Exercise 4
Bivalve Anatomy I: Mytilus edulis and Mercenaria mercenaria

In this exercise students examine and dissect two important bivalve species. Comparisons are made between these species as they occupy distinct habitats and have evolved structures that enhance their lifestyle in each habitat.

SUGGESTED ELEMENTS FOR AN INTRODUCTORY LECTURE

- *Mytilus edulis* occupy hard substrata where they form extensive mats attached via their byssal threads.
- *Mercenaria mercenaria*, in Family Veneridae, one of the largest classes of Bivalves, is a burrower and occupies intertidal to shallow subtidal mud, sandy or seagrass habitats.
- *Mercenaria* are deposit feeders and use siphons to feed on soft sediment, whereas *Mytilus* are filter feeders.

ACTIVITIES
1. Examine shell morphology of *Mytilus* and *Mercenaria*.
2. Identify key features of each shell.
3. Sketch shell morphology.
4. Dissect *Mytilus* and *Mercenaria* to examine structures of the visceral mass.
5. Sketch internal anatomical structures.

VOCABULARY

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<th>Growth rings</th>
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MATERIALS FOR ALL PROCEDURES

Equipment
- Dissecting Microscope

Supplies
- Dissection Kit
- Dissection Tray
- Gloves
- Sea water or Instant Ocean (for living specimens)
- Colored pencils
- Lab notebook
- Ruler
- Bivalve plastimount

Organisms
- *Mytilus edulis*
- *Mercenaria mercenaria*
SUPPLEMENTAL MATERIALS

Marine Clam Dissection Plastomount

http://serc.carleton.edu/microbelife/topics/marinesymbiosis/qpx_dissection.html
http://lanwebs.lander.edu/faculty/rsfox/invertebrates/mytilus.html
http://lanwebs.lander.edu/faculty/rsfox/invertebrates/mercenaria.html


VENDORS FOR MATERIALS

*Mytilus* and *Mercenaria* can be purchased locally at the grocery store (living specimens) or preserved specimens can be purchased from Carolina Biological Supply Co. (www.carolina.com) or Wards (www.wardsci.com).

Plastomount can be purchased from Carolina Biological Supply Co. (www.carolina.com).

This exercise has been modified with permission from *Invertebrate Anatomy OnLine*, an Internet laboratory manual for courses in Invertebrate Zoology.
LAB OBJECTIVES:

1. To examine shell anatomy and be able to identify key morphological features of two model species, *Mytilus edulis* and *Mercenaria mercenaria*
2. To examine internal anatomy and be able to identify key morphological features

In today’s lab you will examine the internal and external anatomy of two representative species, *Mytilus edulis* and *Mercenaria mercenaria*. These two species have very different modes of life with *M. mercenaria* being a burrower and *M. edulis* occupying rocky intertidal shores. As you dissect your specimens examine internal features keeping in mind their respective lifestyles. Sketch the details of the shell and internal anatomy in your laboratory book. Record notes on how the representative species differ morphologically.

*Mytilus edulis* blue mussel

Mussels belong to the Subclass Pteriomorpha and are epibenthic and live on, rather than in, the benthos. This taxon includes the well-known arcs, mussels, scallops, pen clams, and oysters. They may be attached or unattached, with byssus or cementing one valve to the substratum. *Mytilus edulis* is found, often in high population densities, in Europe, on both coasts of North America from the Arctic to the Middle Atlantic States on the east coast and south to California on the west. They form dense, extensive mats on hard substrata. They are valued seafood and support a commercial fishery where they are abundant. They reach approximately 8 cm in length.

Marine mussels are have filibranch gills. The foot is reduced and the mantle margins are not fused. The gills are large and used for filter feeding. There is a tendency for a reduction or loss of the anterior adductor muscle. Siphons are also reduced or absent.

Shell
Like that of all bivalves, it is composed of two similar valves. Each valve is elongate and the exterior is relatively smooth but has concentric growth rings. The anterior end is pointed and the posterior is broadly rounded (Fig 1). The dorsal margin is convex whereas the ventral is weakly concave. There is a slight permanent gape, where the valve margins do not meet, near the middle of the ventral midline between the two valves. This is the byssal gape which accommodates the byssus.

The two valves are held together in life by the long, straight, developed hinge occupying the anterior end of the dorsal margin (Fig 1). Note the narrow, straight, proteinaceous ligament extending for the length of the hinge. Hinge teeth are weakly developed in mussels. The inconspicuous umbos are located at the anterior end in *Mytilus*. The valve is covered by the conspicuous, dark yellowish brown or black, proteinaceous periostracum. This outermost layer of the shell can be seen folded over the ventral edge of the valve in fresh specimens. The three shell layers are, from outside in, the organic periostracum, calcareous prismatic layer, and calcareous, nacreous. The valves are often eroded so that the chalky white calcareous prismatic layer shows through the dark periostracum.

Use your knowledge of the antero-posterior and dorso-ventral axes to determine which valve is right and which left. Mussels are equi valve (right and left valves are nearly identical and symmetrical). The
opposite is inequivalve. Look at the outside of one of the valves. Each valve is strongly asymmetrical, a condition referred to as **inequilateral**. The anterior end of the valve does not resemble the posterior (Fig 1). The opposite is equilateral.

Most of the interior of the valve is pale but the margins are dark. The line separating the two is the **pallial line** (Fig 1). It is the line of attachment of the mantle to the valve.

A small **anterior adductor muscle scar** can be seen at the anterior end of the valve (Fig 1). It lies on the pallial line on the ventral edge of the valve. The much larger **posterior adductor muscle scar** is located at the posterior end, displaced to the dorsal side. These scars mark the sites of attachment of the adductor muscles to the valves.

