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Advanced Topics in Invertebrate Zoology 2020-2021

الدراسات العليا-ماجستير فرع علم الحيوان
الفصل الدراسي الاول

تدريسي المادة :

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Advanced Topics in Invertebrate Zoology

Course for Ph.D students

Department of Biology

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Introduction

The invertebrates include those animals which are without backbone as opposed to vertebrates in which a series of vertebrates constitute backbone. The invertebrate constitutes about 97% of the known animals which number over a million. There is not even positive character which is common to all invertebrates, and the differences between the groups are very large, each group of invertebrates has certain structural peculiarities, a special terminology, and distinct classification. However, the life of invertebrates is as fascinating, revealing and complicated subject as vertebrates. Without a through and carful study of invertebrates it is hardly possible to consider the secrets of life of animals overall.

Present Invertebrate Phyla

Presently there are 30 invertebrate phyla, which are characterized by a unity of basic structural pattern in each of them. This means that in each phylum, though the members may differ in external features, the anatomical features are constructed on the same ground plan in many respects. The common anatomical ground plan exhibits a unique relationship among the groups of structural unit which compose it. Other significant features of inter-relationships among the members of same phylum are functional. Another important feature, by which the members of the individual phylum are related with one another, is common ancestry.

Major and Minor Phyla:

The invertebrate phyla have been divided in to major and minor phyla. The concept of major and minor phyla is based on two factors:

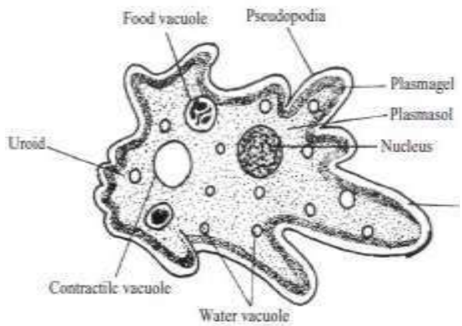
1- The number of species and individuals.
2- Their participation in ecological communities.

One of the basis of the first factor, 11 phyla appear to be clearly major (as is evident from the species number in Table. 1), these are **Protozoa, Porifera, Coelenterata, Platyhelminthes, Rotifera, Nematoda, Mollusca, Annelida, Arthropoda, Ectoprocta and Echinodermata.** On the basis of second factor, if the phyla are represented in great majority of ecological communities, they would be regarded as major phyla. Whereas, the minor phyla from only a fraction of animal communities. Rotifera and Ectoprocta, cannot be considered as major phyla. Although they are greater in number of species, but they are included in minor phyla due to their limited participation in animal communities. Thus, keeping in view the utility of the above two factors, we can regard only nine as major phyla and the rest are minor phyla.

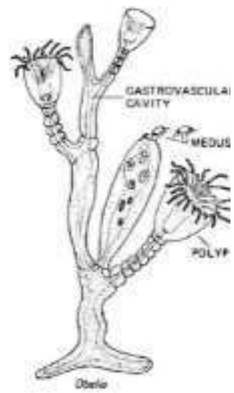
General Characteristics of Invertebrates

Habitat: All the 30 phyla most probably originated in the sea, but not all have successfully invaded the land the freshwater habitats. About 80 percent are found in the terrestrial habitats.

Shape: Animals of varied shape are included among the invertebrates. Amoeba possesses an irregular ever-changing body shape, sponges and coelenterates display plant-like appearance, flatworms are leaf-like and ribbon-shaped and annelids, nematodes are vermiform, while the starfishes are star-shaped, etc.

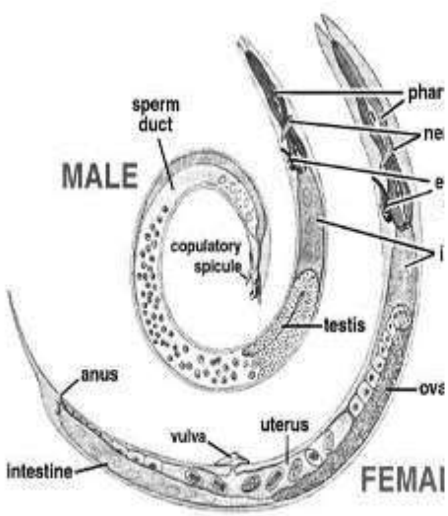


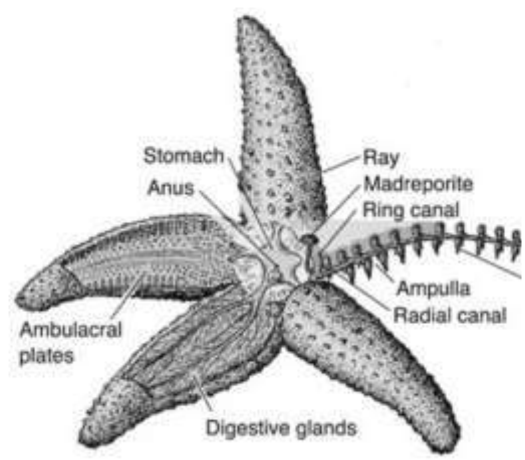
Amoeba



Coelentrata

Flatworm





Starfish

Nematoda

Size: The invertebrate animals exhibit a great variation in size. They range from microscopic protozoans to large-sized cephalopods. The malaria parasite is at the lowest extremity. It occupies only about one-fifth of a human blood corpuscle (RBC). The uppermost extremity is occupied by a species of the giant squids of North Atlantic, *Architeuthis*, has been reported to have attained a total body length of 16.5 meters including tentacles.

Symmetry: Symmetry refers to balanced proportions, or correspondence in size and shape of parts on opposite sides of a median plane.

Asymmetrical Symmetry: In some animals, there are no body axis and no plane of symmetry, hence the animals are called asymmetrical.

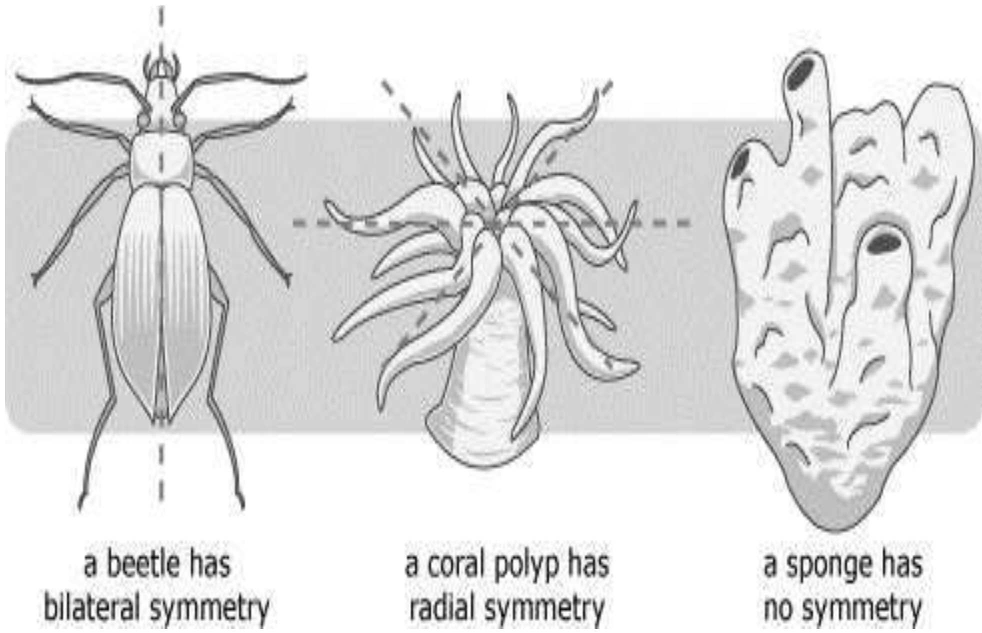
Spherical Symmetry: In spherical symmetry, the shape of the body is spherical and lack any axis. The body can be divided into two identical halves in any plane that runs through the organism's center.

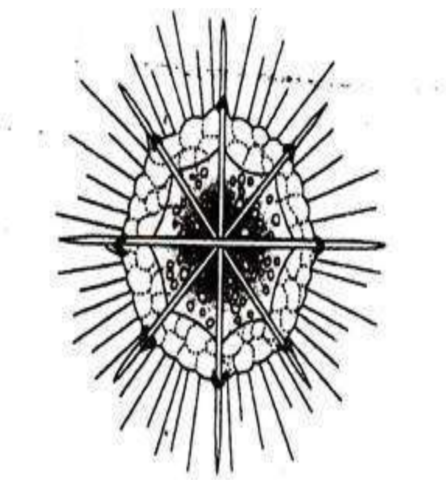
Radial Symmetry: In radial symmetry, the body can be divided into two roughly equal halves by any one of many vertical planes passing through the central axis like the spokes of a wheel. The animals which exhibit primarily radial symmetry are cylinder in form and the similar parts of the body are arranged equally around the axis.

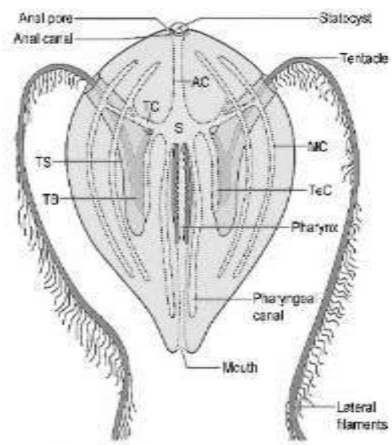
Bilateral Symmetry: In bilateral symmetry, the body parts are arranged in such a way that the animal is divisible into roughly mirror image halves through one plane (mid sagittal plane) only. This plane passes through the axis of the body to separate the two halves which are referred to as the right and left halves.

Biradial Symmetry: The body of animals which exhibits biradial symmetry, represents a combination of both radial and bilateral symmetry. The organs are arranged radially and the body can be divided into two by a mid-longitudinal plane. Ctenophores exhibit biradial symmetry.

Invertebrates represent all types of symmetry. Protozoans display bilateral as well as radial symmetry. Some are asymmetrical. Sponges are either asymmetrical or radially symmetrical. Coelentrates are radially symmetrical. Ctenophores exhibit biradial symmetry. The members of remaining phyla are mostly bilaterally symmetrical. Invertebrates also represent spherical symmetry, principally in spherical protozoan such as Heliozoa and Radiolaria.



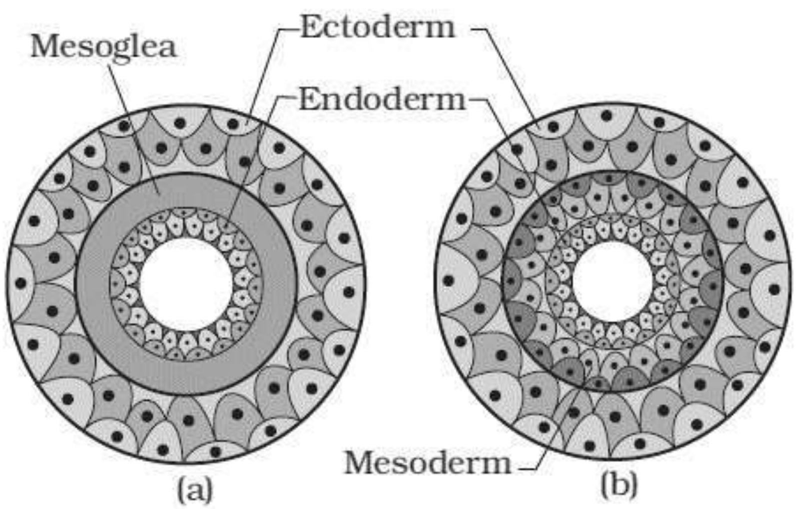




Biradial symmetry

Spherical symmetry

Germ Layers: The germ layers or embryonic cell layers are absent in Protozoa due to its unicellularity. All other invertebrates are either diploblastic or triploblastic. In diploblastic animals, the cells are arranged in two embryonic layers, an external ectoderm and an internal endoderm. An undifferentiated layer, mesoglea, is present in between the ectoderm and the endoderm. While those animals in which the developing embryo has a third germinal layer, mesoderm, in between the ectoderm and endoderm, are called triploblastic. Sponges and coelenterates are diploblastic, whereas other invertebrates are triploblastic.



(a) Diploblastic; (b) Triploblastic

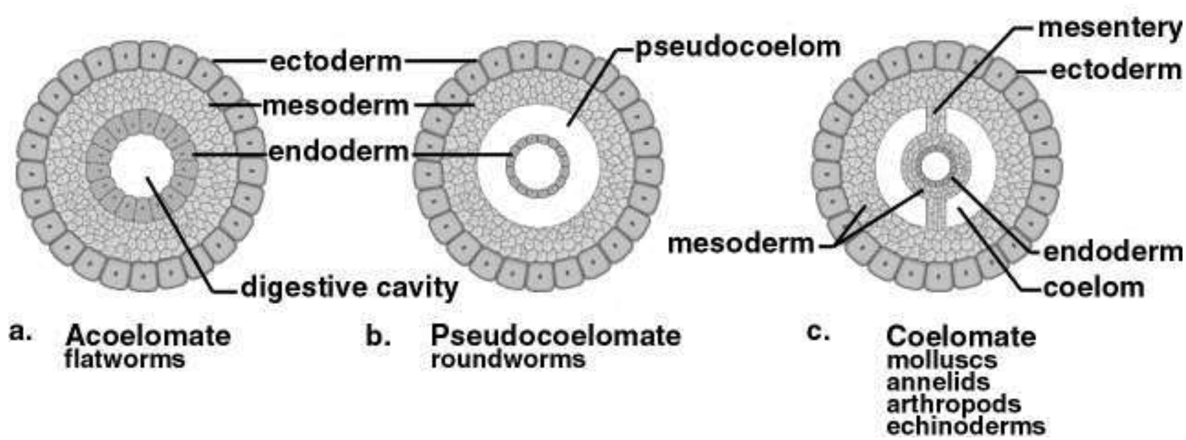
Simple Integument: The body covering of invertebrate animals is simple. In protozoa, it is a delicate plasma membrane, while some have developed a protective covering, pellicle. Most invertebrates possess an outer protective epidermis, which is made of single layer of cells, while in others have further added a non-cellular cuticle or chitinoid covering secreted by underlying epidermis.

Multiple Movement Devices: Various devices for movement are found in invertebrates. Some invertebrate animals are sessile, such as sponges and corals, while others move from one place to another. Protozoa move by pseudopodia, flagella and cilia and contractile myonemes. Coelenterates and molluscs exhibit tentacular movements. Annelids move by setae, parapodia and suckers. Arthropods move with jointed legs, while echinoderms take the help of arms which are with or without tube feet, for their movement.

The Presence or Absence of Segmentation: The members of several invertebrate phyla are characterized by segmentation in their bodies. Certain flatworms exhibit pseudo segmentation, as their long bodies are made up of numerous sections. True segmentation is found in Annelida and Arthropoda.

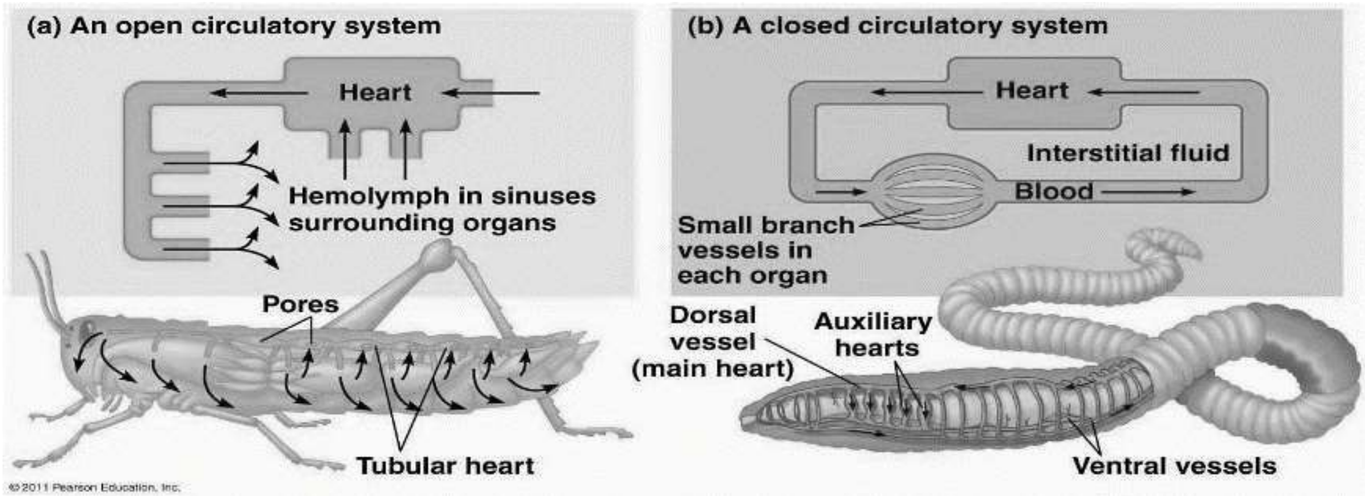
Absence of endoskeleton: The invertebrate animals do not possess any kind of rigid internal skeleton to give support to the body and provide surface for attachment of muscles. Many invertebrates are soft bodied, while some, like arthropods and molluscs, possess hard exoskeleton for supporting and protecting their body.

