Rediscovering Earthworms

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PREFACE

Earthworms have attracted widespread attention due to their significant influence on an array of soil processes and in sustaining soil health. Since Aristotle described these animals as "The Intestines of the Earth" and Charles Darwin's notable observation on the role of earthworms in nature, a good number of scientists have studied the diverse roles earthworms play in the ecosystem and devised methods to utilize their services for a beneficial purpose.

Earthworms inevitably constitute a major share among the dominant soil macrofauna. Their species richness, abundance and distribution pattern reflect edaphic and climatic factors of the geographical zone. Their horizontal and vertical stratification and density contribute to soil formation and sustaining the soil profile. Earthworm population density is a key indicator of soil quality. One of the major contributions of earthworms in soil is their vital role in facilitating the decomposition of organics. These animals significantly enhance aeration of topsoil, thus inducing the growth and activities of aerobic microbes, the primary decomposers. Besides, they increase aggregation and water infiltration in the soil alongside their roles in maintaining a stable carbon to nitrogen ratio and increasing the level of essential nutrients like calcium, phosphorous and potassium.

For the last several decades, earthworms of diverse species have been successfully used in producing vermicompost from biodegradable wastes. With the gradual realization of the harmful impacts synthetic agrochemicals inflict on ecosystems, people all over the world are switching over to organic food. Organic farming demands the production of high-value manures for field applications. Besides conventional compost, the demand for vermimanure has increased consistently over recent years. Vermimanure at present is recommended for the majority of agricultural and horticultural crops. The advantage of vermicomposting is that in addition to producing vermimanure, it facilitates vermiculture to increase the earthworm population.

The potentiality of earthworms as a cost-effective substitute protein supplement in formulating fish and poultry feed has been realized over the last few years. Earthworms are rich in protein, amino acids, fat, minerals, vitamins, etc. and therefore could be successfully used as a substitute for fish meal and soybean meal. Many researchers have reported the remarkable growth of fish and poultry fed with substitute diets that have earthworms as a major component. Earthworm protein has immense nutritional value for humans too.

Due to their permeable skin, earthworms can easily absorb toxic metals and chemicals from the soil and accumulate these in their tissues. Beyond a threshold level, the animals indicate specific alterations in morphology, histology, physiology and behaviour and therefore are considered ideal bioindicators of soil pollution. Researchers have identified several sensitive markers in earthworms, which could be immensely helpful in contamination diagnosis. Earthworms have been successfully used as bioremediating agents.

The book provides information on the diversity and functional role of earthworms in natural terrestrial ecosystems and their multiple utilities as agents for the production of organic manure, an ideal source of nutrition and indicators of ecological perturbations. The authors sincerely believe that the book will be useful to students and faculties of biological and agricultural sciences, researchers working on earthworms and anyone interested in knowing more about this lowly but immensely useful animal.

The authors have referred to many books, research papers and websites to collect and compile information besides their published research results, which have been duly acknowledged. They are grateful to friends, colleagues and family members for their sincere help, constructive criticism and encouragement for writing this book.

CHAPTER ONE

INTRODUCING EARTHWORMS

Earthworms in Darwin's last manuscript

Introducing earthworms in their natural habitats to humankind is not a strange concept. These small animals have already drawn the attention of a large group of scientists. Aristotle once described the earthworm as "The Intestines of the Earth". In early times, when humans began to learn about agricultural practices, the invention of the plough constituted one of the landmark events. However, long before this invention, the soil was naturally and regularly ploughed by earthworms. The importance of earthworms in the soil came to light after publication of Darwin's finding in his book titled *The Formation of Vegetable Mould through the Action of Worms, with Observations of their Habits* in 1881. The book was published six months before his death. Earthworms are fondly called "Darwin's plough". Before that, no one had ever perceived the role of earthworms in soil fertility. Up to the mid-19th century, most people believed that earthworms were pests and harmful to the plants. Darwin was assured about the beneficial role of worms for turning over the soil by moving up and down through the soil layers, chewing it up and excreting it, thereby making it more fertile. After a long period of close observations of earthworms and their habits, Darwin published his findings in the book. His publication demonstrated the influence of earthworms in nourishing the soil by the breakdown of organic matter. Although the book did reach the height of maximum sales at that period, over time it lost its identity. However, with the changing tides, earthworms and their application to boost agricultural production have drawn the attention of a considerable number of soil biologists.

In his book, Darwin (1881) described earthworms as nocturnal animals, and at night they start crawling in large numbers. They can also stay underwater for a long period. Earthworms stay close to the mouth of their burrows and easily become the prey for predator birds. Darwin also described the worms as lacking eyes and ears but able to respond to light, touch and vibrations.

Darwin's book further reveals his observations on earthworm habits and effects on soil (Fig. 1.1). Darwin learned that the meandering activity of worms aerates the soil and influences the chemical composition by rendering soil and plant matter into fertile pellets. Worms are responsible for depositing the topsoil as a by-product of their movements and gut contents. It is estimated that earthworms can move an average of 8 tons of earth for a single acre of cultivated land to produce a new layer of topsoil rich in nitrogen, phosphorous and calcium. Soil biologists also agree with the fact that the juice of earthworm gut contents collected beneath compost bins is an ideal organic fertilizing agent for garden farming. Darwin also experimented and noticed the typical tendency of earthworms to pull down leaves on lying on the soil into their burrows. Although the worms do not have any sense organ, Darwin noticed the degree of intelligence of these animals use to find the best way to drag the leaves into the narrow burrow. He simultaneously studied the sensitivity of these tiny animals towards odours, vibration and light intensity (Edwards, 1981; Feller et al., 2003).

