limited. However if female are receptive over a long period of time, as with elk, the size of a harem a male can control depends upon the availability of female and the number of males the male has energy to defend.

A special form of polygamy is promiscuity, in which males and females copulate with one or many of the opposite sex and form no pair bonds.

Environmental and behavioral conditions result in various types of polygamy. In *polygamy* an individual male gains two or more males. Polyandry is interesting because it is the exception rather than the rule. the female is the competitive individual, since it competes for and defends resources essential for the male. This system is best developed in some shorebirds such as cranes, rails and gull. The female produces multiple clutches of eggs, each of which requires the services of a male. Female compete for available males. After the female lays a clutch, the male beings incubation. Then the becomes sexually inactive, resulting in a scarcity of available.

Reproductive effort

Organisms spend their energy to meet many needs. Some energy must go to growth, to maintenance to acquiring food, to defend territory, and to escape predators. Some must go to reproduction. To achieve optimal fitness, and organism has to budget its energy and time in reproduction. Allocation of time and energy make up an organism's "reproductive effort".

The more energy an organism spends on reproduction, the less it retains to spend for growth and maintenance. For example, the reproducing females of the terrestrial isopod *Armadilliduim vulgar* have a lower rate of growth than non reproducing females. Non reproducing females devotes as much energy to growth as reproducing females devote to both growth and reproduction.

How much energy organisms invest in reproduction varies. The investment includes not only the weight of the progeny, but also the energy expended to nourish it. The lizard *Lacerate vivipara* invests 7 to 9 percent of its annual energy assimilation in reproduction. The mountain salamander spends 48 percent of its annual energy flow on reproduction, including energy stored in eggs and energy costs of brooding.

Some animals reproduce only once in their life span. Some invest all energy into growth, development, and energy storage, and then make one massive reproductive effort and die, for example ; most insects and other invertebrates, and some species of fish, notable salmon. Mayflies may spend several years as larvae before emerging from the surface of water for an adult life of several days devoted to reproduction.

Other organisms choose to produce fewer young at one time and repeat reproduction throughout their life time, such as most vertebrates. For these organisms the problem is timing reproduction - early in life or later. Early reproduction means less growth, later maturity, and increases survivorship, but less time for future reproduction.

Energy investment and parental care

The same energy can produce many small young or one or two large ones. The number of offspring affects the investment each receives. If the parent produce a large number of young, it can afford only minimal investment in each one. In such case, animals provide no parental care. Such organisms usually inhabit disturbed sites, unpredictable environments, or places such as the open ocean, where opportunities for parental care are difficult. By diving energy for reproduction among as many young as possible, these parents increase the chances that some young will successfully settle somewhere.

Parents that produce few young are able to expend more energy on each individual. Some organisms expend less energy during incubation. The young are born or hatched in a helpless condition and require considerable parental care, such as young mice and nestling robins. Other animals have longer incubation or gestation, so the young are born in an advanced stage of development. They are able to move about and forage for themselves shortly after birth, such as gallinaceous birds and ungulate mammals such as cows and deer.

Environmental conditions and number of young

Organisms living in variable environment or facing heavy predation produce numerous offspring, ensuring that some will survive. A large number of young is characteristic of short-lived mammals, insects, and species which reproduce only once in their live. Having few young is a characteristic of long-lived species. Species reproducing many times in their life may adjust the number of young in response to environmental conditions and the availability of resources. Production of young often reflects the availability of food. In times of food scarcity, parents may fail to feed some offspring. In other situations, vigorous young kill their weaker sibs.

Populations growth

The study of Populations reviews the ways Populations change in size. Birth (natality) and deaths (mortality) account for most changes in the Populations. The differences between the two rates determines its growth or decline.

The number of births in a given time period is called " *natality rate*". Also the number of individual dying in a given time period is called " *mortality rate*". Mortality and natality are two major forces influencing Populations growth. Birth minus deaths (b-d) equals the rate of increase. When births exceed deaths, the Populations remains the same. When deaths exceed births, the Populations declines.

Two additional influences of Populations growth are immigration (i), and influx of new individuals into a Population and emigration (e), the dispersal of individuals from a Population. To account for those gains and losses a general formula for the rate of increase (or decrease) is (b + i) – (d + e).

Maximum Populations growth

The maximum rate at which a Population could increase under ideal conditions is known as its "*biotic potential*". Different species have different biotic potential. A particular species biotic potential is influenced by several factors, including the age at which reproduction begins, the percentage of the life span during which the organism is capable of reproducing, and the number of offspring produced during each period of reproduction.

Generally, larger organisms, such as blue whales and elephants. Have lower biotic potentials, whereas microorganisms have the greatest biotic potentials. Under ideal conditions certain bacteria can reproduce by splitting in half every 20 to 30 minutes. At this rate of growth, a single bacterium would increase to Population of more than 1,000,000 in just 10 hours (see figure 3) and the Population from a single individual would exceed one billion in 15 hours.

If one were to plot this increase versus time, the graph would have the "j" shape that is characteristic of "*exponential growth* " the constant reproducing rate that occurs under optimum conditions. Regardless of the organism being considered, whenever its biotic potential is platted versus time, the shape of the curve is the same. The only variable is time, that is it may take longer for a sea lion Population than for a bacterial Population to reach a certain size, but its Population will always increase exponentially under ideal conditions.

Limitation of Population growth (Fig. 4)

Certain Populations may exhibit exponential growth for a short period of time. However, organism cannot reproduce indefinitely at their biotic potentials, because the environment sets limits, which are collectively called "environmental resistance". Using the earlier example. Bacteria would never be able to reproduce unchecked for an extended period of time, because they would run out of food and living space, and poisonous body wastes would accumulate in their vicinity. With crowing, they would also become more susceptible to parasites and predators. As the environment changed, their birth rate would decline and their death rate would increase due to shortages of food, increased predation, increased competition, and stress. The environmental conditions might worsen to a point where death rate would exceed birth rate, and the population would decrease. the number of organism in a population, then is controlled by the ability of the environment to support it.

Over longer period of time, the rate of population growth for most organisms decreases to around zero. This leveling out occurs at or near the limit of the environment's ability to support a population. The "*carrying capacity*" represents the highest population than can be maintained for an indefinite period of time by a particular environment.

When population over a longer period of time is graphed, the curve has a characteristic "S" shape that shows the population's initial exponential increase, followed by a leveling out as the carrying capacity of the environment is approached. Although the S-curve is a simplication of actual population changes over times it does appear to fit the population growth observed in many populations that have been studied in the laboratory and few that have been studied in nature. For example. G.F. Gause grew a single species. *Paramecium caudateum*, in a test tube. He supplied a constant but limited amount of food daily. The population of *Paramecium* increased exponentially at first. The Paramecia became so numerous that the water was cloudy with them. But then their rate of increase declined and their population leveled off.

Sometimes, when a population exceeds the carrying capacity and environmental degradation results, a population crash occurs. In 1910 a small herd of 26 reindeer was introduced on one of Pribilof Islands of Alaska. The herds population increased exponentially for about 25 years unit there were approximately 2,000 reindeer overgrazed the vegetation unit the plant life was almost wiped out. Then, in slightly over one decade, as reindeer died from starvation, the number of reindeer to 8, one third the size of the original introduced population.

Interaspecific Population Regulation

No population continues to grow indefinitely. Even those with exponential growth confront the limits of the environment. Most populations, however, do not behave in an exponential fashion. As the density of a population changes, interactions set in among members of the population that tend to regulate its size.

Population regulation and density dependence

Involved in the concept of population regulation is density dependence. *Density-dependent* effects influence population in proportion to its size. At low density, there is no influence. Above that point, the larger the population becomes the greater is the population of individuals affected. Density – dependent mechanisms act largely through competition for abundant or scanty resources. If the effects of a particular influence do not change with population density, or if the proportion of individuals affected is the same at any density, then the influence is density- independent.

One aspect of population regulation is competition among individuals of the same species for environmental resources (intraspecific competition). Individuals compete only when a resources is in short supply relative to the number seeking it. As long as resources enable each individual to survive and reproduce, no competition exists. When resources are limited, a population may exhibit one of two responses : scramble competition and contest competition. *Scramble competition* occurs when no individual receives enough of the resource for growth and reproduction, as long as the population remains dense. *Contest competition* takes place when some individuals claim enough resources while denying others a share.

Intraspecific competition retards growth and reproduction

Because the intensity of intraspecific competition is density- dependent, it increases gradually at first affecting just the equality of life. Later it affects individual survival and reproduction.

As population density increases toward a point at which resources are insufficient, individuals in scramble competition reduce intake of food. That diet slows the rate of growth and inhibits reproduction. Tadpoles reared experimentally at high densities experienced slower growth, required a longer time to change from tadpoles to frog, and had a lower probability of completing this transformation. These that did reach threshold size were smaller than those living in less dense population. Fish living in overstocked ponds exhibit a similar response to density. Other vertebrate groups, too experience a density – dependent response, especially in fecundity, to increasing numbers. The timing of the response depends upon the nature of the population. Among large mammals with a long life span and low reproduction, regulating mechanisms do not function unit the population approaches carrying capacity. At this point density mechanisms set in and tend to compensate. Among animals with high reproductive rates and short life spans, response to density may occur much earlier.

As population reaches a high density, individual living space become restricted. Often aggressive contacts among individuals increase. One hypothesis of population regulation is that increased crowding and social contact cause *stress*. Such stress triggers hyper activation of the system that controls the endocrine glands. Profound hormonal changes suppress growth, curtail reproductive functions and delay sexual activity. They may also suppress the immune system and break down white blood cells, increasing vulnerability to disease. Social stress among pregnant females may increase intrauterine mortality and cause inadequate lactation. Thus stress results in decrease birth and increased infant mortality. Such population – regulating effects have been confirmed in confined laboratory populations of several species of mice and to a lesser degree in enclosed wild populations of old world rabbits.

Social behavior

Intraspecific competition express itself in social behavior, the degree to which individuals of the same species tolerate one another. Social behavior appears to be a mechanism that limits the number of animals living in a particular habitat, having access to a common food supply and engaging in reproductive activities. It excludes the others. Social behavior limits populations in a density dependent fashion. A population has a substantial portion of population consists of surplus animals that do not breed because they either die or attempt to breed and fail. Such individuals are prevented from breeding by dominant individuals.

Many species of animals live in a group with some kind of social organization. This organization is based on aggressiveness, intolerance and the dominance of one individual over another. Each individual occupies a position in the group based on dominance and submissiveness. In its simplest form, the group includes an alpha individual dominant over all others, a beta individual dominant over others except the alpha, and finally an omega individual subordinate to all others. Individuals settle *social* rank by fighting and threatening at initial encounters between any given pair of individuals or a series of such encounters. once individuals establish social rank**,** they maintain it by habitual subordination of these in lower positions. They reinforce this relationship by threats and occasional punishment meted out by those of higher rank. Such organization stabilizes and formalizes intraspecific competitive relationship and resolves disputes with a maintain of fighting and wasted energy. Social dominance plays a role in population regulation when it affects reproduction and survival in density – dependent manner.

Territoriality and population regulation

Territoriality is a situation in which an animal defends an exclusive area not shared with rivals. Defense follows definitive behavioral patterns-song and call, intimidation displays such as spreading wings and tail in birds and baring fangs in mammals, attack and chase, and marking with scents that evoke escape and avoidance in rivals. As a result, territorial individuals tend to occur in more or less regular patterns of distribution.

The proximate reasons for defending a territory vary. For some it is the acquisition and protection of food, a nesting site, or a mating area or attraction of a mate. The ultimate reason is an increased probability of survival and reproductive success. By defending a territory, the individual forces others into sub-optimal habitat, reducing their reproductive success. At the same time it increases the proportion of its own offspring in the population.

In general territory size tends to be no larger than required. That size may vary from year to year, and from locality to locality, depending upon resources and number of animals seeking space.

For some animals, birds in particular, it is not the size of the territory that counts, but its quality. Some males perhaps the most aggressive, claim the best territories, usually measured by features of vegetation that make them superior nesting sites. Less successful males occupy sub-optimal territories, and some males secure no territory at all, the most successful males are assured of a male, whereas male birds settled on a poor territory many be unable to attract one.

The total available area divided by the minimum size of the territory determines the number of territorial owners a habitat can support. When the available area is filled, owners evict excess animals. These individual make up a floating population.

Density – independent influences

As mentioned before, population growth and fecundity are heavily influenced be density – independent responses. However, there are other, often overriding influences on population growth. These influences are density – independent. By themselves, density – independent influences on the rate of increase do not regulate population growth. Regulation implies feedback. Density – independent influences, however, can have considerable impact on birthrates and death rates. They can mask or even eliminate density – independent regulation.

A cold spring may kill the flowers of oaks, causing a failure of the acorn crop. Because of the failure, squirrels may suffer widespread starvation the following winter. Although the proximate cause of starvation is the density of squirrels and the low food supply, weather was the ultimate cause of the decline. In general, annual and seasonal changes in the environment tend to cause irregular population fluctuations. Conditions beyond an organism limits of tolerance can have disastrous effects. They can affect growth, maturation, reproduction, survival, and movement. They can even eliminate local population.

The influences of weather is irregular and unpredictable. It functions largely by influencing the availability of food. Pronounced changes in population growth often correlate directly with variations in moisture and temperature.

In desert regions a direct relationship exists between precipitation and rate of increase in certain rodents and birds. Kangaroo rat occupies lower elevations in the desert. It has the physiological capacity to conserve water and survive long period of aridity. However, it does require in its environment a level of moisture sufficient to stimulate the growth of herbaceous desert plants in fall and winter. The kangaroo rat becomes reproductively active in January and February, when plant growth stimulated by fall rains, is green and succulent. Herbaceous plants provide a source of water, vitamins, and food for pregnant and lactating females. If rainfall is scanty, annual plants fail to develop and production of kangaroo rats is low. This close relationship to seasonal rainfall and success of winter annuals in also apparent in other rodents and birds occupying similar desert habitats.

Populations interactions

Although the most intense relationships exist between them, individuals of the same species do not live apart from individuals of other species. Living in close association different species interact. They may compete for a shared resource. Such as food, light, space, or moisture. One may depend upon the other as a source of food. They may provide mutual aid, or they may have no direct effect on each other at all.

Interactions between species include : competition predation, parasitism, mutualism and commensalisms.

Interspecific Competition

Interspecific Competition, as in Interspecific Competition, individual seek a resource in short supply, but they are of two or more species. Both kinds of Competition may take place simultaneously. Grey squirrels for example. Compete among themselves for acorns during a poor crop year. At the same time they compete with the white-footed mice, white-tailed deer and wild turkey for the same crop. Because of competition, individuals within a species may be forced to broaden the base of their foraging efforts. Population of various species may be forced to turn away from acorns to food less in demand. Thus Interspecific Competition selects for a broadening of the use of the resource, whereas Interspecific Competition favors a reduction of the use of the resource base.

Like Interspecific Competition, Interspecific Competition takes two forms. Interspecific Competition. Like contest Competition, is direct or aggressive. One Competitor interferes with another's access to resource. Exploitative Competition. Similar to scramble Competition, reduces the abundance of shared resources. Each species indirectly reduces the abundance of the other species. The outcome depends on how attentively each of the Competitors use the resource.

Outcomes of intenspecific Competition

Early in the twentieth century, two mathematicians. The American Alfred Lotka and the Italian Vittora Volterra, independently arrived at mathematical expressions to describe the relationship between two species using the same resource. Lotka – Volterra equations predict four different outcomes of interspecific completion:

A., B.) In two situations, one species uins out over the other. In one case species 1 inhibits further increase in species 2 while continuing to increase itself. In this case species 2 is driven to extinction. In the other case species 2 inhibits further increase in species 1 continuing to increase itself, and species 1 disappears. The Russian biologist A.F. Gause (1934), grew in the laboratory, two of *Paramecium . P. Aurelia and P. Caudatum.* When the two species were grown in separate test tubes. Each species quickly increased its population to a high level. Which is maintained for some time thereafter. When the two were grown together. However, only *P. Aurelia* thrived; *P. Caudatum dwindled* and eventually died out. Under different sets of culture conditions. *P. Caudatum* prevailed over *P. Aurelia* which died out. Gause interpreted this to mean that one set of conditions favored one species, and a different set favored the other. Because the two were similar, given time one or the other would eventually triumph at the other's complete cost.

C) In third situation each species, when abundant, inhibits the growth of the other species more than it inhibits its own growth. Both species hang on in an unstable equilibrium. In the long run one wins. The outcome depends upon which species is the most abundant and upon which species adapts better to environmental change.

D) In the fourth situation neither population can achieve a density capable of eliminating the other. Each species inhibits its own population growth more than that of the other species.

Competitive exclusion principle

In three of the four situations predicted by the lotka-Voltera equations one species drives the other to extinction. The results of the laboratory studies tends to support the mathematical models. These observations have led to the concept called the" Competitive exclusion principle" it states that complete competitors cannot coexist. Basically. If two non interbreeding populations possess exactly the same ecological requirement and live in exactly the same place. And if population A increases the least bit faster than population B. than A eventually will occupy the area completely. B will become extinct.

The competitive exclusion principle assumes that both competitors remain genetically unchanged that immigrants from other areas do not move into the population of the losing species and that environmental conditions remain constant. Such conditions rarely exist. Because they are not ecologically indentical. Two or more species can complete for an essential resource without being complete competitors.

The results of many field experimental studies do suggest that interspecific completion has a large overall effect that varies widely among organisms. For example. The studies show strong competition among toads. Frogs, and arthropods of flowing water. Among herbivores interspecific competition is less significant than intraspecific completion in controlling populations. Among most organisms the effects of intraspecific and intraspecific completion are equally strong.

The better field studies of exclusion are not experimental but observational. Many studies observe the impact of introduced species on native fauna. For example, the moth skink (alizard) disappeared from the Hawaiian Islands, where it had once been fairly common. Soon after the introduction of the metallic skink. The kestrel falcon, had disappeared from most of the islands of Seychelles group following the introduction of the barn owl from South Africa. Both are hole nesters, and the falcon had been eliminated by the aggressive newcomer as result of nest-site completion (Fisher et al., 1969). In these examples and others, competitive exclusion does not fit the theoretical framework described by the Lotka-Voltear equations, Instead exclusion is determined by physiological tolerances and by aggressive behavior.

One species excludes another when it exploits a shared limiting resource more effectively, resulting in an increase in its population at the expense of its competitor. However each organism does best under particular condition. Low temperature rise from time to time, the advantage may shift to another species. When environmental conditions vary, the competitive advantage may shift. As a result no one species will reach sufficient density to displace its competitors. In this manner, environmental variations allow the coexcistence of competition, where under constant conditions, one could exclude the other.

coexcistence

two or more competing species can coexist, although such competition reduces the fitness of all parties. Among some animals, notably dirds, competing species exhibit territorial behavior. This interspecific territoriality reduces the number of breeding individuals of each species that occupy a given area of shared habitat.

Observations of a number of species sharing the same habitat suggest that they coexist by ***Partitioning*** available resources. Animals use different kinds and sizes of food, feed at different times, or forage in different areas. Each species exploit a portion of the resource unavailable to others. Such partitioning is regarded as an outcome of interspecific competition. By dividing the resource, each species avoids direct competition with the others.