Types of Coelom: Presence or absence of a cavity between the body wall and the gut wall is very important in classification. The body cavity, which is lined by mesoderm is called **coelom**. Animals possessing coelom are called **coelomates**, e.g., **annelids, molluscs, arthropods, echinoderms**. In some animals, the body cavity is not lined by mesoderm, instead, the mesoderm is present as scattered pouches in between the ectoderm and endoderm. Such a body cavity is called **pseudocoelom** and the animals possessing them are called **pseudocoelomates, e.g., aschelminthes.** The animals in which the body cavity is absent are called **acoelomates**, e.g., **platyhelminthes** .



Digestion: In invertebrates, the digestion of food takes place within the cell (intracellular digestion) as well as outside the cell (extracellular digestion). In protozoans and sponges, the digestion of food takes place intracellularly. In coelenterates, the digestion of food lakes place both intracellularly as well as extracellularly. All other invertebrates exhibit extracellular digestion.

Circulation: Blood vascular system is well developed in higher invertebrates. Some, like arthropods and molluscs, possess open circulatory system, while in others the blood flows in closed vessels, (closed circulatory system).



Respiratory System: Protozoans, sponges, coelenterates and many worms have a direct diffusion of gases between the general surface of the organism and the environment. In most annelids, the exchange of gases takes place through the moist skin. Gills are common in most higher invertebrates. Echinoderms possess branchiate and tube feet for this purpose. Sea cucumbers have respiratory trees which act as respiratory organs. In insects, the tracheal system is adapted for aerial respiration.

Excretory Mechanisms: In protozoans, sponges and coelenterates, excretion is performed by direct diffusion through cell membranes. Flatworms possess characteristic flame cells, while annelids and molluscs possess true nephridia for the purpose. In insects, the excretory organs are Malpighian tubules. Echinoderms and some other invertebrates have amoeboid cells or phagocytes for storage and disposal of excretory products to outside.

Nervous System: In radially symmetrical invertebrates, e.g., coelenterates, the head is absent and the central nervous system is represented by a ring of nerve-tissue encircling the body. In bilaterally symmetrical invertebrates, the central nervous system comprises a pair of nerve cord running along the mid-ventral line of the body. The nerve ring and the nerve cords bear ganglia. In higher invertebrates, the head ganglia form the brain. Invertebrate nervous system is characterized by solid nerves; these are not hollow within.

Varied Modes of Reproduction: Modes of reproduction vary from simple asexual binary fission to most complicated sexual reproduction. In certain cases, parthenogenesis has also been observed in which an unfertilized egg develops into a complete individual.

Cold-Blooded Animals: All invertebrates are cold-blooded, i.e., they cannot keep body temperature constant all the time**.**

Classification of Invertebrates

There are over 30 phyla dedicated to invertebrates. The major exclusively invertebrate phyla that are still in existence today are the following:

Phylum (includes)	Notable Characteristics	Example
Porifera (sponges)	multicellularity, specialized cells but no tissues, asymmetry, incomplete digestive system	sponges
Cnidaria (jellyfish, corals)	radial symmetry, true tissues, incomplete digestive system	jellyfish
Platyhelminthes (flatworms, tapeworms, flukes)	cephalization, bilateral symmetry, mesoderm,	flatworm

Phylum (includes)	Notable Characteristics	Example
	complete digestive system	
Nematoda (roundworms)	pseudocoelom, complete digestive system	roundworm
Mollusca (snails, clams, squids)	true coelom, organ systems, some with primitive brain	snail
Annelida (earthworms, leeches, marine worms)	segmented body, primitive brain	earthworm
Arthropoda (insects, spiders, crustaceans, centipedes)	segmented body, jointed appendages, exoskeleton, brain	insect (dragonfly)
Echinodermata (sea stars, sea urchins, sand dollars, sea cucumbers)	complete digestive system, coelom, spiny internal skeleton	sea urchin

The organization of invertebrates into each of these phyla is based on their evolutionary relationships to each other. Within each phyla, the organisms share certain traits and a certain level of structural organization. Generally, this organization becomes increasingly complex as invertebrate species diverged and new phyla were formed. The details of this increased complexity will be discussed in the *Invertebrates: Evolution (Advanced)* concept. In this concept we will summarize the types of organisms found within each phylum and briefly list the features that distinguish them from species of other phyla. Each of these phyla is further discussed in later concepts.

Porifera and Cnidaria

The phylum porifera contains the earliest invertebrates: the sponges. Sponges lack true tissues. Instead of tissues, sponges have specialized cells that carry out functions such as digestion and reproduction. Sponges are both extremely simple organisms and very well-adapted in an evolutionary sense. They have been around in a similar form for well over 600 million years. The phylum cnidaria includes jellyfish, hydrozoans, and corals. They are **radially symmetrical** and have true tissues. Many cnidarian species are critical members of the vast coral reefs found in tropical marine regions. An example of a sponge species is shown in **Figure** below.

[Figure 2]

A sponge in its natural marine environment.

Platyhelminthes and Nematoda

Flatworms make up the phylum platyhelminthes. They develop from three embryonic cell layers called **germ layers** and exhibit **bilateral symmetry.** Both flatworms and the roundworms of the phylum nematoda include many parasitic species, a number of which are infectious to humans or livestock. These two phyla therefore have an enormous impact on the health and economy of humans. Unlike flatworms, roundworms have an incomplete body cavity and a complete digestive tract. **Figure** below shows examples of a non-parasitic flatworm and a parasitic roundworm species.

[Figure 3]

A parasitic roundworm (left) and a non-parasitic flatworm (right).

Annelida and Arthropoda

Annelida consists of segmented worms, such as the familiar earthworm and leeches. They exhibit a **closed circulatory system,** a nervous system with a primitive brain, and a specialized digestive system. The closed circulatory system pumps blood throughout the length of the worm's body. Annelids generally have a well-developed body cavity, an excretory system, and a nervous system with a primitive brain.

Arthropoda is an extremely large phylum consisting of over 80% of all species alive on earth today. They include insects, arachnids, and crustaceans. Arthropods have segmented bodies with jointed appendages and an open circulatory system with several hearts. Some species within the phylum arthropoda were the first animals to leave the aquatic environment of their ancestors and venture onto land. Arthropods have a tough exoskeleton made of a complex carbohydrate called **chitin,** and some species have gills for gas exchange. Arthropods also have an excretory system and a nervous system with a primitive brain. Members of the phyla annelida and arthropoda are shown in **Figure** below.

[Figure 4]

An arthropod species (left) and an annelid, the earthworm (right).

Mollusca and Echinodermata

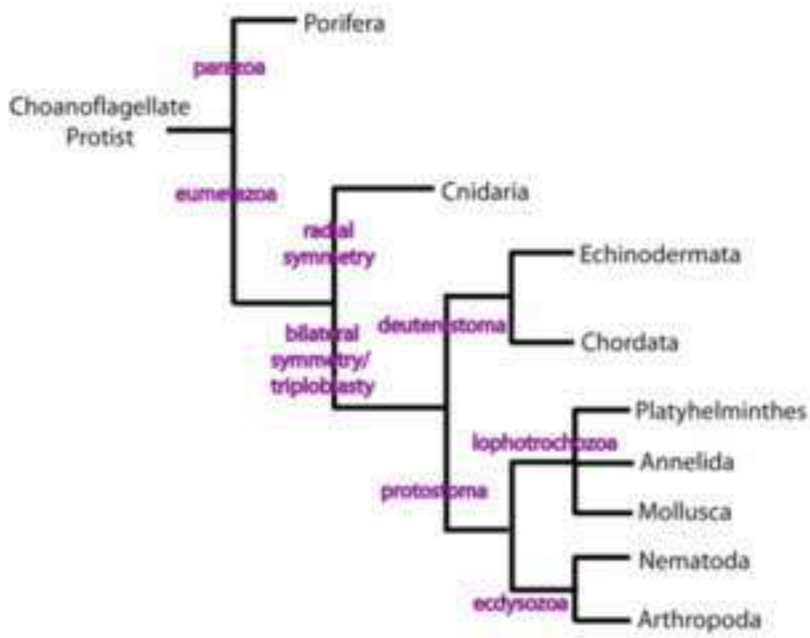
The phylum Mollusca is a highly diverse phylum that includes clams, octopi, and squids. One distinguishing characteristic of mollusks is the presence of a muscular foot called a **mantle** that can be used for locomotion. Many mollusks have a solid exoskeleton made of calcium carbonate. The exoskeleton is secreted by the mantle. Another unique feature of mollusks is a specialized feeding structure called the **radula** that is located within the mouth. The radula contains teeth made of chitin that are used to chew or scrape food. One class of mollusks that includes the squid and octopus has the most highly evolved nervous system of all invertebrates.

Echinodermata is considered the closest related phylum to Chordata. Like chordates, echinoderms have a type of embryonic development in which the opening for the anus is formed prior to the opening that becomes the mouth. The characteristic feature of echinoderms is a spiny surface. They have an internal skeleton made of calcium spines that lies underneath a thin ectodermal layer of tissue. Another interesting trait of echinoderms is that they are bilaterally symmetrical in their juvenile stages but then develop into radially symmetrical adults. In addition, echinoderms have a vascular system that pumps water instead of blood. Echinoderms include sea stars (starfish), sea urchins, and sand dollars. Examples of mollusks and echinoderms are shown in **Figure** below.

[Figure 5]

Invertebrate Evolution

The evolution of invertebrates from the earliest sponge species to the more recent echinoderms established a number of fundamental features of higher organisms. The organization of the eight major phyla of invertebrates into a phylogenetic tree is shown in **Figure** below. Each branch point in the tree represents a significant evolutionary development. These developments led to an overall step-by-step increase in the level of complexity of invertebrates.



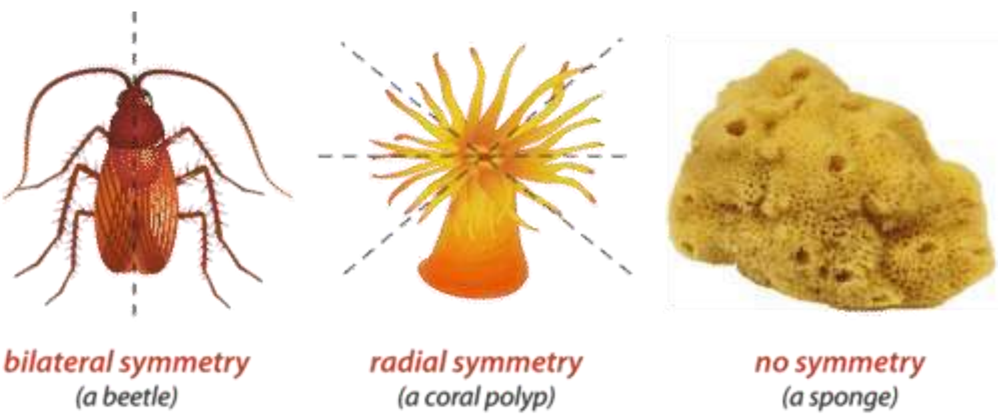
[Figure 2]

This phylogenetic tree shows where different phyla split off and the different characteristics that each developed.

True Tissue

The first multicellular animals, the sponges, exhibit a very simple level of organization. Sponges do not possess true tissues or organs. This is referred to as **parazoa.** Instead, sponges have what is called cellular-level organization. In cellular-level organization, specialized cells carry out certain functions within the organism, such as digestion and reproduction.

The phylum Cnidaria contains what are considered the first **eumetazoans,** meaning that they possess true tissues. A tissue is a group of similarly structured cells that all work together to carry out a particular function. This is a more complex level of organization, termed tissue-level organization, than the cell-level organization seen with the sponges. The development of primitive tissues is the first step in the development of complex organ systems, such as the mammalian respiratory system. Cnidaria were also the first animals to show symmetry in their body plan. They are radially symmetrical which means that if they are divided into two halves from top to bottom, those two halves will be identical no matter where the division is made.
Finally, cnidarians are **diploblasts** meaning that all of their tissues develop from two primary embryonic tissue layers called germ layers. These two layers are the ectoderm (outer layer) and the endoderm (inner layer). The presence of only two germinal tissue layers limits the number of distinct tissues that can be formed within an organism.



[Figure 3]

Symmetry in Invertebrates. Sponges lack symmetry. Radial symmetry evolved first. This was followed by bilateral symmetry. How do the two types of symmetry differ?

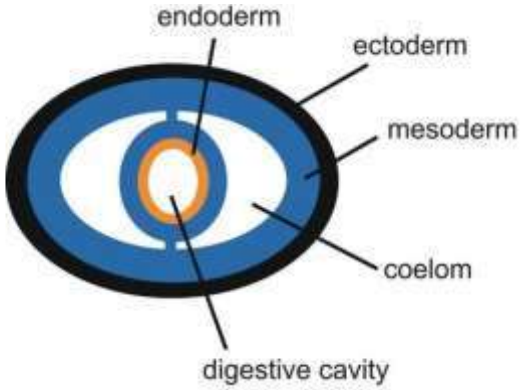
Bilateral Symmetry and Cephalization

The next major evolutionary event within the invertebrate phyla is the transition from radial to **bilateral symmetry**. This is first observed in the various worm phyla. A radially symmetrical animal often has a clearly discernible top and bottom. In the case of cnidarians, the bottom can be distinguished in some life stages by the presence of the mouth. However, each "side" of the organism is exactly the same. This makes it difficult for the animal to sense direction. In contrast, a bilaterally symmetrical animal has a distinct head and a distinct tail region. The head region is referred to as the *anterior end*, and the tail region is referred to as the *posterior end*. Bilateral symmetry means that a cut along the middle of the anterior-posterior axis is the only way to divide the animal into two equal halves. Bilaterally symmetrical animals are able to distinguish forward from reverse. The differences between asymmetry (sponges), radial symmetry (cnidarians), and bilateral symmetry (worms) are illustrated in **Figure** above.

As bilateral symmetry evolves, invertebrate species begin to show a concentration of nervous tissue in the anterior region. This is called **cephalization**. The process of cephalization occurred slowly over time but it ultimately leads to the formation of the brain encased within a true head. This is a prominent feature of vertebrates within the phylum chordata.

The Mesoderm

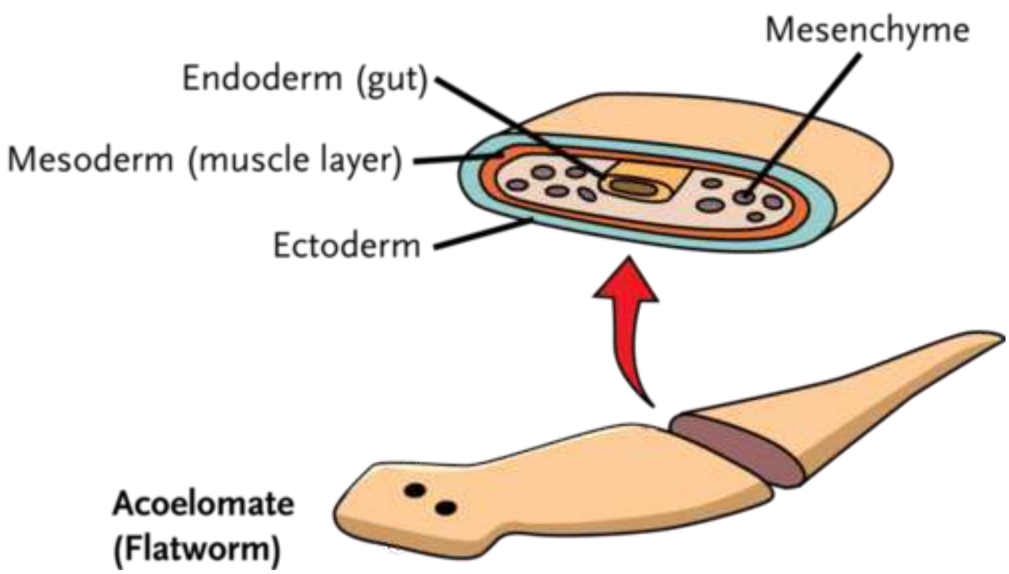
Another evolutionary advancement that arose with bilateral symmetry was the presence of a third tissue, or germ layer, called the **mesoderm.** The mesoderm lies between the ectoderm and the endoderm.



[Figure 4]

The three layers of tissue, or germ layers, are illustrated.

Animals with three germ layers are referred to as **triploblasts.** A number of tissues are derived from the mesoderm, including muscles and the tissues of the vascular system in higher animals. The evolution of the mesoderm is an important step towards the establishment of these organ systems.