During the period of Darwin, earthworms were described as slimy, ugly and senseless creatures because of their surface casting, and having little use except for fish-bait (Graff, 1983). After the publication of Darwin's book, certain noble behaviours of worms, such as their intelligence and role in soil weathering processes were unfolded. According to Darwin, worms monitor the rock weathering process both physically and chemically. Several stone particles or grains of sand with the mixture of hard calcareous concretions formed by the calciferous glands of earthworms showed the grinding action of their gizzards to facilitate the physical weathering of soil. The demonstration of the chemical weathering process by earthworms was carried out by Darwin by putting earthworms into a pot filled with red oxide sand. After some time, he noted the red sand in the casts of worms along with digested leaves. The transformation of the colour of the sand was possible due to the intestinal secretions of the earthworms. He also believed in the similarity of earthworms' digestive acids to soil humic acid. The gut enzymes of worms can digest the ingested organic matter with the mutualistic help of microorganisms (Martin et al., 1987; Lavelle et al., 1995). However, the spectrum of enzymes released from the intestine of different species depends upon their ecological category (Brown et al., 2000).

a b

Figure 1.1: a) Man is but a worm - caricature of Darwin's theory in the Punch almanac for 1882 CUL T992.b.1.45, Cambridge University Library, b) Charles Darwin as an earthworm scientist: caricature from the journal *Punch*, published in the year 1882 (Adapted from Kutschera& Elliott, 2010)

As described by Darwin, the consumption and partial digestion of leaves and rotation of casts by earthworms maintained the dark colour of topsoil. He experimentally demonstrated the formation of the humus layer by the casting and burrowing activities of earthworms in an earthen pot with sand and leaves inside. A large number of leaves buried by earthworms was also mentioned at several places in his book. He further emphasized the catalysis of the decomposition process by earthworms. The last two chapters of Darwin's book described the contribution of earthworms to geomorphology and landscape evolution. He also mentioned the significant role played by earthworms in the erosion–sedimentation cycle and how their action on fine particles in surface casts encourages the movement of particles by wind and water. The erosion of castings and the movement of drain water help the short-term formation of topsoil. The ability of worms to penetrate concrete floors and walls was also mentioned in the book (Feller et al., 2003).

Evolution and classification of earthworms

Earthworms were as old as mammals and dinosaurs and probably lived over 209 million years ago. The earthworm is not preserved in fossil records and very few trace fossils exist. There are over 7000 earthworm species found on all continents except the cold terrains of Antarctica. Based on the distributions, comparative morphology, anatomy and molecular profiles of earthworm species, attempts have been made to find their possible affinities and origins. From the current report of Anderson et al. (2017), it is evident that the introduction of approximately one-third of the earthworm species in North America was from Europe or Asia. Certain species have also been introduced into the previously earthworm-free areas of northern forests since the end of the last ice age ~11,000 years ago. The earthworm classification tree has been categorised into two major branches, both with subgroups in the Northern continent of Laurasia and Southern landmass of Gondwana. The precursors of present-day Oligochaeta (earthworms) were away from the branching of the classification tree. One of these groups consists of at least three families, and another branch contains nearly all familiar European species, which includes the northern subgroup, Lumbricidae, and the southern subgroup, the Megascolecoidae family. Around 178–186 million years ago, the divergences of the two major branches of earthworms occurred between the Northern and Southern Hemisphere, coinciding with the partition of the supercontinent Pangaea 180–200 million years ago during the Triassic period. A continental breakup influenced the early diversification of earthworms. This proposition also supports the fact that earthworms most likely inhabited Antarctica before the continent's southward drift. Sims (1980) supported the continental drift theory and diversification of widespread earthworm superfamilies. Michaelsen (1910) proposed the appearance of worms in the upper Jurassic period, whereas Stephenson (1930) believed that the earthworms evolved in the Cretaceous period. The evolution of earthworms still instigates many theories, but the actual record is still unclear.

Many scientists have classified earthworms, but broadly they are included under the phylum Annelida, class Clitellata and order Oligochaeta. The taxonomy and phylogenetic classification of earthworms again bring controversy according to different taxonomists. Certain taxonomists have placed earthworms in the underclass Oligochaeta (Fig 1.2). The order of earthworms may be classified as Haplotaxida or Lumbriculida. The major terrestrial group of soil animals that come under Oligochaeta is known as earthworms. Worms are classified based on different features such as anatomy, morphology, phylogeny, behaviour and ecology. Michaelsen grouped earthworms into 11 families, and later Stephenson arranged them into 14 families. He proposed that the common ancestor of the terrestrial Oligochaeta belonged to the aquatic Lumbriculidae. The classification of Oligochaeta by Jamieson (1978) has been widely accepted. The Moniligastridae family is considered to be the most primitive, whereas Megascolecidae and Eudrilidae show advanced characteristics. The families such as Glossoscolecidae, Lumbricidae, Hormogastridae and Microchaetidae have few primitive characters and may be considered to have evolved later than the other families. The Lumbricidae probably is considered the most recent family. According to modern taxonomy, the earthworm represents more than 7000 species, and around 18 families are found in all regions except Antarctica (Table 1.1).

