

## Lab 4 - Comparison of Parasitic and Free-Living Worms

### Objectives:

- Understand the taxonomic relationships and major features of the worm phyla, Platyhelminthes, Nematoda and Annelida
- Learn the external and internal anatomy of *Dugesia*, *Clonorchis*, and *Ascaris* and become familiar with the external features of the other specimens
- Learn the defining characteristics of both ectoparasites and endoparasites, focusing on the structural differences between parasites and free-living forms

**Textbook Reference Pages:** pp. 690-696 (top), 698 (middle) - 700 (top), 702-705 (top); pp. 899-901 (top), 903 (middle) - 905; p. 1016

### Introduction:

During this first week of our animal diversity survey, we will study three worm phyla. Our reasons for looking at worms may not be obvious, but they are important nonetheless. All of the phyla of worms that we will examine -- the annelids, the nematodes, and the platyhelminthes -- contain species that are parasites of humans (not to mention other animals and plants). You may already be familiar with some of these creatures: you are likely to encounter leeches (an annelid) simply from wading in a stream or pond, and if you ever had a dog or cat, you probably took it to the vet at least once to be treated for worms (such as roundworms and whipworms, both nematodes, and tapeworms, a platyhelminth).

The parasitic worms that you will examine are for the most part eating and reproducing machines. Consequently, when studying the parasitic worms, take a good look at their digestive and reproductive systems, and then compare them to the digestive and reproductive systems of free-living worms (e.g., earthworms).

### 1) Phylum Platyhelminthes

The phylum Platyhelminthes (*platy*, flat; *helminth*, worm) includes a diversity of marine, freshwater, and terrestrial worms, plus two rather important parasitic groups: the flukes and the tapeworms. Like cnidarians (= hydras, jellyfish, and corals), flatworms have a rather simple body plan and share some features with them. They also have a few morphological advancements over cnidarians. Some characteristics of flatworms are:

- 1) They are **triploblastic**, as all three primary germ layers (e.g., **ectoderm**, **endoderm** and a middle tissue layer, the **mesoderm**) form during embryonic development. As a result, flatworms have well-developed, mesodermal-derived muscle layers. However, they are **acoelomate**, lacking a true body cavity.
- 2) Flatworms lack organs for transporting oxygen to body tissues. As a consequence, each of their cells must be near the body surface for gas exchange to take place, resulting in a **flattened body plan**.
- 3) Flatworms are **bilaterally symmetrical**.
- 4) The digestive system of flatworms, if present, consists of a single opening that serves as both the mouth and anus. This opening, the **mouth**, leads into a branched **gastrovascular cavity**. Both digestion and absorption of nutrients occur in the gastrovascular cavity, obviating the need for a well-developed circulatory system.

- 5) They possess an **excretory system** of **flame cells** and associated **excretory ducts**.
- 6) They possess a complex **reproductive system**. Most flatworms are hermaphroditic, possessing both male and female reproductive organs.
- 7) They possess a **bilateral nervous system** consisting of an anterior "**brain**" (basically, a concentration of nerve cells or **ganglia**) connected to **nerve cords**.

**The phylum is divided into four classes:**

**Class Turbellaria**, free-living marine, freshwater, and terrestrial flatworms.

**Class Trematoda**, parasitic internal flukes

**Class Cestoda**, parasitic tapeworms

**Class Monogenea**, parasitic external flukes

**Specimens of Platyhelminthes**

We will examine live specimens (*Dugesia*) and microscope slides (*Dugesia*, *Clonorchis*, *Taenia*) representative of free-living and parasitic platyhelminthes.

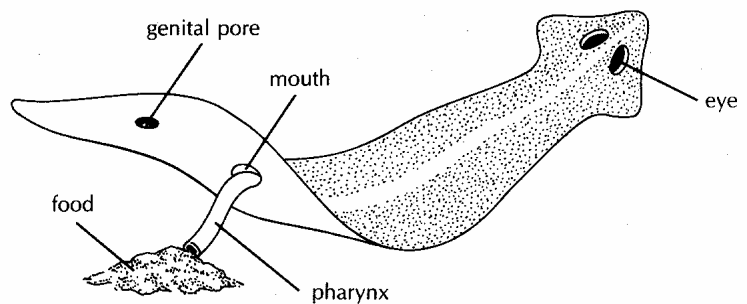
**A) *Dugesia*, Class Turbellaria, live specimen.**

Obtain a live *Dugesia* flatworm by sucking it up from the side or bottom of a glass jar using a medicine dropper. Place the specimen in a small Petri dish, making sure that it is completely covered by pond water, and examine it under your dissecting scope.

*Dugesia* is a common turbellarian (= planarian) that resides in freshwater streams and ponds. Note your animal's shape, pigmentation, and mode of locomotion. *Dugesia*, as well as most free-living flatworms, move over surfaces by means of **cilia** on their ventral surface. Note the pigmented **eye spots**, or **ocelli**, located on the triangular "head" of the animal. These eye spots are sensitive only to light and dark, and are unable to resolve images. On either side of the eye spots are lateral lobes which serve as chemosensory organs. Cover your culture dish (top and sides) with a piece of aluminum foil, and place the dish on a dark background with a microscope light shining on it. After 5 to 10 minutes, remove the foil and observe where your animal is relative to the light. Is your animal positively or negatively attracted to light (= phototactic)? How might this behavior be adaptive for the animal in its natural environment?

*Dugesia* feeds by extruding its **pharynx** from a ventrally-located **pharyngeal cavity**. The **mouth** of the pharynx opens into the **gastrovascular cavity**, which has many branches (**diverticula**) to facilitate digestion. Place a small piece of food into the culture dish and observe the response of your specimen. If you are lucky, you may be able to see *Dugesia* extrude its pharynx and suck up food particles like a mini vacuum cleaner (Figure 1).

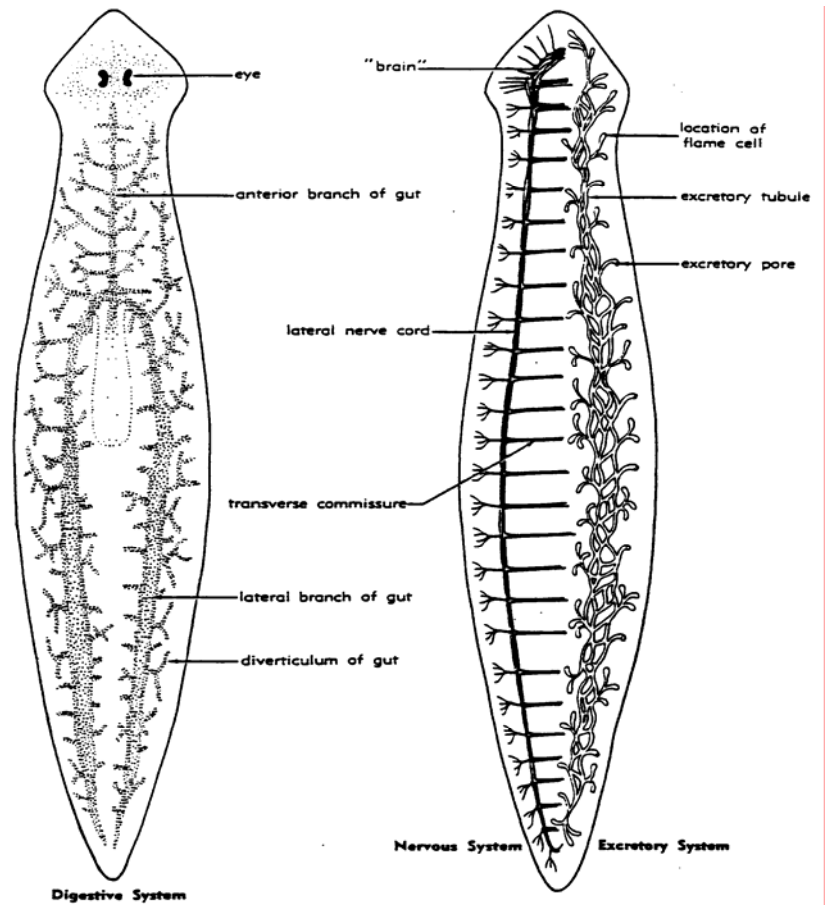
**Figure 1:** Planarian flatworm, *Dugesia*, feeding (from Pechenik 1991, Biology of the Invertebrates).