Predation

Predation is the eating of one living organism (prey) by another (predator). One organism benefits at the other's expense. Predation includes not only carnivory, but parasitism, cannibalism and herbivore. A fly or a wasp laying its eggs on a caterpillar of another species to develop there at the expense of its victim is exhibiting a form of predation called *parasitism.* The parasitoid attacks the host (the prey) indirectly by laying its eggs on the host's body. When the eggs hatch, the larvae feed on the host. Slowly killing it. A deer feeding on shrubs and grass and a mouse eating a seed are practicing a form of predation called *herbivore*. Seed consumption is outright predation because the embryonic plant is killed. A special form of predation is *cannibalism*, in which the predator and the prey are of the same species.

However, there is a close interaction between the predator and the prey. Each influences the fitness of the other. Predation is more than a transfer of energy. It is a direct and often complex interaction of two or more eater and the eaten. The numbers of some predators may depend upon the abundance of their prey. Each can influences the population growth of the other and favor new adaptations.

interactions between the predator and the prey suggest two distinct responses of the predator to changes in prey density. One is for the individual predator to become more numerous increased reproduction or immigration. In the first case, as the prey numbers increase above the carrying capacity, surplus animals are forced out of the best habitat into poorer, insecure habitat where they become vulnerable to predation. Below the threshold of security, or carrying capacity, the prey species compensates for its losses through increased reproduction and increased survival of young. In the second type of response, as the density of the prey increases, the number of predators may also increase. This response mostly involves an increase in the reproductive effort of predator. Because reproduction usually requires a certain minimal time, a lag exists between an increase of a prey population and a numerical response by a predator population.

The relationship between predators and prey is influenced considerably by prey defenses and the ability of predators to overcome them. The predator does not succeed in every encounter, prêt employs different means of defense. Chemical defense is widespread among many groups of animals. Some species of fish release alarm pheromones, inducing flight reactions in members of the same and related species. Arthropods, amphibians, and snakes employ odorous secretions to repel predators. Many arthropods, snakes, frogs are poisonous. Cryptic coloration, includes colors, patterns, shapes and postures that allow prey to blend into the background. Some animals exhibit warning coloration to signal that they are highly toxic. Some others evolve a coloration that resembles or mimics the warning coloration of toxic species. Some animals employ physical means of defense. Clams, armadillos, turtles, and some beetles all withdraw into their armor coat or shell when danger approaches. For some prey. Living in groups is the simplest form of defense. Predators are less likely to attack a concentrated group of individuals. A more subtle form of defense is the timing of reproduction so that most of the offspring are produced in a short period of time. Then prey is so abundant that the Predator becomes satiated, allowing a percentage of the young to escape and grow to less unlnerable size.

As prey have evolved ways of avoiding Predators, Predators have evolved better ways of hunting, Predators, like their prey, may use cryptic coloration to blend into the background. Some use deception by resembling the prey. Robber flies mimic bumblebees, their prey. The female of certain species of fireflies initates the mating flashes of other species, attracting males of those species, which she promptly kills and eats. Predators may also employ chemical poisons, as rattlesnakes do. They may form a group to attack large preys, as lions and wolves do.

Cannibalism

Cannibalism is a special form of Predation. Called Intraspecific Predation. Cannibalism is killing and eating an individual of the same species. It is common to a wide range of animals, aquatic and terrestrial, from protozwoans and rotifers through centipedes, mites, and insects to frogs, toads, fish, birds, and mammals, including humans.

Cannibalism has been associated with stressed population, particularly those facing starvation. Although some animals do not become cannibalistic until other foods run out, others do so when alternative foods decline and individuals are malnourished. Other conditions that may promote cannibalism are : 1) crowded conditions or dense populations. Even when food is adequate: 2) stress, especially when individuals of low social rank are attacked by dominant individuals: 3) the presence of vulnerable individuals – such as nestlings, eggs, or weak individuals that provide easy prey even in the presence of food.

Even at low rates, cannibalism can produce demographic effects. Three percent cannibalism in the diet of walleyes (a predator fish) could account for 88 percent of mortality among the young. Cannibalism causes 23 to 40 percent of mortality among eggs and chicks of herring gulls. 8 percent of young Belding's ground squirrels and 25 percent of lion cubs. Cannibalizing a large proportion of either a population or a vulnerable age class can result in dramatic fluctuations in population.

Cannibalism can rapidly decrease the number of Intraspecific competitors as food become scarce. It decreases as resources become more available to survivors and as vulnerable individuals become scarcer or harder to find. By reducing intraspecific competion at times of resource shortage, cannibalism may actually reduce the probability of local extinction of a population, improve conditions for survivors, and enhance their growth and fecunelity. Conversely, cannibalism can be a selective disadvantage if certain survivors become too aggressive and destroy their progeny.

Parasitism and Mutualism

Coevolution

Sometimes two different species develop an intimate association so that, over time, the course of each species evolution is affected. We call a relation in which two interacting populations appear to strongly influence the evolution of traits in each other "coevolution". Any evolutionary change in one member changes the selective forces acting on the other. They play a game of adaptation and counter adaption. Coevolution is found between parasites and hosts. And between mutualalism.

Most coevolutionary responses appear to be general. For example, plants have evolved chemical defense against a diverse array of herbivorous insects. In turn, many insects have evolved the ability to detoxify a wide range of plant chemicals. Similarly animals have evolved a generalized immune system in response to a wide range of parasites. Flowering plants and their animal pollinators provide an excellent example of coevolution. During millions of years over which these associations developed, Flowering plants evolved a number of ways to attract animal pollinators, such as attractive colors and scents. Also, the animal pollinators, such as insects, hummingbirds, and bats, coevolved specialized body parts and behaviors that enabled them to both aid pollination and obtain nectar and pollen as a reward.

However, period interactions between certain parasites and their hosts or between certain mutualists suggest closer, more specific convolution.

Parasitism

Parasitism is a condition in which two organisms live together, one deriving is nourishment at the expense of the other. Parasites draw nourishment from the tissues of the larger host, a case of the weak attacking the strong (in perdation, the strong predator attacks the weak prey). Mostly the Parasites do not kill their hosts as predators do, although the host may die from secondary infection or suffer stunted growth weakness or sterility.

Parasitic organisms belong to awide range of taxonomic groups, including viruses, bacteria, protists, fungi, and an array of invertebrates among them arthropods.

Parasitic are distinguished by size as microparasites and macroparasites . *Microparasites* include viruses and bacteria, and protozoans. They are characterized by small size and a short generation time. They develop and multiply rapidly within the host and tend to induce immunity to reinfection in hosts that survive the initial infection. The duration of the infection is short relative to the expected life span of the host. Transmission from host to host is direct, although other species may serve as a carrier.

Macroparasites are relatively large. Examples include flatworms, roundworms, flukes, lice, fleas, ticks. They have a comparatively long generation time and direct reproduction in the host is rare. Macroparasites are persistent, causing continual reinfection. They may spread by direct transmission from host to host is indirect transmission involving intermediate hosts and carriers.

Hosts are habitats for parasites, which have exploited every conceivable habitat on and within these hosts. Parasites that live on the skin within the protective cover of feathers and hair are *ectoparasites*. Other, known as *endoparasites*, live within the host, in different tissues and organs.

The impact of parasites on host populations depends on the mode of transmission and the density and dispersion of the host population. Parasites regulate host populations by increasing the host's death rate or decreasing is reproductive capability. Such effects are most evident when parasites invade a population with no evolved defenses. In such eases the disease may be density – independent, reducing populations exterminating them locally, or restricting the distribution of the host.

Mutualism

Mutualism is the name given to associations between two species that bring mutual benefits. The individuals in a population of each mutualist species grow and/or survive and/or reproduce at a higher rate when in the presence of individuals of the other. Each mutualist gains one of a variety of kinds of advantage. Most often this involves food resources for at least one of the parties and frequently, for the other, protection from enemies or provision of a favovrable environment in which to grow and reproduce. In other cases, the species that gets the food provide a service by ridding its partner of parasites (e.g. cleaner fish) or by bringing about pollination or seed dispersal.

Previous ecology texts have generally underemphasized or ignored mutualism. Yet it is an extremely widespread phenomenon. A very significant proportion of the world's biomass depends on it. Most rooting plants have mutualistic mycorrhizae, many flowering plants depend on insect pollinators, and a very great number of animals possess guts which contain mutualistic communities of microorganisms.

Mutualistic links between individuals of different species range from those which are *facultative* (where each partner (symbiont) gains a benefit but is not dependent on the other), through links that are obligate for both partners.

There are many examples of these mutualistic links:

1. The honey guide (an African bird) that has located a bees nest leads the ratel (an African mammal feeds on honey) to it. The mammal tears open the nest and feeds on honey and bee larvae, and later the bird gets a meal of beeswax and larvae. The bird can locate a bees nest but not break it open, while the ratel is in just the opposite situation.
2. The clownfish lives close to a sea anemone and retreats among the anemone's tentacles whenever daner threatens. The fish derives protection from this relationship, but the anemone also benefit because the clownfish attack other fish which come near to eat the sea anemone.
3. Another mutualistic association exists between "*cleaner*" and "*customer*" fish, where the former feeds on ectoparasit and bacteria from the body surface of the latter.

The cleaner fish often hold territories which their customers migrate to the "*cleaning stations*" indeed customers visit cleaning station more often when they carry many parasites. The cleaners gain a food source and the customers remain clean. In an experiment in the Bahamas. Limlaugh (1961) removed all the cleaner fish from patches of reef. The customers developed skin diseases and their populations declined within two weeks.

In the above example, mutualisms have depended on patterns of behavior of the animals involved. In all cases they involves acts of search and usually (but not always) they have food as a reward. Each partner spends a significant part of its life on its own. In many other mutualisms one of the partners is a unicellular organism and is integrated into the life of its multicellular partner as a more or less permanent part of itself. Animals guts and their living inhabitants provide important examples of this phenomenon. In many herbivores, the gut microflora plays a major role in the digestion of cellulose and perhaps also in the synthesis of vitamins. The microflora gain a continuous supply of food and a rather stable environment and the herbivore gains a digestible resource from a diet which own enzymes cannot handle. Some termites feed on wood, but cannot digest cellulose. Its gut contains some flagellate protozoons which digest cellulose. In return the flagellate gains an environment and feeds on some products in the termite's gut.

Commensalism

A " Commensal" organism lives on or around the individuals of some other species (which may be called host) and drives benefit from the association. The host suffers no negative effects.

Van Beneden (1876) wrote. " *The Commensal is simply a companion at the table*". Good examples of Commensals in this sense are the scavengers such as vultures that live on the scraps from the kills of large camivores such as lions. The remora fish uses its suction cup on the top of its head to attach itself to a shark. It thus travels with the shark and eats the leftovers from the big fish's meal.

The term " Commensalism" is now used in a broaden sense to refer to coactions in which the gain is something other than direct access to food provided by the host. Usually the gain is some combination of *transportation, support or shelter*. The use of prairie dog burrows as nest sites for burrowing owls and the use of old bird's nests by deer mice as sites for their own nests are examples of Commensalism.

Commensalism is common in aquatic habitats, especially marine ones. Burrows of polychaete worms are full of crustaceans and other guests. Organisms encrust other organisms. Such as barnacles cover whales. One clam that washed up on a Florida beach had more than 100 animals of 25 species attached to it. Perase (1939) declared that " *sponges are often veritable living hotels*". One sponge sheltered over than 17.000 animals of 10 species.

" *Phoresy* " is a term used to denote the transport of one animal by another. Members of several taxonomic groups such as insects and mollusks, use other animals to carry them, but phoresy is probably best developed among the mites. Some mites use insects simply as a way to get where they need to go.

Community and Ecosystem

Populations of organisms do not live apart from one another as separate entites. Sharing environment and habitat they interact in various ways. These interactions came together in the concept of Community : as assemblage of species in a given place interacting directly and in directly with each other. The Community involves the biota only. The interaction of the biotic Community with the a biotic environment forms the ecosystem.

Community Structure

Although ecologists classify communities in different ways, all communities have certain characteristics that define their biological and physical structure. These characteristics vary in both space and time.

biological structure

the mix of species, including their number and relative abundance defines the biological structure of a community. A community can be composed of a few common species: or it can have a wide variety of species, some common with high population density, but most rare with low population density. When a single or few species predominate withing a community, these organisms are *dominants*.

Dominancey : It is not easy to determine the dominant species. The dominants in a community may be the most numerous, possess the highest biomass, occupy the most space, make the largest contribution to energy flow or nutrient cycling or by some other means control or influence the rest of the community. Some ecologists ascribe to dominant role to those organisms that are greatest in number, but abundance alone is not sufficient. A species of plant, for example, can be widely distributed but exert little influence on the community as a whole. In a forest the small or understory trees can be numerically superior : yet the community is controlled by a few large tree that overshadow the smaller ones. In such as situation the dominant organisms are not those with the largest numbers but those that have the greatest biomass or that occupy most of the canopy space thus control the distribution of light. Ecologists measure such dominants by biomass or basal area.

Among the array of species that make up the community, a few are abundant, but most are rare. This characterstic could be discovered by counting all the individuals of each species in number of sample plots within a community and determining what percentage each contributes to the whole. This measure is known as *relative abundance*.

physical structure

communities are characterized not only by the mix of species, the biological structure, but also by physical features. The physical structure of the community reflects Abiotic factors, such as the depth and flow of water in aquatic environment. It also reflect biotic factors, such as the spatial configuration of organisms.

In a forest, for example, the size and height of the trees and the density and dispersion of their populations define The physical attributes of the community. The form and structure of terrestrial communities reflect the vegetation. The plants may be tall or short evergreen or deciduous herbaceous or woody. Such characterstics can describe growth form. Thus we might speak of shrubs, trees, and herbs.

Vertical structure : (Fig. 5)

Each community has a distinctive vertical structure. On land, vertical structure is determined largely by the life form of the plants – their size branching and leaves – which in turn, influence and is influenced by the vertical gradient of light. The vertical structure of the plant community provides the physical framework in which many forms of animal life are adapted to live. A well-developed forest ecosystem, for example, has several layers of vegetation. From top to bottom, they are the canopy, the understory, the shrub layer, the herb or ground layer, and the forest floor. We could continue down into the root layer and soil strata.

The *canopy*, which is the primary site of energy fixation through photosynthesis, has a major influence on the rest of the forest. If it is fairly open, considerable sunlight will reach the lower layers, will have ample water and nutrients resulting in well developed understory and shrub strata. If the canopy is dense and closed, light levels are low and the understory and shrub layers will be poorly developed.

The understory consists of tall shrubs. Understory trees and younger trees, some of which are the same species as those in the canopy. Species which are unable to tolerate shade will die. Survivors eventually reach the canopy after older tress die or harvested.

The nature of the *herb layer* will depend on the soil moisture and nutrients conditions, the slope position, the density of the canopy and understory, and the exposure of the slope, all of which vary from place to place throughout the forest.

The final *forest floor* is the site where the important process of decomposition takes place and where decaying organic matter release nutrients for reuse by the forest plants.

Aquatic ecosystems such as lakes and oceans have strata a determined by light penetration. They have distinctive profiles of temperature and oxygen. Layers are defined according to light penetration an upper zone, *the trophogenic zone* dominated by phytoplankton, which is the site of photosynthesis, and a lower zone, the *tropholytic zone* in which decomposition is most active.

All communities, both terrestrial and Aquatic, have a similar biological structure, related to these patterns of vertical layering. They possess an autotrophic layer concentrated where light is most available, which fixes the energy of the sun through photosynthesis, producing orgamic carbon compounds from CO_2 . In forests this layer concentrates in the canopy, in grasslands in the herbaceous layer: in lakes and seas, in the upper layer of water. Communities also possess a heterotrophic layer that utilizes the carbon, stored by autotrophs as food source, transfers energy, and circulates matters by means of herbivory, predation in the broadest sense, and decomposition.

Horizontal structure

In a forest, for example, often there are patches of open grass and tall shrubs. Sometimes there are gaps, openings in the canopy caused by the death of a canopy tree, where dense thickets of new growth have claimed the sunlit openings. The *horizontal patchiness* adds to the physical complexity of the Community. This patchy distribution of plants shows influences of both the physical and bidogical environment. In terrestrial Communities, soil structure, soil fertility, moisture sonditions and aspect influence the microdistribution of plants. Patterns of light and shade shape the development of the understory vegetation. Grazing animals have subtle but important effects on the patterning of vegetation, as do Abiotic distribances such as wind and fire. Like vertical structure, horizontal patchiness of plant life influences the distribution and diversity of animals life within the Community. Generally, Communities that are most highly stratified (vertically and horizontally) offer the richest variety of animal life because they contain the greatest assortment of habitats.

Niche

Every organism has its own role within the structure and functions of an ecosystem, this role is its ecological niche. An organism's ecological niche takes into account all aspects of the organisms existence – all the physical, chemical, and biological factors that the organism needs to survive, to remain healthy, and to reproduce. Among other things, the niche includes the physical surrounding in which an organism lives (its habitat) and how it interacts with and is influenced by the nonliving components of its environment (light, temperature, and moisture). An organism's niche also encompasses the organisms it eats, the organisms that eat it, and the living organisms with which it competes. The niche, then, represents the totality of an organism's adaptations, its use of resources, and the life style to which it is fitted.

There are two aspects to an organism's ecological niche : the role the organism could play in the Community, the potential or ***fundamental niche***, and the role it actually fulfills : the ***realized niche***. The niche may be far broader potentially than it is in actuality. An organism is usually capable of utilizing much more of its environment's resources or living in a wider assortment of habitats than it actually does, but various factors such as competition with other species may exclude it from part of its fundamental niche. Thus the life style that an organism actually pursues and the resources that it actually utilizes comprise its realized niche. Because all natural communities consist of numerous species, many of which compete to some extent, the complex interaction among them produced the realized niche of each.

Production Ecosystems

In the concept of the ecosystem, the biological and physical components of the environment are a single interaction system. Like the community, the ecosystem is a spatial concept : it has defined boundaries. The primary focus of ecosystem ecology is the exchange of energy and matter. Exchange from the surrounding environment into the ecosystem are *inputs*. Exchanges from inside the ecosystem to the surrounding environment are *outputs*.

Basic components of ecosystems : (Fig.6)

In the simplest terms, all ecosystems, both aquatic and terrestrial, consist of three basic components – the autotrophs, the consumers, and Abiotic matter. The *producers*, or *autotrophs*, are largely green plants. These organisms use the energy of the sun in photosynthesis to transform inorganic compounds into simple organic compounds.

The *consumers*, or *heterotrophs* use the organic compounds produced by the autotrophs as a source of food. The heterotrophic components of the ecosystem is often subdivided into two subsystems, consumers and decomposers. The consumers feed largely on living tissues, and the decomposers break down dead matter into simple inorganic compounds that are once again used by the producers.

The third, or *abiotic*, components consists of the soil sediments, particulate matter, dissolved organic matter in aquatic ecosystem, and litter in terrestrial ecosystems. All of the dead organic matter is derived from plant and consumer remains and is acted upon by decomposers. Such dead organic matter is critical to the internal cycling in the ecosystem.

The driving force of the system is the energy of the sun. the energy harnessed by the producers flows from producers to consumers to decomposers and eventually dissipates as heat.

Laws of thermodynamics govern energy flow

Production in ecosystems involves the fixation and transfer of energy from the sun. green plants fix solar energy in the process of photosynthesis. The products of photosynthesis accumulate as plant *biomass*. Nonphotosynthetic organisms convert this stored energy into *heterotrophic* *biomass*. This fixation and transfer of energy through the ecosystem is governed by the laws of thermodynamics, which apply to all things in the universe.