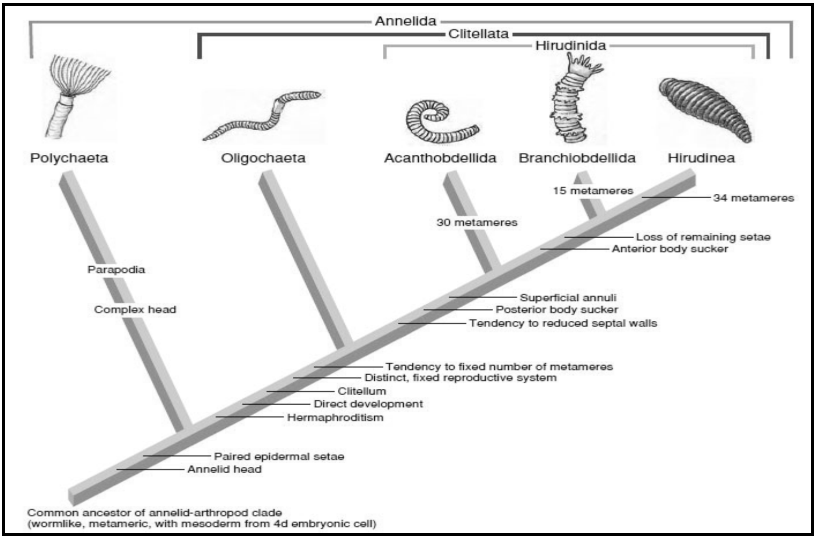

Figure 1.2: Classification of Annelida (Adapted from B.S Media, 2017)

In India, nine earthworm families have been categorised by Julka, 1988, the Glossoscolecidae, Moniligastridae, Lumbricidae, Ocnerodrilidae, Acnthodrilidae, Octochaetidae, Megascolecidae, and Eudrilidae families. The classification has been based on the reproductive features of worms:

- Families with inconspicuous male pores: Almidae, Glossoscolecidae

- Families with conspicuous male pores: Moniligastridae, Lumbricidae, Ocnerodrilidae, Acnthodrilidae, Octochaetidae, Megascolecidae, Eudrilidae

❖ Further, they have been grouped based on the position of male pores:
- Families with male pores on or in front of segment 15: Moniligastridae, Lumbricidae
- Families with male pores behind segment 15: Ocnerodrilidae, Acnthodrilidae, Octochaetidae, Megascolecidae, Eudrilidae

Table 1.1: The regional distributions of the ten recognized major families of terrestrial earthworms (Hendrix & Bohlen 2002)

Family of earthworm	The geographical region of origin
Ailoscolecidae	**Europe**
Eudrilidae	**Africa**
Glossoscolecidae	**Central America, South America**
Hormogastridae	**Mediterranean**
Komarekionidae	**North America**
Kynotidae	**Madagascar**
Lumbricidae	**Europe, North America**
Megascolecidae	**Africa, Central America, North America, South America, Asia, Madagascar, Oceania**
Microchaetidae	**Africa**
Ocnerodrilidae	**Africa, Central America, South America, Asia, Madagascar**

General description of earthworms

Body plan and morphology: Earthworms are elongated, streamlined, soft-bodied invertebrates having ring-like structures (annuli) all over the body. This simple, coelomate and cylindrical animal has segments separated externally by rings and internally by septum. Earthworms have neither any skeletal system nor visible external appendages. These animals have pointed anterior and posterior ends. They lack a true head and the anterior segment is known as peristomium, whereas the posterior segment is known as pygidium. Earthworms have a mouth and a small fleshy projection from the peristomium above the mouth called the prostomium. The last segment contains the anus (Fig 1.3). The pattern of the prostomium is often used as a tool in earthworm taxonomy. Based on the position, prostomium has been categorised into four different types, prolobic, epilobic, tanylobic and zygolobic (Fig 1.4, 1.5). The upper surface or dorsal side of the worm is dark in colour, and the lower surface or ventral side is light in colour. The absence of external locomotory appendages in earthworms is compensated by tiny bristle-like structures, called setae (Fig 1.6, 1.7). Setae are present all over the body except the first and last segment, and the arrangement is either in four pairs (lumbricine) or ring-like structure (perichaetine). The setal arrangement is key for the identification of earthworm species. Setae are closely associated with the outer cuticle of the body and can be detached only by alkali treatment. The retractor and protractor muscles support the motion of setae (Sharma et al., 2009; Dash, 2012).

Size and colour: The size of earthworms varies considerably within individuals and different species from few millimetres to metres. The species *Dichogaster bolaui* is about 1.5 mm long. The earthworm *Megascolides australis* is around 2–4 metres long (Fig 1.8) and *Terriswalkeris terroereginae* is 2 metres long and secretes luminescent mucin. *Drawida nilamburensis*, another Indian species from the state of Kerala, measures about 1 metre.

Earthworms show diverse colours and pigmentation. The pigmentation of the body is related to their ecological niches. Body colours such as grey, purple, red, maroon, brown, and black are commonly found in different species. Some species show heavy pigmentations and glow in the dark, whereas some worms are unpigmented. Protoporphyrin and protoporphyrin methyl esters are the fluorescent compounds deposited in the tissue and may be responsible for pigmentation in worms.