**B) *Dugesia*, microscope slide (Figure 2).**

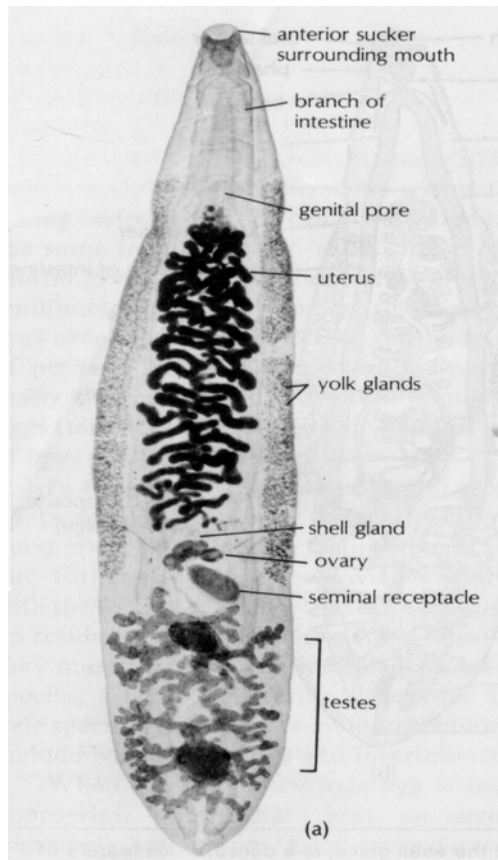
Observe a prepared whole mount of *Dugesia* under low power of your compound microscope. You should see the **eye spots** and the **diverticula** of the gut. Also look for the "**brain**", **nerve cord**, and **excretory system**.

**Figure 2:** *Dugesia*, whole mount (from Stamps, Phillips & Crowe. The laboratory: a place to do science, 3<sup>rd</sup> ed.)

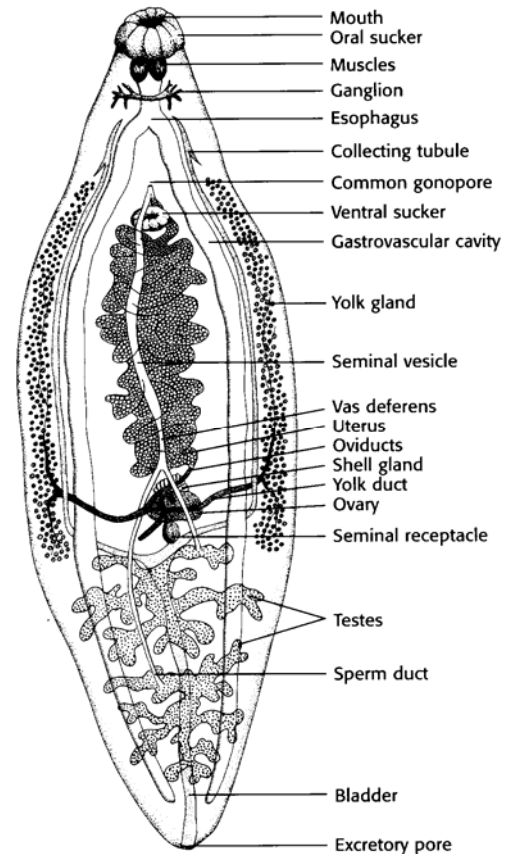


**C) *Clonorchis*, Class Trematoda, preserved specimen and microscope slide (Figure 3).**

*Clonorchis sinensis*, the human liver fluke, is a parasitic trematode found in the bile ducts of humans. Like most parasitic worms, the life cycle of *C. sinensis* is extremely complex and involves several hosts. The adult worm sheds eggs into the bile ducts of its human host, which eventually reach the small intestine and are passed with feces. If the eggs are ingested by the proper species of aquatic snail, they hatch into larvae that then progress through a series of asexual stages, culminating in an infective larval stage known as cercariae. The cercariae are ciliated, and have a tail for swimming. They pass out of the snail, and then briefly swim about in the water until they encounter a fish. Then the cercariae penetrate the muscles of the fish, lose their tails, and remain encysted until the fish is eaten by the definitive (= final host). These encysted larvae are freed in the human small intestine after consumption of improperly prepared fish. The immature flukes migrate through the bile duct and its tributaries throughout the liver, where they develop into adult worms. If untreated, an infection by *Clonorchis* can lead to enlargement and cirrhosis of the liver.



**Figure 3:** Photograph of *Clonorchis sinensis*, with major features identified (from Pechenik 1991, *Biology of the Invertebrates*).



**Figure 4:** Schematic of the trematode, *Clonorchis* (from Hopkins & Smith, 1997, *Introduction to Zoology*).

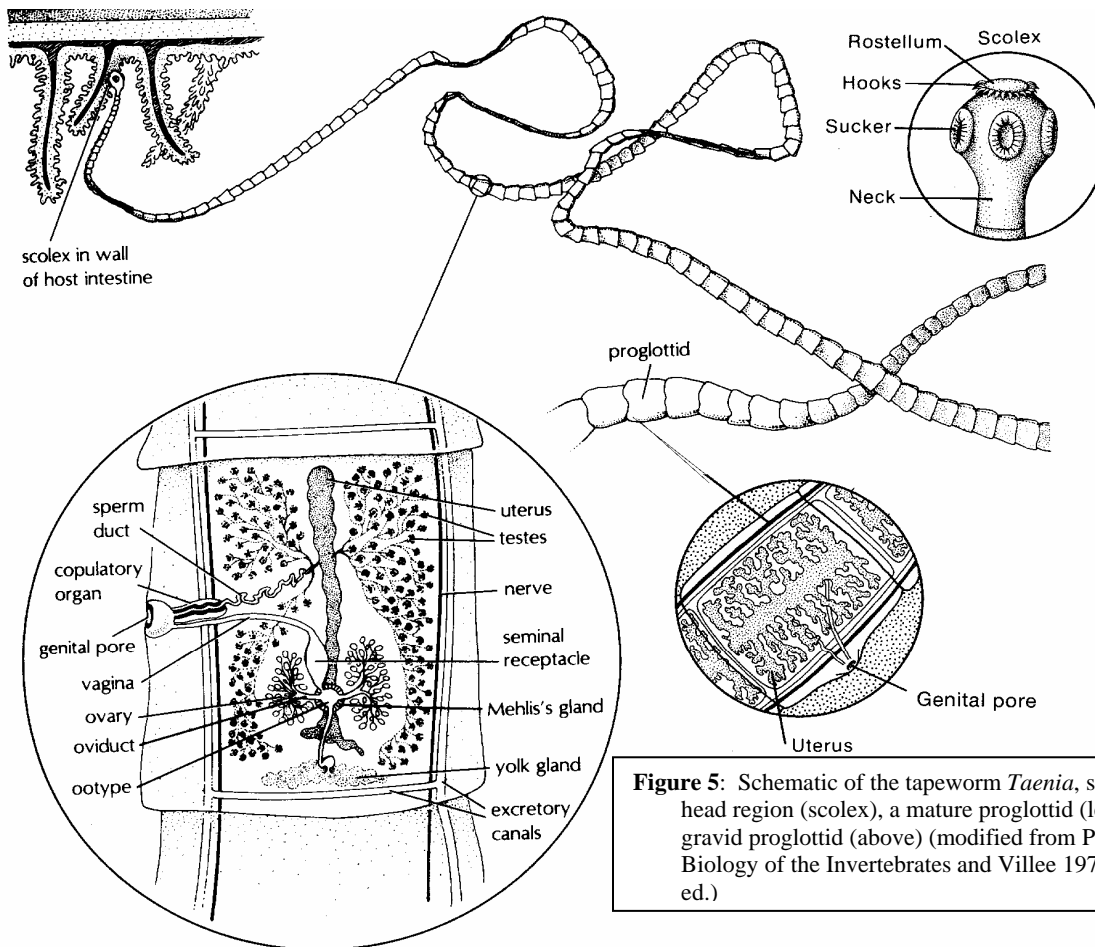
Observe a prepared whole mount of *Clonorchis* under low power of your compound microscope. Unlike flatworms, flukes have a protective **cuticle** covering their bodies (why?). Note the anterior **oral sucker** around its mouth, for attachment to host tissues. A muscular **pharynx** and **esophagus** lead to a two-branched **intestine** (= **gastrovascular cavity**). Slightly posterior to the branching point of the intestine is the **ventral sucker**, or **acetabulum**, that also serves to attach the organism to its host's tissues. A small **excretory pore** is located at the posterior end.