Energy exists in two forms, potential and kinetic. *Potential energy* is stored energy. *Kinetic energy* is energy in motion, which performs work at the expense of Potential energy. The expenditure and storage of energy are governed by the laws of thermodynamics. The first laws of thermodynamics states that energy is neither created nor destroyed. It may change form, pass from one place to another, or act upon matter in various ways. Regardless of what transfer and transformations take place, however, no gain or loss in total energy occurs. When wood burns, the potential energy lost from the molecular bonds of the wood equals Kinetic energy released as heat.

The transfere of energy involves the second law of thermodynamics. It states that when energy is transferred or transfermed part of the energy assumes a form that cannot pass on any further. When coal is burned in a boiler to produce steam, some of the energy creates steam, and part is dispersed as heat to the surrounding air. The same thing happens to energy in the ecosystem. As energy is transferred from one organism to another in the form of food, a large part of that energy is degraded as heat –no longer transferable. The remainder is stored as living tissue.

The flow of energy through Ecosystem

The passage of energy in one direction through an ecosystem is known as energy flow. Energy enters an ecosystem in the form of the radiant energy of sunlight. Some of it is trapped by plants during the process of photosynthesis. Now in chemical form it is stored in the bonds of organic molecules such as glucose. When these molecules are broken apart by cell respiration, the energy becomes available to do work such as repairing tissues, producing body heat, or reproducing. As the work is accomplished the energy escapes the living organism and dissipates into the environment as heat. Ultimately, this heat energy radiates into space. Thus, once energy has been used by living organism, it becomes unavailable for reuse.

The path of Energy Flow : Food Chains

Energy in ecosystem occurs in food chains, in which energy from food passes from one organism to the next in a sequence. Producers start the food chain by capturing the sun's energy through photosynthesis. Herbivores (and omnivores), who reap the energy stored in the herbivore's molecules. At the end of a food chain are decomposers, which use organic molecules in the remains (the carcasses and body wastes detritus) of all other members of the food chain.

Each level in a food chain is called a *trophic level*. The first trophic level is formed by the producers (green plants), the second trophic by primary consumers (herbivores), the third trophic level by secondary consumers (carnivores) and so on.

Simple food chains such as the one just described rarely occur in nature, because few organisms eat just one kind of organism. More typically, the flow of energy through an ecosystem takes place in accordance with range of choices of food. In an ecosystem of avergage complexity, numerous alternative pathways are possible. Thus a *food web*, a complex of interconnected food chains in an ecosystem, is a more realistic model of the flow of energy.

The most important thing to remember about energy flow in ecosystem is that it is one – way. That is energy can move along a food chain or food web from one organism to the next as it is not used. When energy is used, it becomes unavailable for use by another organism in the ecosystem. The ecosystem has to get new energy from sunlight. On the hand materials (matter) move in more or less complete circular systems in the ecosystem. In the other words, materials circular and are not lost from circular ecosystem.

Ecological Pyramids : (Figs 7,8,9,10)

An important feature of energy flow is that most of the energy goining from one trophic level to another in a food chain or food web dissipates into the environment. The relative energy values of trophic levels are often graphically represented by ecological pyramids. There are three main types of pyramids : a Pyramids of numbers, a Pyramid of biomass, and a pyramid of energy.

A Pyramid of numbers shows the numbers of organisms at each trophic level in a given ecosystem, with greater numbers illustrated by wider section of the pyramid. In most pyramids of numbers, each successive trophic level is occupied by fewer organisms. Thus in a typical grassland the number of zebras and wildebeests (herbivores) is greater than the numbers of lions (carnivores).

A Pyramid of biomass illustrates the total biomass at each successive trophic level. *Biomass* is a quantitative estimate of the total mass, or amount of living material. Its units of measure vary: biomass may be represented as a total volume, as dry weight, or as live weight. Typically, Pyramid of biomass illustrate a progressive reduction of biomass in successive trophic levels.

A Pyramid of energy illustrates the energy relationships of an ecosystem by indicating the energy content (usually expresses in calories) of the biomass of each trophic levels. On the whole, energy Pyramids resemble biomass pyramids in shape, but they help to make another rconsequence of the nature of trophic levels clearer : most food chains are short because of the dramatic reduction in energy content that occurs at each trophic levels. A secondary consumer requires an enormous home range – the area needed to obtain enough food – to encompass all the necessary producers, especially if it is a large animal. Thus a large solitary kilometer, whereas a cottontail rabbit, which occupies a lower trophic levels can live on 6 hectares.

Variation in Productivity of ecosystems

The *gross primary productivity* of an ecosystem is the rate at which energy accumulate (as biomass) during photosynthesis – that is, the total amount of photosynthesis in a given period of time. Of course, plants must respire to provide energy of their life processes, and cell respiration acts as a drain of photosynthesis. Energy that remains (as biomass) after cell respiration has occurred is called *net primary productivity*. In other words, net primary productivity is the amount of biomass found is excess of that broken down by plant's cell respiration. Net primary productivity represents the rate at which organic matter is actually incorporated into plant bodies so as to produce growth.

"Net primary productivity = growth prim. produc – plant respiration"

(Plant growth) (Total photosynthesis)

Only the energy represented by net primary productivity is available for the nutrition of consumers and of this energy only a portion is actually utilized by them. Both primary productivity and net primary productivity can be expressed in terms of kilocalories per square meter per year, or in terms of dry weight per square meter per year.

A number of factor may interact to determine the productivity. Some plants are more efficient photosynthesizers that others. Environmental factors are also important. The influx of solar energy, availability of mineral nutrients, availability of water, and other climatic factors are important, as the degree of maturity of ecosystem, and the severity of human modification.

Ecosystem differ strikingly in their productivity. Terrestrial communities are generally more productive than aquatic ones, partly because of the greater availability of light for photosynthesis, and partly because of higher concentrations of available mineral nutrients. Aquatic environments receive less light than terrestrial environments. When sunlight hits the surface of water, much of it is scattered or reflected. Also as light penetrates water, some of it is absorbed by water molecules, reducing the amount of light at greater depths.

Community Succession

Community change overtime

A community of organisms does not spring into exsistense full-blown, but develops gradually through a series until it reaches maturity. The process of community development over time, which involves species in one stage being replaced by different species, is celled succession. An area is initially colonized by certain organisms that are replaced over time by other organisms, which are themselves replaced until a more or less stable community that is a equilibrium with existing environmental conditions develops. The relatively stable stage in a community's development is called a *climax community*. climax communities represent the dominant vegetation of an area, but they are not permanent: they change as environmental conditions change.

Succession is usually described in terms of the changes in the species composition of vegetation of an area, although each successional stage also has its own characteristic animal life. The time involved in ecological Succession is on the order of hundreds or thousands of years, not the millions of years involved in the evolutionary time scale.

Primary Succession : (Fig. 11)

Primary succession is the change in species composition over time in a habitat that has not previously been inhabited by organisms. No soil exists when Primary succession beings. A bare rock surface, such as recently formed volcanic lava, or rock scraped clean by glacial action, is a potential site for Primary succession. Although details vary from one site to another, one might first observe a community of lichen. Because they are the first organisms to colonize bare rock, lichens are called *the pioneer community*. Lichens secrete acids that help to break down the rock apart , beginning the process of soil formation. Over time, the lichens community may be replaced by mosses and drought – resistant ferns, followed in turn by tough grasses and herbs. Once sufficient soil has accumulated grasses and herbs may be replaced by low shrubs, which in turn are replaced by forest trees in several distinct stages. Primary succession from a pioneer community on bare rock to climax forest community may take hundreds or thousands of years. A closer look in *Primary succession* on rock reveals the following. Lichens are able to live on the surface of many rocks and beneath the surface of porous rock in a sheltered and somewhat moister habitat. Lichens are very resistant to desiccation. As generations of lichens pass on rock surface, several important cumulative changes occur. First the biomass of the lichens community increases, so more and more solubilized minerals are stored in the living tissue of the community. Second fine particles of rock become detached from the rock's surface or even within the rock itself. Third, as lichens die, their decomposing remains mix with the rock particles to form a rudimentary soil. Fourth, whenever water is available , it is absorbed by the lichens and retained in their tissues and in the new, thin soil layer for longer periods of time than ever before. As all of these changes occur, an increasing number of tiny animals move into the area and make their homes in the lichens and soil. All these changes – increased biomass, soil development, water retention and an increased number of life form-work together to moderate the harsh conditions under which the pioneer community has lived making it possible for mosses to grow there. In fact, because mosses can grow faster than lichens, they tend to replace lichens that die. The higher productivity of mosses results in a greater accumulation of biomass and ultimately of soil. This leads to futher habitat change, and ferns, grasses and herbs move in.

Primary succession on sand dunes : Lakes and ocean shores often have extensive sand dunes that have been deposited by wind and water. These dunes are not permanent, they move before the wind. Grasses are a common pioneer plant on sand dunes. As the grasses extend over the surface of a dune, their roots help to hold the dune in place and stabilizing it. Much later the shrubs are replaced by pines, which in turn are replaced by oaks. Because the soil fertility remains low, oaks are rarely replaced by other forest trees, they are thus the climax community in primary succession of sand dunes.

Secondary Succession : (Fig. 12)

Secondary Succession is the change in species composition over time in a habitat already substantially modified by pre-existing community : soil is already present. An area opened up by a forest fire, and an abandoned field are common example of sites where secondary succession occurs.

Abandoned farmland in North Carolina (U.S.A) is colonized by a predictable succession of plant communities.

The first year after cultivation ceases, the field is dominated by crabgrass. The following year the dominant species is horseweed. It does not dominate more than one year, however, because its decaying roots inhibit the growth of young horseweed seedlings. In addition, horseweed does not compete well with other plants which become established during the third year after the last cultivation, including broomsedge, ragweed and aster. In years 5 through 15 the dominant plants in the abandoned farmland are pines as shortleaf pine and loblolly pine. Through the buildup of litter (pineneedles and branches) on the soil, pines produce conditions that cause earlier dominance plants to decline in importance to hard wood such as oaks. The climax stage of secondary succession depends primarily on the environmental changes produced by the pine. The pine litter causes soil changes, such as increase in water-holding capacity, that are necessary in order for young oak seedlings to become established.

Animal life in Secondary Succession

As secondary succession proceeds, a progression of wildlife follows the changes in vegetation. Although a few species, the short- tailed shrew for example, are found in all stages and disappear with others. During the crabgrass and weed stage, the habitat is characterized by open fields that support grasshopper, meadow mice, cottontail rabbits, and birds such as grasshopper sparrows and meadowlarks. As young pine seedlings become established, animals of open fields give way to animals common in mixed herbaceous and shrubby habitats. Now white-tailed deer, white-footed mice, ruffled grouse, robins, and song sparrows are common, whereas grasshoppers, meadow mice, grasshopper sparrows, and meadowlarks disappear. As the pine seedlings grows into trees, animals of the forest replace those common in mixed herbaceous and shrubby habitats. Cottontail rabbits give way to red squirrels, and ruffled grouse, robins, and song sparrows are replaced by warbler and veeris. Thus each stage of succession supports its own characteristic wildlife.

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POLLUTION AND ENVIRONMENTAL HEALTH

Pollution is an undesirable change in the physical, chemical or biological characteristics of our air, Land and water that may or that of desirable species, our industrial processes. Living conditions and cultural assets; or that may or will waste or deteriorate our raw material resources. Pollutants are residues of the things we wake, use and throw away. Pollution increases not only because as people multiply the space available to each person becomes smaller, but also because the demands per person are continually increasing, so that each throws away more year by year. As the earth becomes more crowded, there is no longer an 'away'. One person's trash basket is another's living space.

To the 'throw-away" pollutants we must add pollutants that are the inevitable by- products of transportation, industry, and agriculture ; as these human activities expand, so does pollution.

We have already made a strong case for the proposition that pollution is now the most important limiting factor for man (see especially pages 36, 406, and 431). The effort that must now be put into pollution abatement and prevention may well provide the negative feedback that will prevent man from completely raping the earth's resources and thereby destroying himself. The problem is different only in aspect in the sharply divided world of man ; in the undeveloped nations (70 per cent of the world's people) shortage of available food and resources is associated with chronic pollution and disease caused by human and animal wastes, while in the effluent or developed nations (30 per cent of the world's people) agroindustrial chemical pollution is now more serious than organic pollution. In addition, global pollution of air and water mostly emanating from the developed countries threatens everyone (see Singer. 1969).

"" from the Introduction to " Waste Management and Control " a report by the Committee on pollution, National Academy of Sciences. 1966.

In all the chapters of Part 1 of this text the relevance of ecological principles to both the causes of and the cures for particular pollution problems were pointed out. Since, in order to cope with pollution both on a local and global scale, the ecosystematic or holistic approach is necessary, we will attempt in this chapter to present an overview, followed by a brief summary of several of the problem areas that are attracting widespread public attention. Reforms and solutions in these especially critical areas would point the way to total solution.

By far the best textbooks on pollution are the panel reports prepared by the National Academy of Sciences or President's Science Advisory Committee, for example, the Turkey report (1995) " Restoring the Quality of Our Environment," the Spilhaus report (1966) "waste Management and Control, " the Daddario report (1966) " Environment pollution, " and Miller report (1967) "Applied Science and Technological Progress." These and other reports that undoubtedly will be issued at frequent intervals in the future can be obtained at very modest cost from the Superintendent of Documents or the National Academy of Sciences, Washington, D.C.A brief "paperback" review of the different kinds of pollution and their abatement is provided by Benarde (1970). Introductions to the study of water pollution are provided by Hynes (1960), Hawkes (1963), and Warren (1971). Other references will be noted in the sections that follow.

1. THE COST OF POLLUTION

The cost of pollution is measured in three ways, all of which add up to a terrible and increasingly intolerable burden to human society : (1) The loss of resources through unnecessary wasteful exploitation, since as the National Academy's report puts it ” pollution is often a resource out of place" (2) The cost of pollution abatement and control, a sample projection of which is shown in Figure 16-1A; note that while the cleanup of sewage and solid wastes (refuse) is now the most expensive, the cost of abatement of the much more poisonous wastes from motor vehicles and power generation is projected to increase 100 times in the next 30 years (assuming continuation of the kind of uncontrolled urban growth that was discussed in Section 8 of the preceding chapter). (3) The cost in human health. Recognition of this aspect of pollution cost will probably do more to alert egotistical and self-centered man to the rising danger than the other kind of costs, which can be too well hidden by short-term "cost-benefit" manipulations at the local level. Figure 16 – 1B is a dramatic model of what is happening in the public health sector in the United States. As human mortality from infectious diseases shows a precipitous decline, mortality and sickness from environmentally related respiratory diseases and cancer has shown an equally precipitous rise. In a recent review of the human health cost of air pollution Lave and Seskin (1970) estimate that a 50 per cent reduction in air pollution in urban areas alone could save two billion dollars annually in the aggregate cost of medical care and work hours lost in sickness and this does not include the "cost" of human misery or death and disability caused by automobile and industrial accidents. These authors document a strong relationship between all respiratory disease and air pollution; they even go so far as to suggest that there is a great deal of evidence connecting all mortality from cancer with pollution. As environmental stresses on the human body increase, many medical scientists fear a "backlash" in infectious diseases not only because of lowered body resistance, but because viruses (which are linked with cancer in the opinion of many) and other disease organisms will increasingly slip through water treatment and food processing plants as the quality of water and food at the intake deteriorates. Both water treatment and waste treatment (up to now considered as separate problems) must now be linked into a recycle system, as will be briefly discussed in Section 3 (see also page 87). The behavioral consequences of crowding and the breakdown in social structure that accompanies any decline in the quality of the environment has already been noted (see page 250). Maurice Visscher (1967) in another National Academy report states that mental health is probably now the major cause of human morbidity and disability.

2. THE KINDS OF POLLUTION

Classifying pollution can be as difficult and confusing as Classifying lakes or other natural phenomena (see Chapter 11, page 312). Classifications according to environment (air, water, soil, etc) and pollutant (lead, carbon dioxide, solid wastes, etc) are of course, widely used approaches. Large books can and will be written about each of these components. However, from the standpoint of the totality of pollution abatement (that is, from the ecosystem viewpoint) it is important that we first recognize two basic types of pollution.

First are the nondegradable pollutants, the materials and poisons, such as aluminum cans materials salts, long-chain phenolic chemicals, and DDT, that either do not degrade or degrade only very slowly in the natural environment- in other words, substances for which there are no evolved natural treatment processes that can keep up with rate of man-made input in the ecosystem. Such nondegradable pollutants not only accumulate but are often "biologically magnified" as they move in biogeochemical cycles and along food chains (see page 74 for explanation of the concept of biologically magnified"). Also they frequently combine with other compounds in the environment to produce additional toxins. The only possible "abatement" for such pollution is expensive removal or extraction from the environmental life-support system. Although this is possible in a small, temporary spacecraft(see Chapter 20), removal of many such pollutants from the biosphere would be virtually impossible (how could we remove lead from the air we breathe short of requiring 200 billion people to wear gas masks). The obvious and sensible solution (but one that is easier to define than effect) is to outlaw the dumping of such materials into the general environment (or at least control the rate of input so as to avoid toxic buildup) or to stop production of such substances entirely (i.e., to find more degradable substitutes).

Second are biodegradable pollutants, such as domestic sewage, that can be rapidly decomposed by natural processes or in engineered systems (such as a municipal sewage treatment plant) that enhance nature's great capacity to decompose and recycle. In other words, this category includes those substances for which there exist natural waste treatment mechanisms. Heat or thermal pollution, can be considered in this category since it is dispersible by natural means, at least within the limits imposed by the total heat budget of the biosphere (see Chapter 3, Section 1).

Problems arise with the degradable type of pollution when the input into the environment exceeds the decomposition or dispersal capacity. Current problems of sewage wastes result mostly from the fact that cities have grown much faster than treatment facilities. Unlike pollution by toxic nondegradables materials, pollution by degradables is technically is technically solvable by a combination of mechanical and biological treatment in seminatural waste disposal parks (this concept will be developed in Section 4). Again, there are limits to the total amount of organic matter that can be decomposed in a given area and an overall limit to the amount of CO_2 released into the air (see pages 33 and 98). If we are to avoid exceeding the overall limits of the biosphere, we have to preserve something like 4 to 5 acres of biologically productive land and freshwater space per person (plus the oceans), as was suggested in section 8 of the preceding chapter.

The contrast in the effect of two basic kinds of pollution on systems energetic is shown in the graphic model in Figure 16-2. Degradable pollutants that provide energy (organic matter) or nutrients (phosphates, carbonates, etc) will increase the productivity of the ecosystem by providing a subsidy (see pages 45 and 289) when the rate of input is moderate (upper graph, Fig. 16-2). At high rates of input a critical range is reached that is frequently characterized by severe oscillations ("boom and bust" algal blooms, for example). Additional input above this level becomes a stress, and the system essentially becomes poisoned by too much of a good thing. The rapidity with which an unmonitored situation can change from good to bad contributes to the difficulty of recognizing and acting on pollution (which is to say that the hump-backed rate curve tends to have a very sharp apex). To what extent this model is applicable (should we substitute "population" for pollution ") will be considered in Chapter 21. As shown in the lower graph in Figure 16-2, toxic materials are stressful from the very beginning, they increasingly depress productivity as the amount increases, but again the effect may be hard to detect at low, or chronic, levels.