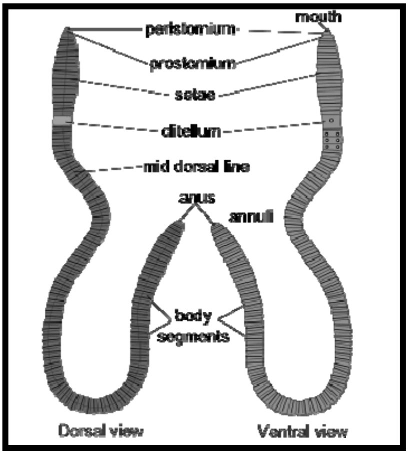

Figure 1.3: External features of earthworm (Adapted from Earthworm: External morphology, Body Wall, Coelom, Locomotion & Digestive System | Study&Score, 2018)

Figure 1.4: Scanning electron microscopic photograph of prostomium in *Eisenia fetida* (Adapted from Earthworms of India, Identification key and digital library)

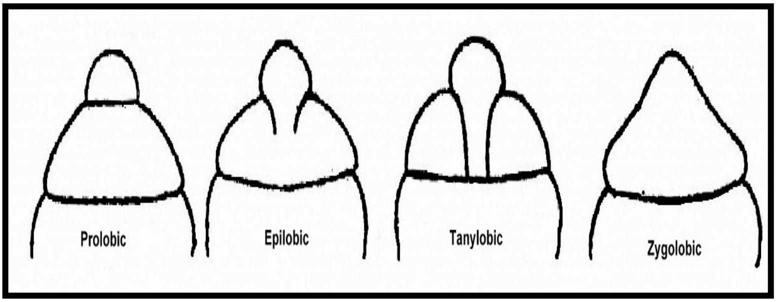

Figure 1.5: Types of prostomium in earthworm (adapted from Earthworms of India, Identification key and digital library)

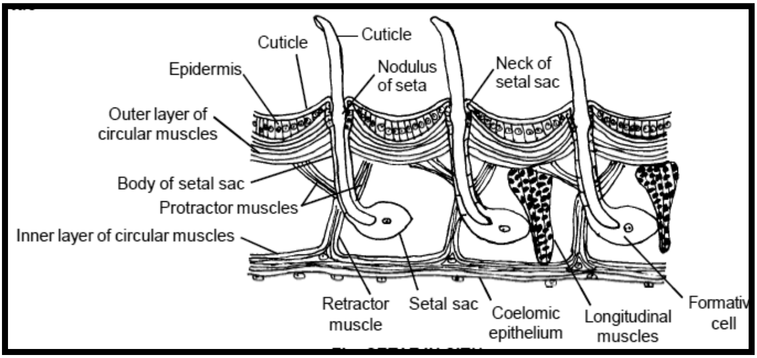

Figure 1.6: Transverse section of earthworm body wall showing setae

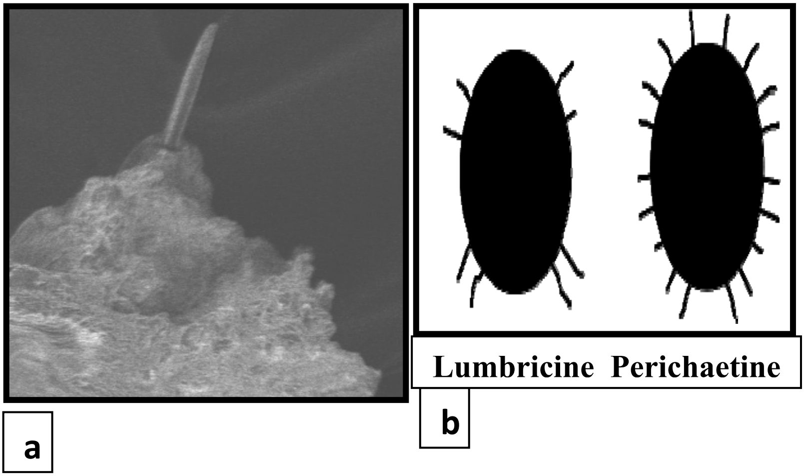

Figure 1.7: a) Scanning electron micrograph showing a) seta in *Eudrilus eugeniae*, b) setal arrangement

Figure 1.8: Photograph of *Megascolides australis* adapted from (*Megascolides australis,* Giant Gippsland Earthworm) - Emily Havlena Classification Project, 2020)

Dorsal pore and Nephridiopore: Dorsal pores are small openings lying along the midline on the upper surface of the earthworms and a passage to expel coelomic fluid from the body to the exterior. The worms throw out the fluid through dorsal pores to keep the skin moist in dry conditions. Hence, the pores are absent in worms of aquatic habitats. Nephridiopores, invisible to the naked eye, are the openings of the nephridia.

Coelom and coelomic fluid: The earthworm has a tube within a tube plan, and the space between the body wall and digestive system is called the coelom. The coelom of earthworm contains coelomic fluid, which acts as a hydrostatic skeleton and helps in burrowing and locomotory activities. The coelomic fluid also protects the internal organs from external jerks and destroys foreign pathogens. The fluid maintains the moist skin of animals for cutaneous respiration. In some species, the fluid has an unpleasant smell to give protection from predators. It contains various types of cells, such as phagocytes, mucocytes, small circular nucleated cells and chloragogen cells. These cells actively participate in the immune system of earthworms (Fig 1.9).

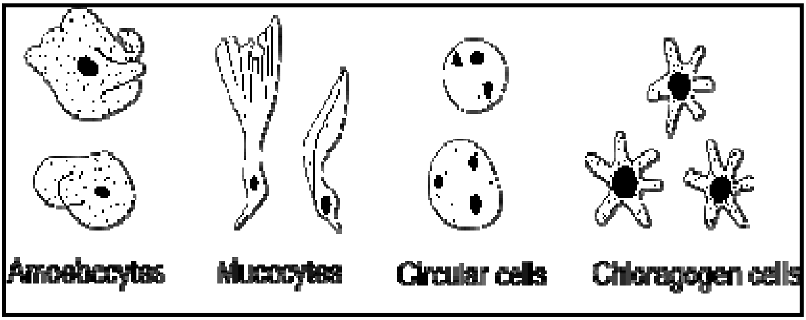

Figure 1.9: Coelomic corpuscles of *Pheretima posthuma* (adapted from Earthworm: Body Wall, Coelom, Locomotion & Digestive System | Study&Score, 2020)