The **scar** of the **anterior pedal-byssal retractor muscle** is a small, pale, slender, elongate depression under the overhang of the anterior edge of the valve below the ligament (Fig 1). The **scar** of the **posterior pedal-byssal retractor muscle** is a large, lobed, narrow, dark area extending anteriorly from the dorsal edge of the posterior adductor scar.

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**External Anatomy**

Living (or preserved) *Mytilus* are easily opened, unlike *Mercenaria*. Hold the mussel with its right valve uppermost. Insert the tip of a screwdriver or the blunt end of a forceps into the byssal gape and twist it to force the valves to gape all around, especially posteriorly. Slip a long, sharp scalpel blade into the posterior gape and cut the posterior adductor muscle. The muscle is easily recognized by feel because it is the only firm, resisting structure in the vicinity. You can also look into the gape and see it. Try to avoid cutting any other tissues around the muscle. It will, however, be necessary to cut the black tissue connecting the right and left mantle skirts at the siphons. The rectum and anus are also in this vicinity and you will want them intact later.

Cut the small anterior adductor muscle. The anterior adductor is on the ventral margin just posterior to the anterior tip of the shell.

Lift the right valve slightly and separate it from the soft tissue (right mantle skirt) adhering to its inside surface. Use a scalpel to scrape the right posterior pedal-byssal retractor muscle and the right anterior pedal/byssal retractor muscle away from the right valve.

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**Figure 1.** Interior of the left valve of *Mytilus edulis* (redrawn from White, 1937).
Remove the right valve. The well developed proteinaceous ligament that extends along most of the length of the hinge and must be cut or torn to remove the valve. Place the left valve, with the animal contained in its concavity, in a small dissecting pan of tap water of sea water.

Figure 2. Lateral view of *Mytilus edulis* showing the byssus.

Figure 3. Lateral view of a dissected *Mytilus edulis* from the right side (redrawn from White, 1937). The right valve, mantle skirt, gill, and labial palps have been removed. Part of the right gill has been removed. The visceral mass has been opened and much of it has been removed.

**Mantle**

The animal is enclosed by the large right and left mantle skirts (lobes) which line the inner surfaces of the two valves (Fig 3). The space between the two mantle skirts is the inhalant chamber of the mantle cavity (Fig 4). In life it is filled with seawater. The two skirts are connected dorsally to each other and are attached to the valves along the pallial line.

The mantle skirts are much thicker than is usual in bivalves because they contain the gonads (Fig 4). When ripe, the male mantle is creamy beige whereas that of females is reddish.
Find the left mantle skirt. It should still be attached to its valve. The mantle margins of mussels provide a good example of the basic tripartite condition characteristic of most bivalves. Look at the ventral margin of the mantle skirt. This margin should still be attached to the margin of the left valve. Cut away the newly secreted periostracum on the edge of the left valve along a 2 cm length of the valve margin. Use fine scissors or a scalpel to do this. Lift the freed mantle margin and look beneath it at the shell. You will see that the mantle is attached to the shell a short distance from its margin. This attachment is accomplished by the pallial muscles in the muscular fold (inner fold) of the mantle margin. This line of muscle attachment parallels the margin of the valve and is the **pallial line**.

Posteriorly, the right and left mantle skirts together form the obscure ventral **inhalant** and dorsal **exhalant siphons** (Fig 2). The skirts are connected by a small, transverse, dark brown **branchial membrane** between the two siphons. The epithelium in the vicinity of the siphons is darkly pigmented. A vertical, median membrane extends ventrally from the branchial membrane. Neither of the two siphons is distinct. They are weakly modified areas of the mantle margin and are not complete tubes as are the siphons of many bivalves. They are short and do not extend from the shell. Being epifaunal, *Mytilus* does not need the tubular siphons characteristic of infaunal burrowers.

**Adductor Muscles**

Examine the two adductor muscles (Fig 2). The **anterior adductor muscle** is reduced and is much smaller than the **posterior adductor muscle** as it is in all mussels. This disparity in the size of the two adductor muscles is referred to as the heteromyarian condition and it is associated with the presence of a proteinaceous holdfast called the byssus. The heteromyarian condition is derived from the more primitive, and more common, dimaryarian condition in which the two adductor muscles are of similar sizes.

**Gills**

Use scissors to remove the right skirt of the mantle. This will expose the large right **gill** extending the length of the mantle cavity on the right side of the visceral mass. A gill is formed of the...
combined filaments attached to the central axis. The entire gill is a **holobranch** (=whole gill) and includes the filaments on both sides of the axis. There is only one gill on the right and one on the left even though it may look to you as if there are two on each side.

Each **holobranch** consists of two **demibranchs**, or half gills, one medial and one lateral (Fig 3). Find the **lateral** and **medial demibranchs** of the right gill.

Each of the two surfaces of a demibranch is a **lamella**. Each demibranch thus has two lamellae (Fig 4). Each holobranch, since it is composed of two demibranchs, has four lamellae.

The two demibranchs are attached to each other along the **central axis** (Fig 4). This longitudinal axis extends the length of the dorsal wall of the mantle cavity between the visceral mass and the mantle skirt. The demibranchs hang freely into the mantle cavity and are attached to the body wall at the central axis.

In cross section each holobranch can be likened to a capital W (W) or, more accurately, a "double V" (Fig 4). The central axis by which the gill is attached to the body is represented by the middle point of the W. Each V of the W is a demibranch. Each demibranch (V) is composed of two lines, \ and /, which represent the lamellae. The four lamellae of the holobranch are the four straight lines of which the W is composed (i.e. W / W).

The two lamellae that drop from the central axis down into the mantle cavity are the **descending lamellae** (Fig 4). Each holobranch has two, each demibranch has one. The descending lamellae of adjacent demibranchs face each other. The lamellae that rise back up into the mantle cavity are the **ascending lamellae**. The descending lamellae of a holobranch are the inner two straight lines of our W (W) and the ascending lamellae are the outer two (\ /).