The remaining conspicuous organs are reproductive structures. The large, branched organs located in the posterior of the organism are the two **testes**. A **vas deferens** connects each testis to a single, median seminal vesicle (not easily seen) that stores sperm and transports it to a **genital pore** located anterior to the acetabulum.

The mid-section of the fluke contains the female reproductive structures. An enormous **uterus** occupies much of the central region of the worm, and stores eggs. On either side lateral to the uterus are **yolk glands** that secrete yolk for egg formation via yolk ducts (not visible). A small, lobed **ovary** can be seen posterior to the uterus, and behind that is a sac-like **seminal receptacle** for storing sperm received during copulation.

**D) *Taenia*, Class Cestoda, preserved specimen and microscope slide (Figure 5).**

Observe a prepared slide of *Taenia* under low power of your compound microscope. Your specimen, *Taenia pisiformis*, is a tapeworm of carnivores (notably, dogs), and closely resembles *T. solium* and *T. saginata*, common parasites of humans contracted by eating poorly prepared beef or pork, respectively. Tapeworms share many features with flukes, including an outer **cuticle**, attachment structures, expansive reproductive organs, and complex life cycles involving intermediate hosts. Unlike flukes, however, tapeworms lack a mouth and gastrovascular cavity, a consequence of their life in vertebrate organs of high nutritional activity (i.e., the small intestine). Bathed by food in their host's intestine, they absorb predigested nutrients across their body surface via diffusion and possibly, active transport.



**Figure 5:** Schematic of the tapeworm *Taenia*, showing the head region (scolex), a mature proglottid (left) and a gravid proglottid (above) (modified from Pechenik 1991, *Biology of the Invertebrates* and Villee 1972, *Biology*, 6<sup>th</sup> ed.)

The body of a tapeworm is divided into four main regions. A small **scolex** ("head") bears **suckers** and an elevated rostellum with curved hooks; the suckers are used for attachment to the host's organs. Immediately posterior to the scolex is a "neck" that produces many **proglottids** ("segments") by asexual budding. Each proglottid is potentially a complete reproductive unit containing both male and female reproductive organs (i.e., each is **hermaphroditic**). Why might hermaphroditism be especially advantageous for an internal parasite?

The second region consists of small, **immature** proglottids nearest to the neck and scolex.

The third region, or mid-section, consists of **mature** proglottids, each with well-developed male and female reproductive organs. These proglottids engage in internal, cross fertilization. In a mature proglottid, locate the lateral **genital pore** that contains both a thin, tubular **vagina** and a stouter **vas deferens**. Trace the vagina posteriorly and note that it passes between two **ovaries** and terminates at a **shell gland** anterior to a **yolk gland**. Eggs are fertilized and "yolked" before passing anteriorly into a sac-like **uterus**. The male reproductive system consists of numerous small, round **testes**, each with a tiny tubule that connects to a single **vas deferens**, which transports sperm to the **genital pore**.

The fourth and posterior region of the tapeworm consists of **gravid** (= "pregnant") proglottids. In gravid proglottids, most of the gonads are atrophied, leaving only an enlarged uterus packed with eggs. These gravid proglottids eventually break off from the body of the adult worm, and pass out of the digestive tract in the host's feces. When a small mammal, such as a rabbit, ingests a proglottid or eggs, the eggs hatch into larvae that then bore through the intestinal wall and then move through the circulatory system where they eventually become encysted in muscle tissue. When the rabbit is eaten by a dog, the encysted larvae are released, and develop into adult worms. As can be seen from the specimen on display, tapeworms can be quite large: *T. solium*, a parasite of the human intestine, can reach a length of 10 feet!

## 2) Phylum Nematoda

Nematodes are probably the most abundant and ubiquitous animals on earth, having invaded virtually every habitat. Most of the approximately 10,000 species of nematodes are free-living, but many are parasites of animals, including humans. *Trichinella spiralis*, for example, is contracted by eating insufficiently cooked pork. The adult worms develop in the human intestine, releasing larvae which move through the lymphatic system, eventually ending up in muscle tissues where they encyst. Other nasty nematode parasites of humans include *Necator americanus* (hookworms) and *Wuchereria*, which results in elephantiasis. Nematodes also are parasites of plants and can cause enormous crop damage; as a result, some large universities have departments of plant pathology devoted to the study of plant pathogenic nematodes.

### Noteworthy characteristics of nematodes are:

- 1) they are **triploblastic**.
- 2) they have a **pseudocoelom**, a cavity incompletely lined by mesodermally-derived tissue.
- 3) the fluid-filled pseudocoelom functions as a **hydrostatic skeleton**.
- 4) they have a complete, **one-way digestive tract**, having both a **mouth** and an **anus**.
- 5) they have a non-living, protective **cuticle** covering their bodies.