[Figure 5]

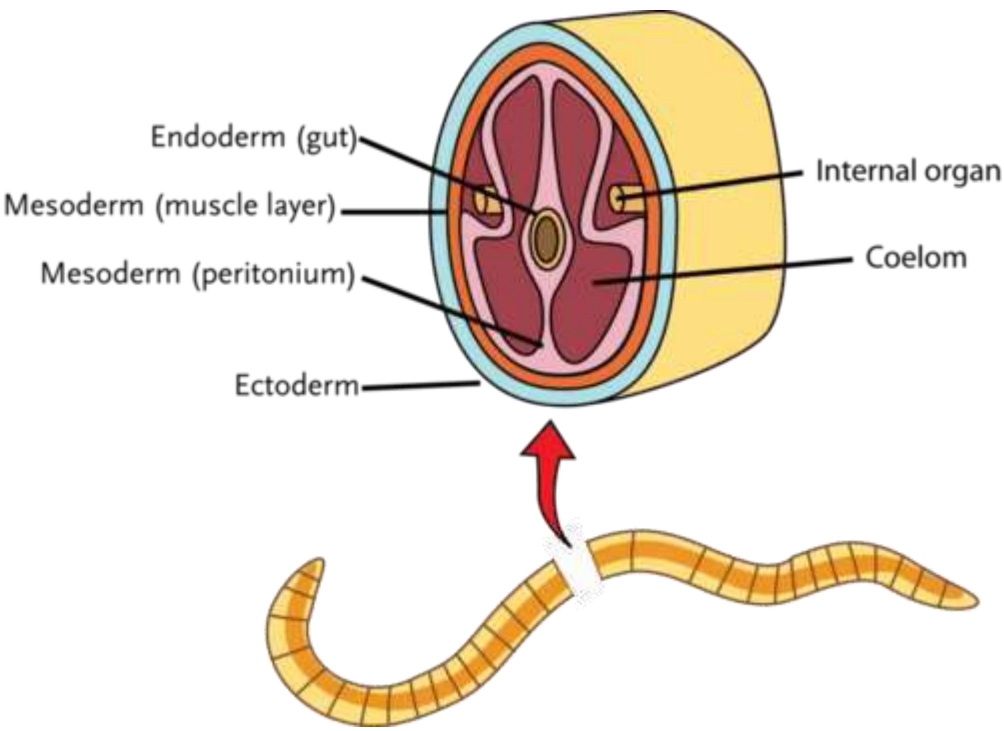
Three Cell Layers in a Flatworm. A flatworm has three cell layers.

Complete Digestive System

Nematodes were some of the first invertebrates to have a complete digestive system with separate openings for the mouth and anus. Porifera, Cnidaria, and Platyhelminthes all have a digestive cavity with a single opening that serves as both a mouth and an anus. The presence of separate openings allows specialization of regions along the digestive tract.

Body Cavity: Coelom

The first animals to show a well-developed **coelom** were the annelids. The coelom is a fluid-filled cavity that forms between the digestive cavity and the body wall. The cavity is lined on all sides by mesodermal tissue. It is important to realize that the coelom, or body cavity, is distinct from the digestive cavity. **Figure** below illustrates the relative position of the coelom and the digestive cavity.



[Figure 6]

Cross Section of an Invertebrate with a coelom. The coelom forms within the mesoderm.

The fluid-filled space of the body cavity allows room for internal organs to develop. The organs suspended within the coelom are often attached to the mesodermal lining, allowing them to remain in a particular place within the body. When the animal is moving, the cushioning of the fluid in the cavity protects the organs. The pressure from this fluid also helps soft-bodied invertebrates hold their shape. This is referred to as a **hydrostatic skeleton.** The hydrostatic skeleton plays an important role in the movement of many invertebrates. Vertebrates contain an internal skeleton and their movements are mediated by the force of muscle contractions on the attached skeletal components. With a hydrostatic skeleton, the contractile force of muscles surrounding the body cavity are opposed by the hydrostatic pressure of the fluid within that cavity. The opposing forces cause shape changes in the animal that produce movement. This evolutionary adaptation allowed coelomates, organisms with a true coelom, to move in an efficient and coordinated fashion without the benefit of an internal, bony skeleton.

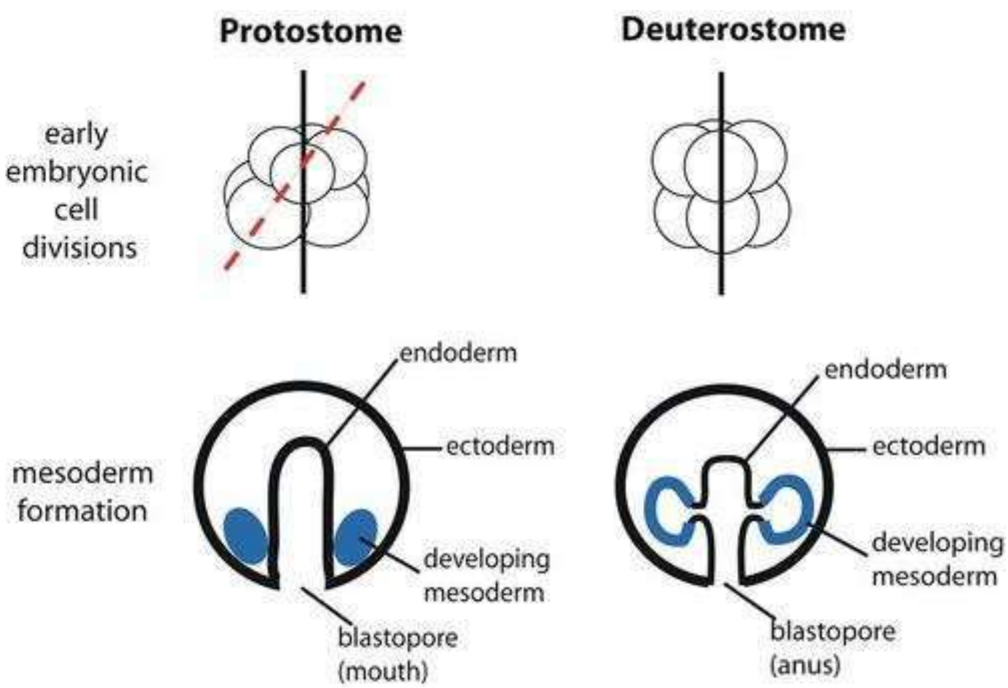
Protostome vs. Deuterostome

The bilateral phyla are divided into two groups based on their patterns of embryonic development: **protostomes** and **deuterostomes**. The characteristics of protostomes and deuterostomes are summarized in the **Table Protosomes vs. Deuterostomes**.

Protostomes vs. Deuterostomes

Protostomes	**Deuterostomes**
Spiral cleavage	Radial cleavage
Determinant cleavage	Indeterminant cleavage
Blastopore = mouth	Blastopore = anus
Schizocoelous	Enterocoelous

In the first few cell divisions of a developing embryo, protostomes generally exhibit a type of cell division called **spiral cleavage,** while deuterostomes exhibit **radial cleavage.** Radial cleavage means that the cell divisions occur parallel to or perpendicular to the axis of the embryo. Spiral cleavage means that the cell divisions occur at an angle to the axis of the embryo. This is shown more clearly in **Figure** below**.** Spiral cleavage is considered to be determinant, meaning that the fate of each cell is fixed as it is formed. In contrast, radial cleavage is considered to be indeterminant, and the fate of a cell can change under certain circumstances. Indeterminant cleavage also means that each cell retains the ability to form a whole organism during these early cell divisions.



[Figure 7]

This diagram shows a comparison of cell cleavage at the 8 cell stage embryo and mesoderm formation later in embryogenesis between protostomes and deuterostomes. In the drawings of early embryonic cleavage, the black line indicates the axis of the embryo prior to cleavage. In deuterostomes cell divisions normally take place along this axis. In protostomes the cell divisions take place at an angle from the embryo axis, indicated in this figure by a red dashed line. This results in an embryo that looks spirally twisted. The bottom drawings show mesoderm formation. In protostomes, the mesoderm develops from a cluster of cells between the endoderm and the ectoderm.

This cluster then divides in the middle to form an opening that becomes the coelom. This is called schizocoelous. In deuterostomes, the mesoderm forms from invaginations of pouches of endodermal tissue. This is termed enterocoelous.

A second distinction between protostomes and deuterostomes is the formation of the mesoderm. In protostomes, the mesoderm forms from a group of cells between the endoderm and the ectoderm. This mass of cells then divides down the middle to form the body cavity. The mesoderm of deuterostomes forms from invaginated pouches of endodermal tissue. This is depicted in **Figure** above.

The third major distinction between protostomes and deuterostomes concerns the fate of the blastopore. As animal embryos develop, they go through several stages, two of which are blastula formation and gastrulation. A blastula is a hollow ball of cells. During gastrulation, one area of this ball invaginates to form a pocket inside of the blastula. The opening formed by this invagination is called the blastopore. In protostomes, the blastopore eventually becomes the mouth of the organism, while in deuterostomes the blastopore becomes the anus, and a second opening formed later in development becomes the mouth. Platyhelminthes, mollusca, annelida, nematoda, and arthropoda are all protostomes. Echinodermata and chordata are deuterostomes.

Ecdysozoa and Lophotrochozoa

As we explored in the *Animals: Classification* concept, there are two general approaches to categorizing organisms: traditional and molecular. The introduction of molecular methods has led to some changes in our understanding of the evolutionary relationships between a number of invertebrate phyla. One example of this is seen with the phyla annelida and arthropoda. Earlier classifications considered these two groups to be closely related based on their segmented body plans. However, the information gathered from molecular studies of phylogeny has made it clear that these two groups are more distantly related. It is likely that their segmented body plans evolved separately, an example of convergent evolution. The fact that a segmented body evolved independently multiple times suggests a strong evolutionary advantage. One advantage of a segmented body is that it allows more flexible movement, particularly in an animal with a solid skeleton. Flexibility around the joint areas connecting the segments facilitates this greater ease of movement.

The most recent classification schemes divide protostomes into two major groups: ecdysozoa and lophotrochozoa. The ecdysozoa includes the phyla nematoda and arthropoda. The species within these phyla have a thick organic layer called a **cuticle** which surrounds the outer surface of their bodies. The cuticle serves as a protective layer, however, it is not able to grow or stretch as the animal increases in size. As the animal grows, it sheds the cuticle in a process called **molting.** This process is shown in **Figure** below.

[Figure 8]

A cicada shedding its cuticle through the process of molting.

Platyhelminthes, mollusca, and annelida make up the lophotrochozoa. Although members of this group may have one of the two features not seen in the ecdysozoa, namely a specialized larval stage called a trochophore larva or a specialized feeding organ called a lophophore, there is no single physical feature that unites these three phyla. This explains why traditional classification did not identify their close evolutionary relationships. However, molecular data strongly suggest that they are close relatives with a shared evolutionary history.

Invertebrates as Bioindicators (part 1)

Bioindicators are species that can be used to monitor the health of an environment or ecosystem . They are any biological species or group of species whose function, population, or status can reveal what degree of ecosystem or environmental integrity is present. Living organism like plant and animal, give particular response for a particular changes in the environment. When any particular changes are found in any ecosystem the bioindicators give a response by changing in their biological, chemical, behavioral and physiological changes.

For the classification of bioindicator there are many scales like; on the basis of pollution, on the basis of habitat, on the basis their physiology, on the basis of their behavior, on the basis of structure etc.

Taxonomic classification include all the living organism which act as bioindicator. In the list of bioindicators flora, fauna as well as chemicals reaction also indicate about environment. According to the flora and fauna, bioindicators are classified as : Plant as bioindicator, Animal as bioindicator.

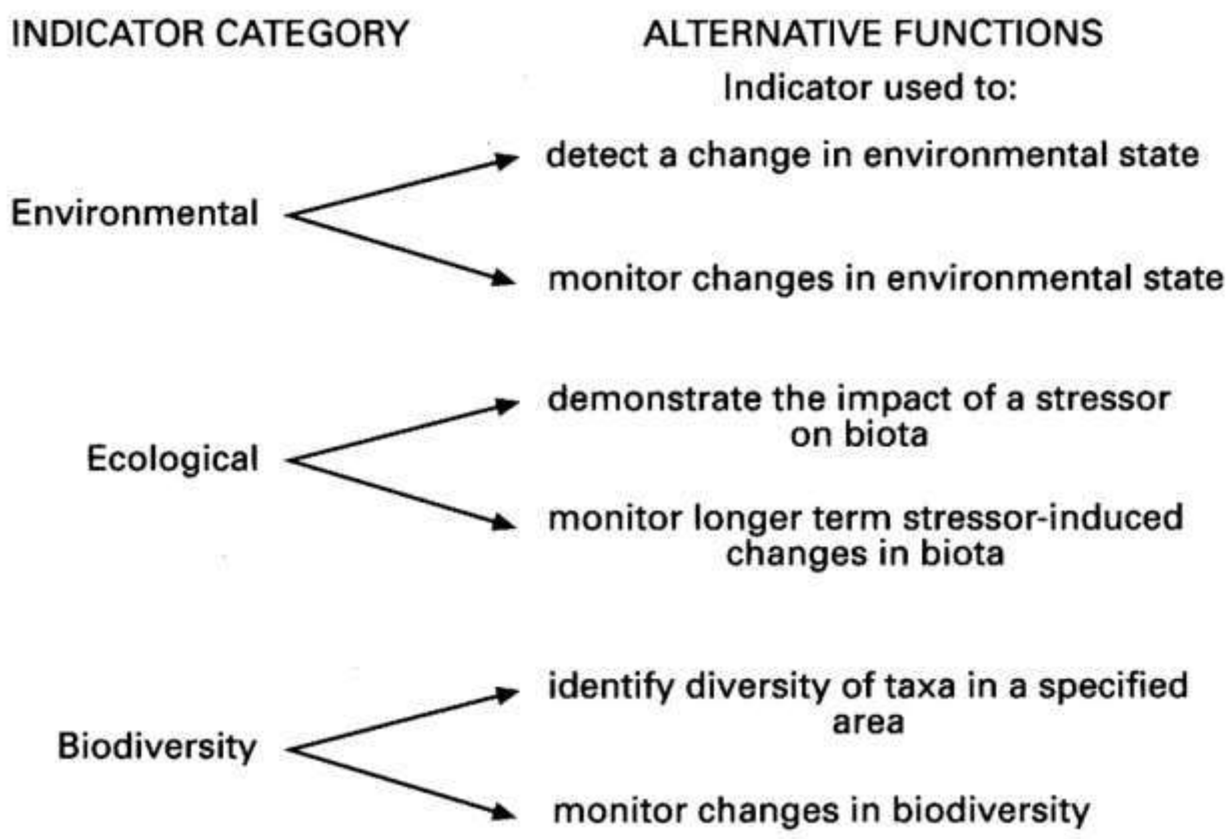
Bioindicator can be defined as ‘‘*a species or group of species that reflects the abiotic or biotic state of an environment, represents the impact of environmental change on* *a habitat, community, or ecosystem, or is indicative of the diversity of a subset of taxa, or of the wholesale diversity, within an area*''.

Bioindicators can be divided into the followings:

1- **Environmental indictor** : acting as early warning indicators of any environmental change to the local environment .

2- **Ecological indicator**: used to monitor a specific ecosystem stress.

3- Biodiversity indicator: to indicate the levels of taxonomic diversity at a site**.**



Environmental and ecological bioindicators can be divided into several categories reflecting their responses to environmental change:

1- **Detectors:** naturally occurring indicators which are sensitive to environmental change and so decrease with added environmental stress.
2- **Exploiters:** increasing in abundance in response to environmental stress.
3- **Accumulators:** organisms which take up chemicals such as heavy metals and can be used to measure toxin levels.

What Can Invertebrates Bioindicate?

McGeoch (1998) divided bioindicators into environmental indicators (changes in physicochemical environment), ecological indicators (impacts of factors on ecosystems), and biodiversity indicators (habitat assessment for conservation). This framework is, however, a little fuzzy with some conceptual overlap between categories, and here we have categorized instead the impacting factors or the habitat properties rather than their bioindicators.

Broadly speaking, bioindicators can be used to indicate:

1- A changing physical environment;

2- A changing chemical environment, particularly with respect to various forms of pollution;
3- The comparative quality or conservation value of habitat;
4- Changes in the ecological status of the habitat with respect to time and place.

How Can Invertebrates Be Used as Indicators?

Invertebrates can indicate changes in the environment through their responses at different levels of organization, ranging from the individual animal to the total invertebrate community. The appropriateness of the level chosen to indicate a changing environment depends on the particular factor(s) that are thought to be acting.

The Individual Animal Level Response

Individual animals may serve as short-term bioindicators of particular environmental conditions, where a response to a particular environmental stress can be demonstrated in their physiology or behavior. For example, in stream-dwelling mayflies and stoneflies, the rate of respiration (physiology) fails to compensate for falling oxygen levels within the water, and this may be coupled with more rapid movement of body parts involved with gas exchange (behavior).