In mussels and scallops, the upper ends of the ascending lamellae are not attached to the body wall and are entirely free (Fig 4). The ascending lamella of the lateral demibranch of the right gill is facing you now (if you have been following instructions). Put your new knowledge to use by naming the remaining three lamellae of the right gill.

In mussels, most ciliary currents on the lamella beat ventrally toward the **ventral food grooves** on the ventral to edges of the demibranchs (Fig 4). In mussels the dorsally directed currents are weak. The currents in the ventral food grooves are longitudinal, toward the labial palps at the anterior end. Look carefully at the ventral edge of a demibranch and find its food groove. A weak anterior longitudinal current exists along the dorsal free edge of the ascending lamellae but not along the central axis of the holobranch.

Mussels and scallops have **filibranch gills**. Such are primitive and are presumed to be the original condition of the lamellibranch gill. In a filibranch gill, adjacent filaments are held together only by ciliary interfilamentar junctions and are easily pulled apart. The eulamellibranch gills of most other bivalves, such as *Mercenaria* are held together by solid, vascularized tissue junctions. The filaments of eulamellibranch gills have, in fact, grown together to form a continuous sheet perforated by small pores.

Each filament bears frontal cilia on its outer edge and lateral cilia on the flat surfaces facing adjacent filaments. The lateral cilia generate the feeding/respiratory current whereas the frontal cilia move food particles along the surface of the gill to the food grooves.

The gills divide the mantle cavity into a ventral inhalant chamber and a dorsal exhalant chamber. Water enters the inhalant chamber from the ventral inhalant siphon. It then passes between the gill filaments to enter the exhalant chamber. It flows back into the sea through the dorsal exhalant siphon. The large **inhalant chamber** is readily visible between the two mantle skirts whereas the exhalant chamber can be seen only by removing or opening a demibranch.

**Labial Palps**

At the anterior end of the visceral mass is a pair of elongate, triangular, flat **labial palps**, one right and one left (Fig 3). The palps are ciliated and are used to transfer food from the gills to the mouth. Each palp consists of a **lateral** and a **medial lamella** associated with the lateral and medial demibranchs respectively. There is one lamella for each demibranch. One surface of each lamella is covered by ciliated ridges and grooves. The ridged surfaces of the two lamellae of a palp face each other. The ridges
are perpendicular to the long axis of the palp. A longitudinal ciliated oral groove extends along the junction between the two lamellae.

Each lamella, medial and lateral, is connected physically with its counterpart on the opposite side. These transverse connections form a pair of lips above and below the mouth. Thus the right and left lateral palps are connected with each other by the dorsal lip above the mouth and the right and left medial palps are connected by the ventral lip below the mouth.

The mouth is a small opening located on the anterior midline of the visceral mass between the dorsal and ventral to lips. The oral groove runs between the upper and lower lips to enter the mouth.

The ciliated ridges and grooves form a sorting field to partially separate the mineral and organic particles collected on the gill surfaces. Ciliary currents in the grooves move mineral particles to rejection currents along the free margins of the lamella. Ciliary currents on the crests of the ridges and in the oral groove move organic particles toward the mouth. The oral groove transports these particles, between the lips, to the mouth. Final sorting will occur in the stomach.

The rejection current runs along the free edge of the lamella to the pointed tip of the palp. Rejected sediment, trapped in mucus and known as pseudofeces, drops into the inhalant chamber of the mantle cavity. Posteriorly directed currents on the ventral mantle margin and posteroventral currents on the mantle surface move the pseudofeces posteriorly to the inhalant siphon. The particles are ejected from this siphon when periodic contractions of the adductor muscles force spurts of water out of the inhalant chamber.

Respiratory Surfaces

The gills are not the only, or even the most important, respiratory organs of mussels. The inner surfaces of the mantle skirts are also responsible for gas exchange but the chief respiratory surfaces are the plicate organs (Fig 4). Each of the two plicate organs is a longitudinal row of transverse folds of epithelium between the gill and the visceral mass. They are heavily vascularized, more so than the gills. Carefully remove the right gill to expose the right plicate organ. Look deep in the crease between the central axis of the gill and the visceral mass. In living specimens the folds are white and show up clearly against the golden brown kidney or dark brown digestive cecum behind them.

Visceral Mass

Removal of the right gill exposes the visceral mass and foot. You should now be looking at the exposed right side of the visceral mass (Fig 3). It is the largest part of the body and contains most of the organs. It lies on the median plane in the center of the mantle cavity. To the left of the visceral mass are the left gill, left mantle skirt, and left valve in that order. Point the anterior end of the animal to your right.

Look at the visceral mass lying between you and the left gill. It is elongated along its antero-posterior axis and is compressed from side to side. Look through the body wall for the large, dark brown digestive cecum, which occupies most of the space in the anterior visceral mass. It is located immediately posterior to the mouth and can be seen through the body wall. The esophagus, stomach, and much of the intestine are embedded in the digestive cecum and visceral mass but will not be seen at this time. If the right gill has been removed, the digestive cecum will be easy to see.

The nephridium is visible in the dorsal mantle cavity under the surface of the visceral mass beside the gill. It is yellow brown. The plicate organ is on its surface.

Foot and Byssus

The small wormlike foot is located in about the middle of the ventral margin of the visceral mass (Fig 3). In mussels the foot is not used for digging and is not a typical bivalve foot. Its function is the formation and manipulation of byssal threads.

The foot is muscular is composed of an outer layer of circular muscles around an inner core of longitudinal muscles. There are also some oblique fibers. The pedal hemocoel inside the foot is a hydrostatic skeleton that allows these muscles to antagonize each other. Contraction of the circular
muscles extends the foot whereas contraction of the longitudinals withdraws it. Partial and selective contraction of the longitudinal muscles can bend the extended foot.