3. THE PHASES OF WASTE TREATMENT

The complete three-step treatment process for liquid wastes is shown in Figure 16-3. As already pointed out (see page 28), secondary treatment is carried out by an engineered biological system in which microorganisms decompose organic matter in the same manner as occurs naturally in soils and sediments. The most common design is the activated sludge system which requires electric pumps or other energy to aerate and circulate the material. Another system is the "trickling filter" system in which the primary treatment effluent moves by gravity over stones or racks of plastic surfaces that create an aerated surface resembling the rapids in a natural stream. The role of detritus-feeding invertebrates in these microbial decomposition systems was discussed on page 31. A study of a secondary treatment plant makes an excellent (and very relevant) exercise for an ecology of secondary treatment, see Hawkes (1963).

Recently primary and secondary treatment have been combined in compact "package" plants that are especially favored for suburban developments and small towns. It should be remembered that compacting the treatment into smaller space requires an increased energy input in terms of power, and also more sophisticated maintenance in terms of personnel who must operate and repair the machinery; any breakdown means instant injection of raw sewage into the environment. This, of course, illustrates again the principle that increased complexity and efficiency in the use of space requires an increase in energy expenditure for "disorder pumpout" (see page 38).

In terms of construction and maintenance costs the cheapest systems are oxidation or waste stabilization ponds, shallow bodies of water (4 to 5 feet deep) constructed so as to expose a maximum surface area to the air. Wastes are pumped into the bottom of the pond, and algae, which grow vigorously in the upper lighted zone, provide the aeration. Such ponds operate as aerobic anaerobic systems in the same manner as naturally fertile lagoons (see Figure 12-3). Use of seminatural design of this sort requires a large amount of space – about one acre for the treatment of household wastes of 100 people – and judicious maintenance. Adding devices for mechanical aeration can of course, increase the per acre treatment capacity. Waste stabilization ponds are now widely used for treatment of sewage from suburban developments, especially in warmer climates, and they are also effective in the partial treatment of industrial wastes from paper or textile mills, food processing plants, oil refineries, and so on. Undoubtedly such ponds will be used more in the future to treat wastes from domestic animal feed lots, poultry plants, and livestock barns; such animal wastes are now largely un treated and are producing very serious pollution of waterways (recall that there are about five times more "equivalent" domestic animals than people in this world ; see page 55). It should be emphasized that the waste stabilization pond is really a "conversion" system, not a complete treatment system; unsanitary organic matter is converted into sanitary algal material and nutrients that are exported to the natural environment where there must be adequate space capacity and food chains to handle it. Harvesting algae for animal food or using pond effluents for aquaculture, irrigation, and other useful purposes are obvious possibilities that need more research.

The effluent from even relatively complete secondary treatment is, of course, still highly polluting in terms of eutrophication (see page 107) and is unfit for direct human use. While the technology of secondary treatment is advanced, tertiary treatment is still mostly in the pilot plant stage. Most cities are still fighting a losing battle to provide adequate secondary treatment when they should be moving on to the complete recycle of tertiary treatment. Thousands of small towns and suburban areas have no treatment facilities at all, or only crude primary treatment. As indicated above in dustrialized agriculture scarcely treats any of its burgeoning wastes (see Brady, 1967, for a review of agricultural pollution). Nature is expected to do the tertiary treatment, which she can do very effectively if allowed enough room; the trouble beings when all the "natural treatment" areas become human living space covered with additional waste-producing urban, agricultural and industrial development. Then man must turn to artificial tertiary treatment, which is several times as expensive as conventional secondary treatment. An estimate of relative cost of the different stages of the relative cost of the different stages of waste treatment is given by Stephens and Weinberger (1968) as follows :

Primary treatment ……… 3 to 5¢ per 1000 gallons

Secondary treatment ……… 8 to 11¢ per 1000 gallons

Tertiary treatment to

remove nutrients ……… 17 to 23¢ per 1000 gallons

Tertiary treatment to pro-

duce drinkable water ……… 30 to 50¢ per 1000 gallons

The lower figures refer to the cost for large plants that process 100 million gallons per day. The capital cost of such a plant for complete Tertiary treatment is of the order of 25 million dollars as compared to 20 million for Secondary treatment and 10 million for Primary treatment. Producing drinking water by Tertiary treatment (complete recycle) is cheaper than desalination (presently estimated to cost at least one dollar per 1000 gallons), and it may soon be cheaper than piping it from distant water sources. The quality of recycled water would also be better than that which millions of urban dwellers now drink.

In less densely populated areas there is increasing interest in using terrestrial ecosystems as well as aquatic ones for tertiary treatment. This makes sense because the surface of terrestrial environments is many times greater than that of freshwater environments. Experiments in which land areas are irrigated with waste water from Secondary treatment plants by means of system of sprinklers indicate that as much as two inches of water per week can be added to the normal rainfall in eastern United States without changing the quality of the ground water (see Parizek et al., 1967; Kardos, 1967; Sopper, 1968;Bouwer 1968). That is phosphates, nitrates, and other nutrients added at this rate were filtered out by the soil-vegetation layer. Growth of crops, pastures, and young forest plantation were also enhanced by this "spray irrigation" of waste nutrients. Obviously a land "filter" of this sort has a greater long-term capacity if there is a harvest removal of nutrients by cropping or grazing. However, past experience with all kinds of irrigation warns that gradual accumulation of nutrients or salts will occur with high-input rates. Experiments currently being conducted will probably have to be continued for many more years before the true tertiary treatment capacity of different kinds of terrestrial watersheds can be determined. In the meantime, it would be prudent to act on the principle that the optimum input will be less than the maximum input that seems to be tolerated in a 3 to 5 year experiment (see page 77 for a discussion of the principle of optimization).

4. THE STRATEGY OF WASTE MANAGEMENT AND CONTROL

Man has three basic options in dealing with waste materials: (1) dump them untreated into the nearest convenient environment such as the air, a river, lake, soil, well, or ocean; (2) contain and treat them within a delimited environmental waste management park where engineered semi-natural ecosystems such as oxidation ponds, spray-irrigated forests, and land fills do most of the work of decomposition and recycle; (3) treat them in artificial chemomechanical regeneration systems. The first option is based on the philosophy that "the solution to pollution is dilution"; it has been and still is the principal waste disposal practice employed almost everywhere. Thus, industries and cities have tended to concentrate along waterways, which provide free sewers. Obviously this option is no longer tenable and must be phased out as fast as possible, no matter what the cost.

The second option provides the most economical method of avoiding general environmental pollution by the fairly dilute but large volume wastes that now so badly reduce the quality of man's living space and endanger his health. Setting aside large areas for seminatural waste treatment would also preserve valuable open space that not only protects environmental quality in general, but provides other uses as well (food and fiber production, atmospheric as exchanger, recreation, and so forth). A waste management park was included in the planned urban area illustrated by the models in Table 15-2 and Figure 15-5. Two examples of the waste park design are shown in Figure 16-4; the upper diagram shows how wastes from oil refineries are treated by means of a series of ponds, and the lower diagram shows a hypothetical plane for treatment of thermal and radioactive pollution from a new atomic power plant. In both instances the water that leaves the delimited treatment area and enters the general public environment is not in any way "polluted". In many cases, waste treatment ponds will, in the words of H. T. Odum (1967 and 1970), "self-design" to cope with the input and thus require a minimum of engineering and maintenance by man. A large, well-designed and efficiently operated sanitary land-fill for the disposal of solid waste disposal park concept.

To exercise the sensible option of letting nature do a lot of the work, large areas of land and water have to be set aside for this purpose, which as already indicated, also provides one of the best safeguards against the kind of over-development discussed in the preceding chapter (Section 8). Thus, new industries and municipal treatment plants should no longer be placed on the banks of streams or in the middle of congested areas where people live, but should be "zoned" or "sited" in the middle of natural areas large enough for treatment of degradable wastes and the containment of the poisonous wastes (such as radioactive wastes, acids, etc.) that should never find their way into the general environment. In the past, urban planners considered 50 to 100 acres an adequate space for an "industrial park". For self contained wastes management 1000 to 10.000 acres may be needed for a large industrial complex (see legend, Figure 16-4; also see page 466). Recycle water and recovery of useful products from wastes should more than pay for the cost of the land. Separating industry and airports from living space also pays dividends in noise abatement, as described in Section 7 of this chapter. The greatest obstacles for " designing with nature" in this manner are legal, economic, and political (see Section 6). If private industry and municipalities do not or cannot (because of inadequate laws) plan ahead, then man will be forced more expensive and technically difficult third option of artificial treatment.

Abiotic treatment and recycling of course, is necessary for some types of wastes, especially in densely populated industrial areas. Mechanical treatment is probably the only option for some components of air population which have to be stopped or reduced at the source. If this is not technically possible, a substitute energy source or industrial procedure must be sought since, as already indicated, we cannot tolerate much longer the costs of air population. If we are backed into a corner and have to turn to expensive artificial treatment of biodegradable wastes as well as the poisons, then who is going to pay the bill! As will be described in Chapter 20, a very sophisticated system for the mechanical treatment of wastes and for regeneration of air and water has been developed for spacecrafts, but the per capita cost is staggering.

We shall close this section on a positive note. The story of Lake Washington, a large body of water surrounded by the city of Seattle and its suburbs, provides a good demonstration of how beleaguered urban areas can reverse the insidious trend of declining water quality by attacking the problem as a whole through a federation of city county, and district governments. The sequence of deteriorating water quality, public outcry, political action, bond issues, sewage diversion, and recovery of water quality is described in detail by Edmondson (1968) and is cited in the popular press as a model for other urban centers (see, for example, an article by Earl Clark in Harper's Magazine, June, 1967). Four indices of water quality in Lake Washington are plotted in Figure 16-5 for the period 1933. Two of the indices represent important physical water characteristics, and two pertain to the diversity and composition of the diatom component of the phytoplankton(i.e., they are community indices). The numbered vertical lines signify important events in the lake's history as listed in the lend of figure. In the 1950s 11 different municipalities dumped increasing amounts of secondarily treated sewage into the lake, resulting in a progressive cultural eutrophication (i.e., nutrient enrichment., see page 58) provided warnings of the deterioration and attracted the wide public attention that paved the way for political action. In 1958, the "Metro" federation was formed and a 120 million dollar revenue bond issue put up to public vote. At first the issue failed because the city voted "yes" and the suburbs "no" (illustrating a chronic American political problem stemming from the fact that suburbs do not realize they are part of the whole urban system), but on a second try the "Metro" bond issue passed. In 1963, about a third of the sewage was diverted from the lake, and by 1968, almost all of it had been diverted. As shown in Figure 16-5, recovery of the lake has been dramatic with all four indices reversing. Edmondson (personal communication) believes that the lake will at least return to its 1930 condition in a few more years. Although large quantities of phosphates and other nutrients are still in the lake, they tend to be buried in the sediments and thereby are withdrawn from the annual biogeochemical cycle. An important aspect of this pollution abatement success story was the fact that University of Washington limnologists had for many years carried on basic studies of the lake so that trends and causes could be documented with certainty; without such information political action might have been delayed, perhaps until it was too late (note the precipitous increase in rate of decline between 1960 and 1963, indicating that the lake may have been "rescued" just in time).

Finally, it must be pointed out that pollution abatement in Lake Washington provided no permanent solution; the lake was saved by merely diverting the effluents to a larger body of water – Puget Sound! The next step is tertiary treatment, which will require another cycle of public education, concerted political action, and bond issues. Perhaps this time, however, it will not be necessary to wait until the ocean deteriorates! As Hasler (1969) has pointed out, case histories such as Lake Washington show that cultural eutrophication can be reversed (see also page 254).

5. MONITORING POLLUTION

Successful pollution abatement, of course, depends not only on treatment and control but also on efficient monitoring of the general environment so that we will know for sure when control measures are needed and whether those in operation are working Monitoring take two basic forms: (1) direct measurement of the concentration of pollutants or of key substances, such as oxygen, which are depleted by pollution and (2) the use of biological indices, which range from bioassays with microorganisms and B.O.D. measurements (see page 16) to the kind of total community indicatory discussed in Chapter 5, Section 6, and Chapter 6, Section4.

As an example of the first type of monitoring air pollution over the large California cities is now monitored by detectors mounted on an airplane, which daily measure and plot the concentration of SO_2, NO_2, CO_2, and other pollutants, over a large regional area, Air pollution indices have become a part of weather reports in many cities. The need for world-wide monitoring of carbon dioxide has already been noted. Biological indices are widely used in monitoring water pollution. In addition to diversity indices (see Figure 6-5) and general species indicators such as shown in Figure 16-6, there are numerous indices of community function that can be useful – for example : the P/R ratio (Figure 16-4A), the ratio of chlorophyll to bacterial biomass (see page 152), the mean size of organisms (pollution favors small organisms over large ones; see Olesby, 1967, and Menhinick, 1964), the amount of hemoglobin in animal biomass as an index of low oxygen, the amount of blue-green algal pigment as an index to carbohydrate pollution and many other indices that need to be carefully studied. Very often the community will contain more "information" about total effects of pollution than can be deduced from the measurement of individual factors. The challenge to ecological research is to find quick ways to "read" this information!

For a review of the chemical Society's 1969 report, "Cleaning Our Environment; the Chemical Basis for Action " and for a review of the biological approach, see the Department of Interior's book. "The Practice of Water Pollution Biology" (edited by Machenthun, 1969).

6. ENVIRONMENTAL LAW

The weakest link in pollution abatement strategy, as in land-use planning, is the inadequate legal protection of environmental quality and the consumer. As outlined in Chapter 9, one of the major principles relating to the development of ecological systems has to do with the distribution of energy in the system. When the ecological system is young, the major flow of energy is directed to production, that is, to growth and the building of complex structure; but as the population density approaches the saturation level, the ecological system matures in the sense that a greater proportion of the available energy is shifted to maintenance of the complex structure that has been created. A parallel, of course, exists in the development of human society, a parallel that is justified because man and environment do constitute an ecological system. It is more than coincidental that we being the new decade of the 1970s with mounting concern for human rights and environmental quality along with increasing unrest among young people and those who maintain our highly complex and technological society. The ecologist views all of these trends as part of a perfectly natural and predictable expression of the basic need to develop new strategies adapted to the mature system.

Up to now the greatest economic rewards and the strongest legal protection have been given to these who produce, build, pollute, and exploit nature's riches; this we can argue, is quite proper in the pioneer stages of civilization, since man must first to some extent subdue and modify his environment in order to survive in it. Mow it is obvious that at least equal rewards and protection must be given to those people, professions, and industries that maintain the quality of human existence; survival in the future depends on finding a balance between man and nature in a world of limited resources. This does not mean that he will need to go back to some of the good, commonsense, old-fashioned things such as returnable bottles, walking and human concern for one's neighbors. Some things, one-way bottles for example, that we once thought represented "progress" turned out instead to be insults to both man and nature. As this transition occurs the basis for economic development shifts from exploitation to recycle, from throw-away to reuse, from quantity to quality. Legal procedures and legal education must adapt accordingly since the law, backed by strong public option, is the chief "negative feedback" that establishes the necessary controls. The traditional "private client-oriented" law must now. University law schools, which have tended to be ultraconservative and isolated from other academic schools, and departments, need to move out of the legal ivory tower and establish better communication links with the environmental and social sciences and to encourage their students to seek better training in these and other relevant subjects. An inventory of environmental law as it is now understood and practiced (see for example, Sherrod, 1970, and Baldwin and Page (eds.) 1970) reveals an urgent need to develop more comprehensive procedures that will counter the excessive fragmentation and help resolve the contradictions that now make it so difficult to deal with pollution (and many other problems) on a legal basis. Not only is environmental law inadequate at the local and national levels, it does not even exist at the international level despite the obvious need to protect the atmosphere and the oceans. There is no more important area than environmental law, a field that provides unlimited challenge to the motivated youth of today.

Murphy (1967), in an interesting book entitled Governing Nature, points out that restrictions and governmental regulations alone are inadequate to avoid pollution; there must be economic and legal incentives as well. He discusses effluent charges, cost internalization of product costs, tax relief for industries that plan ahead on waste disposal, and other means of providing rewards for group behavior in the public interest (see also Hardin, 1968, and Crowe, 1969).

7. SOME PROBLEM AREAS

Air pollution

The magnitude of air pollution in an industrialized country such as the United States is indicated by the data in Table 16-1. These data (1966) only show the relative importance of pollutants and sources because the absolute amount increases by the year. Although the country-wide and global aspects are serious enough (see Singer,1969), it is the local concentrations that build up over such cities as Tokyo, Los Angeles, and New York during temperature inversions (i.e., air trapped under a warm upper layer that prevents the vertical rise of pollutants) that cause the greatest immediate concern. As already suggested (page 432),

Table 16-1. The Relative Magnitude of Air pollution in the

		[illegible]illion Metric Tons/Yr
y pollutant		
Carbon monoxide	[illegible]5	[illegible]2%)
Oxides of sulfur	[illegible]3	[illegible]8%)
Hydrocarbons	[illegible]5	[illegible]2%)
Particulate matter	[illegible]2	[illegible]0%)
Oxides of nitrogen		[illegible]%)
Other gases and vapors		[illegible]%)
y Source		
Transportation	[illegible]4.8	[illegible]9.9%)
Industry	[illegible]3.4	[illegible]8.7%)
Generation of electricity	[illegible]5.7	[illegible]2.5%)
Space heating	8	[illegible].3%)
Refuse disposal	3	[illegible].2%)

Total	25.0

` Data from the report of the National Academy of Sciences, "waste Management and Control" (1966). Increases are projected for at least 20 years. The situation will get worse before (or if) it gets better.

Air pollution provides the negative feedback signal that may well save industrialized society from extinction because : (1) it provides a clear danger signal that man must somehow soon "power down" in the concentrated use of industrial energy, (2) everyone contributes to it (by driving a car using electricity, buying a product, and so on) and suffers from it, so it cannot be blamed on a convenient villain, and (3) a solution must evolve out of holistic consideration since attempts to reduce any one source, or any one pollutant, as a separate problem is not only ineffectual but might only divert that pollution to one of the other categories.

Air pollution also provides an excellent example of synergism (see page 92) in that combinations of pollutants react in the environment to produce additional pollution which greatly aggravates the total problem. For example, two components in automobile exhaust combine in the presence of sunlight to produce new and even more toxic substances, known as "photochemical smog" as follows:

$$\text{Nitrogen oxides + Hydrocarbons} \xrightarrow{\text{Ultraviolet radiation in sunlight}} \text{Peroxyacetyl nitrate (PAN) and Ozone } (O_3)$$

Both secondary substances not only cause eye-watering and respiratory distress in man, but are extremely toxic to plants; ozone increases respiration of leaves, killing the plant by depleting its food, while PAN blocks the "Hill reaction" in photosynthesis, thus killing the plant by shutting down food production (see Taylor et al., 1961). The tender varieties of man's cultivated plants become early victims so that certain types of agriculture and horticulture are no longer possible in the vicinity of the big cities. Other photochemical pollutants that go under the general heading of polynuclear aromatic hydrocarbons (PAH) are known carcinogens.