### Specimens of Nematodes

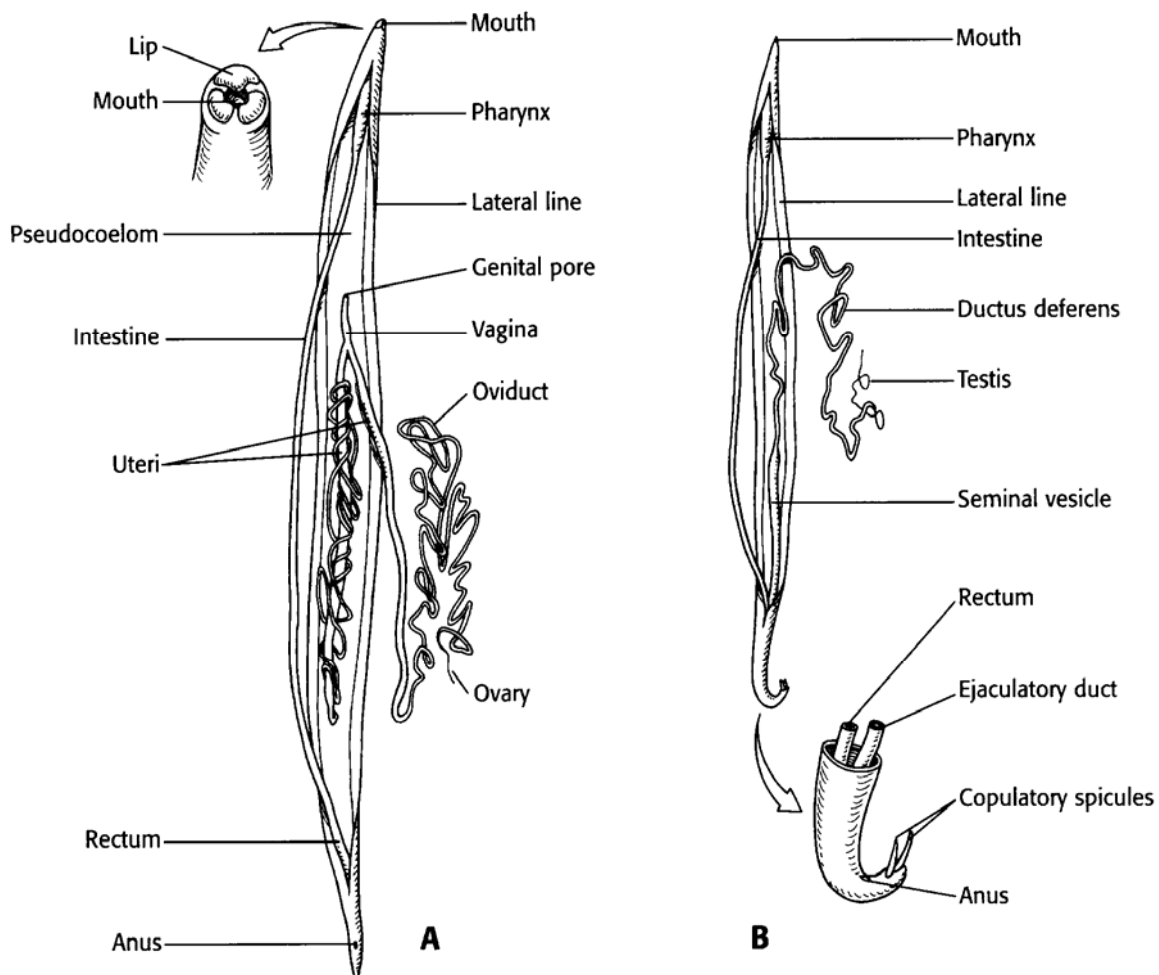
We will examine preserved specimens of *Ascaris lumbricoides*, commonly known as the roundworm, an intestinal parasite of humans. Humans contract *Ascaris* by ingesting eggs from the soil. Once ingested, the eggs hatch, releasing larvae. The larvae bore through the small intestine and migrate via the venous and lymphatic systems to the lungs. There the larvae continue to grow, and pass through several larval stages. After a few weeks, the larvae are coughed-up, literally, and then swallowed, where they develop into mature adults in the small intestine.

**A. *Ascaris*, external morphology (Figure 6)**

Examine preserved specimens of male and female ascarids. The male is smaller, and has a curved, posterior end for grasping the female during copulation. These differences in size and morphology are examples of **sexual dimorphisms**. Why do you think sexes of *Ascaris* differ in size?

**B. *Ascaris*, internal morphology (Figure 6)**

Obtain an *Ascaris* worm from your laboratory TA. Female *Ascaris* are somewhat easier to dissect, because their larger size makes it easier to find and identify various organs. However, you should examine both a dissected male and female worm, so ask around in lab to find a dissected worm of the opposite sex. Determine the dorsal surface by locating the anus, which is on the ventral side. Then, place the animal in a dissecting pan, pinning it at both the head and tail ends, dorsal side up. Using fine scissors or a scalpel, carefully cut along the midline of the dorsal surface to expose the internal organs. Pin the body wall back so that organs are exposed, and submerge your animal in water so that its internal organs float freely.



**Figure 6:** External and internal anatomy of A. female and B. male *Ascaris* (from Hopkins & Smith, 1997, Introduction to Zoology).

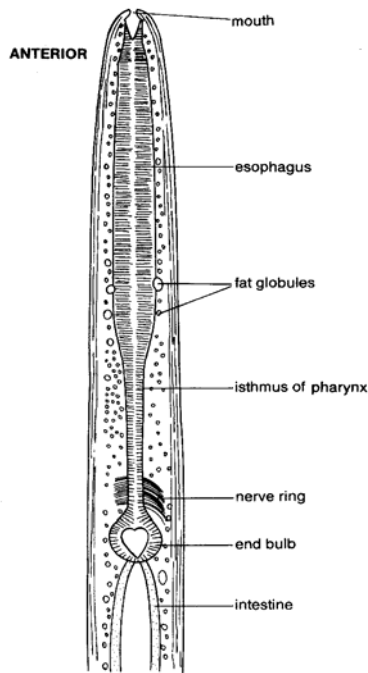
Note the body cavity, which is a false coelom (**pseudocoel**). How does this pseudocoel differ from a true coelom? The two, faint lateral stripes are **lateral lines** that bear excretory canals which empty into an excretory pore, located anteriorly on the ventral surface (not visible). Other, fainter longitudinal streaks are bundles of **longitudinal muscle**, formed from embryonic mesoderm. There are no circular muscles. Given the absence of a hard, bony skeleton and circular muscle, how do you think a nematode moves?

The straight, tubular digestive system for the most part is undifferentiated (why?) and consists of a **mouth, pharynx, intestine, and anus**.

The most conspicuous organs in the pseudocoel are the tubular reproductive organs. Nematodes are very prolific, and females of some species may shed thousands of eggs daily. Carefully uncoil the reproductive organs, which are Y-shaped. The **vagina** is located at the base of the Y, and the two arms are the **uteri**. Each uterus connects to an **oviduct**, which in turn connects to an **ovary**. The uterus, oviduct, and ovary are continuous and have no obvious demarcations between them, although the uterus tends to be slightly larger in diameter.

**C) *Tubatrix aceti*, live specimen** (Figure 7)

The 17th century Dutch haberdasher, Antoine van Leeuwenhoek, was a pioneer in applying the microscope to the study of living organisms. He was the first to make people aware of the incredible diversity of organisms that were living in and around us, but were too small to see. He was also a bit of a "wise guy". When hoity toity "ladies" would visit, he liked to make them gag by pulling out his microscope and showing them "the little eels" that were wiggling around in the vinegar that they were eating during dinner. He mentioned, apparently with some delight, that these high society ladies would leave his house, swearing never again to use vinegar in their food preparation.



We have some of Leeuwenhoek's little eels alive and ready to watch in lab this week. Examine some of the vinegar eels, known as *Tubatrix aceti*, using a dissecting microscope and a depression slide. Vinegar eels are free-living, non-parasitic nematodes that inhabit, as their name would suggest, vinegar. As is true of all nematodes, vinegar eels are pseudocoelomate, and possess a fluid-filled, **hydrostatic skeleton** and a body wall lined with **longitudinal muscle**. How do these characteristics affect their pattern of locomotion? How does their locomotion compare to the locomotion of an earthworm (p. 9)? Can you explain why these animals differ in their patterns of locomotion?

**Figure 7:** Anterior end of the vinegar eel, *Turbatrix aceti*, a free-living nematode (from Wallace et al. 1989, Invertebrate Zoology).



### 3) Phylum Annelida

The phylum Annelida includes approximately 15,000 marine, freshwater, terrestrial, and parasitic species. It is the archetypal ‘wormy’ phyla, with the majority of forms possessing a long, thin shape. The long shape is attained in annelids by metameric **segmentation**, a linear repetition of body parts and organs. Segmentation has enabled annelids to become particularly adept at a particular type of locomotion, burrowing. In addition to segments, other annelid features include:

- 1) A triploblastic, bilaterally-symmetric body plan with a true **coelom**; that is, their body cavity is completely lined by mesodermally-derived tissue (the peritoneum).
- 2) The fluid-filled coelom functions as a **hydrostatic skeleton**.
- 3) A **closed circulatory system** with dorsal and ventral blood vessels, with one to many "hearts"; often with hemoglobin as a respiratory pigment.
- 4) A **nervous system** including a **cerebral ganglion** (= brain).
- 5) An excretory system consisting of **nephridia**.
- 6) A **complete, one-way, digestive tract**, with a separate **mouth** and **anus**.
- 7) **Longitudinal** and **circular** muscles.