Clitellum and genital apparatus: A glandular girdle-like thick band appears in sexually mature earthworms, restricted to certain segments, known as the clitellum. The position, shape and colour of the clitellum may vary in different species, hence this feature is useful in the identification of earthworms (Fig 1.10). The clitellum is present between 10-13 segments in Moniligastridae, 15-23 segments in Glossoscolecidae, 24-33 segments in Lumbricidae. The shape also varies, such as annular in Megascolecidae and saddle-shaped in *Dichogaster qffinis.* The colour varies from orange to yellow and red. In adult earthworms, certain areas on the ventral side may be depressed or swollen, called genital markings or tubercula pubertatis, respectively. Genital markings around genital setae and copulatory setae are called genital tumescences and copulatory tumescences, respectively. The external openings of the reproductive organs are known as genital pores. The openings of the vasa differentia (male pores) and oviducts (female pores) vary in different families and hence are useful taxonomic characters. The position of male pores may be on segments 13, 15 or 18 and the female pores on segment 14. In some families such as Megascolecidae and Octochaetidae, male pores are coupled with prostatic pores (Dash, 2012).

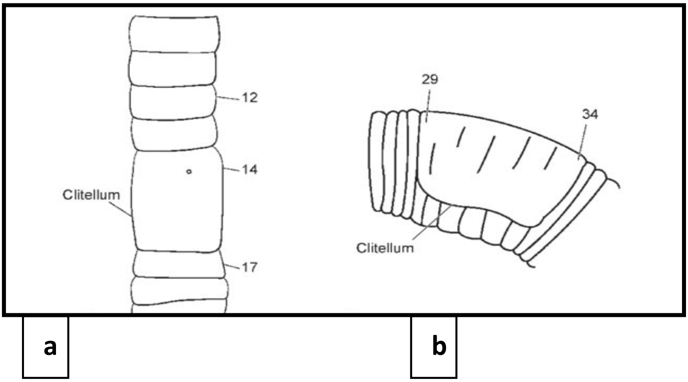

Figure 1.10: Schematic diagram of different shaped clitellum, a) annular (b) saddle shaped (adapted from Plisko & Nxele, 2015)

Reproduction and life cycle

Earthworms are hermaphrodites. Although the organisms have both testis and ovary, they prefer cross-fertilization. Copulation may occur above the ground or below the soil surface. Two mature worms come side by side with the alignment of the anterior prostomium region opposite to each other for the mutual exchange of sperm. The setae of the pairing worms help to hold the animals together during the mating process. The spermathecal opening of one worm is fitted with the male gonopore of the other. In certain species, such as *Lampito, Perionyx, Drawida*, the male pore is close to the spermathecal opening of another individual. Still, in *Eisenia* and *Bimastos*, the male pore is situated at a distance and the movement of sperm occurs through longitudinal grooves (Fig 1.11, 1.12). As the body moves, the spermathecae of each worm are filled with the sperm of the partner. The copulation lasts for hours and ends with the separation of partners. Each individual produces a coat-like structure in the clitellar region after receiving male gametes from another individual.

The coat is produced from the jelly-like substance secreted by the clitellum and becomes hard after exposure to air, forming the cocoon. The worm wriggles out, and the cocoon collects the sperm from the spermathecal opening along with the eggs—the two ends of the cocoon close, carrying both sperms and eggs inside to initiate fertilization. Cocoon shapes, sizes and colours are different in different species, and the cocoon contains albuminous fluid to nourish the developing worms (Fig 1.13). The structure may be egg-shaped, as in *Lampito mauritii*, spherical as in

Drawida calebi or spindle-shaped, for example in *Perionyx excavatus*. The colour of the cocoon varies from white to cream. The developing time for cocoon is known as the incubation time, and it is species-specific. The incubation time is also affected by soil moisture and temperature. The average period of incubation is about 7–10 days in a warmer climate and longer in colder regions. The emergence of a juvenile from the cocoon is followed by sexual maturation, thus initiating the life cycle (Dash, 2012). Earthworms continue to grow throughout their life by proliferating segments to form a growing zone just in front of the anus (Fig 1.14).

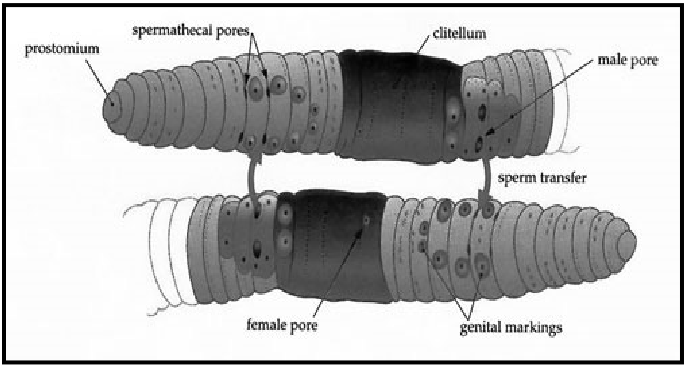

Figure 1.11: Genital pore of earthworm (adapted from Pokhrel, 2016)

Figure 1.12: Mating of earthworm (adapted from www.Sciencescore.com)