Another dangerous synergism results when SO_2 which might normally be carried away and oxidized in the atmosphere, adsorbs on particulate pollution (dust, fly ash, etc.), contacts wet tissue (such as the inside of one's lungs) or moisture droplets, and turns into sulfuric acid! Such "acid" pollution is not only a health hazard, but it corrodes metal and limestone, causing millions of dollars in damage to man-made structures. There is also another kind of synergism between cigarette smoking and air pollution. Air pollution in a city can subject the nonsmoker to the same level of blood poisoning by carbon monoxide as is experienced by a one-pack-a-day smoker (see Goldsmith and Landaw, 1968). According to Lave and Seskin (1970), the city dweller who smokes runs 10 times the risk of lung cancer as does the rural man who does not smoke.

For additional information on air pollution, see the 1965 AAAS report (Dixon, chairman) and Stern (1968).

Insecticides

To establish an objective of the highly controversial subject of pest control it may be helpful to think in terms of what Carroll Williams (1967) calls the "three generations of pesticides, "namely, (1)the botanicals and inorganic salts (arsenicals, etc), (2) the DDT generation (organochlorines, organophosphates, and other "broad-spectrum" poisons), and (3) the hormones ("narrow-spectrum" biochemicals) and biological controls (parasites, etc.), which aim at pinpointcontrol without poisoning the whole ecosystem.

The first generation pesticides were adequate to keep grandfather well fed when farms were small and diversified, farm labor plentiful, and cultural practices favorable for blocking massive buildups of pests. DDT and the other potent broad-spectrum insecticides not only ushered in an era of industrialized agriculture, but they were supposed to "solve" all pest problems for ever. As is now all too evident, this optimism is partly responsible for the severe "backlash" that resulted form the almost senseless saturation of the environment with the persistent (i.e., they degrade very slowly) broad-spectrum poisons to the point that we now must phase out the use of many of them. Unheeded warnings of an entomological backlash (i.e., pest outbreaks actually induced by spraying) were voiced in the 1950s (see Soloman, 1953, and Ripper, 1956), and the poisoning of entire food chains was dramatically brought to public attention in 1962 by Rachel Carson's famous book, Silent Spring. The detailed work of Nicholson, Grezenda et al. (1964) demonstrated how whole watersheds become contaminated by the uncontrolled use of agricultural pesticides. Finally, the insidious effect of DDT and other chlorinated hydrocarbons on the nervous system and sex hormone metabolism of vertebrates (including man) is just now being documented (see page 75). In retrospect, then, it appears only a temporary respite a kind of holding action, in man's continuing war with insects and other competitors, and they must now be gradually replaced by other, more ecologically sound procedures. In the meantime these substances have produced one of the world's most serious pollution problems; a paraphrase of Wurster's (1969) evaluation of the problem follows:

The chlorinated hydrocarbon insecticides, now among the world's most widely distributed synthetic chemicals, are contaminating a substantial part of the biosphere. There are dispersed throughout the environment in currents of air and water. Their movement and widespread distribution throughout the world is explained by their solubility characteristics and chemical stability, and especially their tendencies to adsorb on organic matter, to by transported in air droplets, and to become concentrated in food transfers from plants to herbivores to carnivores. Their broad toxicity indicates a potential for biological effects on many kinds of organisms. The chlorinated hydrocarbons are seriously degrading biotic communities in many parts of world. They have been shown to destroy larval staes of valuable aquatic food organisms and to depress photosynthesis of marine phytoplankton (which could have grave effects on the gaseous balance in the atmosphere). While direct effects on the hormone balance in man have not yet been demonstrated, concentration levels in human tissue are now high enough that such effects, and also cancer and deleterious mutations, could occur in the future (since they have been demonstrated to occur in laboratory animals), especially if nothing is done to control and monitor the further use of these potentially hazardous chemicals.

As was noted on page 199, a fundamental difference exists between the controlled use of nonspecific poisons on crops where causes and effects are known, and the broadcast of these same poisons in forests and other natural or seminatural areas where total effects are unknown and the probability of backlash very great. Pesticide pollution has been greatly aggravated by unnecessary aerial spraying of entire andscapes. Other "unforeseen" problems arise because new insecticides are tested (often very superficially) at the organism level of organization and then used at ecosystem level without further testing. Thus, even though a chemical kills insects in cages and does not kill a laboratory rat, this does not mean that it is safe to use in nature. Again we have a case where trouble occurs because the agricultural and commercial specialist does not know the difference between a population and an ecosystem! Examples of ecological studies in which the ecosystem is the "guinea pig" or experimental testing ground are the studies of Barrett (1968) and Malone (1968).

brown (1961) presents an objective review of four cases of mass insect control programs. At one extreme he describes the highly successful control of fruit flies based on detailed scientific information and judicious use of chemicals. At the other extreme he cites the campaign to eradicate the imported fire ant (Solenopsis) as an example of (1) too little study before mass spraying was started and (2) a misdirected Federal governmental mission motivated mostly by politics and carried out, against the advice of most knowledgeable scientists, to the point of "overkill". Several millions of dollars have been spent in mass aerial spraying on the theory that "saturation bombing" could eradicate the insect once and for all. Some control has been obtained by this massive onslaught but eradication is not in sight, and aquatic and terrestrial wildlife has suffered grievously in the meantime. The tragedy of such a situation is that better control could have been obtained with far less expenditure of public funds and less general damage to the environment if the means for the individual land owner to control the ants on his own land if local campaigns at the county or state levels where the problem was acute had been set up.

As the mass use of persistent broadspectrum poisons is phased out, it is evident that the strategy of pest control will increasingly evolve into what economic entomologists call integrated control (see Smith and Reynolds, 1966: Smith and van den Bosch 1967; Chant, 1966 and 1969; Kennedy, 1968; and the FAO Symposium on "Integrated Pest Control"). The concept of integrated control involves coordinated use of a mixed bag of weapons, including old-fashioned but common-sense cultural practices, judicious use of degradable or "short-lived" chemical pesticides, and greater use and simulation of nature's own control methods, i.e., biological control (see review by Kilgore and Doutts [eds], 1967) and the third generation of pesticides as outlined at the beginning of this section. The arsenal for integrated control includes the following:

1. Predators – such as the highly effective use of lady beetles and lacewings against agricultural pests, or beetles to control weeds (see Huffaker, 1958).
2. Parsites – such as calcid wasps, which successfully control a number of major pests.
3. Pathogens – such as viruses and bacterial infections that are specific for a pest.
4. Decoy plants- cultivation of law-value crops to attract pests away from high value crops (Stern et al.,1969).
5. Rotation and diversification of crops.
6. Chemical or radiation sterilization (see Chapter 17, page 457).
7. Hormonal stimulants – such as juvenile hormones that prevent insects from completing their life cycle (see Williams, 1970).
8. Pheromones – sex lures and other bio-chemicals that regulate pest behavior (see page 32).
9. Degradable chemical insecticides – organic phosphates and others.
10. Artificial selection for disease and pest resistance rather than for short-term yield as such.

Truly it can be said that eternal vigilance, study, and trained professionals are part of the "disorder pumpout" in the agroeco-system. There is no "one-shot" solution, nor will there ever be one. For reviews of pesticide problems, see Moore (1966), Rudd (1964), and Mrak (1969).

Herbicides

Like modern insecticides, herbicides were first applied on a large-scale basis shortly after World War II. Initially, they were used to clear power line right-of-ways; subsequent uses have included clearing of railroad and highway right of-ways, weed control in agriculture and forest management, and sadly, as crop destruction and forest defoliation agents in warfare. They have proved most valuable when used in a selective manner in agriculture and forest management situations; their usefulness becomes increasingly questionable in nonselective, blanket spraying of large areas particularly when the effects on ecosystem structure cannot be accurately predicted (note parallel in misuse of pesticides). It has been estimated that at least 50 million acres of right of-ways in the United States have been sprayed from 1 to 30 or more times (Eggler, 1968). Although some of this spraying is necessary, much of it is of such a general, nonselective nature that it cannot be justified on either economical or ecological grounds.

Generally, herbicides fall into two groups, depending upon their mode of action. Those in the first category, which includes monuron and simazin, interfere with photosynthesis and thus cause the plant to die from lack of energy. The second group is typified by the commonly used 2.4-D(2.4-dichlorophenoxyacetic acid) and 2.4.5-T(2.4.5-Trichlorophenoxyacetic acid). The mechanisms of action in this second group are not clearly understood. Two associated, but not identical, effects are involved; defoliation and systematic herbicidal action. Oddly enough, at low concentrations these chemicals can cause increased retention of fruits and leaves and are used for this purpose in agriculture. At higher concentrations they initiate a chain of reactions that result in a weakening and eventual rupturing of the abscission layer at the base of the petiole where the leaf blade attaches to the stem. By itself such simple defoliation does not usually kill a plant, and regeneration can normally be expected to follow. In certain plants, however, there is the additional effect of drastically increased cell proliferation in tissues such as phloem, which results in blockage of nutrient transport and formation of harmful lesions. In these susceptible plants there is little chance for successful recovery. Broad-leafed herbaceous plants are particularly susceptible to 2.4-D while 2.4.5-T and a mixture of 2.4-D and 2.4.5-T are effective on woody plants.

Effects of 2.4-D and 2.4.5-T on ecosystems are poorly understood. Obviously they are capable of modifying plant communities and indirectly affecting herbivores and carnivores. Knowledge of effects on aquatic systems and soil microbes is scarce. The direct toxicity to animals appears to be low. However the production of 2.4.5-T has been characterized by the presence, often in the final product of symmetrical 2.3.6.7 tetrachlorodibenzon-p-dioxin, usually referred to as "dioxin". This compound has been shown to be teratogenic, or fetus-deforming, at extremely low concentrations. In addition, it has been implicated in the occurrence of severe acneform skin changes in factory workers who produce 2.4.5-T . For these reason 2.4.5-T is considered a dangerous compound unless the final product contains on "dioxin" Furthermore, the possibility of "dioxin" formation from 2.4.5-T or intermediate breakdown products by thermal (wood burning) or metabolic routes has not been satisfactorily investigated.

Political questions aside, the use of herbicides (2.4-D , 2.4.5-T, "picloram: and cacodylic acid) in South Viet Nam is of particular ecological interest because of the large amount of land sprayed (at least 10 per cent of the country) and the heavy doses used (commonly an order of magnitude or higher than recommended for use in the United States). Aerial spraying, usually from specially converted C-123 aircraft, was carried out between 1962 and early 1970; each plane carried a 1000 gallon tank and was capable of spraying a swath 150 meters wide by 9 kilometers long, or roughly 333 acres, in two minutes. Investigation of the sprayed areas by Fred Tschirley (1969) revealed that mangrove associations were destroyed by a single application. Semideciduous forest were damaged very little by a single treatment but significant changes in the forest and subsequent bamboo invasion occurred in areas that had received multiple sprayings. Two of compounds routinely used in Viet Nam are highly restricted in the United States. "picloram" has been characterized by Galston (1970) as a herbicidal analog to DDT because of its relative persistence in soils. Cacodylic acid contains over 50 per cent arsenic and repeated use may lead to build up of arsenic in soils.

Insecticides and herbicides together are powerful "drugs" in the ecosystem since they modify the function of vital systems the consumers and producers. It is now being suggested that these substances be under licensed control of trained professionals, just as are drugs used to treat the human body.

Noise pollution

Yet another serious threat to the quality of man's environment is noise pollution. If we define noise as "unwanted sound"., then noise pollution is unwanted sound "dumped" into the atmosphere without regard to the adverse effects it may have. The term "noise" is also used in electronics and communication science to refer to perturbations that interfere with communication. Such noise increases with the complexity and information content of systems of all kinds. Thus, man faces a growing problem with "electronic pollution" as radio communication intensifies. In the broadest sense, then, noise pollution is another "unforeseen backlash" in the concentrated use of power.

It is now clear that high intensity sound, such as that emitted by many industrial machines and aircraft, when continued for long periods of time is not only disturbing to man (and probably other vertebrates), but also it permanently damages hearing. Even a comparatively low level of noise interferes with human conversation, causes emotional and behavioral stress, and threatens the "domestic tranquility" guaranteed by our constitution. Accordingly, sound must be considered a potentially serious pollutant and a grave threat to environmental health. Therefore, measurement, abatement, regulations, and legal restrictions on noise pollution must be considered along with efforts to control the "chemical" components of air pollution.

The unit of measurement for sound is the decibel (db). This is not an absolute unit of measurement but a relative one based on the logarithm of the ratio of sound intensity (I) to a reference level (I_o), arbitrarily established as a sound pressure of 0.0002 microbars (dynes per cm^2 or an energy of about 10^{-16} watts), which originally was judged to be an intensity just audible by man. Thus,

$$\text{bel} = \log_{10} \frac{I}{I_o}$$

and

$$\text{decibel} = 10 \log_{10} \frac{I}{I_o}$$

Accordingly, 10, 20, and 100 decibles represents 10 times, 100 times, and 10^{10} times the threshold intensity, respectively. It is important to recognize the logarithmic nature of this scale.

The area of human hearing extends in frequency from about 20 to 20.000 cps (cycles per second) and in intensity from 0 to greater than 120 db (at which point the intensity causes physical discomfort), a 10^{12-} fold or greater than range. Ordinary conversation, which is in the frequency range 250 to 10.000 cps, registers between 30 and 60 db, while noise under a jet airplane at takeoff may rise in excess of 160 db. The effect on man varies with the frequency or "pitch" of the sound. The "sound pressure level" is judged to be of greater "loudness" for the higher pitched than for the lower pitched sounds. For example, a jet plane producing sounds at a 100 db intensity is reted by most people as twice as noisy and disturbing as a prop plane producing sound at the same decibel level, because its noise output contains more high-frequency energy.

Loudness as perceived by people is expressed in units called sones. This is also a relative unit -1 sone equals the loudness of 40 db sound pressure at 1000 cps. Forty db sound at 5000 cps seems twice as loud and is, therefore, assigned the value of 2 sones. On this scale 50 sones and above is too loud for comfort at any frequency) within the range of hearing. In general, 85 db (10 to 50 sones, depending on frequency) can be considered the critical level for ear damage. Noise level may have subtle effects and be of even greater concern to the general population. People being to complain when unwanted noise levels in residential areas reaches 35 to 40 db, and they being to threaten community action when it reaches 50db! A major problem in noise control lies in the difficulty of evaluating complex noise, which contains energy in a number of octave bands – that is, the kind of noise that is most often irritating. Finally, sudden noise, such as a sonic boom, produces a "startle effect" that can be more disconcerting than continuous noise. Sonic booms can also produce physical damage to property (broken windows, etc.).

The threat of noise is another compelling reason for man to preserve a Lebensraum large than the minimum space necessary for his day-to-day physiological and psychological necessities. Enforced zoning and planning that separates industrial noise, highways, and so on from living space is obviously needed along with increased attention to the technology of noise abatement. As of 1970, only a few cities and states have enacted laws to control noise, and fewer still do anything about measurement or enforcement. In southern California, we are told, decibel meters are being installed along highways, and trucks and cars are being stopped not only for exceeding the speed limit set at 82 decibels! Even more important are enforced building codes that require soundproofing in the construction of buildings and apartments. People cannot live in peace when they are crowded into cities and separated from each other by only paper-thin walls!

In metropolitan areas greenbelt vegetation, and open space in general, may have as great a value in sound amelioration as in air purification. Robinette (1969) points out that plants are efficient absorbers of noise, especially noises of high frequency. A dense evergreen hedge can reduce the noise of garbage collection by 10 db)i.e., a tenfold attenuation). Border planting along highways or streets can be effective if plantings are lower towards the noise source and higher towards the hearer, thus not only absorbing but also deflecting the noise upward. A 50-foot wide band with an inner strip of dense shrubs and an outer band of trees can be quite effective (a sort of forest edge that is also good for small wildlife). As with most other excesses in our society, the problem of drawing lines is difficult. Sound is necessary for human existence, and much of that produced by nature (bird song) and man (music) is pleasant and purposeful. Again, as in all aspects of pollution the problem comes when there is too much of an otherwise "good thing". Then the two greatest blocks to solution are (1) the lack of public awareness of and concern for the dangers and (2) the economic pressure to delay or do nothing as long as the money is rolling in. to really solve a problem such as airport noise, it is necessary to do two things simultaneously and continuously; (1) reduce noise at its source as far as technically possible and (2) zone the area around the airport so that no one is allowed to build a house or factory within 10 miles of the airport (for their own protection under equal protection rights of government and to avoid future citizen lawsuits that disrupt economic development) A big "green belt" of farms and forests around a jetport would be valuable not only as a noise absorber but also as an air purifier, food and fiber producer, and recreational area! Such a twofold attack on the problem is what ecologists call "ecosystem thinking" For additional discussions of noise pollution, its effects, and its abatement, see Gloring (1958), Kryter (1970), Rhodda (1967), and Burns (1969).

Noise abatement would make a good crusade for the younger generation not only because they are unwittingly contributing to the excess (amplified rock music, for example), but more importantly because an environment free of unwanted noise is likely to be a quality environment in other respects.

Other Problem Area

Radioactive and thermal pollution are considered in the next chapter, while additional aspects of the technology of detection and control of wastes are discussed in Chapter 18, 19, and 20. Pollution as a motivating force in social, economic, and legal reforms is again emphasized in Chapter 21.

A RDIATION ECOLOGY

Radiation ecology is concerned with Radioactive substances, radiation, and the environment. There are two rather distinct phases of radioecology which require different approaches. On the one hand we are concerned with the effects of radiation on individuals, populations, communities, and ecosystems. The other important phase of radiation ecology concerns the fate of radioactive substances released into the environment and the manner by which the ecological communities and populations control the distribution of radioactivity. The testing of atomic weapons has added on a global scale man-made radioactivity to that which is naturally present. While weapons testing has been greatly curtailed since 1962, the threat of nuclear war remains. The continued development of nuclear power for peaceful uses, which must be accelerated as the supplies of fossil fuels dwindle, means that increasing volumes of radioactive wastes must be anticipated, monitored, and controlled, as must be done for other dangerous pollutants (see Chapter 16). On the more positive side, radioactive tracers and providing very valuable tools for research. Just as the microscope in all its forms extends our ability to study structure, so tracers in all their forms extend our ability to study function. A number of ecological examples of the usefulness of tracers have been noted in Part 1 (see pages 60, 93, and 98).

The most useful sourcebooks on radio-ecology are the symposia volumes edited by Schultz and Klement (1963), Hungate (1966), and Nelson and Evans (1969) ; see also polikarpoy, (1966).

1. REVIEW OF NUCLEAR CONCEPTS AND TERMINOLOGY OF ECOLOGICAL IMPORTANCE

In order to facilitate subsequent discussion and presentation of data, some of the more important concepts and terms used in radiation ecology are very briefly discussed below. For further information, see books by Lapp and Andrews (1954), Glasstone (1958), Comer (1955), Overman and Clark (1960), and Chase and Rabinowitz (1967).

Types of Ionizing Radiations

Very high-energy radiations that are able to remove electrons from atoms and attach them to other atoms, thereby producing positive and negative ion pairs, are known as ionizing radiations, in contrast to light and most solar radiations which does not have this ionizing effect. It is believed that ion ionization is the chief cause of injury to protoplasm and that the damage is proportional to the number of ion pairs produced in the absorbing material. ionizing radiations are sent out from radioactive materials on earth and are also received from space. Isotopes of elements that emit ionizing radiations are called radionuclides or radioisotopes.