The Species Population-Level Response

Responses here involve changes that are apparent only when observing multiple individuals (populations) of single species in response to an external factor. Such factors may induce changes in population density as a result of effects on invertebrate performance that enhance or reduce rates of recruitment/ mortality. There may also be changes in the ‘‘quality’’ of the individual animals, either in the short term through detrimental impacts on growth and development or in the long term through genetic selection . Species-level responses are most easy to interpret when they are linked to single clearly defined factors, particularly physical or chemical features of their environment. The distribution of particular monophagous species of herbivorous insect on their host plants, for example, serves as a sensitive indicator of changing environmental temperatures.

The Community-Level Response

Monitoring community-level responses is complex in that it involves integrating the responses of numerous species populations. However, the community response provides a valuable perspective with regard to the biological magnitude of changes. There is generally little question that a community response is significant because it reflects changes for multiple species, whereas indicator species responses involve only one species, and many other species are potentially unaffected. In addition, in a world with complex sources of disturbance, the multispecies approach makes use of more biological monitoring tools (i.e., species).

Communities possess several attributes useful for bioindication. These include the number of species present (species richness), the relative abundances of the different species, and the presence of ‘‘important’’ species. These important species may be keystone species, in the ecological sense, that is, species having several other species depending upon them for their existence and where removing them would instantly eradicate several other species.

Selection of indicators is based on the following principles

1- Use of several different taxa rather than relying on a single indicator may give more robust results .
2- A quantitative indicator value needs to be associated with the bioindicators (ideally in a linear relationship).
3- The taxa used as indicators need to be reliably identified, sampled and quantified.
4- Higher and/or lower taxa chosen have well-known and stable taxonomy, with ease of identification emphasized.
5- Biology of organisms is well known, particularly in response to stress factors or to changes in habitat properties of interest.
6- Organisms are abundant, surveyed, and easily manipulated.
7- Higher and lower taxa chosen are distributed on a scale that matches the spatial and temporal requirements of the study.
8- The chosen taxon or groups of taxa are representative of the whole community, or, if not, then their responses are strongly correlated with a known stress factor.

In addition, a number of other issues should be considered. These include

1- the economic significance or aesthetic appeal of the biomonitoring group chosen.

2- the logistics and cost of biomonitoring and evaluation compared with alternative methodologies.

The ideal system is inexpensive, simple, easy to implement, quick, reliable, and easily understood by nonprofessionals. This ideal clearly is hardly ever achievable, and any biomonitoring system is a compromise between precision and cost. There is, nevertheless, an inherent danger that chosen indicator systems can become overcomplicated relative to the problems being addressed. It is important, therefore, that the methodology be optimized for the parameters being used .

Why Use Invertebrates?

Invertebrates may often be particularly good environmental and ecological bioindicators:

1- Their small size makes them sensitive to local conditions.
2- Their mobility enables them to move in response to changing conditions.
3- Short generation times result in rapid numerical responses, and variability in ecological characteristics give a wide range of specific environmental response taxa.
4- Invertebrates also have effective active and passive dispersal mechanisms that often allow wide dissemination and rapid recolonization of disturbed habitats.

5- Many invertebrate species fluctuate in the abundance of individuals present, which may provide indication of subtle changes in environmental conditions but may also confound highly local factors with more general environmental change.

6- Invertebrates are easy to sample in large numbers, they are ideal for studies focusing on species richness (alpha-diversity), species turnover (beta-diversity) and comparisons of community similarity between different landscape features.

Alpha diversity refers to the average species diversity in a habitat or specific area. Alpha diversity is a local measure.

Beta diversity refers to the ratio between local or alpha diversity and regional diversity. This is the diversity of species between two habitats or regions.

Having thus established that invertebrates probably have the better overall potential to serve as good bioindicators, the problem then is choosing which organisms or subsets of communities to use. Literatures showed that a multitude of different aquatic and terrestrial invertebrates from protozoa, oligochaete and nematode worms, isopods, microcrustacea, Collembola, mites, spiders, and insects have all been suggested as bioindicators. Which of them, however, is the best or most appropriate for a particular situation remains a question for debate.

There are some disadvantages when using invertebrates as bioindicators. The most significant of these is the taxonomic challenge, where a relatively low proportion of species are known or described taxonomically. This is especially the case in biodiversity-rich areas, such as the tropics, although strategies such as parataxonomy, morphospecies, strictly designated voucher specimens and new breakthroughs in molecular identification techniques (particularly DNA barcoding) help to overcome this challenge.

The utility of invertebrates for assessing environmental conditions in aquatic ecosystems has thus long been recognized, and this has spawned a variety of biological monitoring tools that use aquatic invertebrates . These monitoring methods recognized that different invertebrate taxa tolerate organic pollution to a lesser or greater extent and that their differing responses can be used to indicate water quality. For example, in rivers, invertebrate groups such as larvae of Plecoptera and Ephemeroptera were shown to be pollution intolerant, whereas other taxa, such as tubificid worms and particular species of chironomid midge larvae, survived under deoxygenated conditions.

Invertebrates as Bioindicators (part 2)

Invertebrates taxa used as indicators:

Nematoda

Nematodes have traditionally been used as accumulator species in soil due to the followings:

1- They are ubiquitous in all habitats that provide available organic carbon sources.
2- In soil, some nematodes feed on higher plants, some on fungi or bacteria; others are carnivores or omnivores.
3- They vary in sensitivity to pollutants and environmental disturbance.
4- Their low mobility
5- Their ability to accumulate toxins.

The use of this group as a bioindicator group still needs to be developed, with promising results coming from their use as soil health indicators in some regions.

Mollusca

Molluscs have some important characteristics to be a suitable indicators:

1- They are easy to record .
2- They are easy to identify.
3- The persistence of snail shells in non-acidic environments means that species richness can possibly be evaluated more accurately than is possible with most

taxa. However, use of empty shells in compiling species lists may result in the inclusion of locally extinct species and the approximate age of shells needs to be taken into account.

4- Many species are highly sensitive to local geological factors and this sensitivity needs to be taken into account when using molluscs as biodiversity indicators .
5- The tissue of mussels can be used to test for toxins locally, as mussels are sessile and accumulate toxins and thus are good accumulator species .

But they have low dispersal abilities so will reflect local conditions but not colonization, so may be good indicators of habitat quality but not of the early stages of recovery.

Diplopoda

Dilopoda may be considered to be good bioindicator due to:

1- Diplopoda is a common group generally present in wood but also in grassland and in agriculture ecosystems.
2- Diplopoda could be considered a ubiquitous taxon, since it was observed in all the soils.
3- Diplopods are detritivores, therefore their assemblage composition, species diversity and population density correlate with vegetation structure.
4- Diplopods are associated with more stable environments, with a significant relationship between soil nutrient quality and microbial activity.

5- Diplopods are able to discriminate between areas with different recovery ages, even if their significance for ecological restoration is not really understood yet.

Millipedes are potentially useful indicators of diversity in some locations, particularly in tropical or subtropical forests. Millipedes may be indicators of the diversity of the decomposer communities in upper soil layers. They have mainly been used as indicators of habitat characteristics and the effects of management and restoration due their dispersal ability, some being highly mobile and able to recolonize disturbed areas rapidly, whereas others are much more sedentary and sensitive to local conditions.

However, they have some issues:

1- There are still many taxonomic issues to resolve.

2- They are often not easy to identify except by a specialist.

Chilopoda

As predators of soil fauna, centipedes are sometimes well suited to indicate diversity of organisms restricted to these systems.

The use of centipedes may be limited due to

1- Their low diversity in most systems.

2- Most centipedes are highly mobile

3- Little is known of their microhabitat sensitivity but they have been used in habitat quality indication.

4- They have the drawback that in the lower and southern latitudes

5- Their taxonomy is poorly known.

Araneae

Spiders have been used as indicators in several locations due to the followings:

1- They are diverse.
2- Relatively easily identified, although many families are taxonomically unstable and difficult to identify.
3- As spiders are predators, they accumulate pollutants and pesticides from their prey and so can be used as ecological accumulators to indicate environmental toxin levels .

Acari

Mites have frequently been used as indicators of diversity, habitat quality, and for ecosystem monitoring, as well as for monitoring the progress of habitat management, particularly in soils. They have been particularly significant in indication of recovery after fire, including in evaluation of different burning regimes. They also appear to be sensitive to toxins and have a role in pollution indication. Mites have a variety of life styles and feeding behavior, and include predators, parasites and herbivores. There are dome problems with mites to be used as indicators:

1- Their extremely high diversity
2- Poorly worked taxonomy.
3- Their difficult identification.

Opiliones

Harvestmen are predators, and reflect changes in the food web of the leaf-litter habitats. Most species have poor dispersal abilities and are slow to recolonize disturbed areas. They therefore make good indicators of high quality habitats but not of early stages of ecosystem recovery.

Pseudoscorpiones

Pseudoscorpions have been used to indicate soil quality but are generally too scarce and too difficult to identify to be useful for indicating diversity.

Crustacea

Crustaceans are frequently used as bioindicators and biomonitors in various aquatic systems due to the followings:

1- They are a very successful group of animals.

2- They are distributed in a number of different habiats including marine, terrestrial and freshwater environments.

3- Some of the special features of crustaceans, particularly of reproduction strategies, may be highly important for the interpretation of data from bioindicator studies using these organisms, and for the development of ecotoxicological endpoints.

Odonata

The Odonata (Dragonflies) are a group of insects that have been extensively used as environmental indicators of stream health. They are relatively good indicators due to:

1- They are easy to identify

2- They are environmentally sensitive taxon which has been effectively used to monitor freshwater systems. Some other used dragonflies for determining the ecological status of river and floodplain systems.

Orthoptera

Orthoptera are considered to be important bioindicators due to the followings:

1- They are sensitive to environmental changes.

2- They are fill essential position in foodwebs.

Grasshoppers and crickets indicate ecological change and the effects of habitat management. They may also be sensitive to pollution. The species *Melanoplus frigidus* is climatically sensitive and may be used to indicate climate change (Finch et al. 2008). Grasshoppers are highly sensitive to changes grassland condition and have great potential still to be explored. Grasshoppers correlated closely with butterflies as indicators of landscape transformation in South Africa .

Mantodea

Mantodes have been used as indicators in many ecosystems due to:

1- They are predators, so they reflect the diversity and condition of lower levels of food-webs.

2- They are highly mobile, and so are sensitive indicators of temporal changes in ecosystems.

3- Most locations have only low levels of mantid diversity and abundance and so they are most likely to be used as general indicators of system health rather than their species composition being used as a precise indicator of diversity of system condition.

But hey are also not always easy to sample in any large numbers and so this would also need to be taken in account when selecting them as bioindicators.

Hemiptera

Bugs have rarely been used as bioindicators in terrestrial environments. Some Hemiptera taxa may have potential role due to

1- The order as a whole is highly diverse.

2- The order covers a wide range of ecological forms.

3- The order is abundant in almost every type of habitat.

Although species in many families are difficult to identify. Relatively easily identified families such as Reduviidae could be used as indicators of predator diversity.

Thysanoptera

Most species are pollen feeders associated with a narrow range of plants, and therefore they indicate floral diversity. Collection and identification may not be straightforward, and direct assessment of floral diversity will be more practical in most cases.

Diptera

Most of Diptera taxa are rarely used as indicators because:

1- The taxonomy of most families of flies is unstable

2- Identification is often difficult, consequently they are rarely used as indicators.

Some taxa of Diptera would be useful indicators due to their ecological diversity. A small number of relatively easily identified families may be useful: Predators such as Asiliidae and pollinators such as Syrphidae.

Coleoptera

Beetles can be used for indicating many kinds of alterations in the environment. This is due to

1- The high number of species with varying habitat requirements .

2- Their sensitivity to different environmental factors (moisture, soil quality).

Beetles may be considered to be representative of insects in general due largely to their taxonomic and ecological diversity. However, this also creates problems, as the order as a whole is too diverse for practical sampling at most sites. Beetles have been used to indicate specific habitat characteristics that may be useful in conservation planning. They have been more extensively used in indicating levels of habitat disturbance or monitoring habitat management .

The tiger beetles (Cicindelidae) are thought to be good indicators due to:

1- They have a relatively stable taxonomy

2- They are easy to record,

3- They are ecologically well known.

4- They include widespread and specialized species

5- They may have diversity patterns that correlate with other taxa

Lepidoptera

Of the Lepidoptera, butterflies have been particularly significant indicators owing to their conspicuousness and ease of identification

Hymenoptera

Within the Hymenoptera, ants are potentially good indicators due to:

1- They are diverse.

2- They are abundant

3- They are easily recorded

4- They are present in most habitats.

Contribution of Invertebrates to agriculture

Invertebrate species are predominant in the food webs, and among the ecosystem engineers, associated with agriculture. They have a major influence on productivity and therefore play a key role in food security. The vast majority of the invertebrate species in agro-ecosystems belong to the phyla Arthropoda (especially the Insecta), Annelida and Nematoda. From an ecological perspective, these animals play important roles in food webs as:

1- Primary consumers (herbivores).

2- Higher order consumers (predators and parasitoids)

3- Mutualists (facultative and obligate pollinators).

4- Parasites of plants, invertebrates and vertebrates.

5- Saprophytes (mediators of decomposition, and energy and nutrient flows into and out of agricultural ecosystems).

In this lecture we focus on three key groups that act in a positive way on agriculture, and may be used, manipulated or moved to benefit agriculture:

1- Soil invertebrates.

2- Biological control agents (BCAs).

3- Pollinators.

I- Soil Invertebrates

Soil invertebrates are a very important component of agricultural biodiversity, and largely determine the structure and the basic functions of natural ecosystems. Key taxonomic groups of soil invertebrates include **Nematoda, Oribatida, Collembola, Diptera, Hymenoptera, Isoptera, Myriapoda, Isopoda, Arachnida, Coleoptera, Mollusca and Oligochaeta**. They are an integral part of agricultural ecosystems and are key actors in maintaining soil health, ecosystem functions and production. The presence of a range of species and organisms capable of supporting critical soil processes is essential for the maintenance of healthy productive soils in the face of changing environmental conditions.

Classification of soil invertebrates

Soil biodiversity has generally been classified by size or by the functions and processes that the organisms mediate. Three main groups are distinguished according to body size :

1- **Macro-invertebrates** or macrofauna (body length >2 mm).

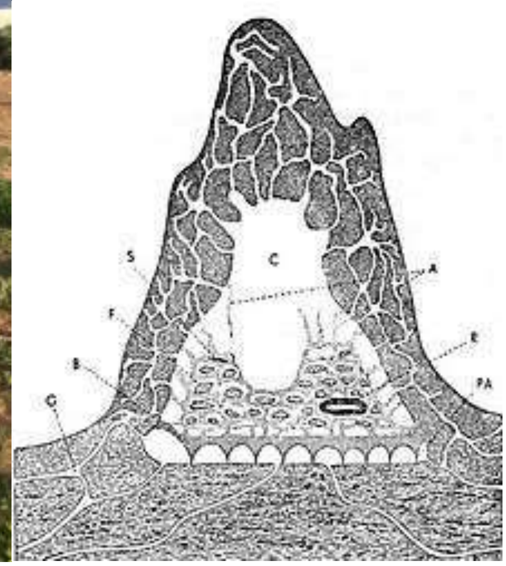
2- **Meso-invertebrates** or mesofauna (body length ranging between 0.2 and 2 mm).

3- **Micro-invertebrates** or microfauna (body length < 0.2 mm).

Soil invertebrates include '**full-time inhabitants**' – such as many micro- and meso-arthropods, earthworms and macro-invertebrates – and '**part-time inhabitants**' such as soildwelling insect larvae and adults, such as solitary bees in semi-arid areas or mound-building insects.

Functional classification of soil invertebrates

Soil invertebrates contribute significantly to many ecosystem functions including decomposition, nutrient cycling and maintenance of soil physico-chemical properties. We can define a functional group as ‘a set of species that have similar effects on a specific ecosystem-level biogeochemical process’. The functions that soil biota carry out depend largely on the efficiency of their digestive systems (which themselves depend on the organisms’ interactions with soil microorganisms, such as bacteria) and on the occurrence and abundance of the biogenic structures they produce in the soil. **A biogenic structure** is a physical structure of biological origin, e.g. termite mounds, earthworm casts, etc.



Termite mounds:the mound is constructed out of a mixture of soil, termite saliva and dung. Although the mound appears solid, the structure is incredibly porous. Its walls are filled with tiny holes that allow outside air to enter and permeate the entire structure.

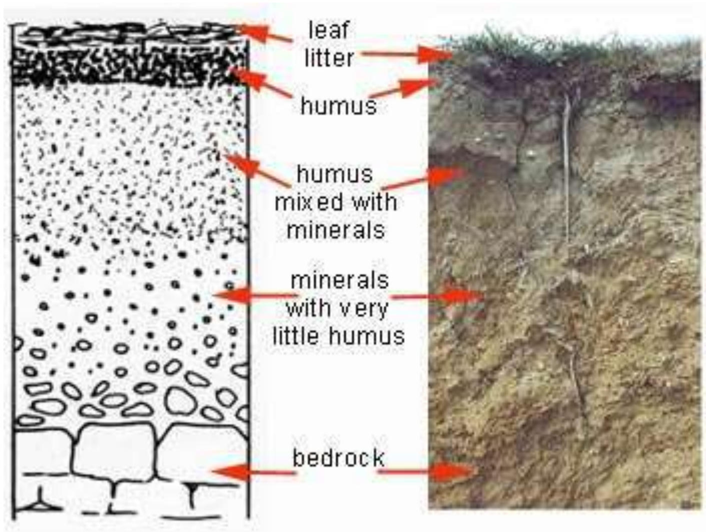
Earthworm cast: Earthworms excrete material known as casts. These may be laid in the soil, where they add to soil mixing, or at the soil surface. Surface casts are usually deposited by earthworms that form vertical burrows.