The phylum is divided into three classes, two of which are characterized by tiny bristles (**setae**) in their body walls:

**Class Polychaeta** (= many setae), marine species such as sandworms that usually possess fleshy, lateral extensions (**parapodia**) from their body wall.

**Class Oligochaeta** (= few setae), freshwater and terrestrial species (e.g., earthworms).

**Class Hirudinea**, leeches, which lack setae and move in an inch-worm fashion using anterior and posterior suckers, or swim via undulations.

**Earthworm dissection:** Obtain a preserved specimen of the earthworm (*Lumbricus*) for dissection. Identify the dorsal and ventral surfaces. Make an incision on the dorsal surface from the prostomium (mouth) to the middle of the body. Carefully cut and pin back the skin to expose the internal anatomy. Use Figure 8 to identify the structures listed below, and consider the basic function of each structure as you examine it.

**You should be able to identify the following structures on a dissected earthworm:**

clitellum	seminal receptacle	mouth
prostomium	crop	gizzard
pharynx	intestine	esophagus
septum	ventral nerve cord	seminal vesicle
hearts	cerebral ganglia (“brain”)	nephridia
dorsal blood vessel		

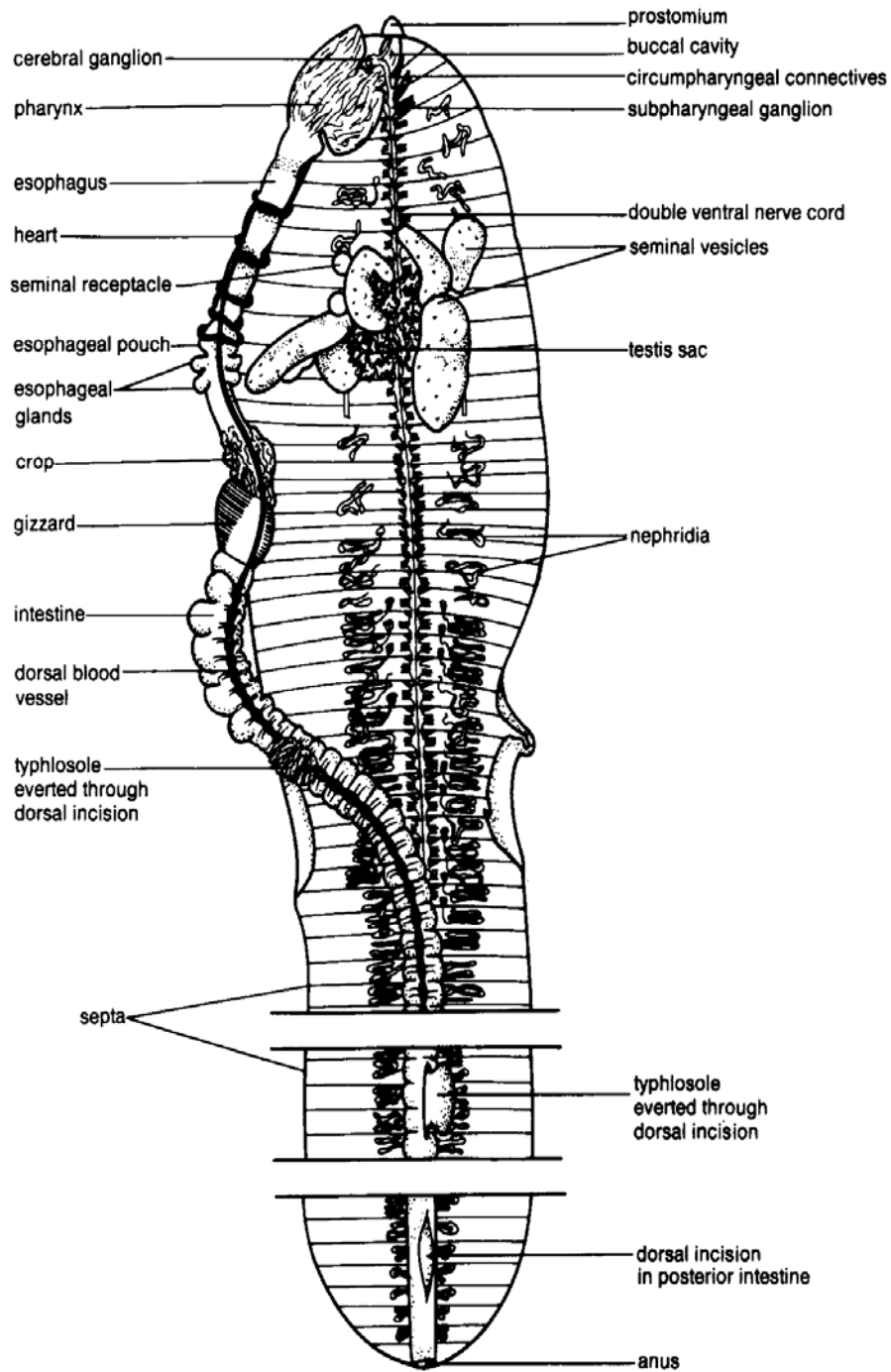


Figure 8. Internal anatomy of the earthworm, *Lumbricus* (from Wallace, et al., 1989; Invertebrate Zoology)

***Hirudo*, preserved specimen** (demonstration), ectoparasite

Observe the specimens of *Hirudo*, a leech representative of the class *Hirudinea*. Leeches probably evolved from oligochaetes, and are the most specialized of annelids. Some leeches are predaceous, but most are external parasites of other animals, and have several adaptations for a parasitic lifestyle. Their body is dorso-ventrally flattened, and the first and last segments are modified to form suckers. Why is a flat shape useful for ectoparasites? Can you think of any arthropod parasites that have flat shapes? Except in primitive species, the internal segmentation has been lost. Consequently, the movement of leeches differs somewhat from other annelids, and depends on the use of suckers for attachment to the substrate. Given what you know about locomotion in earthworms, how do you think a leech uses its suckers to move about? The mouth of the leech has toothed jaws, which it uses to make an incision in its host to feed on its blood. An anticoagulant, hirudin, secreted into the wound keeps the host's blood flowing. What arthropods might benefit from having such an anticoagulant? Like oligochaetes, leeches are hermaphroditic, bearing both male and female reproductive organs.