Of the three ionizing radiations of primary ecological concern two are corpuscular (alpha and beta) and one is electromagnetic (gamma radiation and the related x-radiation). Corpuscular radiation consists of streams of atomic or subatomic particles which transfer their energy to whatever they strike. Alpha particles are parts of helium atoms and are huge on the atomic scale of things. They travel but a few centimeters in air and may be stopped by a sheet of paper or the dead layer of the skin of man, but on being stopped they produce a very large amount of ionization locally. Beta particles are high-speed electrons – much smaller particles that may travel a number of feet in air or up to a couple of centimeters in tissue and give up their energy over a longer path. Ionizing electromagnetic radiations, on the other hand, are like light, only of much shorter wavelength (see Figure 5-6). They travel great distances and readily penetrate matter, releasing their energy over long paths (the ionization is dispersed). For example, gamma rays penetrate biological materials easily; a given "ray" may go right through an organism without having any effect or it may produce ionization over a long path. Their effect depends on the number and energy of the rays and the distance of organism from the source, since intensity decreases exponentially with distance. Important features of alpha, beta, and gamma radiation are diagrammed in Figure 17-1. Thus we see that the alpha, beta, and gamma series is one of increasing penetration but decreasing concentration of ionization and local damage. Therefore, biologists often class radioactive substances that emit alpha or beta particles as "internal emitters" because their effect is likely to be greatest when absorbed, ingested, or otherwise deposited in or near living tissue. Conversely, radioactive substances that are primarily gamma emitters are classed as "external emitters" since they are penetrating and can produce their effect without being take inside.

There are other types of radiation which are of at least indirect interest to the ecologist. Neutrons are large, uncharged particles which in themselves do not cause ionization, but, like a bull in a china shop, they wreak local havoc by bumping atoms out of their stable states. Neutrons thus induce nonradioactive materials or tissues through which they pass. For a given amount of absorbed energy, "fast" neutrons may do ten times, and "slow" neutrons five times, the local damage of gamma rays. neutrons are restricted to the vicinity of reactors or atomic explosion, but, as indicated above, they are of primary importance in the production of radioactive substances which can and do become widely distributed in nature. X-rays are electromagnetic radiations very similar to gamma rays, but originate from the nucleus of the atom and are not sent out from radioactive substances dispersed in the environment. Since they and gamma rays have similar effects and since X-rays are easily obtain from an X-rays machine we may conveniently use them in experimental studies on individuals, populations, or even small ecosystems. Cosmic rays are radiations from outer space that are mixtures of corpuscular and electromagnetic components. The intensity of Cosmic rays in the biosphere is low, but, as discussed in chapter 20, they are a major hazard in space travel. Cosmic rays and ionizing radiation from natural radioactive substances in soil and water produce what is known as background radiation to which the present biota is adapted. In fact, the biota may depend on this back ground radiation for maintaining genetic fluidity. Background varies three to four fold in various parts of the biosphere. In this chapter we are concerned primarily with the artificial radioactivity which is added to background.

In order to deal with radiation phenomena two types of measurement are needed : (1) a measure of amount of radioactive substances in terms of number of disintegrations taking place and (2) a measure of radiation does in terms of the energy absorbed, which is capable of causing ionization and damage.

The basic unit of the quantity of a radioactive substance is the curie (Ci), which is defined as the amount of material in which 3.7×10^{10} atoms disintegrate each second, or 2.2×10^{10} disintegrations per minute (dpm). The actual weight of material making up a curie is very different for a long-lived, slowly decaying isotope as compared with a rapidly decaying one. Approximately one gram of radium, for example, is a curie while very much less (about 10^{-7} grams) of newly formed radio-sodium would emit 3.7×10^{10} disintegrations a second! Since a curie represents rather large amount of radioactivity from the biological standpoint, smaller units are widely used; millicurie (mCi) = 10^{-3} Ci; (formerly called a microcurie (μCi) = 10^{-6}Ci; nanocurie (nCi) (formerly called a millimicrocurie, mμc) = 10^{-9} Ci; picocurie (pCi) (formerly called a micromicrocurie, μμc) = 10^{-12} Ci. The possible range of activity is so tremendous that one must be careful about the position of the decimal point! The curie indicates how many alpha or beta particles or gamma rays are streaming from a radioactive source, but this information does not tell us what effect the radiation might have on organisms in the line of fire.

The other important aspect of the radiation, the radiation does, has been measured with several scales. The most convenient unit for all types of the radiation is the red, which is defined as the absorbed does of 100 ergs of energy per gram of tissue. The roentgen (R) is an older unit, which strictly speaking is to be used only for gamma and x-rays. Actually, so long as we are dealing with the effects on living organisms, the rad and the roentgen are nearly the milliard (mrad), is convenient for the kind of environment. It is important to emphasize that the roentgen or rad is a unit of total does. The does rate is the amount received per unit time. Thus, if an organism is receiving 10 mR per hour, the total does in a 24 hour period would be 240 mR or 0.240 R. as we shall see, the time over which a given does is received is a very important consideration.

Instruments that measure ionizing radiations consist of two basic parts, (1) a detecter and (2) a rate meter or electronic counter(scaler). Gaseous detectors, such as Geiger tubes, are often used to measure beta radiation, while soild or liquid scintillation detectors (substances which convert the invisible radiation to visible light that is recorded by a photoelectric system) are widely used to measure gamma and other types of radiation.

Radionuclides (Radioisotopes) of Ecological Importance

There are various kinds of atoms of each elemental substance, each with a slightly different make-up, some radioactive, some not radioactive. These varieties of elements are called isotopes. Thus, there are several isotopes of the element oxygen, several isotopes of the element carbon, and so on. The isotopes that are radioactive are the unstable ones which disintegrate into other isotopes, releasing radiations at the same time. Each isotopes is identified by a number, its atomic weight; each radioactive isotopes, or radionuclide as they are more generally called, also has a characteristic rate of disintegration that is indicated by its half-life. Some radionuclides of ecological importance are listed in Table 17-1. One will note in Group B of Table 17-1 that calcium 45 is the radioactive isotope of calcium; it has an atomic weight of 45 and loses half its radioactivity every 160 days. Half-life is constant for a given nuclide (i.e., the rate of decay is not affected by environmental factors) and varies from a few seconds to many years, depending on the radionuclide. In general, extremely "short-lived" radionuclides are of little interest ecologically. A variable which affects the penetrating power of radiation is its energy. Most radionuclides of ecological interest have energies between 0.1 and 5 Mev (million electron volts). Relative energy of each isotope in Table 17-1 is indicated (see standard references for exact values). The greater the energy the greater the potential danger to biological material within the range of the particular type of radiation. On the other hand, energetic isotopes are easier to detect in very small amounts and hence make better 'tracers." For example, energetic gamma emitters such as cobalt-60, cesium-134, scandium-46, or tantalum-182 provide useful "tags" for following the movement of animals hidden from view under the bark of a tree or in the soil.

Table 17-1 Radionuclides of Ecological Importance

roup A. Naturally occurring isotopes which contribute to background radiation.

UCLIDE	ALF-LIFE	ADIATIONS EMITTED	
ranium-235 (^{235}U)	$\times 10^8$ yrs	lpha[3]	amma[0]
ranium-238 (^{238}U)	5×10^9 yrs	lpha[3]	
adium-226 (^{226}Ra)	520 yrs	lpha[3]	amma[0]
horium-232 (^{232}Th)	4×10^{10} yrs	lpha[3]	
otassium-40 (^{40}K)	3×10^9 yrs	eta[2]	amma[2]
arbon-14 (See Group B.)			

Very low energy, less than 0.2 Mev; [1] relatively low energy, 0.2-1 Mev; [2]high energy, 1-3 Iev; [3]very high energy, over 3 Mev.

roup B. Nuclides of elements which are essential constituents of organisms, and, therefore, nportant as tracers in community metabolism studies as well as because of the radiation they roduce.

UCLIDE	ALF-LIFE	ADIATIONS EMITTED	
alcium-45 (^{45}Ca)	50 days	eta[1]	
arbon-14 (^{14}C)	568 yrs.	eta[0]	
obalt-60 (^{60}Co)	27 yrs.	eta[1]	amma[2]
opper-64 (^{64}Cu)	2.8 hrs.	eta[1]	amma[2]
odine-131 (^{131}I)	days	eta[1]	amma[1]
on -59 (^{59}Fe)	5 days	eta[1]	amma[2]
ydrogen-3 (Tritium) (^{3}H)	2.4 hrs.	eta[0]	
Manganese-54 (^{54}Mn)	300 days	Beta[2]	Gamma[2]
Phosphorus-32 (^{32}P)	14.5 days	Beta[2]	
Potassium-42 (^{42}K)	12.4 hrs.	Beta[3]	Gamma[2]
Sodium-22 (^{22}Na)	2.6 yrs.	Beta[1]	Gamma[2]
Sodium-24 (^{24}Na)	15.1 hrs.	Beta[2]	Gamma[2]
Sulfur-35 (^{35}S)	87.1 days	Beta[0]	
Zinc-65 (^{65}Zn)	250 days	Beta[1]	Gamma[2]

Also barium-140 (^{140}B), bromine-82 (^{82}Br), molybdenum-99 (^{99}Mo) and other trace elements

Group C. Nuclides important in fission product entering the environment through fall-out or waste disposal.

NCULIDE	HALF-LIFE	RADIATIONS EMITTED
The strontium group		
Strontium-90 (^{90}Sr) and	28 yrs.	Beta[1]
daughter yttrium-90 (^{90}Y)	2.5 days.	Beta[2]
Strontium-89 (^{89}Sr)	53 days	Beta[2]
The cesium group		

Cesium -137 (^{137}Cs)	33 yrs.	Beta^{2}	Gamma
daughter barium-137 (^{137}Ba)	2.6 min	Beta	Gamma^{1}
Cesium -134 (^{134}Cs)	2.3 yrs.	Beta^{1}	Gamma^{2}
The cerium group			
Cerium-144 (^{144}Ce) and	285 days	Beta^{1}	Gamma^{0}
daughter praseodymium-144(^{144}Pr)	17 min.	Beta^{2}	Gamma^{2}
Cerium-141 (^{141}Ce)	33 days	Beta^{1}	Gamma^{1}
The ruthenium group			
Ruthenium-106 (^{106}Ru) and	1 yr	Beta^{0}	
daughter rhodium-106 (^{106}Rh)	30 sec.	Beta^{3}	Gamma^{2}
Ruthenium-103 (^{103}Ru)	40 days	Beta^{1}	Gamma^{1}
Zirconium-95 (^{95}Zr) and daughter	65 days	Beta^{1}	Gamma^{1}
Niobium-95 (^{95}Nb)	35 days	Beta^{0}	Gamma^{1}
Barium-140 (^{140}Ba) and daughter	12.8 days	Beta^{1}	Gamma^{1}
lanthanum-140(^{140}La)	40 hrs.	Beta^{2}	Gamma^{2}
Neodymium=147(^{147}Nd) and	11.3 days	Beta^{1}	Gamma^{1}
daughter promethium-147 (^{147}Pm)	2.6 yrs	Beta^{1}	Gamma
Yttrium-91 (^{91}Y)	61 days	Beta^{2}	Gamma^{1}
Plutonium-239 (^{239}Pu)	2.4×10^{4} yrs	Alpha^{3}	Gamma^{1}
Iodine -131 (see Group B)			
Uranium (see Group A)			

From the ecological point of view, radiounclides fall into several rather well defined groups, as shown in Table 17-1. Naturally occurring radiounclides form one group, (a), while isotopes of metabolically important elements form another group, (B), especially important as tracers. A third important group of radiounclides, (C), are those produced by the fission of uranium and certain other elements; they involve mostly elements that are not metabolically essential (^{131}I is an exception). However, this group is the dangerous group because fission isotopes are produced in large amounts in both nuclear explosions and controlled nuclear operations, which produce power or other useful forms of energy. While most of these nuclides are not essential constituents of protoplasm they readily enter biogeochemical cycles and many of them, notably the strontium and cesium nuclides, become concentrated in the food chain, as was noted in Section 4, Chapter4. Note that a number of isotopes in group C have a "daughter isotopes " (an isotope formed during the decay of another isotope), which may be more energetic than the "parent".

It is projected that someday man will be able to harness the fusion power of the hydrogen bomb as a replacement for the fission power that is now the basis of current nuclear power developments. Such a development would eliminate the fission products but there would still remain problems involving tritium (^3H) and radioactivity induced by neutrons.

2. COMPARATIVE RADIOSENSITIVITY

Even before the atomic age was ushered in by the explosion of the first atomic bomb, enough work had been done with x-ray to indicate that organisms differed widely in their ability to tolerate massive does of radiation. Comparative sensitivity of three diverse groups of organisms to single doses of x-ray or gamma radiation is shown in Figure 17-2. Large, single doses delivered at short time intervals (minutes or hours) are known as acute doses, in contrast to chronic doses of sublethal radiation that might be experienced continuously over a whole life cycle. The left ends of the bars indicate levels at which severe effects on reproduction (temporary or permanent sterilization, for example) may be expected in the more sensitive species of the group, and the right ends of the bars indicate levels at which a large portion (50 per cent or more) of the more resistant species would be killed outright. The arrows to the left indicate lower range of doses that would result in death or damage to sensitive life-history stages such as embryos. Thus, a dose of 200 rads will kill some insect embryos in the cleavage stage. 5.000 rads will sterilize some species of insects, but 100.000 rads may be required to kill all adult individuals of the more resistant species. In general mammals rate as the most senisitive and microorganisms are the most resistant of organisms. Seed plants and lower vertebrates would fall somewhere between insects and mammals. Most studies have shown that rapidly dividing cells are most sensitive (which explains why sensitivity decreases with age). Thus, any component –whether a part of an organism, or a population- which is undergoing rapid growth is likely to be affected by comparatively low levels of radiation regardless of taxonomic relationships.

The effects of low-level chronic doses are more difficult to measure since long-term genetic as well as somatic effects may be involved. In terms of growth response Sparrow (1962) has reported that a chronic does of 1 R per day continued for 10 years (total does 25.000 R) produces about the same amount of growth reduction in pine trees (which are relatively radiosensitive) as an acute does of 60 R. any increase in the ionizing radiation environment above background, or even a high natural background, can increase the rate of production of deleterious mutations (as can many chemicals and food additives that man now imposes on himself).

In higher plants sensitivity to ionizing radiation has been shown to be directly proportional to the size of the cell nucleus, or more specifically to chromosome volume or DNA content (Sparrow and Evans, 1961; Sparrow and Woodwell, 1962: Sparrow et al., 1963). As shown in Figure 17-3 sensitivity to radiation varies almost three orders of magnitude as does chromosome volume for a group of seed plants. Plants with large chromosome volumes are killed by an acute does of less than 1000 rads, while plants with small or few chromosome may survive 50.000 rads or more. Such relationships suggest that the larger the chromosomal "target" the more likely are direct "hits" by atomic "bullets."

In higher animals no such simple and direct relationship between sensitivity and cellular structure has been found; effects on specific organ systems are more critical. Thus, mammals are very sensitive to low doses because rapidly dividing blood-making tissue in the bone marrow is especially vulnerable. A number of workers have reported that the LD_{50} (= lethal does for 50 per cent of population) of certain wild rodents is about twice that of the laboratory white mouse or white rat (Gambino and Lindberg, 1964; Golley et al., 1965; Dunaway et al., 1969), but the reasons for this difference in closely related species has not yet been adequately explained.

Differential sensitivity is of considerable ecological interest. Should a system receive a higher level of radiation than that under which it evolved, adaptations and adjustments will occur that may include the elimination of sensitive strains or species. Examples of radiation-induced reduction in species diversity and changes in community structure are given in Section 3.

Radiation stress can alter key population interactions such as predator-prey equilibria, as shown in experiments with mites reported by Auerbach (1958), or bring on a pest irruption, an example of which is noted in the next section.

At this point we should take note of the order of magnitude of natural or background radiation doses to which organisms are accustomed, so to speak. background radiation comes from three main sources : (1) cosmic rays, (2) potassium-40 in vivo (within living tissues), and (3) external radiation from radium and other naturally occurring radionuclides in rocks and soils. The following are estimated doses from each of these three sources in millirads per year received at five locations (see Polikarpov, 1966) :

Sedimentary rock at sea level : 35 + 17 + 23 =75

Granitic rock at sea level : 35 + 17 + 90 =142

Granitic rock, 3000 m altitude : 100 + 17 + 90 =207

Sea surface : 35 + 28 + 1 =67

100 meters below sea surface : 1 + 28 + 1 =30

There may be no actual threshold for radiation effects. Geneticists have generally agreed that there is no threshold for genetic mutations. At present, we resort to the stopgap measure of establishing "minimum permissible levels" for both does and amount of different radionuclides in the environment. This is a good procedure so long as it is recognized that these permissible levels do not actually represent any known thresholds. Actually, during the past decade the "permissible levels" for man have been revised downward. There is a widespread feeling that since man seems to be as radiosensitive as any other organisms, all we need do is "monitor" the radiation levels and keep them low in that microenvironment where man actually lives. Loutit (1956) summed up this viewpoint as follows; : "it is our belief that, if we take sufficient care radiobiologically to look after mankind, with few exceptions the rest of nature will take care of itself." This is dangerous oversimplification. Radioactive pollution of the soil, the oceans, or other environments where man does not actually live will be documented in Sections 4 and 5, any Radioactive substance with a long half-life introduced into the environment any-where in the biosphere will sooner or later find its way into man's body. To look after man radiobiologically we must take sufficient care of the ecosystem.

Differential radiation sensitivity within the species has an important practical application in insect control. As noted on page 447 in the previous chapter, radiation sterilization is one of the weapons in man's arsenal for "integrated" pest control. Male screw-worm flies, for example, can be sterilized by an acute does of about 5000 R with little effect on the viability and behavior of the flies. Sterilized males released into the wild population will mate normally, but, of course, no offspring will be forthcoming. By flooding the natural population with large numbers of sterile males this major pest of animal husbandry has been controlled in the southern United States (Baumhover et al., 1955; Knipling, 1960). For a review of the possibilities for this kind of population control, see Bushland (1960), Knipling (1964, 1965, 1967), Cutcomp (1967), and Lawson (1967).

3. RADIATION EFFECTS AT THE ECOSYSTEM LEVEL

The effects of gamma radiation on whole communities and ecosystems have now been studied at a number of site. Gamma sources, usually either cobalt-60 or cesium-137, of 10.000 Ci or more have been placed in fields and forests at the Brookhaven National Laboratory on Long Island (see Woodwell, 1962 and 1965), in a tropical rain forest of Puerto Rico (see H. T Odum and Pigeon, 1970), and in a desert in Nevada (see French, 1965). The effects of unshielded reactors (which emit neutrons as well as gamma radiation) on fields and forests have been studied in Georgia (see Platt, 1965) and at the Oak Ridge National Laboratory in Tennessee (see Witherspoon, 1965 and 1969). A portable gamma source has been used to study short-term effects on a wide variety of communities at the Savannah River Ecology Laboratory in South Carolina (see McCormick and Golley, 1966: Monk 1966b; McCormick, 1969). A lake bed community subjected to law-level chronic radiation from atomic wastes has been under study at the Oak Ridge National Laboratory for many years.