Using two criteria (efficiency of their digestive systems and the occurrence and abundance of the biogenic structures they produce in the soil) , three large functional groups of invertebrates can be distinguished :

1. **Micropredators** – within this group are the smallest invertebrates, including nematodes. They do not produce biogenic structures. Their main role in soil is to stimulate the mineralization of soil organic matter by preying upon micro-organisms inside soil micro-foodwebs.

2. **Litter transformers** – some members of the mesofauna and macrofauna live in the leaf-litter layer and participate in the decomposition of plant litter through comminution

(breaking up particles) and digestion. They rely on micro-organisms for their digestion, mainly using the external rumen strategy: their faecal pellets act as incubators and they re-ingest them after some period of incubation to take advantage of the assimilable organic compounds released and probably also the microbial biomass accumulated . They produce structures in the litter soil environment, which, being mostly organic. Some litter transformers, as they change resources from one physical state to another, also carry out some soil ecosystem engineering activity; for example, Diplopoda (millipedes) ingest leaf litter and produce faecal pellets with structure and physical properties that are different from the previously ingested plant litter.



3. **Ecosystem engineers** – This functional group comprises organisms that produce solid organo-mineral physical structures through which they are able to modify the availability or accessibility of water, trophic and spatial resources for other organisms. They include earthworms, ants and termites and a few other animals that can excavate soil and produce a wide variety of aggregated structures that have physical and chemical properties

different from the surrounding soil. Their activities and production of biogenic structures can modify the abundance of organisms and the structure of their communities. The accumulation of the structures produced by ecosystem engineers forms functional domains in soil: the ‘drilosphere’ of earthworms, ‘termitosphere’ of termites or ‘myrmecosphere’ of ants. These provide habitats for rather specific communities of smaller invertebrates and micro-organisms . Soil ecosystem engineers also play important roles in the basic soil processes:

1- Hydric functions (water infiltration, storage at different tensions and release)
2- Organic-matter dynamics (sequestration in stable aggregates),
3- Soil chemical fertility and plant growth.

Dung beetles, soil-nesting bees, solitary predatory wasps, invertebrate root herbivores and desert isopods, among other invertebrates, also dig small holes and burrows in the soil. However, the effects of these invertebrates in soil ecosystems are more localized and, with some exceptions, their roles have barely been assessed.

Soil nesting bee

II- Biological Control Agents (BCAs)

Biological control is defined here as the use of natural enemies to regulate pest populations. BCAs are generally present in and around agricultural ecosystems, where they feed on pests and regulate their numbers. Where BCAs are absent, or are not present in sufficient numbers to regulate pest populations, they may be introduced into the cropping system. Pests are generally considered to include all species (invertebrate, vertebrate, weeds and diseases) causing harm to human interests. BCAs are all those species that are natural enemies of pests. They include invertebrates, vertebrates and microorganisms, although only invertebrates are considered in this lecture.

BCAs are primarily predators, parasitoids and diseases of arthropod pests, and herbivores that feed on weed pests.

1- **Predators:** Almost all classes and orders of Arthropoda contain species with predatory lifestyles, and arthropods dominate this guild in and around sustainable cropping systems. Predators consume more than one prey item, and generally many prey items, to complete development of the immature stages; and they often must feed as adults in order to reproduce. The Acari, Arachnida, Opiliones – mites, spiders and harvestmen, respectively – are common predators, and among insects, the orders Odonata (dragonflies), Hemiptera (true bugs), Neuroptera (including lacewings), Coleoptera (beetles), Diptera (flies) and Hymenoptera (bees, ants and wasps) contain predator species of key importance in sustainable cropping systems. Although there are exceptions, most predators are generalist or oligophagous feeders – i.e. they consume more than one prey species, and often feed at more than one trophic level: eating herbivores, other predators, and, in the case of true omnivores, plants.

2- **Parasitodes**: an insect whose larvae live as parasites which eventually kill their hosts, e.g. an ichneumon wasp. Parasitoid lifestyles are considerably more specialized, and are common only in the insect orders Diptera and Hymenoptera. Parasitoid females lay one or more eggs in or on a single host individual. As a result, a parasitoid individual normally kills only one host individual during its development. As the host is killed during parasitoid development, these species cannot be considered parasites; although they must overcome host defenses, and form intimate physiological and biochemical relationships with their hosts, in much the same way that parasites do. As a general rule, parasitoids specialize on a few host species, and the life history of most parasitoid species is tied closely to that of the host or hosts, although some species are fairly broad generalists.

3- **Diseases that act as BCAs**, many points relating to invertebrate BCAs also apply to diseases. Nematoda include some true parasites that do not kill their hosts. The entomopathogenic nematodes some of which are used in augmentative biological control, occupy a niche that is generally considered to be a disease functionally – mainly because reproduction in the dying host leads to a large number of individual nematodes being produced by a single dead host. *Steinernema* spp. (Steinernematidae) and *Heterorhabditis* spp. (Heterorhabditidae) are produced for use as augmentative biological control products. Infective nematodes are suspended in water and are applied as a spray or a drench, in much the same way as a microbial pesticide.

4- **Biological control of weeds with invertebrates** is, at present, mostly tackled using classical biological control. There is, however, some potential for augmentative releases of classical arthropod BCAs of weeds. Any herbivore that is suitably host-specific and likely to be damaging can be used. Among invertebrates, these are almost all insects, with an increasing preponderance of beetles, particularly Curculionidae or weevils and Chrysomelidae or leaf beetles, being used as classical BCAs against weeds.

III- Pollinators

A pollinator is a biotic agent (vector) that moves pollen from the male anthers of a flower to the female stigma of a flower to accomplish fertilization and seed setting. Pollination services by animals, especially insects, are one of the most widespread and important processes that structure ecological communities in both natural and agricultural landscapes. An estimated 60–90% of the world's flowering plants depend on insects for pollination, and these include a great many economically important plant species. Crop pollination used to be (and often still is) provided by wild pollinators spilling over from natural and semi natural habitats close to crop fields. This service has generally been free and therefore has received little attention in agricultural management. If wild pollinators are lacking or additional pollination is required, as is the case in many intensive agricultural production systems, farmers can buy or rent managed honeybees (*Apis mellifera* L.; Hymenoptera: Apidae) or sometimes other species (e.g. bumble bees, alfalfa leafcutter bees and alkali bees).

Bioactive compounds from invertebrates

INTRODUCTION

Multicellular non-chordates starting from the phylum porifera to echinodermata are normally found in the salt water and their ability to live in this halobiotic environment are due to their special adaptations, metabolic activities, secretions are all different from that of other animals and hence majority of them produce bioactive substances, which enables them to combat in that harsh environment.

Many groups of invertebrates produce specific substances that serve them as:

(1) defensive agents against predators, parasites and infections .

(2) chemicals for intraspecific and interspecific communication. Some of these compounds have interesting properties which could potentially be exploited in pharmacology.

The compilation of various literatures and study of bioactive compounds and their medicinal importance from marine non-chordates are as follows:

Bioactive compounds from marine poriferans

Sponges are traditionally rich sources of bioactive substances.

1- Anti-malarial drugs like Manzamines are reported from marine Sponges (Poriferas). Since, the first report of Manzamine A in 1986 and some 40 related compounds have been described from more than a dozen of species of Poriferas . It has been reported that Manzamine A has potent antimalarial activity against rodent malarial parasite *Plasmodium berghei* in vivo.

2- Marine sponges are a good source of unusual sterols and these sterols have the function on biological membranes. The sulphated and alkaloid sterols have exhibited antimicrobial activity.

3- Numerous drugs from marine sponges have been identified as a source of targeting microtubules. The anti-cancer activity of these agents may lie mainly in their inhibitory effects on spindle microtubule dynamics, rather than in their effects on microtubule polymer mass .

Bioactive compounds from coelenterates

1- The jelly fish in general release nematocyst venom from the tentacles which causes painful injuries. The venoms are generally a complex mixture of enzymes and pain-producing factors. The nematocyst venom of *Plexaura physalis* is a mixture of toxic proteins and enzymes, which showed multiple action including dermonecrosis, neurotoxicity, hemolysis and cardiotoxicity . Several species of sea anemones produced toxins that are polypeptides or proteins. The toxins are found very useful tools for studying the voltage dependent Na+ channels in nerve and cardiac muscle cells. It has been suggested that coelenterate toxins would be suitable for studies of tumor cell cytolysis in vitro and in vivo.

2- A number of diterpenoids of *Xenia* sp. exhibited mild-to-potent cytotoxic activities against human lung carcinoma (H460) and liver carcinoma (HepG2) cell lines .

Bioactive compounds from annelida

Marine polychaete (phylum Annelida) has been found to treat several pathophysiological conditions such as arthritis, osteoporosis, bone cancer etc.

1- The most important antimicrobial peptide (AMP) to be isolated from marine annelid is Hedistin. It is purified from the ragworm, *Nereis diversicolor*. Both native and synthetic hedistins are active against Gram-positive and Gram-negative bacteria .

2- The potent bioactive compounds from marine polychaete *Glycera dibranchiata* Coelomic fluid of this annelid exhibited antibacterial activity.

3- The most potent known natural thrombin inhibitor from blood-sucking leeches (*Hirudo medicinalis*), hirudin has served as a standard for designing the natural coagulation inhibitors as an anticoagulant drug. The pharmacological profiling of the isolated thrombin inhibitor has shown that native hirudin is an antithrombotic agent of high quality. However, its clinical use has remained limited, because the substance has not been available in adequate amounts. The progress in molecular biology has stimulated the interest in the structure and function of hirudin. This development resulted in the production of recombinant hirudins (r-hirudins) through gene technology. The biological properties of hirudin combined with the ready availability of recombinant forms make the specific thrombin inhibitor well-suited for use as an antithrombotic drug.

Bioactive compounds from arthropoda

Several bioactive compounds have also been isolated from marine arthropods.

1- The most remarkable bioactive substance is Limulus Amoebocyte Lysate (LAL). It is an aqueous extract of blood cells (amoebocyte) from horseshoe crab *Limulus polyphemus*. LAL reacts with bacterial endotoxin or lipopolysaccharides (LPS), which is a membrane component of Gram negative bacteria. The reaction is the basics of LAL test that is used for the detection and quantification of bacterial endotoxin . In 1970, the US Food and Drug Administration (FDA) approved LAL for testing drugs, products, and devices that come in contact with blood. Prior to date much slower and expensive test were done on rabbits for the purpose.

2- Shrimp is one of the most popular seafoods worldwide, and its lipids have been studied for biological activity in both, muscle and exoskeleton. Free fatty acids, triglycerides, carotenoids, and other lipids integrate this fraction, and some of these compounds have been reported with cancer chemopreventive activities. Carotenoids and polyunsaturated fatty acids have been extensively studied for chemopreventive properties, in both *in vivo* and *in vitro* studies. Their mechanisms of action depend on the lipid chemical structure and include antioxidant, anti-proliferative, anti-mutagenic, and anti-inflammatory activities, among others.

3- *Ozius rugulosus* (Crustacean) showed antibacterial activity against human pathogens *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and *Escherichia coli* K1.

4- Bioactive molecules from ticks: Perhaps the best-studied source of tick bioactive molecules is tick saliva. Tick saliva includes a cocktail of potent proteins that aid in the feeding of the tick on a mammalian host and improve pathogen transmission from a tick to a mammalian host. These proteins are known to act as:

a- Anticoagulants

b- Immunosuppressants and immunomodulators

c- Platelet inhibitors

d- Vasodilators

e- Inhibitors of wound healing

Many of these functions have potential uses in the treatment of disease.

5- Hymenoptera have venom glands producing several chemicals, which are stored in their reservoirs. The venom can be injected through a true sting or a barbed tip that is directed into the victim's body. All Hymenoptera venoms have protein or peptide elements, many with pharmacological properties. The study of social Hymenoptera (bees, wasps, and ants) venom proteins is of great interest, since these venoms can trigger serious allergenic reactions in humans. Most of these proteins are enzymes, specific toxins, or other bioactive molecules. They can be toxic (local) or allergenic reactions to Hymenoptera venoms. These venoms can result in pain, local inflammation , itching, and irritation as immediate responses that after some hours are attenuated.

Melittin is the main compound responsible for most of these reactions, and it is present in several bee venoms. Melittin is the main component (40–60% of the dry weight) and the major pain producing substance of honeybee (*Apis mellifera*) venom . Melittin is a basic peptide consisting of 26 amino acids.

Ant venoms are constituted by a simple organic acid mixture as in Formicinae, or even of complex mixtures of proteins and neurotoxins as in Ponerinae and Myrmicinae, like in bees and wasps. The enzymes found in ant venoms are the same as currently found in other Hymenoptera families, and are of great importance in allergic processes.

Bioactive compounds from molluscs

1- A bioactive compounds that have pronounced antileukemic activity

a- Spisulosine, isolated from the marine clam, *Spisula polynyma*

2- Dolatriol, isolated from marine mollusca *Dollabella auricularia* has pronounced antileukemic activity.

3- A bioactive compound Isoguanosine was isolated for hypotension and relaxation of smooth muscles in mammals from marine *Diaulula sandiegensis*.

4- compound Hexadecylglycerol was isolated from *Archidoris montereyensis* showed antibacterial activity *in vitro* against *Staphylococcus aureus* and *Bacillus subtilis*.

5- The metabolites of *Aplysia dactylomela* were reported as cytotoxic and antitumor activity *in vivo*.

Bioactive compounds from echinoderms

The metabolites of Echinoderms as bioactive compounds mainly are saponins. These are found in sea-urchins, starfishes, sea cucumber etc. Another bioactive compounds at asterosaponins were reported as hemolytic, antineoplastic, cytotoxic, antitumor, antibacterial, antiviral antifungal and antiinflammatory activities .

The neuroendocrine system of invertebrates (Part 1):

All phyla in the animal kingdom that have a nervous system also possess neurosecretory neurons. The results of studies on the distribution of neurosecretory neurons and ordinary epithelial endocrine cells imply that the neurohormones were the first hormonal regulators in animals. Neurohemal organs appear first in the more advanced invertebrates (such as mollusks and annelid worms), and endocrine epithelial glands occur only in the most advanced phyla. Similarly, the peptide and steroid hormones found in vertebrates are also present in the nervous and endocrine systems of many invertebrate phyla. These hormones may perform similar functions in diverse animal groups. With more emphasis being placed on research in invertebrate systems, new neuropeptides are being discovered initially in these animals, and subsequently in vertebrates.

The endocrine systems of some animal phyla have been studied in detail, but the endocrine systems of only a few species are well known. The following discussion summarizes the endocrine systems of some invertebrate phyla .

Endocrine and neuroendocrine cells

Cells in multicellular animals communicate through signaling mechanisms that take place at direct intercellular contacts, or that involve signals released systemically into the extracellular space where they diffuse over large distances and are able to affect targets far removed from the signaling source. There are two mechanisms:

The first mechanism, communication of cells that are in direct contact, is developed to a state of high complexity in the nervous system. Here, a multitude of signals in the form of neurotransmitters chemically couple networks of neurons at specialized cell–cell contacts, the synapses.

The second mechanism of cell–cell communication defines the endocrine system. It involves secreted signals, hormones that affect target cells in a less directed way, since all cells expressing receptors for a given hormone will react when that hormone is released. The endocrine system in bilaterian animals consists of multiple specialized cell populations, sometimes compacted into glands that are found in all parts of the body, and are derived from all three germ layers. Endocrine glands regulate a large number of homeostatic mechanisms. They include:

1- The activity of neurons and muscles

2- The activity of pigment cells during specific behaviors (food intake, fight and flight, and reproduction),

3- The activity of visceral muscle and exocrine glands (digestion)

4- The control of major metabolic pathways (synthesis, storage, and release of carbohydrates and lipids).

5- The control of the ionic milieu through absorption and excretion.

6- The formation and maturation of gametes, and growth and regeneration of the body.

In many instances, endocrine glands form an integrated system in which hormonal production and release is controlled through feedback loops. Most hormones found throughout the animal kingdom are short polypeptides, produced by proteolytic cleavage from larger precursor proteins, called **prohormones**. Similar to other secreted proteins, peptide (pro)hormones are produced in the rough endoplasmic reticulum, processed through the Golgi apparatus, and stored in membrane-bound vesicles. The steroid hormones (e.g. cortisone or estrogen in vertebrates and ecdysone in arthropods) are derived from the lipid cholesterol. Juvenile hormone in insects is an ether derivative of a polyunsaturated fatty acid. Like other lipids, these hormones are synthesized in the smooth ER and are not stored in vesicles.