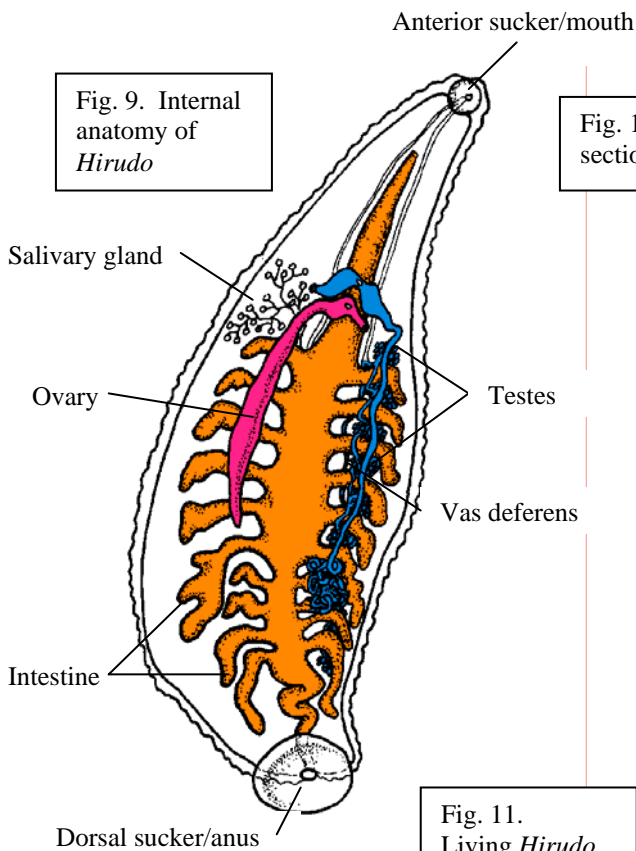


Fig. 10. Cross-section of *Hirudo*

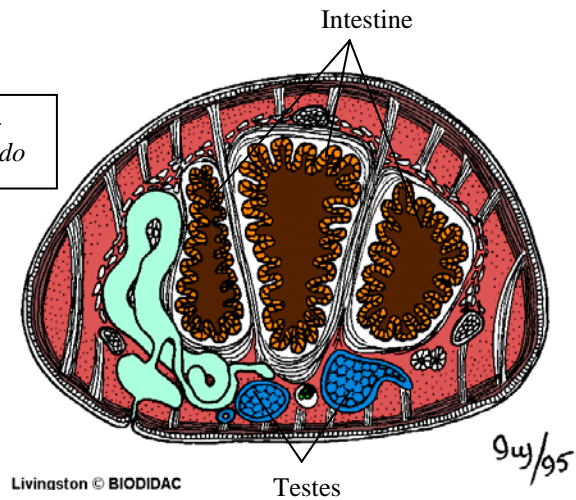
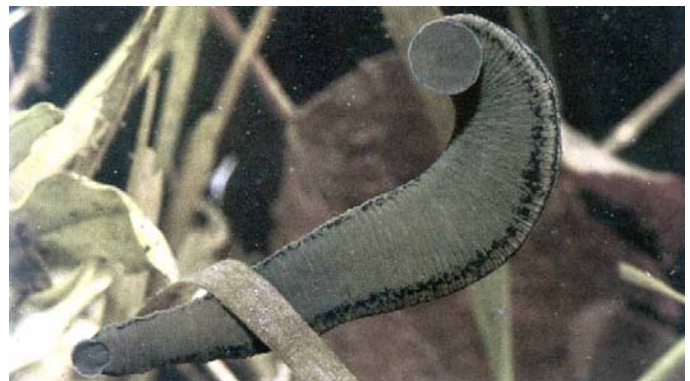


Fig. 11. Living *Hirudo*



## Labs 4-6: Invertebrate Organ Systems

### DIGESTIVE SYSTEM (FOOD PROCESSING)

**Textbook Reference Pages:** pp. 1075 (middle) - 1078 (middle)

Movement, coordination and sensing things all require energy, so organisms need ways to **capture and process energy** from their environment. In some organisms (plants), this is a matter of directly harnessing the sun's energy to convert carbon to glucose (photosynthesis), but in many other organisms, locating and immobilizing prey to obtain energy is a complex process. Once animals have located and/or subdued their food, that food needs to get broken down into smaller bits, nutrients like glucose need to get absorbed into the body system, and waste products must be eliminated. This requires some sort of **digestive system**.

You probably know the story in mammals (like you) - you break apart the food with your **teeth** and enzymes (amylase) found in your **saliva**, then you swallow the smaller bits, and enzymes in your **stomach** and **small intestine** break it down further. Although substances like alcohol and caffeine can be absorbed across the stomach lining (hence the buzz when consumed on an empty stomach), the site of most absorption of nutrients occurs in the **small intestine**. The surface of the small intestine is lined with **villi**, projections into the lumen of the intestine that dramatically increase the surface area for digestion. The small intestine has three specialized regions: 1) the **duodenum**, where most digestion occurs, 2) the **jejunum**, and 3) the **ileum**, where (with the jejunum) 90% of the absorption of nutrients occurs. From the small intestine, waste passes into the **colon** where water and ions are absorbed into the body, and undigested wastes are eliminated through the **rectum** and **anus**.

So, what happens in other organisms that are not you? How do invertebrates go about the processes of acquiring food, where do they digest it, and where do they absorb it? Knowing what they need to do, think about what types of materials each organism consumes, and try to locate the likely places that these processes occur. Refer back to Figure 8 and to your dissected earthworm to answer these questions for the free-living earthworm.

### INFORMATION PROCESSING AND SENSORY INPUT

**Textbook Reference Pages:** pp. 943-946 (top) and 977 (bottom) - 979

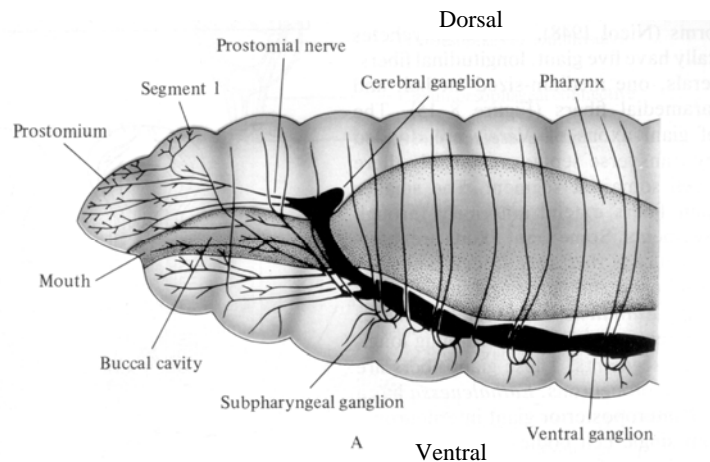
The bodily processes of multicellular organisms need to be coordinated, and to do this, most animals have a nervous system, which enable them to coordinate and regulate the activities of different body parts via rapid electrical signaling. The simplest type of nervous system consists of simple **sensors**, which receive information, **effectors** such as muscles and glands, which carry out responses to stimuli, and a system of **nerves** that run between them. Some organisms, like cnidarians (e.g., *Hydra*), can exist with a simple network of neurons since their lives are spent attached to the substratum, and responses to their environment do not need to be well coordinated.

For animals that move about to locate food or mates, more-sophisticated sensory detection and coordination of responses is necessary. In these animals, we see the development of simple to complex **brains** (or **ganglia**, which are accumulations of nerve cell bodies, in the case of invertebrates), well-defined sensory systems, and developed effectors (like muscles). In addition, the nerves that run between these components of the nervous system become increasingly more developed from simple to complex organisms. When you look at the brains (ganglia) in the specimens over the next several weeks, you should notice where they are located and how complex they are. You should also look at some of the sensors (such as eyes), the effectors, and the nerves that run between them and the ganglia in these specimens. In particular, pay attention to where the major nerves are located (are they on the dorsal side or the ventral side?).

### Examples of Invertebrate Nervous Systems:

**Brains:** In the invertebrates, we see the development of simple brains (**ganglia**) that you should try to find today in the earthworm (*Lumbricus*, Phylum Annelida, Figure 12) and later in squid and crayfish.

**Figure 12:** Head region of the earthworm (*Lumbricus*), showing the organization of the nervous system in this region. A major nerve cord runs from the ventral ganglion down the length of the animal (from Withers, 1992, Comparative Animal Physiology).