The foot has a longitudinal byssal groove along its posterior margin (Fig 4). The byssal gland is located at the base of the foot and byssal groove (Figs 3, 4). You may be able to see byssal threads emerging from it. The byssal groove originates at the gland, which secretes liquid protein that is formed into threads by the byssal groove. The threads are attached to the substratum by the foot and then allowed to harden.

Collectively the resulting cluster of protein threads is the byssus (Fig 3). It may or may not be present in your animal. It is a holdfast extending from the visceral mass to the substratum. The proximal ends of the threads enter the visceral mass and are attached to numerous muscles, the byssal retractor muscles that run through the mass to insert on various parts of the shell (Fig 3). These white muscles can be seen easily through the integument of the visceral mass of *Mytilus*.

**Pedal and Byssal Muscles**

The foot and byssus are moved with respect to the body by a set of extrinsic muscles that originate on the shell and insert on the foot or byssal gland. Among these is a pair of anterior pedal-byssal retractor muscles of the foot and byssus (Fig 3). These are white, cordlike muscles extending from their origin at the base of the foot along the anterior edge of the visceral mass. They diverge slightly to their separate insertions on the shell under the anterior end of the ligament. You found their scars earlier and may want to refer once again to the empty valve to confirm their position.

Several pairs of posterior byssal retractor muscles originate at the base of the foot and fan out dorso-posteriorly to their insertions on the shell in a line anterior to the posterior adductor muscle. These are also white, cordlike paired muscles. The retractor muscles can retract the foot but their primary function is to pull the animal to the substratum to which the byssus is attached.

The anteriormost of this series of muscles is sometimes known as the posterior pedal retractor muscle (Fig 3).

**Internal Anatomy**

**Hemal System**

The pericardial cavity is located dorsally at the very top of the visceral mass, just ventral to the middle of the dorsal margin of the shell. In *Mytilus* it is posterior to the hinge. It is a coelomic space and is lined with peritoneum. The walls of the cavity are thin and translucent in *Mytilus*.

Open the pericardial cavity carefully with a shallow, dorsal, longitudinal cut made with fine scissors. It may already have been opened accidentally. The posterior intestine, which is the rectum, extends longitudinally through the cavity but is enclosed for most of its length by the ventricle of the heart.

The heart is associated with the rectum in the anterior part of the pericardial cavity. In *Mytilus* the single ventricle is a pale yellowish mass that surrounds the tubular rectum. At its anterior end the ventricle swells to form the aortic bulb at the base of the aorta. The rectum passes through the center of the bulb.

With fine scissors open the left wall of the aortic bulb and look for the openings of the major arteries. The aorta is median and unpaired and exits the bulb on its dorsal anterior wall, dorsal to the rectum. It supplies the anterior mantle and dorsal esophagus with blood. The paired posterior pallial arteries arise from the lateral floor of the aortic bulb. They supply the posterior mantle. A very large, unpaired coeliac artery exits the floor of the aortic bulb on its midline. It immediately branches into several important arteries to the stomach, intestine, and digestive ceca. (In *Geukensia*, a posterior aorta exits the ventricle posteriorly and runs ventral to the rectum. There is no posterior aorta in *Mytilus*).

On each side the ventricle connects with a membranous atrium. Hold the mussel erect, with its dorsal edge up and focus on the ventricle. Pull the ventricle to one side and you will see the atrium being stretched on the opposite side by its connection with the ventricle. The atria extend ventrolaterally on the
sides and floor of the pericardial cavity. Each of the two atria occupies most of the length of the cavity and is attached posteriorly to the other atrium. Their lumina are not continuous, however. The atria receive oxygenated blood from the efferent branchial vessels draining the gills.

The lobulated brown **pericardial glands** are associated with the atria. They are a part of the excretory system and are involved in the production of the primary urine in the pericardial cavity.

**Reproductive System**

Mussels are gonochori. The gonads extend throughout most parts of the body except the gills, muscles, and foot (Fig 4). Most of the gonad is in the mantle skirts, thus accounting for the unusual thickness of the mantle in these bivalves. Some of the gonad is in the visceral mass (Fig 4). Ovaries are reddish in *Mytilus*, whereas testes are cream.

On each side of the body the many lobes of the gonad connect by a converging system of ducts leading to the gonopore on the tip of the **genital papilla**. This papilla is located on the roof of the mantle cavity where the medial demibranch attaches to the visceral mass. This places it in the exhalant chamber dorsal to the medial demibranch but you can see it without dissection because the gill is not attached to the foot.

**Excretory System**

The two **nephridia**, or kidneys, are complex, elongate, brown organs lying in the roof of the mantle cavity at the base of the gills (Fig 4). They extend from the labial palps to the posterior adductor muscle. In your dissection the right kidney should be easy to see under the cut edge of the left gill and plicate organ. Anteriorly it may lie on the surface of the digestive cecum, which is also brown, but darker, so the two are readily distinguishable.

Each nephridium connects to the pericardial cavity via a renopericardial canal. Each of the two renopericardial canals opens from the pericardial cavity via a small pore in its anterior floor. Each nephridium empties into the exhalant chamber via a nephridiopore located atop the tiny urinary papilla on the base of the posterior side of the larger genital papilla.

Pericardial glands are also associated with the excretory system. The pericardial glands invest the outer walls of the atria and give that part of the heart its characteristic brown color.

**Nervous System**

The nervous system consists of the usual bivalve ganglia, connectives, and nerves. The major features of the system are superficial and can be revealed simply by removing the epidermis covering them. An extensive dissection is not necessary. Care should be taken to avoid damage to the digestive system, which you have not yet studied.