In addition to endocrine glands, many neurons of the central and peripheral nervous system produce hormones which are released locally into the extracellular space, as well as into the blood stream . In most cases, hormones (all of them of the peptide class) synthesized by neurons are the same that are also produced by non-neuronal endocrine cells.

Neurons that produce hormones are called neurosecretory cells (NSCs). NSCs, and the structures their axons target, form the neuroendocrine system (Fig. 1). In vertebrates, the neuroendocrine system includes the hypothalamus and pituitary, as well as peripheral neurons of the autonomic nervous system that target endocrine cells in the adrenal medulla, the intestinal wall, and the pancreas. NSCs form a distinct population of nerve cells, which are recognized by their content of large peptide-storing vesicles. Vesicles are distributed throughout the cell body, axon, and synapse of the NSC, rather than being restricted to the synapse, like regular neurotransmitters . Furthermore, release of neurohormones, occurring through fusion of the vesicles with the cell membrane, occurs not only at synapses but also anywhere along the soma and axon (Fig. 1B). In this way, the released neurohormone affects multiple cells which are within reach of the NSC.

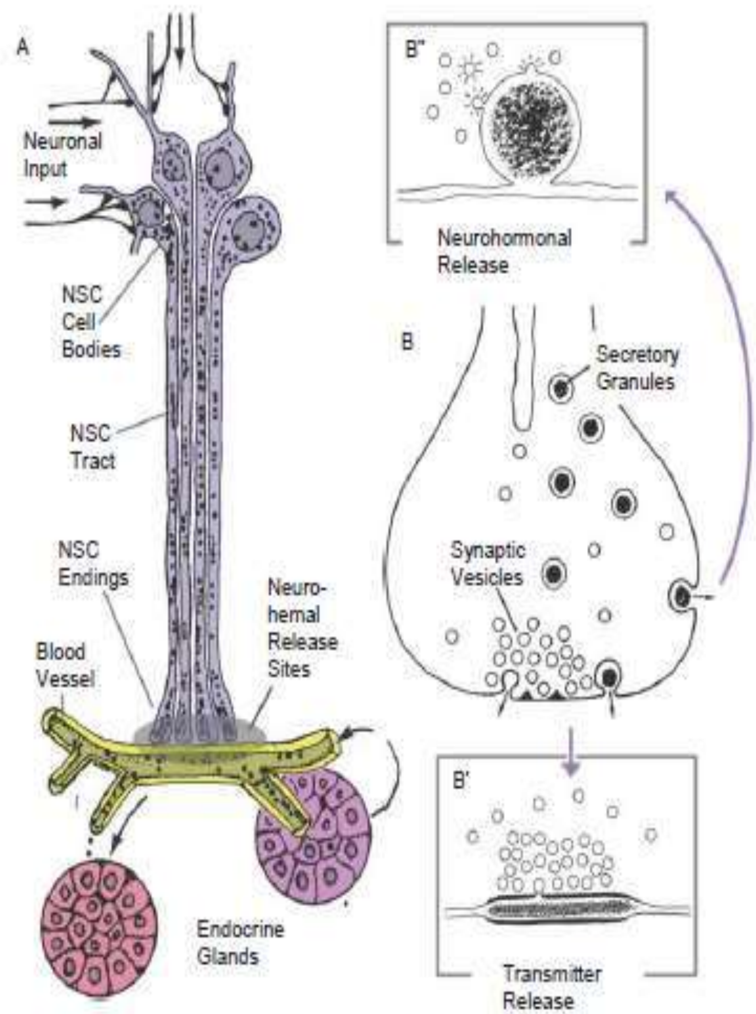


Figure 1 Structure of the neuroendocrine system. (A) Somata of neurosecretory cells (NSCs) are located in the central nervous system and receive neuronal input from presynaptic neurons. NSC axons project to peripheral neurohemal release sites that are frequently in close contact with endocrine cells targeted by the neurohormones released at the NSC terminals (after Scharrer & Scharrer 1963). (B) Ultrastructural aspects of neurotransmitter release (B') and neurohormonal release (B"). Neurotransmitter release occurs exclusively at presynaptic sites from 50 nm vesicles. Neurohormones are stored in large vesicles found throughout the NSC and released outside synapses (after Golding & Pow 1988).

Structure of the neuroendocrine system in invertebrate phyla

Origins: the neuroendocrine system of cnidarians

In cnidarians, endocrine cells occur as scattered neurons and epithelial cell in the epidermis and gastrodermis . **Neurosecretory cells (NSCs)** comprise both:

1-Sensory cells.

2-Subepidermal ganglion cells.

Cnidarians possess almost the full range of **neurotransmitters, neurohormones, and non-neuronal hormones** present in chordates or arthropods. Neuropeptides in cnidarians act as transmitters mediating communication of neurons within the nerve net and stimulating effector organs . Peptides act as stimulators or inhibitors; no specific behavioral responses have been associated with any particular peptide. For example, FMRFamide-expressing cells, mostly bipolar sensory neuron, are concentrated in the tentacles. These neurons control the feeding response: tentacular movement leading to prey capture and ingestion. FMRFamidergic neurons in the planula larvae of the anthozoan (coral) *Hydractinia echinata* exert a tonic effect on motility. Planulae settled on a substratum migrate toward light and then initiate metamorphosis into polyps. Migration occurs in rhythmic bursts of active movement interrupted by resting periods. The peptide LWamide extends the active periods longer, thereby speeding up migration, whereas RFamide has the opposite effect .Beside their role as neurotransmitters, peptides have been shown to systemically act like true hormones on development, and reproduction. Cnidarians reproduce sexually (haploid gametes released in the seawater) and asexually by budding. Development typically undergoes multiple phases where small larval forms (planula) give rise to polyps which then change into medusae. Cnidarians, like many other simple invertebrates, show a pronounced capacity of regeneration, where a small piece of the body can regenerate into the full organism. Each of these reproductive and growth phenomena is under the control of neurohormones released by the NSCs .

The neuroendocrine system of Annelida

The only certain source of hormones in annelids is the central nervous system, most importantly the supraesophageal ganglion. Neurosecretory cells are common and widely distributed in the nervous system and presumably secrete hormones.

Annelid hormones are concerned with the control of

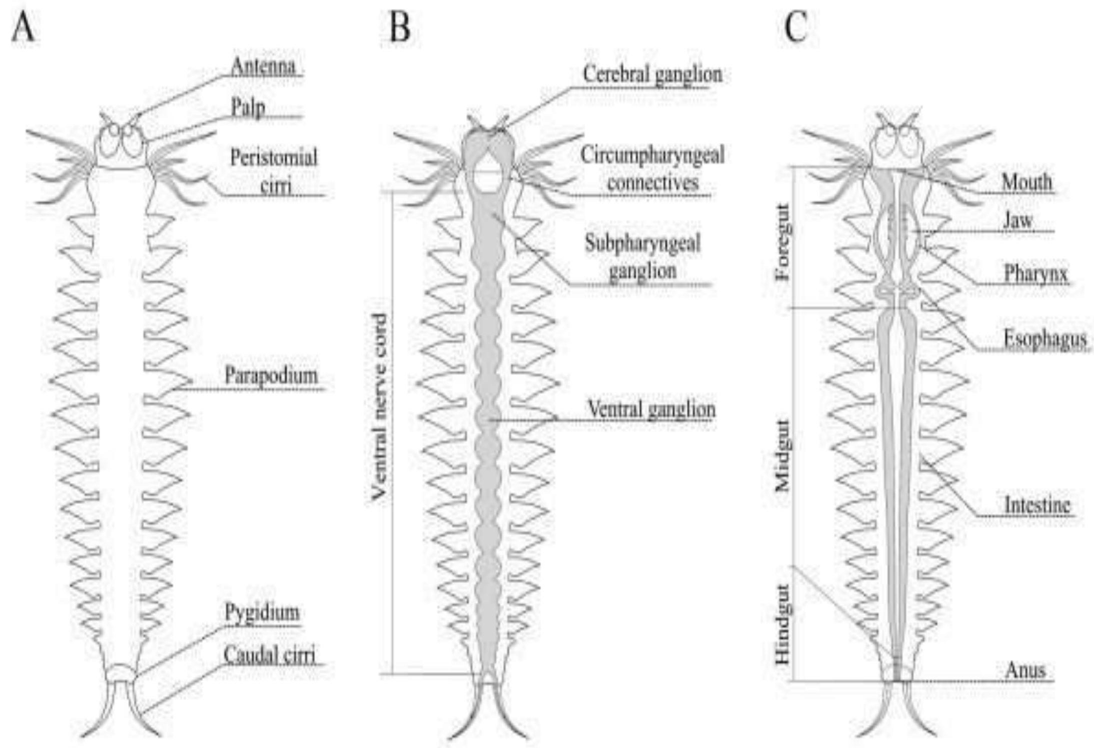
1-Sexual maturation

2-Reproduction

3-Normal and regenerative growth

4- In a few worms, they control the color change.

The cerebral ganglion (brain) of *Nereis*, a marine polychaete worm, produces a small peptide hormone called nereidine, which apparently inhibits precocious sexual development. There is a complex just beneath the brain that functions as a neurohemal organ. The epithelial cells found in this complex may be secretory as well, but this has not been proved. Neurohormones are released from the infracerebral complex into the coelomic fluid through which they travel to their targets.



In the lugworm, *Arenicola*, there is evidence for a brain neuropeptide that stimulates oocyte maturation.

In nereid polychaetes, sexual maturation is inhibited by a juvenile hormone secreted by the supraesophageal ganglion. As the hormone level falls in response to an environmental stimulus, maturation processes begin, and they are completed in the total absence of the hormone.

In nereid polychaetes, both normal and regenerative growth require the presence of a hormone secreted by the supraesophageal ganglion. Possibly the growth hormone is identical with the juvenile hormone, since growth and regeneration fail when the juvenile hormone ceases to be secreted. In lumbricid oligochaetes and many polychaetes, regeneration proceeds in the absence of the anterior nervous system so that if growth is controlled by hormones they are not cerebral in origin.

<u>The neuroendocrine system in mollusks</u>

Within the phylum Mollusca, the class Gastropoda (snails, slugs) has been studied most extensively. The cerebral ganglion (brain) of several species (*e.g., Euhadra peliomorpha*, *Aplysia californica*, and *Lymnaea stagnalis*) secretes a neurohormone that stimulates the hermaphroditic gonad (the reproductive gland that contains both male and female characteristics); hermaphroditism is a common condition among mollusks. This gonadotropic peptide hormone (a hormone that has the gonads as its target organ) is stored in a typical neurohemal organ until its release is stimulated.

The hermaphroditic gonad of *Euhadra* secretes testosterone (identical to the vertebrate testosterone), which stimulates formation of a gland that releases a pheromone for influencing mating behaviour.

The optic gland of the octopus (of the class Cephalopoda) influences development of the reproductive organs on a seasonal basis. It is not known, however, whether any neurohormones are involved or whether this is purely a neurally controlled event.

Within the brain cortex of terrestrial snails (pulmonates), several peptide hormone producing ‘nuclei’ have been described. Among these are:

1-The caudo-dorsal cells (CDCs),

2- Bag cells (BCs)

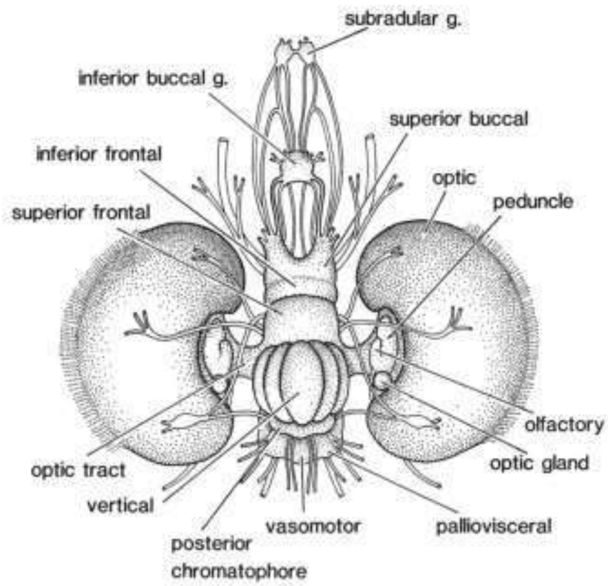
3-Latero-dorsal cells (LDCs)

4- Mediodorsal cells (MDCs)

All of these cell groups produce axons terminating underneath the glial sheath and releasing their hormonal content into the hemolymph. The CDCs, controlling ovulation and egg laying behavior, produce complex recurrent axons terminating in several glialbounded neurohemal ‘compartments’ located in the brain commissure. The LGCs form a large, bilateral cluster of peptidergic NSCs in the dorsal brain. They control body growth and receive synaptic input from peripheral sensory neurons located in the epidermis of the head. Outside the populations of NSCs, several non-neuronal populations of endocrine cells, have been described. They are located within or close to the glial sheath around the brain, are possibly of mesodermal origin, and are innervated by brain neurons. Among these endocrine structures are:

1-The dorsal bodies and lateral lobes (in pulmonates): The lateral lobes are functionally regulate body growth; the dorsal bodies produce a female gonadotropic hormone, as well as ecdysteroid hormones.

2-Optic glands (in cephalopods): The optic gland in cephalopods produces gonadotropic hormones and receives inhibitory input from neurons of the brain .


subradular g.
inferior buccal g.
superior buccal
inferior frontal
optic
peduncle
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olfactory
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vertical
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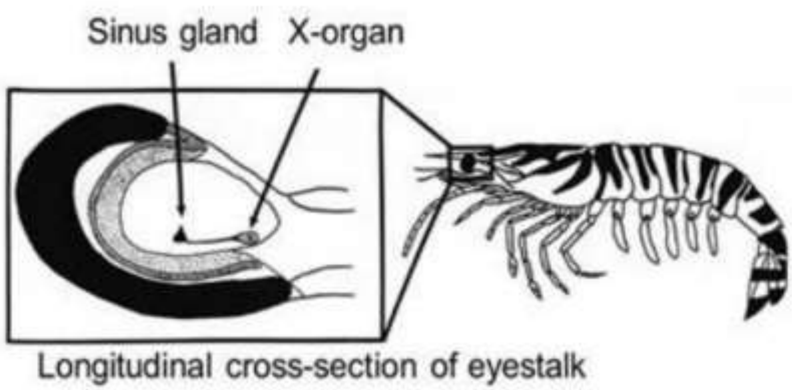
palliovisceral
posterior
chromatophore

The neuroendocrine system of invertebrates (Part 2):

Neuroendocrine system of arthropods

Crustacea

Among the crustaceans, the major neuroendocrine system consists of the neurosecretory **X-organ** and its associated **neurohemal organ**, **the sinus gland**. Both an X-organ and a sinus gland are located in each eyestalk, and together they are termed the **eyestalk complex**. Two endocrine glands are well known: **the Y-organ** and **the androgenic gland.**



In Crustacea, many important functions are controlled by hormones:

1- Color change.

2- Retinal pigment migration.

3- Growth and molting.

4- Metabolism.
5- Reproduction.
6- Development and maintenance of secondary sex characters .

The hormones of crustaceans may be grouped into two groups:

1- **Energetic hormones**: Those which control effector organs (chromatophores, muscles).
2- **Metabolic hormones**: Those which control the more gradual sequences of growth, development and reproduction.

Most of the information about crustacean hormones has been obtained from studies on decapods, but a fair amount is also known about the hormones of the isopods and amphipods.

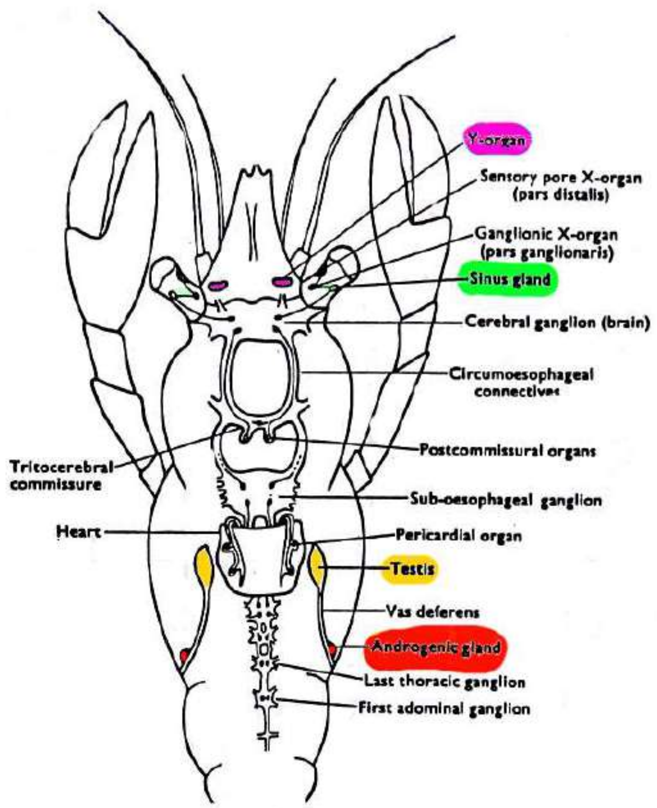
The X-organ–sinus-gland complex is located in the eyestalk. The X-organ passes its secretions to the sinus gland, which acts as a release center into the blood. Hormones liberated from the sinus gland have been shown to influence molting, gonad development, water balance, blood glucose, and the expansion and contraction of pigment cells both in the general body and in the retina of the eye.