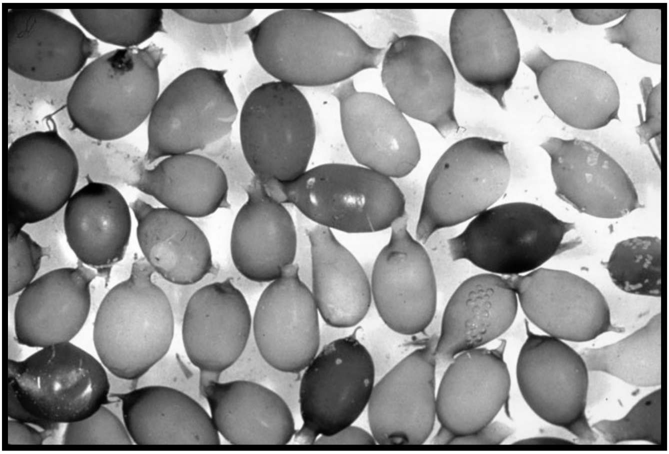

Figure 1.13: Cocoons of earthworms (adapted from www.earthwormsoc.org.uk)

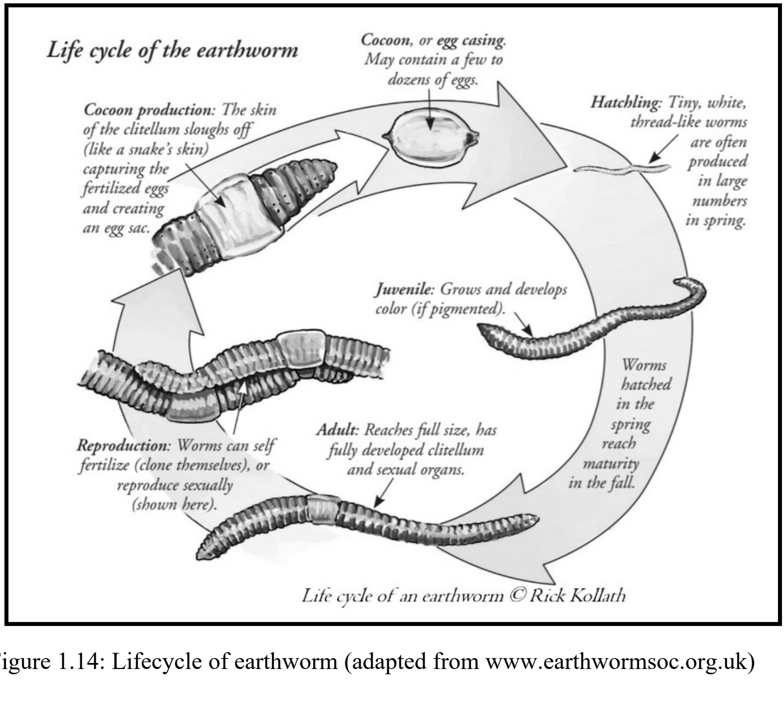

Figure 1.14: Lifecycle of earthworm (adapted from www.earthwormsoc.org.uk)

Food, predator and parasitic relationships

In general, earthworms are omnivorous, consuming both plant materials and animals like protozoa. They feed on organic matter, dead grass and also sometimes on berries and vegetables. They may also feed on algae, bacteria and fungi. The daily ingestion of food varies from 100 to 300 mg/g of a worm's body weight. According to a study, earthworms can uptake 8 to 20 g cattle dung/year as food (Dash, 2012).

Earthworms can be a good source of food for many vertebrate predators, such as fish, birds and mammals, and are an easy target for many organisms, such as centipedes, ants, carabid and staphylinid beetles, and their larvae. Worms are also attacked by various internal parasites, including protozoans, platyhelminthes, rotatorians, nematodes and dipterans. The protozoan *Spirochaeta* sp., bacterium *Bacillus* sp. and fungal pathogens live in different parts of the earthworm's body as parasites. The most common sites for parasites include the alimentary tract, blood vascular system, testes, spermathecae, seminal vesicles, coelom and also the cocoons of the worms. Several platyhelminthes and nematodes also cause infection to the worms (Dominguez & Edwards, 2010).

Behaviour of earthworms

Darwin's book made the worms popular for their interesting behaviours. He described the intelligence of worms in food collection and the protection of their burrows through his self-declared experiments. Darwin also demonstrated the plugging of burrows by earthworms to protect themselves. However, the intelligence of worms discussed in his published book is a controversial argument for soil biologists. Several workers on earthworms claim that an invertebrate having a cerebral ganglion might not be able to possess intelligence rather than instincts. The learning process of worms in reward or punishment patterns could be a reflection of instincts. The criticism of Darwin's observations is continuing as further research is required for a better understanding of earthworm behaviour (Brown et al., 2003).

Some worms show an alarm response by secreting mucus to escape predators (Ratner & Boice, 1971). Avoidance behaviours of earthworms due to xenobiotic exposures is a well-documented phenomenon. Worms prefer to escape from a habitat contaminated with toxic agrochemicals. Certain worms also adopt coiling behaviour to overcome the stress induced by physical and chemical factors (Mishra et al., 2017).

Unfavourable environmental conditions in the habitat may compel earthworms to become inactive in a process called aestivation or diapause. For their survival, they move deeper into the soil, reduce their metabolic rate and secret protective mucus. They remain in a coiled ball to sustain in adverse conditions of water loss until conditions become favourable. An interesting behaviour of earthworms has been studied in *Eisenia foetida* showing that these worms could communicate and influence each other's behaviour to travel in the same direction by forming active herds (Fig 1.15). The behaviour of earthworms will require future research to address unanswered questions.