### Invertebrate Vision Systems:

In response to their environment, most plants and animals have evolved some means of detecting light. This detection is generally the consequence of a chemical change in the organism resulting from the absorption of light energy. Plants display a general sensitivity to light; that is, they have no specific light-sensitive organs, yet they are able to detect light and grow or bend toward it. In animals, there is a tendency toward concentration of light-sensitive cells into specific areas or organs (e.g., the eyespots in planaria). The development of the eye represents perhaps the greatest concentration of light-sensitive cells in an organism. Increasing complexity of association with the nervous system allows the organism to perceive not only changes in light intensity, but also movement and form.

In today's lab, examine the eye spots of *Dugesia* (a planarian worm) as you test whether *Dugesia* move towards or away from light. Which other species of worms have eyes? Why don't the other species of worms have eyes?

## RESPIRATORY SYSTEM (EXCHANGE OF GASES)

**Textbook Reference Pages:** pp. 1024-1028

Even if animals have food in the form of glucose, to actually convert it into useable energy (such as a lot of ATP) requires oxygen, with carbon dioxide produced as a byproduct. Therefore, animals need to have a method of obtaining oxygen from their environment and for releasing carbon dioxide, and thus need a **respiratory system**. What is the mechanism of the exchange of gases? The answer is **simple diffusion** of dissolved gases, whereby oxygen and carbon dioxide move down their concentration gradients at the exchange surface - oxygen coming into the system and carbon dioxide going out. There is more to gas exchange, however. If there is no movement of the respiratory medium (water or air) across the exchange surface (skin, gills, lungs, etc.), then the two gases will reach equilibrium at the site of exchange, and the organism will suffocate.

So, with these two components of gas exchange (movement of respiratory medium and the passive diffusion of dissolved gases into/out of the body), how have organisms across evolutionary time been able to meet their oxygen demands? In the simplest and most ancestral organisms, like the flatworms, there is no need for elaborate respiratory organs because gas exchange can occur across the body surface. With their flattened body plan, the body surface of a flatworm is never far from the body interior and oxygen can easily diffuse into the body's core. We will look at flatworms in this week's lab, to get an idea from what body plan all the animals you will see in this course have likely evolved. Basic geometry can tell us much about the total body surface area to body volume ratio for three dimensional organisms: as organisms increase in size their insides (volume) increase more rapidly than their outsides (surface area). This means that simple **cutaneous** (skin) gas exchange would not work as organisms increased in size through evolution. Consequently, as organisms increase in size and complexity, we see an increase in the sophistication of the respiratory structures.

Even with this increase in the complexity of these structures, there are three basic factors that evolution has acted upon to meet the oxygen demands of these larger animals: 1) increasing the surface area of the exchange surface, 2) decreasing the distance of diffusion between the respiratory medium and the blood at the exchange surface, and 3) maximizing the concentration gradients of O<sub>2</sub> and CO<sub>2</sub> between the respiratory medium and the blood at the exchange surface (countercurrent exchange systems). Notice here that we mentioned the exchange between the respiratory medium and the blood - although we are presenting them as separate systems, it is critical that you understand the relationship between the respiratory and circulatory systems.

In addition to looking for the above processes in your study of the various organisms, you should also pay attention to the characteristics of the environments of the particular animals of study. Clearly there are drastic differences in the implications of living in water or living in air, and you should think about the limitations and benefits of both types of respiratory media as you look at these animals. Specifically, water holds 20X less oxygen than air and respiratory structures that evolved in water don't work in air, because air is not as supportive as water.

**Earthworm Respiratory Surface** - Look at your dissected earthworm. Do you see any specialized structures (lungs, gills) for gas exchange? How does an earthworm exchange gases? For a hint, look at the diagram of the earthworm circulatory system below (Figure 13).

## CIRCULATORY SYSTEM (MOVEMENT OF BODY FLUIDS)

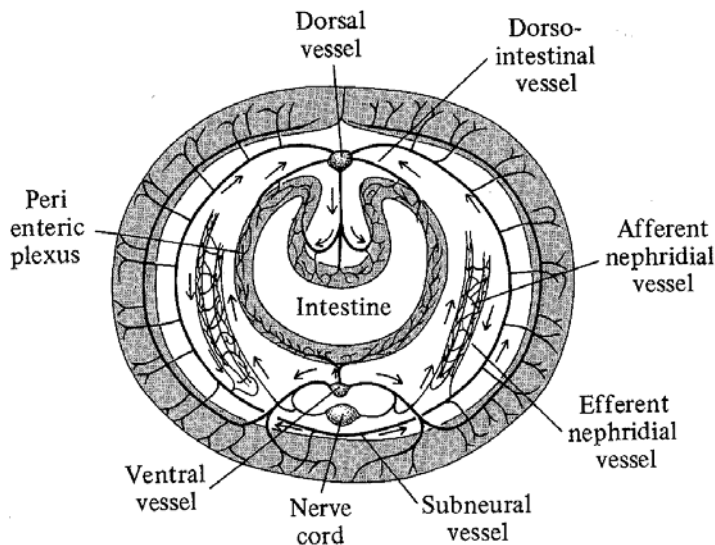
**Textbook Reference Pages:** pp. 1045-1047 (middle)

Of course, without a means of distributing both the food (glucose) and the gases (O<sub>2</sub> and CO<sub>2</sub>) throughout the body, e.g., without a **circulatory system**, having gone to the trouble of finding a meal is useless. A circulatory system is essential in the transport of gases, nutrients, and hormones, as well as critical to maintaining homeostasis and protection of the body from infection. In lab, we will focus on the importance of the circulatory system for transport.

Now that you know the functions of the circulatory system, what are the major components of the system? A true circulatory system consists of one (or more) pump(s), blood vessels and fluids. Circulatory systems are of two types: **open** or **closed** (you should understand the meaning of those terms). Simpler organisms such as planaria have a gastrovascular cavity to distribute materials to different body parts. Earthworms and squid have closed circulatory systems, whereas crayfish have open systems. Thus, you should think about the puzzle of why certain organisms may have *lost* a closed circulatory system over evolutionary time.

You will not have the opportunity to look at the cellular components of blood in lab, but be sure to look at the invertebrate hearts and vessels, and think about the issues raised above.

### Earthworm Circulatory System (Figure 13):



**Figure 13:** The closed circulatory system of an oligochaete annelid (*Lumbricus*) has a dorsal and ventral vessel and capillary beds in the gut, viscera, and skin; arrows indicate direction of blood flow (from Withers, 1992, *Comparative Animal Physiology*)

## EXCRETORY SYSTEM (WATER AND SALT BALANCE)

**Textbook Reference Pages:** pp. 1093-1097

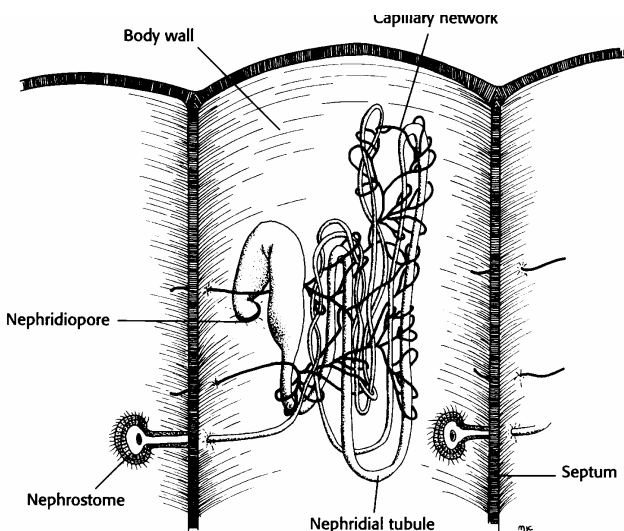
There are consequences to cellular metabolism, in terms of the waste products that are produced as a result of the breakdown of nitrogen-containing molecules (such as amino acids).