The Y-organs lie in the maxillary segment of decapods and are the source of molting hormones, or ecdysteroids, which promote molting and interact with molt-inhibiting hormones from the X-organ.

The brain and thoracic nerve centers produce hormones that promote the development of the sex organs.

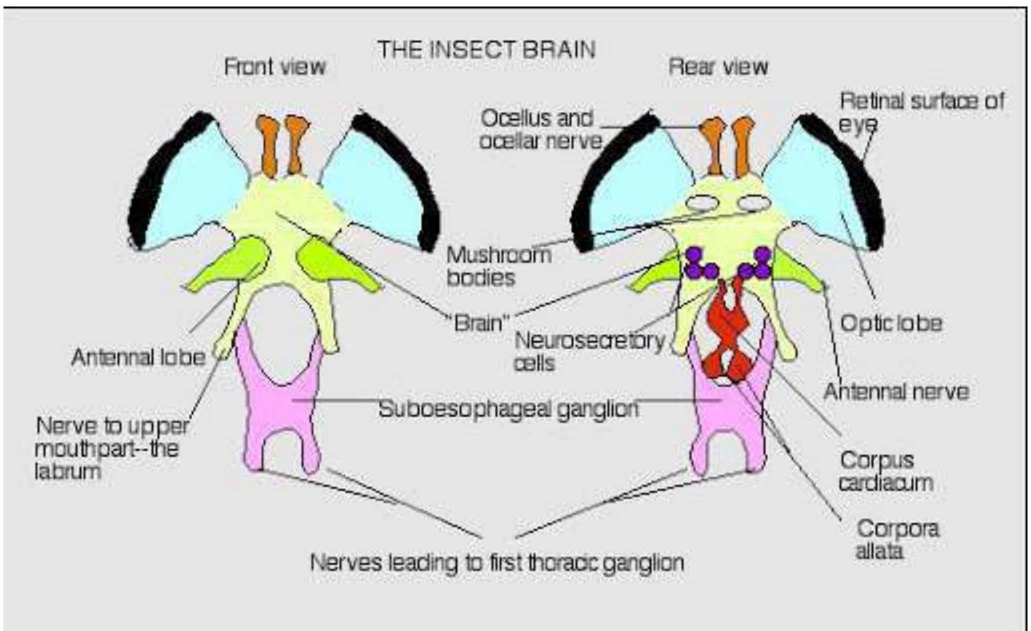
In addition, **certain glands attached to the male reproductive** ducts control the development of the male reproductive system; their removal from a young male will cause it to develop into a female. **The female ovary also acts as an endocrine organ**; its endocrine secretions control the development of the female reproductive system.

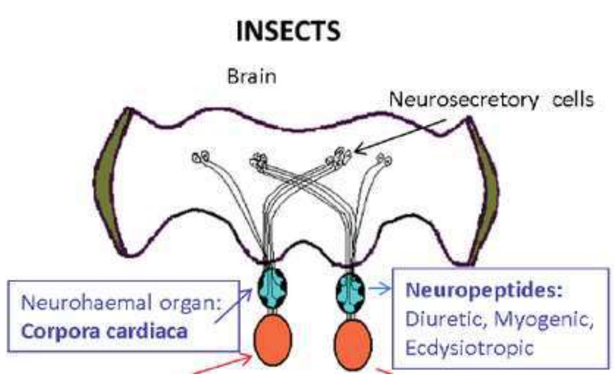
The **androgenic gland** has been described in a variety of crustacean species—isopods, amphipods and decapods. It has been shown to play a role in the regulation of male differentiation and in the inhibition of female differentiation.



Class Insecta

Neurosecretory, neurohemal, and endocrine structures are all found in the insect endocrine system. There are several neurosecretory centers in the brain, the largest being the pars **intercerebralis**. The paired **corpora cardiaca** (singular, corpus cardiacum) and the paired **corpora allata** (singular, corpus allatum) are both **neurohemal organs** that store brain neurohormones, but each has some endocrine cells as well. The ventral nerve cord and associated ganglia also contain neurosecretory cells and have their own neurohemal organs; *i.e.,* the multiple perisympathetic organs located along the ventral nerve cord. The insect endocrine system produces neurohormones as well as hormones that control molting, diapause, reproduction, osmoregulation, metabolism, and muscle contraction.





Molting

A peptide neurohormone that controls molting is secreted by the pars intercerebralis and is stored in the **corpora cardiaca** or **corpora allata** (depending on the group of insects). This brain neurohormone is known as the prothoracotropic hormone (PTTH), and it stimulates the prothoracic glands (also called ecdysial or molting glands). In turn, the prothoracic glands release the steroid ecdysone, which is the actual molting hormone. Ecdysone initiates shedding of the old, hardened cuticle (exoskeleton). Size seems to trigger molting in lepidopterans (moths, butterflies), although the mechanism is not understood.

In immature insects, **juvenile hormone** is secreted by the **corpora allata** prior to each molt. This hormone inhibits the genes that promote development of adult characteristics (e.g. wings, reproductive organs, and external genitalia), causing the insect to remain "immature" (nymph or larva). The corpora allata become atrophied (shrink) during the last larval or nymphal instar and stop producing juvenile hormone. This releases inhibition on development of adult structures and causes the insect to molt into an adult . At the approach of sexual maturity in the adult stage, brain neurosecretory cells release a brain hormone that "reactivates" the **corpora allata**, stimulating renewed production of **juvenile hormone**. In adult females, juvenile hormone stimulates production of yolk for the eggs. In adult males, it stimulates the accessory glands to produce proteins needed for seminal fluid and the case of the spermatophore. In the absence of normal juvenile hormone production, the adult remains sexually sterile.

Diapause

Some insects enter diapause during development. Diapause is characterized by cessation of development or reproduction, decrease in water content (dehydration), and reduction in metabolic activities. It usually is preceded by an accumulation of nutrients resulting in hypertrophy of the fat bodies. Environmental factors (such as temperature, photoperiod, and food availability) cause storage of neurohormones, and the corpora allata become inactive. Termination of diapause can be brought about by reversing the environmental conditions that induced the diapause. Although juvenile hormone can terminate diapause, it triggers diapause in some insects. The stage of the life history may be important in determining the role of JH. For example, in imaginal diapause (characterized by cessation of reproduction in the imago, or adult), the absence of JH initiates diapause. In lepidopterans, a peptide that initiates diapause has been isolated from the subesophageal ganglion.

Reproduction

In some insects the pars intercerebralis secretes a neurohormone that stimulates vitellogenesis by the fat body (vitellogenesis is the synthesis of vitellogenin, a protein from which the oocyte makes the egg proteins). This neurohormone is stored in either the corpora cardiaca or the corpora allata, depending on the species. Uptake of vitellogenin by the ovary is enhanced by JH. In most insects, JH also stimulates vitellogenin synthesis by the fat body. There is evidence that other neurohormones secreted by the pars intercerebralis also influence reproduction. Some induce other tissues to secrete pheromones that influence reproductive behaviour of other individuals. In the live-bearing tsetse fly, *Glossina*, a neurohormone released from the corpora allata stimulates milk glands that provide nourishment to the developing larvae.

The milk gland is a unique tissue in the Dipteran order (found only in species within the superfamily Hippoboscoidea.

Osmoregulation

All insects produce a diuretic hormone and many produce an antidiuretic hormone as well. Insects feeding exclusively on a liquid diet (such as plant sap or blood) have only the diuretic hormone that allows them to eliminate excess fluid and salts through the malpighian tubules (the insect kidney). These osmoregulatory neurohormones are produced both in the brain and in the ventral nerve cord.

Myotropic and metabolic factors

One or more small peptide neurohormones are produced in the brain and ventral nervous system and are stored in the corpora cardiaca and perisympathetic organs, respectively. These myotropic factors stimulate heart rate as well as contractions of the kidney tubules and digestive tract. The corpora cardiaca were named for the heart-stimulating action produced by extracts of these organs. The glandular portion of the corpora cardiaca is thought to secrete the hyperglycemic hormone that causes a rapid increase in blood levels of trehalose, the "blood sugar" of insects. It is sometimes called the hypertrehalosemic hormone. This hypoglycemic hormone apparently is identical to the myotropic factors in at least one species, the American cockroach. An adipokinetic neurohormone released from the orthopteran corpora cardiaca (locusts, grasshoppers) causes the release of diglycerides into the blood during, and immediately after, flight. It is a peptide similar to the myotropic factors.

Phylum Echinodermata

Female sea stars (starfishes) are the only echinoderms that have been studied extensively. A neuropeptide called the gonad-stimulating substance (also called the gamete-shedding substance) is released from the radial nerves into the body cavity about one hour before spawning. Gonad-stimulating substance has been reported in more than 30 species of sea star. This neuropeptide contacts the ovaries directly and causes formation of 1-methyladenine, an inducer of oocyte maturation and spawning. This same hormone has been demonstrated in the ovaries of the closely related sea urchin, where it also promotes maturation of the oocyte.

Invertebrates and ecosystem services

Invertebrates affect most all ecosystem services.

1- **Supporting services**

(a) Primary production

Primary production is essential to ecosystems at local and global scales because it bridges solar and biological energy and affects material cycles.. Ultimately, primary production provides humans with resources, including food and biofuel. Invertebrates positively and negatively affect primary production through direct and indirect interactions.

(*i*) Pollination

Roughly three fourths of all plants and one third of all crops by volume are pollinator-dependent to some degree. Insects provide most of the animal pollination in natural and agricultural systems globally . In unmanaged habitats, pollination facilitates primary production that supports entire ecosystems. Insufficient pollination may make plant species more vulnerable to extinction by reducing fecundity, seed and fruit set, and genetic variability. In agricultural systems, invertebrate pollinators are responsible for successful production of most vegetables, fruits, nuts, seeds, and forage crops that sustain dairy and livestock production. Pollinator scarcity can lead to increased production costs by reducing crop yield and quality or even total crop failure. Invertebrate pollinators consist largely of insects, especially wild and managed bees. The economic value of invertebrate crop pollination in the U.S. is estimated at $3.66 billion/year for unmanaged, native pollinators and $3.7–$13 billion/year (2010 USD) for the European honeybee. These values, based on commercial production, are probably underestimates because they do not consider the multibillion dollar value of home garden and natural vegetation pollination to property owners or outdoor enthusiasts. However, predacious or parasitic invertebrates can also reduce invertebrate pollination services, as in the case of *Apis mellifera* (honey bee) declines due to mite infestations.

(ii) Seed dispersal.

In general, invertebrates move seeds short distances (<10m for some ant species) compared to dispersal by vertebrates or wind (>10 km)

b) Decomposition

Most primary production eventually enters detrital food webs, where invertebrates are the dominant consumers. Invertebrate detritivores fragment detritus into fine particles, easily used by microorganisms , and produce frass, which increase detrital nutrient quality. Invertebrates also foster decomposition by dispersing fungal and bacterial prop agules throughout the litter layer. Invertebrate-mediated decomposition also supports secondary production and enhances the formation of soil and aquatic sediments, maintaining ecosystem structure and function in benthic (freshwater and marine) and detritus based food webs.

(c) Nutrient cycling

Invertebrates can redistribute and alter nutrient availability within an ecosystem through consumption and egestion of plants and detritus, and by physically moving materials and disturbing sediments via bioturbation and bioerosion. Invertebrates also impact the spatial distribution of nutrients between ecosystems. They redistribute nutrients from one system to another during outbreaks and emergence events.

(d) Hydrologic flux

Invertebrates influence water movement within and between ecosystems. Within ecosystems, detritivores decrease litter quantity and burrowing soil invertebrates (e.g., earthworms) increase soil porosity, both of which enhance infiltration rates. Conversely, invertebrates with compact frass decrease soil porosity and infiltration rates. Invertebrate herbivores increase plant water loss by damaging plant tissues, and allow more precipitation to reach the ground by decreasing canopy cover . Similarly, benthic organisms in both freshwater and marine systems, especially burrowing organisms or deposit-feeding organisms, can increase porewater turnover (irrigation) and increase water in sediments, blurring the boundary layer between water and sediment. In marine systems, larger burrowing organisms, such as large polycheate worms (*Nereis*) and lugworms (*Arenicola*), may especially increase porewater exchange in shallow coastal sediments.

e) Habitat formation and modification

Many invertebrates are ‘ecosystem engineers’, i.e., organisms whose presence or activity alters their physical surroundings or changes resource flow, thereby modifying or creating habitats and influencing associated species. These habitat changes range from local to biogeographic-scale modifications, and help to maintain biodiversity, nutrient and biogeochemical cycles, and physical environments. For example, reef-building coral species form three-dimensional structures that serve as habitat for most coastal fish species and protect coastal communities from strong ocean currents.

(2) Provisioning services

Provisioning services are goods obtained from ecosystems. Humans use invertebrate products for food, clothing, medical treatments and building materials. Here, we focus on provisioning services produced directly by invertebrates, although invertebrates indirectly affect the production of many other products both positively and negatively. For example, crop pests negatively impact food production, but allow for the establishment of a multi-billion dollar pesticide industry. Collectively, goods provided by invertebrates comprise a multi-billion dollar industry and improve human quality of life.

(a) Natural products

(i) Food.

Many invertebrates, including crustaceans and mollusks, are farmed and consumed globally. Some invertebrates are used as food for aquaculture, like the brine shrimp fed to farmed prawn and fish. Insects, with high protein and caloric content, comprise a large proportion of some human diets. In addition, other invertebrates, including jellyfish and tarantulas, are regarded as delicacies. Humans also consume products made by invertebrates, such as honey.

(ii) Household goods and ornamental resources.

Invertebrates supply many common household goods.

1- Silk is extracted from silkworm (*Bombyx mori*) cocoons.

2- Scale insect secretions are used to produce shellac, (Shellac is a resin secreted by the female lac bug " *Kerria lacca* "on trees in the forests of India and Thailand)and cochineal, the 'natural red 4' dye used in cosmetics and paints, which is extracted from the dead insect *Kermes vermilio.*

3- Marine sponges are used for various applications, including household cleaning and helmet lining.

4- Corals and other marine invertebrates produce calcium carbonate, which is used for construction materials.

5- Amberized mosquitoes and fossilized trilobites are used in jewelry, and other invertebrates create expensive ornamental products including pearls and red coral.

(iii) Biochemicals and pharmaceuticals.

1- Insects secrete hormones and substances used in birth-control hormones, wound-healing promoters, antiviral agents, and cardiotonic factors.

2- Sea urchins contain holothurin, which is used to treat coronary disorders and cancer.

3- Octopuses produce a compound that eases hypertension.

4- Sponges have antiviral properties that suppress the common cold.

5- Chitin from crustacean skeletons cures fungal infections, heals wounds, and kills malignant cells.

However, some invertebrates, through harmful stings and bites, create a need for the development and use of biochemicals and pharmaceuticals. For example, life-saving antivenom is extracted from several species of scorpions, spiders, ticks, and jellyfish.

(3) Regulating services

Regulating services are those that regulate ecosystem processes or maintain ecosystem structure. We focus on how invertebrates affect water quality, stabilize food webs, and help regulate diseases and pests/invaders. Additional regulating services are described in other sections (e.g., erosion control and storm protection in the section on habitat modification).

(a) Water quality

Invertebrate filtering of particles and contaminants from water counters eutrophication and pollution. In shallow marine and freshwater ecosystems, bivalves (i.e., mussels and oysters) often comprise most invertebrate biomass and filter 10–100% of the water column, though insects and other invertebrates also contribute. By transferring energy and nutrients from the water column to the benthos, bivalves can remove pelagic and drifting contaminants and help reduce toxic phytoplankton blooms. Invertebrates and their diversity are important biological indicators of water quality. The presence or absence of particular taxa is used in bioassessment protocols to examine habitat heterogeneity and water quality in aquatic ecosystems.

In the case of the invasive zebra mussel (*Dreissena polymorpha*), excessive water filtration has altered the Great Lakes, greatly reducing plankton levels and increasing water clarity.

(b) Food web stability

The high taxonomic diversity and biomass of invertebrates helps to reduce fluctuations in the community composition and intensity of interactions within food webs. Increased species richness may generate sufficient functional redundancy to buffer against perturbations.