The paired cerebral ganglia are situated beside the esophagus (Fig 3). They are beside the posterior margin of the lower lip touching the medial edge of the anterior pedal-bysial retractor muscle. In life, the ganglia usually contain orange or reddish neuroglobin and, when they do, are easily seen through the thin integument, without dissection or magnification. If they lack this pigment (as preserved specimens always do) they will be harder to find.

Carefully remove the integument covering the area described above. Look for the right cerebral ganglion in the corner between the lower lip and the anterior pedal-bysial retractor muscle. You may want to insert a blunt probe into the mouth to help you find the esophagus. The thick cerebral commissure arches over the esophagus to connect the right and left cerebral ganglia.

A large common trunk of the cerebropleural and cerebrovisceral connectives exits each cerebral ganglion and extends posteriorly beginning on the ventral border of the anterior pedal-bysial retractor muscle. The trunk curves around the lateral border of the retractor and ends on the dorsal surface of the posterior end of that muscle. On the way around the lateral edge of the muscle it bifurcates into the cerebropedal and cerebrovisceral connectives.

The cerebropedal connective extends posteroventrally along the anterior pedal-bysial retractor muscle to the pedal ganglion. The connectives and the ganglion can be seen by cutting the epithelium...
covering the groove between the pedal-bysal retractor and the visceral mass medial to it. The ganglion is usually yellowish or orange. Nerves to the foot, byssal gland, and both pedal-bysal retractor muscles arise from it. The two pedal ganglia touch each other on the median plane and their neurons are connected by the short transverse pedal commissure.

The cerebral ganglia, cerebral commissure, cerebropedal connectives, pedal ganglia, and pedal commissure make up a circumesophageal nerve ring that loosely encircles the esophagus. A small nerve arises at the point where the common trunk bifurcates. It runs to a statocyst located near the surface of the body in the angle between the cerebropedal and cerebrovisceral connectives.

The cerebrovisceral connective on each side extends posteriorly across the outer surface of the digestive cecum in the visceral mass. It lies just inside the integument and crosses the lateral surfaces of the dorsal ends of the posterior pedal-bysal retractor muscle. It parallels and is medial to the line of attachment of the gill to the body. In this area it can be seen as a white band through the transparent epithelium. The cerebrovisceral connective has branches to the digestive cecum, intestine, gonad, and nephridia. The areas surrounding the retractor and adductor muscles may have been damaged when you cut the muscles to open the shell. If that is the case it may be necessary to trace the cerebrovisceral connective on the other side.

The cerebrovisceral connective extends posteriorly to the visceral ganglion (Fig 4) located on the ventral, slightly anterior, surface of the posterior adductor muscle. The right and left visceral ganglia are close together and are connected by the transverse visceral commissure. Nerves to the mantle, siphons, nephridia, foot, and posterior adductor muscle arise from the visceral ganglia. It is possible that the visceral ganglia were destroyed when you cut the posterior adductor muscle.

Digestive System

Dissect the tiny slit-shaped mouth on the median plane between the upper and lower lips (Fig 3). It opens into a short, straight esophagus. Insert a blunt probe into the mouth to reveal the location of the esophagus. Leave the probe in the esophagus and with fine scissors cut along the probe. This will open the esophagus with a lateral longitudinal incision along the right side of the visceral mass. The esophagus runs straight posteriorly, angling slightly dorsally, to open into the anterior end of the stomach (Fig 3). The esophagus and stomach are embedded in the digestive cecum. Extend the incision posteriorly into the stomach.

The esophagus widens suddenly in the anterior dorsal visceral mass to become the stomach located ventral to the posterior part of the hinge (Fig 3). Continue the incision along the left wall of the stomach. Rinse the inside of the stomach with squirts of water from a pipet and look at its lumen and walls.

The sorting field is a complex of ciliated ridges and grooves on the stomach wall whose function is to separate digestible organic particles from indigestible mineral particles. The organics are sent to the digestive cecum for digestion and the minerals directly to the intestine to become feces.

A thin chitinous plate, the gastric shield, is located on the anterior wall of the stomach. The crystalline style is a transparent, jelly-like rod that protrudes into the stomach from the style sac and rests against the gastric shield. It is composed of digestive enzymes, especially carbohydrases and lipases, but there are no proteases in it. The style is very long and extends far back into the style sac, which is combined side by side with the intestine, to the level of the posterior adductor muscle. This portion of the intestine is known as the descending intestine (= direct intestine). You will follow it soon but in the meantime do not pull the crystalline style out of the style sac. The enzymes of the style are secreted by the style sac epithelium and the style can be reabsorbed when it is not needed. It is often absent in individuals that have not fed recently.

The style sac and descending intestine exit the posterior end of the stomach. They are joined side by side and their lumina are continuous. A pair of opposing typhlosoles, or ridges, separate the lumen of the tube into two parallel and contiguous channels, one of which houses the style and is the style sac. The other is the descending intestine. The style sac continues a distance posteriorly and then ends blindly.
Cilia in the walls of the style sac rotate the style causing its anterior end to rub against the gastric shield. This abrades its anterior end and releases enzymes into the stomach lumen. Rotation of the style also helps pull a string of mucus and food particles into the stomach from the mouth. This string originated on the gills and labial palps. Several ducts from the digestive cecum open into the stomach. Their number and position vary from individual to individual. In some individuals there is a ventral diverticulum of the stomach (Fig 3).

The intestine leaves the posterior end of the stomach and loops through the visceral mass before eventually reaching the anus. It is composed of three regions of approximately equal length (Fig 3), of which the last is the rectum. The rectum (Fig 3), which is the posterior third of the intestine, can be seen without any additional dissection as it passes through the pericardial cavity. The rectum ends at the anus located in the exhalant chamber above the posterior adductor muscle (Fig 3). The posterior rectum is often damaged when the posterior adductor muscle is cut to open the shell early in the dissection.