Figure 17-4 summarizes the effects of the Brookhaven gamma source that was placed in an oak-pine forest (the same one whose productivity and biomass are depicted in Figure 3-3). The source was unshielded for 20 hours each day, allowing investigators to make observations and take samples during a 4-hour period each day when the source was lowered into a shielded pit. A chronic radiation gradient resulted, varying from 1000 rads at 10 meters from the source to no measurable increase above background at 140 meters, as shown by the concave curve in the upper diagram in Figure 17-4. Sedges were the most resistant plants; certain heath shrubs and grasses were slightly less resistant. Pines were considerable more sensitive than oaks (pines have larger nuclei and do not resprout when terminal buds are killed). Growth inhibition in plants and reduction in species diversity of animals were noted at levels as low as 2 to 5 rads per day. Although an oak forest persisted at rather high does rates (10 to 40 rads per day), the trees were stressed and in certain zones become vulnerable to insects. In the second year of the experiment, for example, an outbreak of oak leaf aphids occurred in the zone receiving about 10 rads per day; in the zone aphids were more than 200 times as abundant as in the normal, un radiated oak forest. In summary, five zones were apparent along the radiation gradient : (1) a central zone in which no higher plants survived, (2) a sedge (Carex) zone, (3) a shrub zone of blueberries and huckleberries, (4) a stressed oak forest, and (5) the intact oak-pine forest where growth inhibition was apparent but no individual plants were killed outright. Similar results have been obtained in other studies in which forest vegetation has been exposed to ionizing radiation. Where forests have been exposed to intense radiation for short periods, as at the site of the unshielded reactor in Georgia (see Platt, 1965), an old-field vegetation of annual weeds and grasses appeared after the overstory trees were apparently killed, but in the following years (with no additional radiation) many of the hard-wood trees recovered by sending up dense growths of root and trunk sprouts (showing that only the above-ground parts had been killed), producing a sort of coppice vegetation that soon shaded out all of the old-field vegetation.

While, as we noted in the preceding section, one can predict the relative sensitivity of individual on chromosomal volume, there are other factors such as growth form or species interactions which may greatly modify response of species in intact communities. Herbaceous communities and early stages of succession are more resistant in general than mature forests not only because many species of the former have small nuclei, but also because there is much less "unshielded: biomass above ground, and the small herbs can recover more quickly by sprouting from seeds or from protected underground parts (see Figure 14-2). Thus, community attributes such as biomass and diversity play a role in determining vulnerability quite apart from the chromosomal volumes of individual species.

As with all kinds of stress, reduction in species diversity is associated with radiation stress. In another experiment at Brook-haven (see Woodwell, 1965) old-field vegetation was subjected to a radiation does of 1000 rads per day. The dry matter production of the irradiated community was actually higher than that of nonradiated controls, but the species diversity was dramatically reduced. Instead of the normal mixture of many species of forbs and grasses, the irradiated old-field area developed into an almost pure stand of crabgrass (which probably would not surprise the citizen who fights crabgrass in his lawn!); recall the discussion in Section 4 of Chapter 6 about relationships between productivity, stability, and diversity.

4. THE FATE OF RADIONUCLIDES IN THE ENVIRONMENT

When radionuclides are released into the environment, they quite often become dispersed and diluted, but they may also become concentrated in living organisms and during food-chain transfers by a variety of means, which we have previously lumped under the general heading of "biological magnification" (see pages 74-75). Radioactive substances may also simply accumulate in water, soils, sediments, or air if the input exceeds the rate of natural radioactive decay. In other words we could give "nature" an apparently innocuous amount of radioactivity and have her give it back to us in a lethal package!

The radio of a radionuclide in the organism to that in the environment is often called the concentration factor. A radioactive isotope behaves chemically essentially the same non radioactive isotope of the same element. Therefore, the observed concentration by the organism is not the result of the radioactivity, but merely demonstrates in a measurable manner the difference between the density of the element in the environment and the organism. Some of the earliest data on the concentrative tendencies in the both aquatic and terrestrial food chains were obtained by radioecologists at the AEC Hanford plant on the Columbia river in the eastern Washington state (see Foster and Rostenbach, 1954; Hanson and Kornberg, 1956; Davis and Foster, 1958). Here, trace amounts of induced radionuclides (^{32}P , etc) and fission products (^{90}Sr, ^{137}Cs, ^{131}I, etc) are released into the river, into waste holding ponds, and into the air. The concentration of phosphorus in the Columbia River is very low, only about0.00003 mg per gm water (i.e., 0.003 ppm), whereas The concentration in egg yolks of ducks and geese that obtain their food from the river is about 6 mg per gm. Thus, a gram of egg yolk contains two million times more phosphorus than a gram of water in the river. We would not expect to find a concentration factor for radioactive phosphorus quite this high since, while it was moving through the food chain to the eggs, some decay would occur (this nuclide has a short half-life). Thus reducing the amount. Occasionally a concentration factor as high as 1.500.000 was recorded, but the average was lower (about 200.000) (Hanson and Kornberg, 1956). Some other concentration factors reported were as follows: 250 for cesium-137 in muscle and 500 for strontium-90 in bone of water birds, as compared with concentration of these nuclides in the water of waste ponds in which these birds were feeding. The concentration of radioactive iodine in the thyroids of jack rabbits was 500 times that in the desert vegetation, which in turn had concentrated the nuclide released into the air in stack gases from the atomic plant, Concentration factors for strontium-90 in various parts of an aquatic food web at another site of atomic energy development are depicted in Figure 17-5.

While radioactivity does not affect the uptake of the isotope by living systems, it does, of course, have detrimental effects on active tissues once it is absorbed. The point is that allowance must be made for "ecological concentration" in establishing "maximum permissible levels" of release into the environment. Isotopes that are naturally concentrated in certain tissues (such as iodine in the thyroid or strontium in the bone) and/or those with long effective half-lives are obviously the ones to watch out for. Also, the concentration factor is likely to be reater in nutrient-poor environments than in nutrient-rich ones as will be documented in the next section. In general, concentrative tendencies can be expected to be greater in aquatic than in terrestrial ecosystems since nutrient fluxes in the "thin" media of water are more rapid than in the "thick" media of soil. For additional information on radio-ecological concentration processes, Polikarpov (1966).

Man's opportunity to learn more about environmental processes through the use of radioactive troubles he is having with environmental concentration. The uses of radioactive tracers for ecological study have been reviewed by Odum and Golley (1963), and numerous examples are to be found in the proceedings of the two International Symposia (Schultz and Klements, 1963; Nelson and Evans, 1969). Tracers are obviously extremely useful in charting biogeochemical cycles and in measuring flux rates in steady-state systems; examples of such uses were given in Chapter4. They are also important in studies of community metabolism; carbon-14, for example, has become a basic tool for the measurement of productivity in aquatic ecosystems (see page 60). Tracers are also useful in charting the movements of organisms at the population level and in mapping food webs. Two examples will suffice to illustrate some of these some of these possibilities.

In a study of the impact of predation on populations of cotton rats in field enclosures protected and exposed to predators Schnell(1968) "tagged" each animal with a radioactive pin inserted under the skin of the back. The tag not only enabled the investigator to locate live animals missed by live-trapping program but also dead animals or remains left by a predator which would never be found by conventional observations. Thus, Schnell was able not only to plot accurate survivorship curves (see page 174 for explanation of this form of graphic analysis) for each population, but he could determine the exact cause of mortality for most of the animals.

Some aspects of the use of radionuclide tracers to isolate and chart food chains in intact natural communities are shown in Figure 17-6. In one study, the two dominant species of plants in a one-year abandoned field were labeled (Fig. 17-6A), and the transfer of the tracer to arthropods followed for a period of about six weeks. As shown in Figure 17-6B, "sap" feeders such as aphids become radioactive first, followed by foliage grazers and then predators. Thus, the trophic position of a particular species could be roughly determined by the shape of the uptake graph. More importantly, a map of the food-web network could be worked out, as shown in Figure 17-6C. of the more than 100 species of insects present in the community only about 15 species were removing an appreciable amount of tracer from the dominant plants, and most of these were feeding on one of the species. The fact that one codominant was being grazed more heavily than the other was an unexpected finding, one that would not have been evident without the use of the tracer. For details of this and other similar studies, see E. P. odum, and Kuenzler, 1963; Wiegert, Odum, and Schnell, 1967; de la Cruz and Wiegert 1967; Wiegert and , Odum, 1969; Ball, 1963; Crossley, 1963; Reichle and Crossley, 1965. Some of the limitations of tracer studies are discussed by Shure (1970).

5. THE FALLOUT PROBLEM

The radioactive dust that falls to earth after atomic explosions is called radioactive fallout. These materials mix and interact with natural particulate materials in the atmosphere (natural fallout, see Figure 4-3) and the increasing amount of man-made air pollution. The kind of radioactive fallout depends on the type of bomb. First, it may be well to distinguish between the two types of nuclear weapons, the fission bomb, in which heavy elements such as uranium and plutonium are split, with the release of energy and radioactive "fission products, " and the fusion bomb , or the thermonuclear weapon in which light elements, (deuterium) fuse to from a heavier element, with the release of energy and neutrons. Since an extremely high temperature (millions of degrees) is required for the latter, a fission reaction is used to "trigger" the fusion reaction. In general, the thermonuclear weapon produces less fission products and more neutrons which induce radioactivity in the environment) than does a fission weapon per unit of energy released. According to Glasstone (1957), about 10 per cent of the energy of a nuclear weapon is in residual nuclear radiation, some of which becomes widely dispersed in the biosphere. The amount of radioactive fallout produced depends not only on the type and size of the weapon, but also on the amount of environmental material that gets mixed up in the explosion.

Fallout from weapons differs from atomic waste material in that the radionuclides are fused with iron, silica, dust, and whatever happens to be in the vicinity to form relatively insoluble particles. These particles, which under the microscope often resemble tiny marbles of different colors, vary in size from several hundred microns to almost colloidal dimensions. The smaller particles adhere tightly to the leaves of plants where they may not only produce radiation damage to leaf tissue but may be ingested by grazing animals and dissolved by the digestive juices in the alimentary canal. Thus, this kind of fallout can enter the food chain directly at the herbivore, or primary consumer, trophic level. Fallout from small atomic weapons or nuclear explosions used for peaceful purposes (excavation of harbors, canals, or surface mining) is mostly deposited in a narrow linear pattern downwind, but some of the smallest particles may become widely dispersed and come down in rain at long distances. While the total amount of radioactivity decreases with distance from a nuclear test, it was early discovered that certain biologically significant nuclides, especially strontium-90, reached a peak in wild animal populations 50 to 100 miles from the "ground zero" of the explosion(see Nishita and Larson, 1957). This is explained by fact that ^{90}Sr has two gaseous precursors ($^{90}Kr \rightarrow ^{90}Rb \rightarrow ^{90}Sr$) and is therefore formed relatively late after the bomb detonation; this results in its inclusion in the smaller particles (less than 40 microns), which descend at greater distances and more readily enter food chains. Cesium-137 also has gaseous precursors and is unfortunately a significant component of the more soluble" long distance" fallout. The large, powerful "megaton" weapons that were freely tested in the early 1960s ejected material into the stratosphere, resulting in a global contamination with a world-wide fallout that will contamination with world-wide fallout that will continue for many years. The amount of fallout received by an area is roughly proportional to the rainfall. In the United States, for example, the accumulated deposition of strontium-90 by 1965 was estimated to be about 200 mCi per square mile in wet regions (eastern deciduous forest regions, for example,) as compared to 80 mCi in dry regions (deserts, grasslands, etc.). (see Klement, 1965). Studies following the weapons tests on the Pacific atolls showed that the kinds of radio-nuclides that enter marine food chains are rather strikingly different from those that enter terrestrial food chains (see Seymour, 1959; Palumbo, 1961). Elements of radioactive fallout that form strong complexes with organic matter such as cobalt-60, iron-59, zinc-65, and manganese-54 (which are all nuclides induced by neutron bombardment) and those that are present in particulate or colloidal form (^{144}Ce, ^{144}Pr, ^{95}Zr, and ^{106}Rh) transfer in the highest amount to marine organisms. In contrast, it is the soluble fission products such as strontium-90 and cesium-137 that are found in the highest amounts in land plants and animals. Since it was the induced isotopes, which complex with detritus, that were found in marine animals but not in marine plants or terrestrial organisms, it appears that the prominence of deposit-feeding and filter-feeding organisms in marine ecosystem food chains accounts for this difference. This is another instance in which contaminants may bypass the primary trophic level and enter directly the animal portion of food chains.

The quantity of fallout radio-nuclides that enters food chains and eventually becomes transferred to man depends not only on the amount received from the air (which, as was already indicated, is a direct function of precipitation) but also on the structure of the ecosystem and the nature of its biogeochemical cycles. In general, a larger proportion of fallout will enter food chains in nutrient-poor environments. In nutrient-rich environments high exchange and stronge capacities of soils or sediments so dilute the fallout that relatively little uptake by plants occurs. A matlike vegetation on thin soils, such as is found on moors, heaths, granite outcrops, alpine meadows, and tundras, acts as a fallout trap (also epiphytes in tropical ecosystems), enhancing uptake by animals (see Russell, 1965), as does an active detritus food pathway. Two examples of these trends are illustrated by the data in Tables 17-2 and 17-3. Sheep on hill pastures in England accumulate 20 times as much strontium-90 in their bones as do sheep in the valleys because of the low calcium content and mat-like vegetation characteristic of the hill pastures (Table 17-2). In Table 17-3 we see that the concentration of cesium-137 in deer (measured in pCi per kilogram wet weight of animal) is much higher in the sandy, low-lying coastal plain of the southeastern United States than in the adjacent Piedmont region where soils are well drained and have a high clay content. Rainfall in these two regions does not differ.

Fallout radio-nuclides (especially ^{90}Sr and ^{137}Cs) have been and are being passed on to man via the food chain, although concentrations in human tissues are not generally as high as those in sheep and deer. Man is somewhat protected by his position in the food chain and by food processing and cooking, which remove some of the contamination. However, in 1965, in arctic and subarctic regions (Alaska and northern Finland, for example) where reindeer or caribou meat is consumed, cesium-137 in man was 5 to 45 nCi/kgm body weight (= 5000 to 45000 pCi/kgm) according to Hanson et al. (1967) and Miettinen (1969); this is every bit as high as the concentration in coastal plain deer (compare with Table 17-3). The reindeer and caribou themselves become highly contaminated by feeding on the mat-like vegetation. Thus, "exposed" human populations such as the Eskimos and Lapps are subjected to internal radiation doses appreciably higher than background, although no one knows how harmful this is . in 1965, the amount of strontium-90 in the bones of children in the United States was estimated to be 4 to 8 pCi/kgm calcium in bone (see Comar, 1965);since then most surveys have indicated that this level has not risen appreciably. Again, no one can say whether this small amount is harmful, but as one of many "pollution stresses" it is certainly not doing anyone any good!

6. WASTE DISPOSAL

Although fallout problems are critical, waste disposal from peaceful uses of atomic energy is potentially afar greater problem, assuming again that we do not have an all-out atomic war. Not enough attention is now being given to the ecological aspects of waste disposal, which is the limiting factor to full exploitation of atomic energy. As Weinberg and Hammond (1970) have stated, the energy available in nuclear sources seems "essentially inexhaustible" but environmental side effects of a very large production of such energy impose the actual limit. This is another expression of the principle stated in Chapter 16; it is not energy itself that is limiting to man but rather the consequences of pollution that result from the exploitation of energy sources.

It has been customary to consider three categories of radioactive wastes;

- High –level wastes-liquids or solids that must be contained since they are too dangerous to be released anywhere in the biosphere. About 100 gallons of such high-level wastes are generated by each ton of spent nuclear fuel. As of 1969, 80 million gallons were stored in 200 underground tanks at four U.S. atomic Energy Commission sites, with 2×10^6 cubic feet of new storage space needed annually, a rate that will increase as nuclear power generation increases. Alternatives to tank storage that are being considered include (1) conversion of liquids to inert solids (ceramics) for burial in deep geological strata and (2) storage of liquids and solids in deep salt mines. The large amount of heat generated by high-level wastes compounds the problem; heat can "melt" the walls of salt mines or cause small earthquakes if injected into certain types of geological fissures.
- Low-level wastes-liquids, solids, and gases that have very low radioactivity per unit volume but are far too voluminous to be contained completely; therefore, they must somehow be dispersed into the environment in such a way and at such a rate that the released equilibrium radioactivity does not appreciably raise background or become concentrated in food chains.
- Intermediate-level wastes-those with radioactivity high enough to dictate local containment, but low enough so that it is possible to separate out high-level or long-lived components and handle the bulk as low-level waste.

The uranium fuel cycle in power generation includes the following phases : (1) mining and milling, (2) refining (chemical conversion), (3) enrichment (percentage content of uranium-235 increased), (4) nuclear fuel element fabrication, (5) burn up of nuclear fuel in the reactor, (6) spent fuel reprocessing, and (7) burial or other containment of wastes. Although most of the radioactive wastes are generated in the reactor, the most difficult waste management problems occur during reprocessing (phase 6) when fission products (see Table 17-1C) are removed from the spent fuel elements. Reprocessing plants and burial grounds are located at different sites from the nuclear power plant itself, which means that there is an ever-present danger of accidents when spent fuel elements or the high-level wastes must be disposed of at the reactor site (especially when fuel elements leak or break) and during mining and fuel preparation. Thus, radioactive contamination of the environment is an ever-present threat during the entire cycle. To minimize the threat large protective areas of land must be set aside, especially for phases 5,6 and 7. For example, nuclear burial grounds have to be quite large since one acre is required for each 50.000 cubic feet of high-level waste or 100.000 cubic feet of intermediate- or low level materials. Such sites have to be continuously monitored to make certain that the surface water, water table ,and air are not contaminated (see Figure 17-7). Land and water requirements for the power plant and its waste treatment environment are considered later.

As long as fissionable material is used as a fuel source (uranium, thorium, plutonium, etc.) large quantities of waste fission products (the same radionuclides involved in fallout) plus residual amounts of the fissionable materials could well be the limiting factors in exploiting the theoretically "inexhaustible" atomic energy sources. Hugh "megacurie" quantities of the long-lived species (^{90}Sr, ^{137}Cs, ^{129}I, ^{99}Tc, ^{238}Pu, ^{240}Pu, ^{241}Am, ^{243}Am, and ^{244}Cm) would have to be stored. Currently used reactors are expected to be replaced in the next 15to 20 years by "breeder" reactors, in which a catalytic burning of uranium-238, thorium-232, or perhaps lithium-6 results in a self-regeneration of fissionable material (see Weinberg and Hammond, 1970, for an evaluation of breeder reactors). Such a fuel cycle greatly reduces the fuel requirement but does not solve the waste disposal problem. Assuming that someday it will be possible to employ fusion power (see page 411), the fission products would then be eliminated but induced radionuclides would be increased – especially tritium, which could contaminate the entire global hydrological cycle. Frank Parker (1968) of Oak Ridge calculates that "release of tritium generated by a power economy, if the nuclear power were all fusion, would result in an unacceptable world-wide dosage by the year 2000." For an additional discussion of radioactive wastes, see Fox (1969).

If radioactive wastes do not prove to be the limiting factor in the exploitation of nuclear energy, then the limiting factor will be waste heat; or as is most likely, it will be a combination of the two that will set the overall pollution constraint. What has come to be known as thermal pollution will become an increasingly serious problem since low utility heat is a by-product of any transfer of energy from one form to another as dictated by the second law of thermodynamics. To some extent the shift from fossil fuel to atomic power reduces air pollution but increases water pollution. Thus, to generate one kilowatt hour of electricity the waste heat released to the atmosphere and to cooling water is 1600 and 5300 BTU respectively for a fossil-fueled power plant, and 500 and 7600 BTU respectively for a present-day nuclear power plant (see Table 3-1 for conversion to BTU to kilocalories). Thus, an average size nuclear power plant that produces 3000 megawatts of electricity also produces waste heat at the rate of more than 20×10^9 BTU per hour.