(c) Disease regulation

Invertebrates serve as hosts for countless parasites and pathogens; conversely, invertebrate predators and parasitoids also regulate many parasites and disease vectors. As the number of invertebrate species is still unknown, the number of pathogens and parasites that use invertebrates as hosts is also unknown. Nevertheless, pathogens and parasites are important ecosystem components that regulate host populations and species interactions. Many infectious human diseases are transmitted by invertebrate vectors, including Lyme disease (ticks) andWest Nile Virus (mosquitoe). Nine of the 13 priority diseases identified by the Special Programme for Research and Training in Tropical Diseases are either transmitted by invertebrate vectors (e.g. malaria, dengue, onchocerciasis), use invertebrates as hosts (schistosomiasis), or are caused by invertebrates (e.g. helminthes, schistosomiasis). However, many invertebrates also control invertebrate vectors of disease. For example, a variety of arthropods prey on ticks in nature, including nematodes, spiders, mites, predatory hemipterans and ants. Additionally, many invertebrate natural enemies are being developed for vector control. Schistosomiasis, caused by parasitic flatworms that use snails as intermediate hosts, can be controlled by trematode parasites or snail species that compete with host snail populations.

(d) Pest/invader control

Biocontrol is the use of organisms to reduce the abundance of pest populations and thus decrease pest damage. Invertebrates control crop-feeding insects and disease vectors through parasitism, direct predation, or transmission of viruses, bacteria and toxins.

Quantitative descriptors of Diseases caused by Invertebrates

Most quantitative descriptors such as prevalence and mean abundance are point estimates based on samples from the whole population of hosts.

(1) **Prevalence**. Prevalence is the number of hosts infected with 1 or more individuals of a particular parasite species (or taxonomic group) divided by the number of hosts examined for that parasite species. It is commonly expressed as a percentage when used descriptively and as a proportion when incorporated into mathematical models. Prevalence is intended as a descriptive statistic for presence-absence data on parasites in a sample of hosts and is used when it is desirable to classify hosts into 2 categories, infected and uninfected, without regard to when the infected hosts acquired their infection.

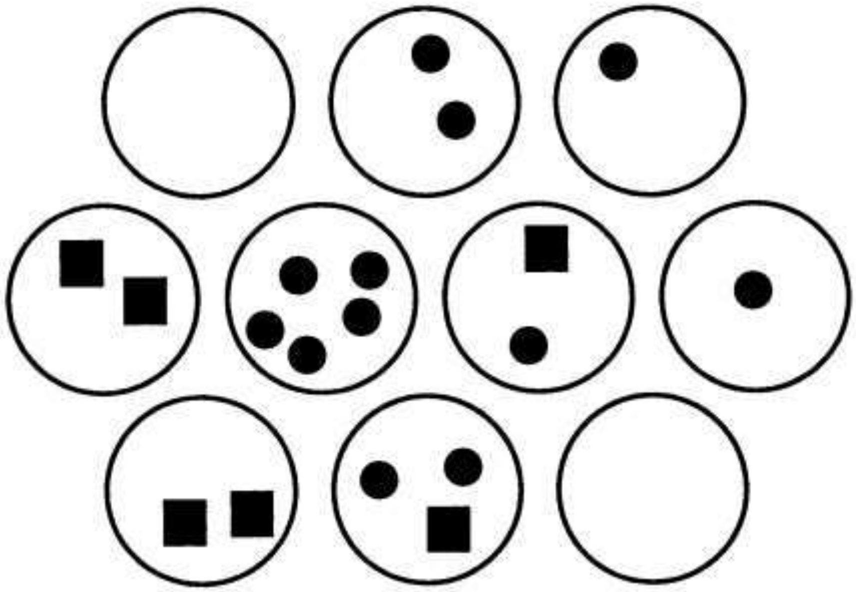


Figure 1

In Figure 1, 10 host individuals are infected with none, 1, or 2 species of parasites. The prevalence of the circle parasite is 6/10 = 0.6 (or 60%)

The prevalence of the square parasite is 4/10 = 0.4 (or 40.

(2) Incidence. Incidence is the number of new hosts that become infected with a particular parasite during a specified time interval divided by the number of uninfected hosts present at the start of the time interval. Remarks: Incidence is a descriptive statistic used to determine the risk of acquiring new infections by individuals in a population of hosts. Incidence is applicable only to the uninfected individuals in the host population, without regard to the number of hosts with existing infections. An example of the calculation of incidence. "In an epizootic of an acute viral disease on a dairy farm with a population of 100 susceptible cows, 7 became sick on day 1 of the outbreak, 15 on day 2 and 10 on day 3. The daily attack rates would be: 7/100 = 0.07 (7%), 15/93 = 0.16 (16%), and 10/78 = 0.12 (12%), respectively." Note the decrease in the denominator as hosts acquiring the infection in 1 time interval are now removed from the susceptible pool for subsequent intervals. Incidence is most commonly used to monitor the spread of clinical disease in populations of humans or domestic animals because determining the number of preexisting cases of the disease is relatively.

(3) Density. Density is the number of individuals of a particular parasite species in a measured sampling unit taken from a host or habitat, e.g., in units of area, volume, or weight. Remarks: Density is used widely in the ecological literature and can be equally applied to parasites. When the sampling unit is an individual host, it would be proper to report infections as "A density of X parasites per infected host (or per host)." However, because of the frequency with which parasitologists use the host as the sampling unit, the terms intensity and abundance, with their implied sampling units, are more concise and seem preferable. We, therefore, recommend that density be used when an accurate census of all parasites in a host is difficult or impossible to make. For example, an efficient density measure of *Trypanosoma lewisi* might be the number of flagellates per milliliter of rat blood. In any case, it is important to specify the denominator to avoid confusion.

(4) Intensity (of infection). Intensity (of infection) is the number of individuals of a particular parasite species in a single infected host.

Intensity is a form of density with the sampling unit specifically defined as an individual infected host. Therefore, intensity is a convenient measure for parasitologists because hosts are discrete and natural sampling units. In Figure 1, 6 hosts are infected with circle parasites, and the intensities are 1, 1, 1, 2, 2, and 5. Four hosts are infected with square parasites, and the intensities are 1, 1, 2, and 2.

The potential confusion of intensity with other forms of density makes it necessary to define it following initial use. Alternative terms for intensity: Although a few authors will likely continue to use synonyms (worm burden, parasite load, and degree, level, or extent of infection), we recommend the use of intensity.

<u>(5) Mean intensity</u>. Mean intensity is the average intensity of a particular species of parasite among the infected members of a particular host species. In other words, it is the total number of parasites of a particular species found in a sample divided by the number of hosts infected with that parasite. Remarks: In Figure 1, the mean intensity for circle parasites is 12 divided by 6 or 2, whereas for square parasites it is 6 divided by 4 or 1.5.

<u>(6) Abundance</u>. Abundance is the number of individuals of a particular parasite in/on a single host regardless of whether or not the host is infected. Remarks: Abundance is also a form of density, and it differs from intensity in that, by definition, an intensity of 0 is not possible whereas an abundance of 0 is appropriate. In Figure 1, the abundances of the circle parasites are 0, 0, 0, 0, 1, 1, 1, 2, 2, and 5, and the abundances of square parasites are 0, 0, 0, 0, 0, 0, 1, 1, 2, and 2. We find the distinction between intensity and abundance to be useful because, in some studies, only the infected host sub-population is of interest; in other studies, the whole host population is of interest. Often in community studies, one might wish to examine phenomena such as cooccurrences where 0-sized populations are important.

(7) **Mean abundance**. Mean abundance is the total number of individuals of a particular parasite species in a sample of a particular host species divided by the total number of hosts of that species examined (including both infected and uninfected hosts). It is thus the average abundance of a parasite species among all members of a particular host population. For example, in Figure 1, the mean abundance of circle parasites is 12 divided by 10 or 1.2; for square parasites, it is 6 divided by 10 or 0.6.

The nesting of parasite populations

(8) Infrapopulation. A parasite infrapopulation includes all individuals of a species in an individual host at a particular time. Remarks: In Figure 1, there are 10 host individuals, but only 8 hosts have infrapopulations; there are, however, 10 infrapopulations: 6 of circle parasites, 4 of square parasites.

(9) Component population: all individuals of a parasitic species in/on all members of a host population at a particular time.

(10) Suprapopulation: all individuals of a parasitic species (whether on or off a host) at a particular time.

(11) Infracommunity: A community of parasite infrapopulations in/on a single host. Remarks: In Figure 2, there are 15 hosts and 11 infracommunities. If individuals do respond to the presence of other species, it is at this level that any selection pressures will occur.

(12) Component community: all infrapopulations of parasites in/on all members of a host population at a particular time.

Remarks: In Figure 2, there are 5 component communities: triangle and square final hosts, octagonal and circle intermediate hosts, and free-living phases.

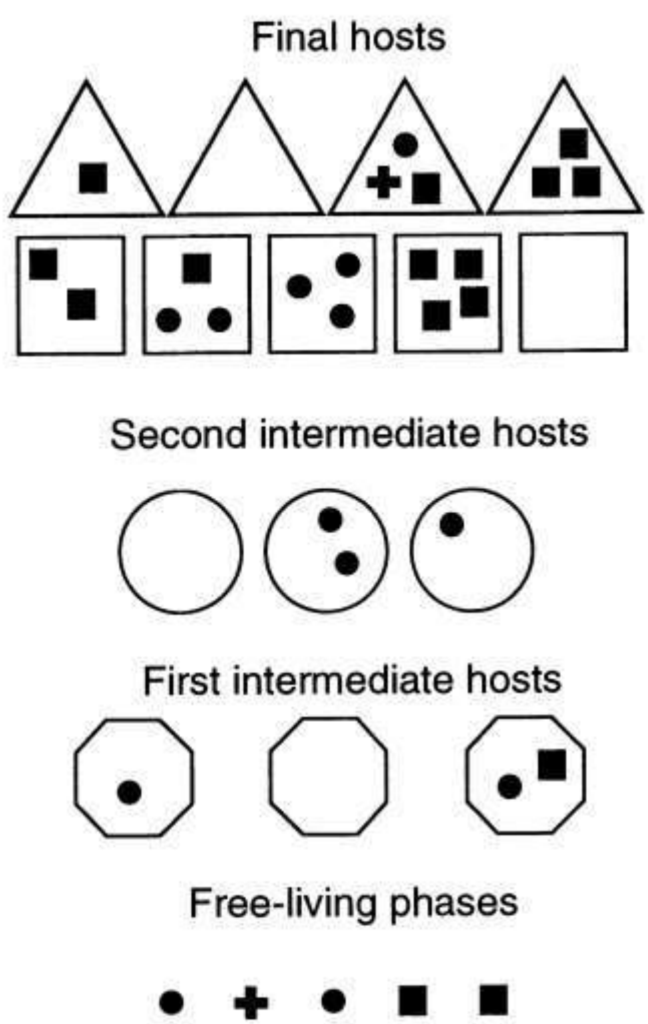


Figure 2

Aggregation of parasites

Parasites are generally **aggregated** among hosts, and it is commonly believed that aggregation is an important feature of the population biology of these organisms. Parasites aggregation creates variability among hosts in the effects of parasites, so the net effect of parasitism on the population of hosts often depends not just on mean parasite burdens, but also on the variability of burdens. From an individual parasite's point of view, aggregation creates variability in the number of other parasites occurring in the same host. If parasites experience density dependence in reproduction or mortality, either due to direct interactions or interactions mediated through the host, then aggregation may change the parasite population growth rate.

Processes that lead to aggregated parasite distribution can broadly divided into two categories: those that produce variability among hosts in exposure to parasites, and those that create variability either in host acceptability to the parasites or in host immune responses.

A fundamental aspect of the relationship between parasites and hosts is contained in the distribution of parasites amongst hosts. This distribution has repeatedly been shown to be clustered or aggregated in the sense that typically, ***a few hosts harbor many parasites, while the remainder of the hosts are virtually parasite free***. Aggregation has very significant implications for both hosts and parasites because of the following:

1- It affects their genetics and evolution.
2- It has been recognized to have many consequences for public health management.
3- It has been recognized to have many consequences for livestock management.
4- Aggregation has been shown to affect parasite ecology by stabilizing host-parasite population dynamics.
5- Aggregation has been shown to affect parasite ecology by facilitating interspecific co-infection as a result of increased host susceptibility.
6- Aggregation also influences parasite evolution by, e.g., increasing the level of intra-specific competitive interaction .
7- Aggregation of parasites amongst hosts affects the transmission of infectious human diseases.

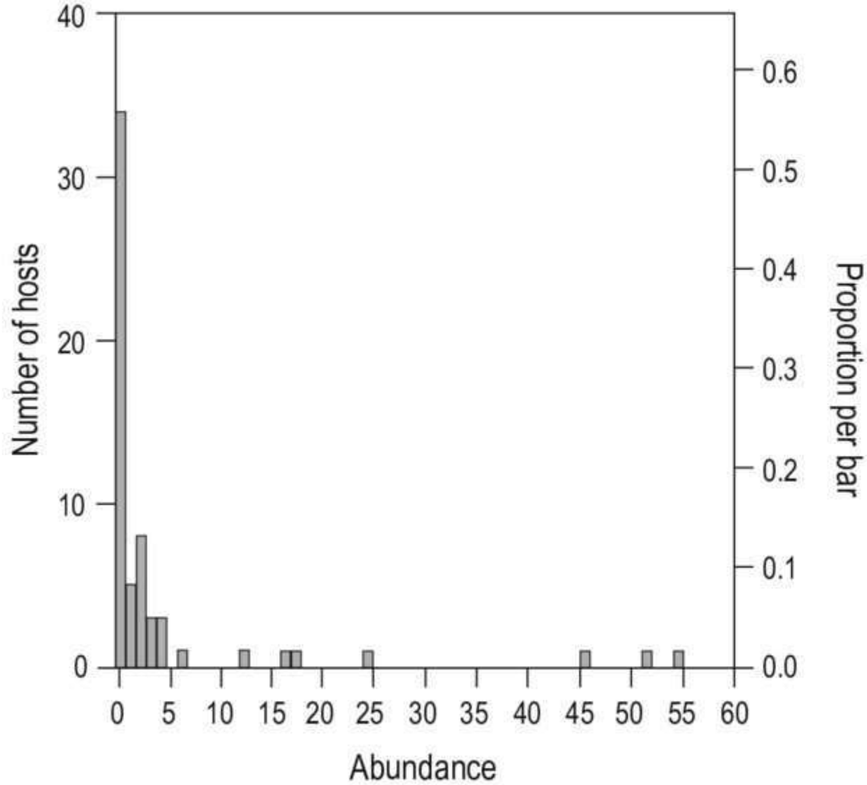
A quantitative understanding of the mechanisms which lead to the observed levels of aggregation is thus essential for the knowledge of parasite ecology and evolution. One of the most fundamental issues in the field is to what extent differences in parasite loads reflect differences in the exposure of hosts to the infective stages of a parasite, or differences in the success of a parasite in infecting its hosts . The processes that are potentially involved in producing the distribution of parasites amongst hosts are two types:

(i) The number of encounters between a host and a parasite or a source of parasites

(ii) The number of parasites that are ultimately carried by a host, which result from a single encounter with a parasite or a source of parasites.

These two processes, henceforth referred to as ‘encounters’ and ‘success’

Exhaustive empirical surveys have shown that, almost without exception, macroparasites (parasitic helminths and arthropods) are aggregated across their host populations, with most individuals harbouring low numbers of parasites, but a few individuals playing host to many.Parasites are invariably aggregated across the host population, with the majority of the parasite population concentrated into a minority of the host population. In human communities, for example, generally less than 20% of individuals harbour 80% of the helminth parasite population. Thus, a relatively small number of individuals in the ‘tail’ of the parasite distribution are responsible for most parasite transmission and play an important role in the persistence of the parasite .



Box 2.1. Measures of aggregation

If the parasite population was distributed randomly amongst hosts, the variance (s^2) of the parasite distribution would be approximately equal to its mean (m), i.e.

Random distribution: $s^2 = m$ (1)

For an aggregated distribution, the variance is greater than the mean, i.e.

Aggregated distribution: $s^2 > m$ (2)

Thus, we can quantify the degree of aggregation simply as the ratio of the variance to the mean:

Variance-to-mean ratio = s^2/m (3)

You will notice that this ratio varies from zero (when parasites are uniformly distributed amongst hosts), through unity (for a truly random distribution of parasites), to a number equal to the total number of parasites (for a maximally aggregated distribution).

- Exercise: A dataset is comprised of information collected on 12 host, each of which was necropsied and the number of roundworms counted. The number of infected hosts were 7.
- One host infected with 10 *(Adult worm)*

- One host infected with 5 *(Adult worm)*
- One host infected with 1 *(Adult worm)*
- One host infected with 1*(Adult worm)*
- One host infected with 1*(Adult worm)*
- One host infected with 1 *(Adult worm)*
- One host infected with 1 *(Adult worm)*

- **Calculate the aggregation**

  Solution:

  Aggregation = variance to mean ratio

Mean abundance should be calculated

=20/12

=1.66

Variance =S^2

$$s^2 = \frac{\sum (X - \overline{X})^2}{N-1}$$

=8.78

Variance/ mean

= 8.78/1.66

= 5.4875