Although it is impractical to trace the intestine posterior to the style sac. The descending intestine extends posteriorly from the stomach and lies beside the style sac as has been discussed. The descending intestine and style sac continue side by side posteriorly to a position dorsal to the posterior adductor muscle. Here the intestine makes a sharp bend dorsally, to the right, and then turns and runs back anteriorly as the ascending intestine (= recurrent intestine) (Fig 3).

The posteriormost region of the intestine is the rectum. Upon reaching the vicinity of the esophagus the ascending intestine reverses direction and turns posteriorly to become the rectum. The rectum extends posteriorly and enters the pericardial cavity. The rectum leaves the pericardial cavity posteriorly and runs over the dorsal curve of the posterior adductor muscle to terminate at the anus in the exhalant chamber.
Mercenaria mercenaria northern quahog

The clam Mercenaria mercenaria (= Venus mercenaria), variously known as the northern quahog (pronounced CO hawg), hardshell, littleneck, cherrystone, or chowder clam, is a common and commercially important species on the east coast of North America where it lives in soft sediments in shallow water.

External Anatomy

Shell

Study a complete, dried, empty shell. The thick chalky shell of Mercenaria consists of two similar valves, which fit tightly together to enclose and protect the soft parts of the animal (Fig 5). The exterior of each valve is rough and ornamented with irregularly spaced, raised, concentric growth ridges.

Figure 5: External and internal features of the shell valves of the hard shell clam, Mercenaria mercenaria. Modified from Cesari and Pellizzato, 1990.

The shell is bilaterally symmetrical and the plane of symmetry passes through the hinge to divide the shell into right and left valves. The valves are nearly identical in size and shape, a condition referred
to as **equivalve**. Some bivalves, oysters for example, have right and left valves of different size and shape and are inequivalve.

Each valve is strongly convex outwards and bears a conspicuous raised protuberance, the **umbo** (= beak), on its dorsal surface near the hinge (Figs 5, 6). The umbo is the oldest part of the valve and the concentric growth ridges are centered around it. When the valves are closed, the umbos almost touch each other on the midline. The umbos are dorsal and slightly anterior to the middle of the hinge.

The two valves are joined dorsally at the flexible (in life) **hinge** and are free to separate from each other along the ventral margin. The dark brown, proteinaceous **hinge ligament** occupies part of the hinge (Fig 7). The hinge ligament is a good dorsal landmark. The small (in life) gap between the ventral margins of the opened valves is the **gape**. The gape of dead specimens is far wider than in life.

Use the hinge and umbos as landmarks to recognize **dorsal** and **anterior**, respectively, and, having accomplished that, decide which valve is **left** and which is **right**. Find **posterior** and **ventral** and identify the **plane of symmetry**.

![Diagram of bivalve anatomy](image)

Figure 7. **Interior of the left valve of the shell of Mercenaria mercenaria.**

Place the two valves together and look at the dorsal surface. The most obvious features are the umbos. Anterior to the umbos is a conspicuous, heart-shaped depression known as the **lunule** (Fig 6). It is a characteristic feature of Veneridae. Posterior to the umbos is a broad, flat, indistinctly defined platform, the **escutcheon**. The free edge of the posterior right side of the escutcheon overlaps the free edge of the left so that, even when the clam is open, this part of the gape is protected, perhaps from falling sand grains.

Viewed from the side, each valve is lopsided, with a longer bluntly pointed posterior end and a shorter, smoothly rounded anterior end. (The posterior end of *Tapes* is not pointed.) Valves with asymmetrical anterior and posterior halves are said to be **inequilateral**. *Mercenaria* and *Tapes* are only moderately inequilateral, mussels are strongly inequilateral.

Look at the medial side of one of the two valves (Fig 6). Dorsally, the margin is occupied by the hinge, which is the articulation between the two valves. The hinge ligament is a conspicuous feature of the hinge. The ligament is composed of protein (conchiolin) and may or may not be present on dry empty shells. Look at a fresh, undissected specimen and find the ligament if your empty shell does not have one. The ligament of living animals is elastic but that of dry valves is hard and brittle.

The hinge is equipped with strong **teeth** to assure the proper alignment between the valves each time the shell closes. The teeth are located on a platform called the **dental shelf** (Fig 6). Most conspicuous of these are the short, vertical, or oblique **cardinal teeth** located directly ventral to the tip of the umbo. Each valve has three cardinal teeth but one tooth on the left is obscure making it appear as if
there are only two teeth on this side. A **posterior lateral tooth** is located posterior to the cardinal teeth. It is a long, low, rough, irregular ridge with its long axis oriented anterior to posterior. Unlike the cardinal teeth it does not look like a tooth.

The anterior and ventral margins of the valves bear fine teeth known as **denticles** (Fig 6). The denticles probably prevent shear (sideways slipping) when the valves are pulled tightly together by the powerful adductor muscles. Hold the two valves together as they would be in a living clam with its valves closed. If you have the cardinal teeth properly aligned, the valves will fit snugly together and cannot be made to slip past each other.

The large, smooth **anterior** and **posterior adductor muscle scars** are easily seen at their respective ends of the inside of each valve (Fig 6). In intact clams the two adductor muscles run transversely from one valve to the other and their action is to pull the valves together (adduct) and hold them closed. Two additional muscles, the anterior and posterior pedal retractor muscles, insert on the shell near the adductor muscles. The **anterior pedal retractor scar** is separated by a small space from the anterior adductor scar and is under the anterior end of the dental shelf. (The anterior pedal retractor muscle scar is easy to see in *Tapes* and is located just anterior to the dental shelf.) The **posterior pedal retractor scar** is continuous with the posterior adductor scar (Fig 6).