Figure 1.15: Herds formed by earthworms (adapted from California Academy of Sciences, 2020)

Anatomy of earthworms

Digestive system: The alimentary canal of an earthworm is a long tube consisting of a mouth, pharynx, oesophagus, gizzard, stomach, intestine and anus. The mouth leads to the buccal cavity and pharynx. The muscular pharynx is enriched with pharyngeal glands that secrete proteolytic enzymes, mucin and carbohydrates. The pharynx leads to the oesophagus, which bears a thick-walled gizzard running up to the stomach and intestine. The calciferous gland associated with the oesophagus is found to release excess calcium in the form of calcium carbonates (Fig 1.16b). The elimination of calcium helps to maintain the acid-base balance of the body. The intestine is a long tube containing a pouch-like structure called the intestinal caeca. Many enzymes, for example, amylase, lipase, invertase, etc., are secreted and regulated by the stomach and intestine. The internal surface area of the intestine may be increased by the presence of a large dorsal fold, the typhlosole. The shape of the typhlosole varies from a low ridge to a well-developed lamella, either bifid or trifid. The intestine of earthworms can be divided into three distinct regions, namely, the pre-typhlosolar region, typhlosolar region and post-typhlosolar region. Several pairs of supraintestinal glands are located on the posterior wall of the typhlosole. The circular opening in the last segment is called the anus, and it releases the undigested food materials in the form of a worm cast. The structural components of the alimentary canal, the gizzard, calciferous gland, intestinal caeca, supra-intestinal glands and typhlosole, are important in the classification of earthworms (Fig 1.16).

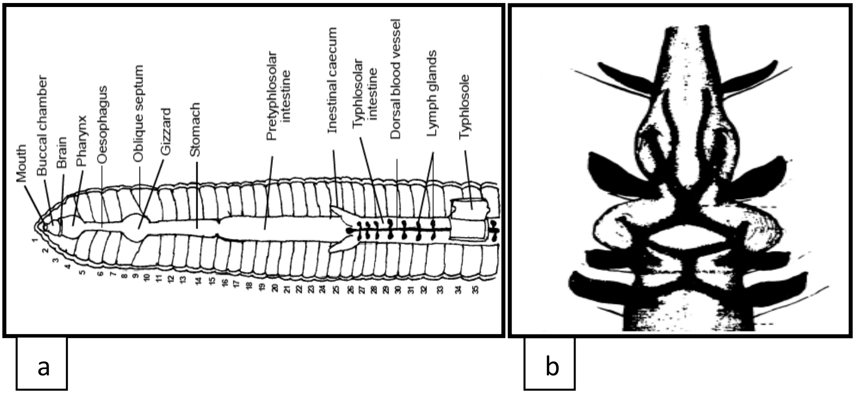

Figure 1.16: a) Digestive system of earthworms (adapted from *Earthworm, Chapter Notes, Class 11, Biology EduRev Notes*, 2016), b) Calciferous gland (Julka, 1988)

Excretory system: The excretory organs of earthworms are coiled tubes known as nephridia, which excrete the nitrogenous wastes present in the coelomic fluid. The presence of different types of nephridia in different species or their absence in the first few segments provides a clue about the identification of earthworms. The nephridia may be one pair, holonephridia, or more than one pair, meronephridia. There are three types of nephridia based on their location, namely pharyngeal, integumentary and septal nephridia. Pharyngeal nephridia contain neither nephridiopore nor nephrostome; integumentary nephridia contain nephridiopore but not the nephrostome. Septal nephridia are attached to both sides of septa in each segment and bear the nephrostomes. Either type of nephridia may be open (stomate) if nephrostomes persist or closed (astomate) in the absence of the nephrostomes. The duct of nephridia opens to either the exterior (exonephric) or into the alimentary canal (enteronephric) (Fig 1.17). The nephridia consist of three parts: nephrostome, body and terminal duct. Nephrostome is a funnel-shaped externally ciliated structure and opens into the coelomic cavity. The funnel leads into a narrow neck, which is continued into the body of the nephridium. The end part of nephridium is known as the terminal duct. Septal nephridia release the waste products through canals and ducts into the lumen of the intestine, whereas pharyngeal nephridia discharge the nitrogenous metabolic waste directly into the buccal cavity and pharynx from where these are passed outside with undigested food through the anus. Integumentary nephridia discharge the wastes products directly to the exterior of the body through nephridiopores.

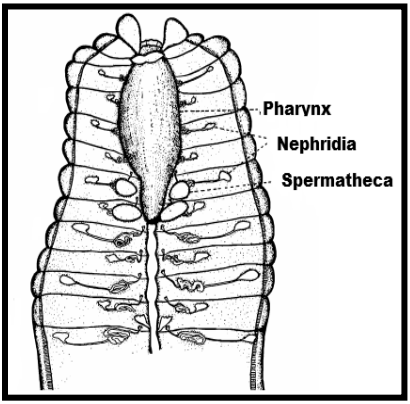

Figure 1.17: Excretory system of earthworms (adapted from Julka, 1988)

Circulatory system: The circulatory system of an earthworm is a closed type and consists of thick muscular blood vessels called the heart or pseudoheart, loops and blood vessels. The dorsal vessel may be single or double and is closely associated with the mid-dorsal line of the alimentary canal. The ventral vessel is located just below the digestive tract and is suspended from it by a mesentery. The subneural vessel lies beneath the nerve cord. The supra-oesophageal vessel is either single or double and important for taxonomic characters and runs along the dorsal wall of the gut in the anterior segments. The extra-oesophageal vessel is situated anteriorly, and latero-parietal vessels are on the latero-ventral side of the gut. The paired commissural vessels connect the ventral vessels with the dorsal or supra-oesophageal vessels. The heart is known as a lateral heart when it opens into the dorsal vessel and oesophageal heart when it opens into the supra-oesophageal vessel (Fig 1.18). The number and position of hearts have taxonomic importance. The blood of earthworms is red due to the presence of haemoglobin and contains colourless nucleated amoebocytes in the liquid plasma.