The surface cooling capacity of water ranges from about 1.5 to 7.5 BTU per hour per ft^2 per $°F$. difference between air and water, depending on wind and water temperatures. Consequently, a lot of water surface is required to disperse heat, something on the order of 1.5 acres per megawatt in temperate locality, or 4500 acres for a 3000-megwatt power station. In a 1970 task force report* it was recommended that each 2400-megawatt nuclear plant include 1130 acres for plant operations and containment of radioactive wastes and 7000 acres of water surface for cooling. Accordingly, if we take option 2 in the waste disposal strategy (as described on page 438), we should think in terms of a minimum area of 10.000 acres for each moderate –sized power plant in accordance with the concept of the waste disposal park (see Figure 16-4); this includes making use of by product heat for fish culture or other useful purposes.

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* "Nuclear Power in the South." Report of south ern Interstate Nuclear Board, 800 Peachtree Street, Atlanta, Georgia 30308.

The use of powered cooling devices such as cooling towers can reduce the space needed of course, but at a considerable cost, since this would essentially be taking costly option 3 in the overall waste disposal strategy. As with other wastes it is always tempting to rely on the oceans for cooling, but as another recent task force report † warns, the oceans can no longer be regarded as a dumping ground for all of man's wastes, while almost everyone predicts that thermal pollution will be an increasingly serious local problem, there is no agreement as to its ultimate effect on the global heat balance. For a discussion of this aspect, see Peterson (1970).

The local detrimental effects of thermal pollution on aquatic ecosystems can be listed as follows; (1) A rise in water temperature often increases the susceptibility of organisms to toxic materials (which will undoubtedly be present in waste water). (2) Critical "stenothermal" periods in life histories may be exceeded (see page 108).

(s) Elevated temperatures tend to foster replacement of normal algal populations by less desirable blue-greens (see page 306). (4) As water temperature rises, animals need more oxygen, yet warm water holds less (see page 126).

For additional information on biological effects of thermal pollution, see Naylor (1965), Mann (1965), Clark (1969), and Krenkel and Parkrt (eds.) (1969).

7. FUTURE RADIOECOLOGICAL RESEARCH

In this brief review we have tried to show that the problems of radioactivity in the environment and the thermal consequences of the use of unclear energy will compound the already extremely critical pollution constraints on the further development of industrialized man. On the positive side we have tried to indicate some of the exciting possibilities for study made possible by isotopes. Up to now the interdisciplinary field of radiation ecology has been primarily preoccupied with description and technology; it must now move to a position of making major contributions to the theory of ecosystems. Radiation procedures offer powerful means for solving the twofold problem of ecosystems, that of relating the one-way flow of energy to the cycling of materials and of discovering how physical and biological factors interact to control the functioning ecosystem. Only by understanding these matters in depth can man act as his own error detector and correct for perturbations, caused by his technology, that increasingly disrupt the life-support systems of the biosphere (E. P. Odum, 1965).

In the not too distant future the radio-ecologist may well be one of those who must help decide when to contain and when to disperse the waste materials of the atomic age. If the ecologist does not know what to expect in the biological environment, who does?

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† See "Ocean Dumping, A National Policy" A report to the President prepared by the Council on Environmental Quality, 1970.

SPECIAL HABITATS

AQUATIC ECOSYSTEMS- FRESHWATER TYPES

Introduction:

An ecosystem is a biological environment consisting of both biotic and abiotic Components. All the organisms living in a particular area may interact with the nonliving (abiotic) physical components of the environment such as air, soil, water and sunlight.

Ecosystems are classified into water-based aquatic and land-based terrestrial ecosystem categories. Based on the quality of water involved, the aquatic ecosystems are further classified into fresh water and
marine water types.

Freshwater ecosystems are a subset of Earth's aquatic ecosystems. **They include lakes and ponds, rivers, streams and springs, and wetlands.** They can be contrasted with marine ecosystems, which have a larger salt content. Freshwater habitats can be classified by different factors, including temperature, light penetration, and vegetation.

The freshwater ecosystems are generally classified into two major groups as, **lentic and lotic ecosystems.** The term Lentic ecosystems is given to standing water bodies or still water bodies. The LENTIC Ecosystems includes all standing water bodies like Lakes, ponds, swamps or bogs. The term lotic ecosystem is given to the flowing water bodies. The LOTIC Ecosystems include all flowing water bodies like river, springs, creek. The subject of study of freshwater ecosystems is known as limnology.

Almost all ecological factors like temperature, light, pH, dissolved gases, dissolved salts in water, turbidity, alkalinity, depth and areal distribution, all of these parameters play an active role in controlling the habitat of aquatic ecosystems. Hence, it is necessary to study the freshwater ecosystems in detail. The following aspects are highlighted in this module:

1. River Ecosystem
2. Ecological factors of Rivers
3. Life along rivers
4. Lake Ecosystem
5. Ecological factors of Lakes
6. Life in lakes

1. RIVER ECOSYSTEM

Water is an essential component of life. Surface water resources are the mostly preferred locations for life settlements. Most of the human civilizations were originated near water courses, especially along the major rivers. A river is a large natural course of flowing water obtained from precipitation. The surface water moves down along the slopes due to the action of gravity.
Streams, tributaries, brooks, creeks and springs are the different types of water courses classified based on their dimension and distribution.

A river water is always on the move. Every river has its own longitudinal profile and different cross-sections. The longitudinal profile indicates the nature of slope existing at different places and levels.

The cross-section of a river varies from headwater zone to the mouth. These are called as river valleys which may be ranging from sharp canyons and gorges to wider flat streams nearer to the delta. The velocity of water flowing in a stream is not uniform along the longitudinal profile, also within their cross sections.

A river is a powerful geological agent. It has the capacity to erode, transport and deposit the sediments. These are called as river alluvium. The alluvial deposits, clay and silt of a river are the materials preferred for different activities. A river may be called as major, medium and minor river based on its catchment area, number and length of streams and tributaries, stage of development, and its discharge of water. A river may be called as a perennial river when there is continuous flow of water throughout the year, an intermittent river when the flow is seasonal, an ephemeral river when the flow is occasional or rare.

The following are the terms used to denote the small portions of rivers.

* Pool is a segment where the water is deeper and moving slowly.
* Riffle - is a segment where the flow is shallower and more turbulent
* Headwater , in a river, is the point of origin of the stream.
* Channel is the river courses developed by constant erosion.
* Floodplain is the flatland existing on either side of the stream that are subject to seasonal flooding.
* The confluence of a river is called as the mouth. This is the point at which the stream discharges all its load into a sea or other static body of water.

A flowing river water carries enormous amount of salts in solution and sediments in suspension. It also rolls up a lot of bed load along the bottom. The water flowing through a river is called as its discharge. The volume and velocity of river discharge depends on several geomorphic factors.

The suspended and bed load sediments carried along with other organic matter in the flowing water control the characteristics of the river ecology. The life along rivers, vary from its head/ source to the mouth, from stream to stream, from country to country.

The velocity of flow and force, nature of substratum like alluvium or rock bottom may determine, some of the habitat of a river course.

2. ECOLOGICAL FACTORS OF RIVERS

The ecology of running waters is unique from that of other aquatic habitats. The following are the unique features of Freshwater Aquatic ecosystems

1. Flow is unidirectional, in lotic ecosystems
2. There is a state of continuous physical change.
3. There is a high degree of spatial and temporal heterogeneity at all scales (microhabitats).
4. Variability between lotic systems is quite high.
5. The biota is specialized to live with flow conditions.

The major abiotic factors controlling the lotic ecosystems are:

a) Slope and geomorphic conditions including the nature of substratum.
b) Physico-chemical properties of water. Temperature, color, alkalinity, pH and dissolved oxygen.
c) Flow velocity and quantity.
d) Type and amount of suspended and bed-load sediments.
e) Turbidity.
f) Thickness of water column and the depth of light penetration.
g) The climatological factors like atmospheric temperature, humidity, sun shine hours, evapotranspiration and wind.

Depending upon the temperature of water, streams are classified into iso-thermal and non-isothermal streams. In all the rivers, most of the abiotic parameters vary both in space and time.
The Interface between the land and water and the interface between water and air play a significant role in controlling the environmental conditions of an area.

Characteristics of lotic adaptations:

The animals and plants living in lotic environments have certain specific adaptations.
They are subjected to varieties of dynamic environmental factors, like water currents, pollutants and suspended sediments.
Lotic habitats are influenced by the effect of continuously moving water, pollution, suspended sediments, floods and other human activities.
The unique characteristics of running water habitat are :

1. The establishment of a firm attachment with the substratum. Most of the sponges, diatoms and moss are examples of these. They live on the wooden logs, stones, rock exposures.
2. The swimmers are expected to have hooks or suckers to maintain grip over the polished surfaces.
3. Some of them build nets around them for food trapping.
4. Some of them , like snails and worms, may have sticky bottoms to move long the base.
5. The life living in rivers, have a stream-lined shape of the body. They may have a body rounded anteriorly and tapering posteriorly.
This is for a free-swimming habit against the water currents.
6. Some have a flat body to stay within the cracks and crevices of rocks.
7. Rheotaxis is a feature seen in rivers. This is the capacity, or mechanism by which fishes and other animals swim against the currents and rapidly flowing water.
This is the resistance capacity of many lotic forms.
8. Clinging habitat is another feature of Life in river ecosystems. Some organisms mostly stay closer and nearer to the hard bodies or materials.
9. Some of the life forms in rivers have the characteristic feature of Osmo regulation. Especially, the Protozoans eliminate excess water through a contractile vacuole.

For respiration, life systems in rivers have respiratory siphons.
Eg. The Mayfly is equipped with gills.

The productivity is more in streams than standing waters.
The temperature is not constant along the river course.
Oxygen content is high at all levels, due to the flowing water.
C02 occurs as carbonate and bicarbonate salts.
Turbidity is a limiting factor of river ecosystems.
The pelagic adaptations include both planktonic and nektonic adaptations.
Floating and swimming organism come under these groups. Planktons possess typical body structures. They are bladder like, needle-like and hair-like.
Walled bodies and locomotory structures like cilia, appendages, fins and musculature are common to these life.
Some of them are characterised by light and thin skeletons.

3. LIFE ALONG RIVERS

In rivers, there are varieties of life like fishes, plants, animals, and numerous microorganisms that survive. Many of them we may not be able to see.

In addition to these, along the river banks, trees and shrubs grow as shelter belts for birds and mammals.
Many tiny organisms exist in river waters. They play a crucial role in maintaining the food supply for the entire ecosystem. They act as feeders, collectors, and grazers. They help in breaking down the plant matter that grows along streams or falling from the overhanging vegetation.
The river snails work for processing the calcium present in water to build their shells.
Some of the trees and plants act as shades for other life and filter the pollutants and extract trace metals from the sediments.
Predator -prey relationships are more along the rivers. The larger fish eats the smaller ones and smaller predatory organisms parasitize the larger fish commonly in rivers.
Varieties of local and migratory birds, snakes, frogs, bears and other land animals, including cattle and humans, all come to the river for drinking water, fihsing, preparing food, bathing, washing and living.
Every life along rivers produces waste which becomes food for some other type of feeder.
The producers or autotrophs are the green plants including the chemosynthetic micro organisms present in rivers.
The micro consumers of rivers are the herbivores, predators and parasites.
The decomposers or micro consumers are the worms, bacteria and fungi.
In a stream ecosystem, food is constantly being produced, consumed and recycled. Pollution and other human activities can change the food source and impair the life cycles of the creatures living in and around the water courses.
As all living beings along the river depend on one another, any change in the system parameters will affect all others as well.
Example:
a) Floods in rivers.
b) Dumping solid wastes into rivers.
May hamper the normal living environments.

Longitudinal zonation in rivers:

Streams exhibit two habitats - rapids and pools.
So, the stream organisms may be divided into rapid communities and pool communities.
The nature of communities existing in rivers, depends on the
a) type of stream bottom
b) density of population.
The river bottom may be containing sand, pebbles, clay, bedrock or rubble rock.
The rapids community are called as Torrential fauna, as they are subjected to the turbulence created by the currents.
Eg. A blackfly larva which exists in the rock bottom is an example to this group.
The pools community includes the burrowing types, which are living along the stream banks or bottom. Eg. Mayfly nymph and the Dragon-flynymph. There is also a zonation in the stream communities.
The Headwater species are different from the deltaic species. The gradational changes in communities are due to the changes in temperature, velocity of water flow and the quality of water including its pH.

4. LAKE ECOSYSTEM

A Lake is a large standing water body, surrounded by land.

The formation of lakes, their physico-chemical conditions and the organisms inhabiting within them, are studied under the branch of science called LIMNOLOGY. In Greek " Limne " means lake or marsh.

Lake ecosystem is also called as "lacustrine environment".

Lakes and reservoirs are more or less closed but mostly dynamic ecosystems.

Lake, as an ecosystem has several budgets as heat budget, water budget and biomass budget. There are about 1350 lakes and reservoirs in the world.

Lake water and life are subjected to several natural and man-made threats. Lakes involve complex of interrelated mechanical (currents, waves and sediment transport), Physical (thermal and ice phenomena) , Chemical and biological processes.

Lakes are always under the direct influence of rainwater, river water, sedimentation, biomass and productivity of organisms.

Lake ecosystem maintains a state of equilibrium with reference to these factors, which are seasonally varying. An important feature of lakes, is the evaporation of water from its surface. Sedimentation is a regular process in lakes.

The movement of water masses, occurs in the form of waves, currents, turbulent mixing and wind tides. Mostly they are caused by the wind. The waves have an abrasive power and the capacity to cut off the earth's materials. The sediments deposited within the lakes are called as lacustrine deposits. Lakes create little worlds of their own. Water-plants of all shapes and sizes live under the surface of lakes. Some of the plants are attached to the lake bottom, and others float free. This vegetation provides food for water creatures such as bugs, snails, and fish.

Lakes are also the favourite haunts of waterfowl such as ducks, geese, swans, flamingos, egrets, cranes, and others. Land animals use lakes for drinking water. They also obtain food from lakes in the form of fish, birds, and plant life.

5. ECOLOGICAL FACTORS OF LAKES

The stagnant lake water has certain characteristic features with reference to the abiotic and biotic factors.

1. The light penetration in lakes depends on the turbidity of water.
2. The water temperature varies with reference to space (including depth) and time (including time and seasons).
3. Only the water at the top is exposed to the air. This leads to decomposition at the bottom. Hence, the dissolved oxygen is relatively low in lake waters, than river waters. It may also decrease with depth.
4. The life in lakes, their adaptations and distribution depends on the gradations of oxygen content, light and temperature.

Considering the depth and area of a lake, three distinct ecological zones can be identified in lakes. They are

a) Littoral zone

b) Limnetic zone and

c) Profundal zone.

The littoral zone is the edge areas of the lake extending from the water surface down to 6 to 10 m. This shallow water zone is inhabited by rooted plants. This zone is further divided into Epilimniotic and Hypolimniotic zones.

Epilimniotic zone extends from the water surface up to 6m and the hypolimniotic zone extends from 6m to 10 m.

Limnetic zone is the open water zone extending to a depth upto the effective light penetration. This is dominated by plankton.

Profundal zone includes the bottom and the deep water beyond the depth of light penetration. It contains the heterotrophs. This zone exists only in lakes and is normally absent in ponds.

In these ecosystems, the depth of effective light penetration is called as the compensation level. This is the depth at which photosynthesis just balances respiration.

The characteristic life in lakes varies with reference to the depth zones . The life in lakes and their abundance, distribution and diversity are influenced by the stratification and movement of oxygen and nutrients.

The energy source is the sunlight . The light penetration is controlled by the turbidity of water. Based on light penetration, the lake can be divided into two zones as:

1. TROPHOGENIC ZONE- This is almost corresponding to the epilimnion zone, dominated by photosynthesis.
2. TROPHOLYTIC ZONE. This is a Lower layer wherein the decomposition is expected to be more active. This zone corresponds to the hypolimnion zone.

Based on ecological factors lakes are classified into the following three types:

a) Oligotrophic lakes
b) Eutrophic lakes
c) Dystrophic lakes

Oligotrophic lakes are of very good depths. The water is transparent and the biotic components are poor. The pH of water is low. Nitrogen is negligible. Organic contens are poor. The deeper layers are rich in biota.

The Eutrophic lakes are shallow water bodies with rich organic matter and plankton and other biota. Such condition comes when the lake is old.

Dystrophic lakes may be deep or shallow but rich in humus and poor in carbon-di-oxide content. The faunal growth is also poor in such lakes.

6. **LIFE IN LAKES**

The organisms living in water may be classified into the following types.

1. The surface living organisms, which are called as Planktons, whose movements are mostly controlled by the currents. Algae, protozoa, rotifers, copepods and cladocera belong to this group.
2. Animals living at the bottom of water bodies are called as Benthos. These are further divided according to the mode of feeding into filter feeders and deposit-feeders (or sediment feeders). Midge larvae, clams and other microscopic organisms thrive as benthos.
3. Active swimming forms called as Nektons. Fishes, aquatic insects, water beetles, amphibians, turtles, water snakes, tadpoles of frogs and Tilapia live as nektons.
4. Organisms (both plants and animals) attached or clinging to stems and leaves of rooted plants or projected surfaces. These are called as Periphytons. Sessile algae, fungi, protozoa, hydra, microcrustacea, rotifera and snails come under this category.

5. The organisms which are resting and swimming on the surface of water, are called as Neustons. Insects, mosquito larvae, some bacteria and algae come under this group. In a lake or a pond ecosystem, most of these aquatic habitat exist.

Lake ecosystems are characterised by three adaptations as floating vegetation, submerged vegetation and animal adaptations.

The floating plants have poorly developed root systems. To remain afloat, the leaves and stems are filled with air-spaces. The upper surface of the leaves is waxy. The floating leaves are larger and broader. The submerged vegetation possess certain modifications for their growth and survival. The leaves lack a cuticle.

The productivity of a lake or pond ecosystem differs depending upon the depth, nutrients, light penetration, light availability and biota. In moderately shallow lakes and ponds, light penetration is more. Organic matter and nutrients also accumulate in heavy amounts. In such water bodies, productivity is higher.

Conclusion:

The Aquatic biodiversity is a primary concept in environmental analysis of aquatic ecosystems also provide a home to many species including the phytoplankton, zooplankton, aquatic plants, insects, fish, birds, mammals, and others. In summary, aquatic biodiversity includes all unique species and habitats, and the interaction between them. They are organized at many levels, from the smallest building blocks of life to complete ecosystems, encompassing communities, populations, species, and genetic levels. It has enormous economic and aesthetic value and is largely responsible for maintaining the overall environment.

Humans have long depended on aquatic resources for food, medicines, and materials as well as for recreational and commercial purposes such as fishing and tourism. Several Factors affect these conditions.

They are overexploitation of species, introduction of exotic species, pollution from urban, industrial, and agricultural activities, as well as the habitat loss and alteration through damming,
and diversion of water into other places.

All these contribute to the declining levels of aquatic biodiversity, especially the freshwater ecosystems. It is necessary to adopt certain conservation strategies to protect and conserve the aquatic life and to maintain the balance of nature and support the availability of resources for future generations.