The **pallial line** runs from one adductor to the other and parallels the ventral margin of the valve. It is the site of insertion of pallial muscles in the mantle and is indented sharply beside the posterior muscle scar. This V-shaped indentation is the **pallial sinus** and is a recess in the line of pallial muscles for the withdrawn siphons. (“Pallial” is another word for mantle.)

The inside of each valve of *M. mercenaria* is white with posterior purple markings. The shells of this species were cut into beads and used by east coast North American Indians as money, called wampum. This is the basis of the scientific name “mercenaria” (*mercenari* = hired for wages).

The typical mollusc shell consists of three layers. The outermost is the periostracum composed of the protein conchiolin. This layer is thin, eroded, and insignificant in *Mercenaria*. The dull, chalky **prismatic layer** (ostracum) is the middle layer. It is exposed on the outside of the valve due to the absence of the periostracum. The innermost layer, and the one in contact with the clam, is the calcareous **lamellar layer** (hypostracum) which is smooth and glossy. (The thin, brown periostracum of *Tapes* remains intact and the prismatic layer is not evident.)

**Soft Anatomy**

Open the shell of your clam to study the soft anatomy within. The adductor muscles keep the shell closed and it cannot be opened until they are severed. If you are dissecting a preserved specimen, the valves may already be pegged open with a wooden wedge. If this is the case, you may skip the remainder of this paragraph and proceed to the instructions for cutting the adductor muscles.

If you have a living specimen or an unpegged preserved specimen, you must make anterior and posterior openings in the shell to give you access to the adductor muscles so you can cut them. This is not easy to do but the best procedure is to use a pair of pliers to pinch away the anterior and posterior edges of the shell. Do not strike the shell as it cracks easily. First refer to the empty valves to help determine the positions of the two adductor muscles and begin removing the shell closest to them.

Gain access to the anterior adductor first by pinching away the anterior edges of the contiguous valves. You will not be able to get as close to the posterior adductor muscle as to the anterior because the posterior shell does not provide a raised edge to pinch. Remove enough shell to create a narrow opening at each end.

Insert a scalpel blade into the anterior opening and feel for the adductor muscle. Use the longest and sharpest blade you have but be very careful that you do not cut anything until you find the muscle. The muscle is firm, rubbery, and unyielding whereas the other tissues are soft and do not resist gentle probing. The muscle is easy to recognize by touch. Once you have found the muscle, sever it completely with the scalpel. Do the same with the posterior adductor muscle. The pedal retractor muscles should be cut also.
Arrange the clam so the left valve is up, facing you, and you are looking at the left side of the animal. With all the muscles severed, carefully lift the left valve a little so you can see into the gape. The body will be cradled in the concavity of the right valve but a thin sheet of tissue, the left mantle skirt, adheres closely to the inner surface of the left valve. Slip the blunt end of your scalpel handle between the left mantle skirt and the left valve and use it to free the soft tissue from the shell. Carefully work the scalpel handle around the stumps of the adductor muscles being careful that you do not damage the mantle. Note the two pedal retractor muscles that insert on the shell beside the much larger adductor muscles. Cut them now if you did not do so earlier. When the mantle is free, detach the left valve at the hinge and set it aside.

**Muscles**

Look at the left side of the clam and find the **anterior and posterior adductor muscles** (Fig 7). The muscle fibers run transversely, across the clam, from valve to valve and their action is to adduct, or close, the valves.

Each muscle is composed of two distinct regions (Fig 7). The anterior part of the anterior adductor muscle and the posterior part of the posterior adductor muscle are **catch muscles** composed of smooth muscle fibers with abundant connective tissue. They are capable of sustained, slow contraction and in life are white. The remainder of each muscle is the **fast muscle** composed of obliquely striated fibers with abundant supplies of myoglobin and mitochondria but with relatively little connective tissue. In life fast muscle is red due to its myoglobin. Fast muscle contracts and relaxes rapidly but fatigues easily and is incapable of sustained contraction. The adductor muscles are opposed by the elastic recoil of the hinge ligament.

The pedal retractor muscles are paired. Find one of the small **anterior pedal retractor muscles** (Fig 7). It is a short cord of muscle and connective tissue running from the anterior end of the foot to the shell. The **posterior pedal retractor muscles** are similar cords extending from the posterior end of the foot to the shell. The retractors pull the foot back into the shell as is necessary before closing the gape, or, when digging, to pull the clam toward an expanded foot anchored in the sand. Mercenaria lack a pedal protractor muscle.

 Mercenaria exemplifies the **dimyarian** condition in having two similar adductor muscles. Many bivalves, notably scallops and oysters, are monomyarian and have only one adductor muscle (the posterior). Others, such as mussels and pens, are heteromyarian and have a large posterior muscle and a reduced anterior muscle.

Bivalves do not have abductor muscles to open the valves. The adductor muscles extend across the animal from one valve to the other. When they contract they pull the valves together, close the gape, and stretch the elastic hinge ligament. When the muscles relax, the ligament returns to its original resting shape and in doing so pulls the dorsal ends of the valves toward the midline (toward each other). This, of course, means that the ventral margins of the valves move away from each other, thereby opening the shell and creating a narrow gape through which the foot can be extended.

The ligament of Mercenaria is outside the hinge. Some bivalves also have an internal ligament (= resilium) on the inside of the hinge that is compressed, rather than stretched, when the valves close. When the muscles relax, the elastic resilium pushes the valves apart, and this also opens the gape. Mercenaria does not have a resilium.

**Mantle Skirts**

The bivalve body is enclosed on the right and left by two large, thin double layers of body wall (Fig 10). These are the **right and left mantle skirts**. Each is a thin sheet of tissue, free at the ventral edge but connected with the body dorsally. The pallial muscles attach the mantle skirt to the shell along the pallial line.