In general, the earthworms lack respiratory systems, but exceptions are seen in species like *Brachiodrilus hortensis* which has large areas called gills for gas exchange. Respiration in worms occurs through their highly vascular skin. Earthworms directly absorb oxygen from the environment and also release carbon dioxide to the outside.

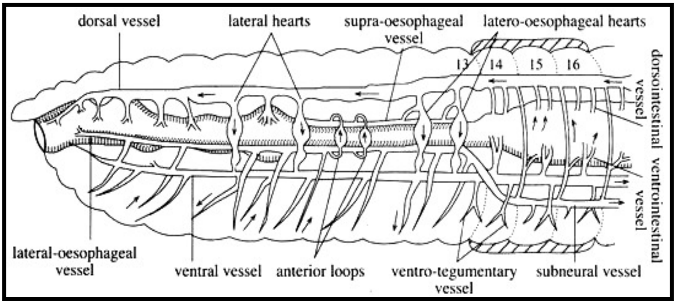

Figure 1.18: Circulatory system of earthworms (adapted from https://www.notesonzoology.com/earthworm/circulatory-system-in-earthworm**)**

Nervous system: The nervous system of an earthworm includes a pair of cerebral ganglia, called the brain, a ventral nerve cord and a pair of circumpharyngeal connectives (Fig 1.19). The nerve collar is formed by the connection of the brain to these connectives. The ventral nerve cord, situated just below the alimentary canal, bears a ganglion in each segment and sends peripheral nerves to various organs. The peripheral nervous system regulates both motor and sensory nerves. The nervous system conducts reflex actions even after being disconnected from the brain. Earthworms lack sense organs for vision and hearing, but the apical nerve ending of the skin is sensitive to stimulus. The sense of taste and smell are controlled by special epithelial cells of the buccal sac. Pieces of evidence suggest the neurosecretory potential of some neurons in earthworms. These neurosecretory substances play vital roles in different activities such as locomotion, feeding, reproduction, osmoregulation, growth and regeneration. Neuropeptides secreted in *Eisenia foetida* are associated with rapid muscle contraction during locomotion and feeding behaviour, including salivation (De Vries-Schoumacker,1977). The neuropeptides found in various species play different roles according to their niche requirements.

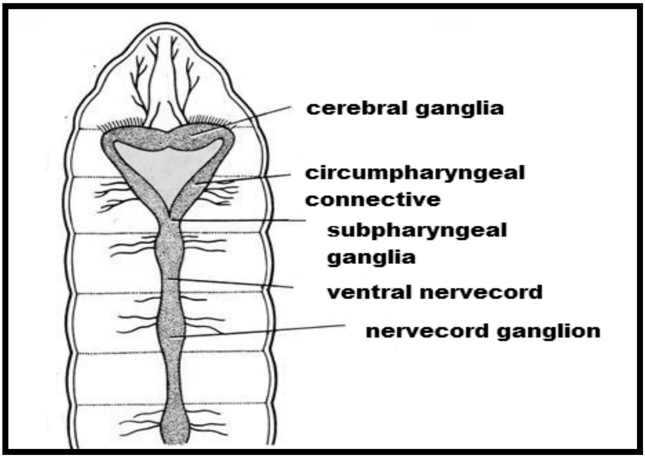

Figure 1.19: Nervous system of earthworms

Reproductive system: Earthworms are hermaphrodites having both male and female reproductive systems in one individual (Fig 1.20). The external openings of gonads are called genital pores, which lie on the ventral side of the worms. Paired testes (holandry) and paired ovaries (hologyny) are seen in megascolecoid earthworms. The number of testes and ovaries may be reduced to a single pair known as meroandry and progyny, respectively. The testes are either paired or unpaired and may lie free in their segments or are enclosed in special coelomic chambers, called testis sacs. In some species, the male pores are united with openings of accessory reproductive organs called prostate glands. The male funnels lead to the vasa deferentia, which may be straight or coiled. The ducts may unite with each other before opening to the exterior, or they may discharge separately on the body surface. The posterior end of the vas deferens is known as bulbus ejaculatrice and is enlarged into an ejaculatory bulb. Pair of seminal vesicles lie lateral to the corresponding testis and are connected to the testis sacs. The spermathecae are sac-like structures with the ampulla, one or more diverticula and a duct opening to the exterior. The structure of the spermatheca varies in different species. Setae associated with spermathecal pores are known as copulatory setae and those with prostatic pores as penial setae. The female reproductive system contains a pair of ovaries and a female gonopore. The ovaries are situated below the gut and on each side of the nerve cord. The oviductal funnel leads to oviducts, which in turn run posteriorly to meet the female gonopore.

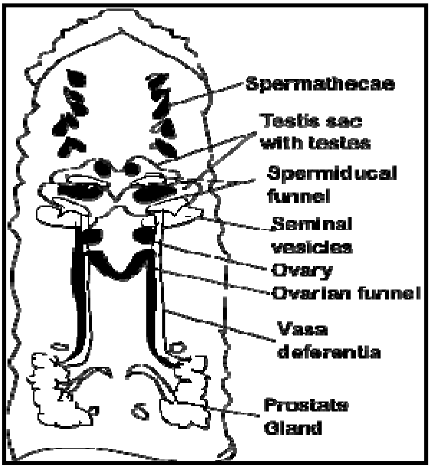

Figure 1.20: Reproductive system of earthworms

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