Organisms have solved this problem by having an **excretory system**, in which they remove nitrogenous wastes as well as regulate the amount of salt and water in their systems. All animals would die without the ability to shed nitrogenous waste products from the breakdown of proteins and nucleic acids. However, in these labs, we are going to focus on the **osmoregulatory** functions of invertebrate and vertebrate excretory systems.

Animals have adapted to survive in many different habitats, and consequently, have very different needs in terms of the regulation of water and salts. Fortunately (for us) they use a set of structures for osmoregulation that are similar in the way they function, so that we can learn a common set of facts to base our understanding of excretory systems in general.

One of these "facts" is that water moves by passive processes, based on simple diffusion. Across membranes, water moves by osmosis down its concentration gradient, to equalize the osmolarity (amount of stuff in solution) on either side. So, to get water to move to the right place, animals need to regulate the "stuff" in solution - salts, proteins, etc. Simple organisms in relatively constant conditions often osmoconform to their environments, but as organisms get more complex, conforming to the environment is not the best option. More complex organisms developed scales or skin that are impermeable to water movement, but as you know from learning about respiratory systems, there must be some area on the organism that is permeable to gases and water. It is at these regions that organisms have to control the salts and water entering and leaving the body, while maintaining an effective exchange of gases at the site (such as the gills).

You should specifically pay attention to three issues as you examine the excretory systems of each kind of animal: 1) What are the characteristics of its environment? 2) How does it cope with maintaining homeostasis in terms of balancing water and salts (i.e., does it have an impermeable skin? does it actively regulate salts? is it an osmoconformer?), and 3) What are the major structures involved in regulating water and salts? In addition, pay attention to the similarities that arise due to homology (structures derived from a common origin) and similarities that are due to convergence (like the extreme similarities in the shape of the earthworm nephridia and the vertebrate nephron). Over the next three weeks, you will have the opportunity to see the systems of two freshwater invertebrates - the earthworm (Figure 14) and the crayfish, respectively - as well as Malpighian tubules, which are the excretory organs of insects.



**Figure 14:** A single **nephridium** of the earthworm, *Lumbricus*. As you look at the structure under the microscope, try to identify the major features listed in the diagram and think about how similar it looks to a vertebrate nephron. In addition, why have we categorized the earthworm as a freshwater organism? (from Hopkins & Smith, 1997, Introduction to Zoology).



# Animal Diversity and Organ Systems Lab I: Worms

The questions that follow will more specifically guide your analyses. The list of questions is not exhaustive, but should direct your attention to specific key points of the worm systems that you will see today. Some questions will require that you synthesize information from lectures, your book **and** the lab.

## Questions on Worm Phylogeny:

1. What are the major features of the platyhelminthes?
2. What are the major taxonomic divisions in the phylum *Platyhelminthes*?
3. What are the major features of the nematodes?
4. What are the major features of the annelids?
5. What are the major taxonomic divisions in the phylum *Annelida*?
6. If comparing two organisms, what characteristics do they share because of homology (history)? What do they share because of convergent evolution?
7. How are parasitic worms similar and different from their free-living relatives? What structures have they lost? What structures/organs are expanded?
8. Are there features that are common between the ecto- and endoparasites that you observed? What are the differences between these types of parasites?
9. Why is a flat shape useful for ectoparasites? Can you think of any arthropod parasites that have flat shapes?

## Questions on Organ Systems Anatomy and Physiology:

### Circulatory System:

1. What structure does *Dugesia* use for circulation?
2. What are the three major components of circulatory systems?
3. How does blood (hemolymph) transport differ between organisms with closed and open circulatory systems?
4. What type of circulatory (open or closed) does an earthworm have? How many hearts does it have?
5. Does *Ascaris* have a specialized circulatory system? Why or why not?

### Respiratory System:

1. By what process does the exchange of gases across a respiratory surface occur?
2. What are the three factors that evolution has acted upon to increase the efficiency of gas exchange across respiratory surfaces?
3. How do an earthworm, *Dugesia* and *Ascaris* exchange gases?

### Digestive System:

1. What are the three major processes that occur in the digestive system?
2. How does an earthworm process its food? What structure manually breaks down food particles?
3. What is the function of the intestine in all animals? What are the implications of increasing the length (and/or surface area) of the small intestine? How is the surface area of the earthworm intestine increased?

4. What structural feature(s) does the gastrovascular cavity of *Dugesia* share with the intestine of the earthworm?
5. Why is the digestive tract of *Ascaris* so unspecialized and why don't tapeworms have one at all?
6. The mouth of the leech has toothed jaws, which it uses to make an incision in its host to feed on its blood. An anticoagulant, hirudin, secreted into the wound keeps the host's blood flowing. What arthropods might benefit from having such an anticoagulant?

#### **Nervous System:**

1. In the earthworm, what structure(s) act as the "brain" (e.g., anterior accumulation of nerve cell bodies)?
2. What about the major nerve cord – is it dorsally or ventrally located?
3. Is your specimen of *Dugesia* positively or negatively attracted to light? How might this behavior be adaptive in their natural habitat?

#### **Excretory System:**

1. Why is osmoregulation a challenge for an animal that inhabits freshwater (e.g., *Dugesia* and earthworms)?
2. How have these animals solved the problems of osmoregulation (e.g., what structures are involved)?
3. How do the different types of worms excrete metabolic wastes?

#### **Musculoskeletal Systems and Movement:**

1. What type of skeleton do annelids (e.g., earthworms) and nematodes have?
2. What kind of body wall muscles (circular and/or longitudinal) do nematodes have?
3. Describe how the muscles and skeleton interact to produce the characteristic writhing movements of nematodes.
4. What kind of body wall muscles (circular and/or longitudinal) do earthworms have?
5. How does the earthworm's mode of locomotion differ from the mode of locomotion of a nematode? Do the earthworm's segments give it an advantage in locomotion over nematodes, and if so, how?
6. What role does the nervous system play in locomotion of earthworms?
7. Given what you know about locomotion in earthworms, how do you think a leech uses its suckers to move about?
8. Turbellarians (such as *Dugesia*) lack any type of skeleton, yet you saw them move in the Petri dish. How, then, did they move from place to place?

#### **Reproductive System:**

1. Why might hermaphroditism be advantageous in an internal parasite?
2. Why do you suppose hermaphroditism evolved in earthworms? Why do you think the sexes are separate in polychaetes, but not in other classes of annelids?
3. Earthworms copulate yet have external fertilization. Describe the fertilization process in earthworms.
4. The sexes are separate in *Ascaris*. Compare and contrast the external and internal anatomy of the two sexes.

## On-Line Worm Quiz

Student understanding of the worm lab subject matter will be assessed via a short, on-line quiz. The quiz will be available for all students to take from 8 AM on Monday, March 10<sup>th</sup> until 12 noon on Tuesday, March 11<sup>th</sup>. You will access the quiz via a link in the Lab Quiz folder on the Bio 18 course Blackboard page. You will have up to 45 minutes to complete the quiz, and the clock will start ticking once you open the quiz link.

More detailed directions for completing the quiz will be available once you open the quiz link. **READ THESE DIRECTIONS CAREFULLY!** An incorrect keystroke will be enough for Blackboard to immediately kick you out of the quiz. Please e-mail Dr. Emerson immediately, if you have any problems completing the quiz.

This is a "closed book" quiz, and we expect that you will respect the Amherst College Honor Code and not rely upon other sources of information (e.g., books, lab manual, notes, other Web sites or other people) while you are taking the quiz. We also ask that you do not discuss the contents of the quiz with any other students in the course after you take it. The Biology 18 lab will remain unlocked until 8 AM on Monday, March 10<sup>th</sup>, so that students may review the worm lab materials. **PLEASE DO NOT REMOVE ANY OF THESE MATERIALS FROM THE LAB.**