**Mantle Cavity**

Between the right and left mantle skirts lies a large space, the mantle cavity, in which lies the body (Fig 7, 9). The mantle cavity is continuous with the sea and is filled with seawater. Without
cutting tissue, lift the left mantle skirt and find the **mantle cavity**. It is divided into a large ventral region below and beside the body, known as the **inhalant chamber** (= branchial chamber), and a smaller dorsal region above the body, the **exhalant chamber** (= suprabranchial chamber) (Fig 9). The two chambers are separated from each other by the gills. The space you see now is the spacious inhalant chamber and you cannot yet see the much smaller exhalant chamber.

Look into the mantle cavity (inhalant chamber) and make a quick identification of the most conspicuous features of the body so you can use them for landmarks later. With the left mantle skirt held out of the way, closest to you is the long, leaflike **left gill** (Fig 7, 9). Medial to the gill is the large bulging **visceral mass** with the thinner, muscular, bladelike (in life) **foot** attached to its ventral midline. Lift the foot and visceral mass to see the **right mantle cavity, right gill, right mantle skirt, and right valve**, in that order.

**Mantle Folds**

Study the ventral margin of the right mantle skirt with magnification. The mantle margin of *Mercenaria* and other venerid clams is composed of four folds although most bivalves have only three (Fig 4). The homologies between the four venerid folds and the three folds of other bivalves are unclear but the extra fold probably arose through subdivision of the inner fold.

![Diagram of mantle cavity and folds](image8)

**Figure 8.** The left side of *Mercenaria mercenaria* with the left valve and left mantle skirt removed.

![Diagram of internal anatomy](image9)

**Figure 9.** Internal anatomy of *Mercenaria mercenaria.*
The outer fold, which is adjacent to the shell, secretes the prismatic layer and periostracum (Fig 4). The lateral side of the outer fold secretes the prismatic layer of the shell whereas the medial side secretes the periostracum. The lamellar layer is secreted by the entire lateral surface of the mantle skirt.

The inner fold is muscular and in Mercenaria is double. The wide border of the mantle, from its free edge to the pallial line, is thicker than the rest of the mantle due to the presence of the pallial muscles that insert on the shell along the pallial line. These muscles can be seen radiating across the mantle border peripheral to the pallial line. Tug gently on the free edge of the right mantle and observe that (in life) it is firmly attached to the shell along the pallial line.

The middle fold lies between the inner and outer folds and is sensory. It is weakly developed in Mercenaria.

The groove between the outer and middle folds is the periostracal groove. In living specimens the freshly secreted periostracum can be seen extending out of this groove across the exposed surface of the margin of the valve. It is a very thin, transparent, delicate, glistening membrane.

Siphons

Posteriorly, the right and left mantle skirts coalesce with each other across the midline to form the two short tubular siphons (Fig 9). The siphons are darkly pigmented and each has short sensory tentacles surrounding its outer aperture. The ventral one is the inhalant siphon and the exhalant siphon is dorsal. These short tubes are formed by the fused right and left posterior mantle skirts. The siphons are elaborations of the fused right and left mantle margins. The sensory tentacles are part of the middle mantle fold, which is the sensory fold. In its life position Mercenaria is shallowly embedded in sediment with only the tips of the short siphons exposed above the sediment surface. It is appropriate that the greatest concentration of sense organs is on the siphons rather than around the periphery of the gape.

The inhalant siphon brings water into the inhalant chamber. Insert your blunt probe into the external opening of the inhalant siphon and show that water entering here would enter the inhalant chamber of the mantle cavity. Water in the inhalant chamber passes through tiny openings, the ostia, in the gills to enter the exhalant chamber, from which it then exits via the exhalent siphon.

A delicate fold of tissue, located dorsal to the inner aperture of the inhalant siphon and known as the siphonal membrane, can be extended from its retracted resting position to partially cover the inner aperture of the inhalant siphon. This deflects water that normally would have gone directly to the gill surfaces, to the ventral inhalant chamber where it stirs and resuspends the accumulated debris and pseudofeces so they can be more easily expelled by the next contraction of the adductor muscles. The siphonal membrane is easily seen on the dorsal surface of the inner aperture of the inhalant siphon.

Dorsal to the siphons the entire right and left mantle margins are fused to each other on the midline beneath the hinge. A special secretory region of the dorsal mantle, ventral to the ligament, is called the subligamental ridge. It secretes the ligament.

Gills

With scissors, remove the left mantle skirt and look at the left gill. Each gill consists of a central axis from which are suspended sheets of fused filaments. On each side is a single complete gill, or holobranch (Figs 11). A holobranch is composed of two delicate, leaflike demibranchs, or half gills. These are the outer lateral demibranch and the inner medial demibranch (Figs 11). The two are joined dorsally along the central axis which is attached to the body.

Each of the two surfaces of a demibranch is a lamella (Fig 11). One surface is the descending lamella firmly attached to the central axis and the other is the ascending lamella weakly attached to either the mantle or the visceral mass. In Mercenaria the connections of the ascending lamellae to the body are fragile and the margins of the gills are easily torn free of their attachments. At present you are probably looking at the ascending lamella of the lateral demibranch of the left gill.
The ciliated longitudinal groove along the ventral edge of each demibranch is a **ventral food groove** used to transport food particles anteriorly to the mouth (Fig 11). The ciliary beat in the food grooves is anterior, toward the head, labial palps, and mouth whereas that of the lamella is either dorsal or ventral.

During feeding and respiration a water current bearing food and oxygen enters the inhalant chamber via the inhalant siphon. The water enters the ostia and passes into the water tubes of the exhalant chamber. Food particles are filtered from the current as it passes through the ostia, remain on the inhalant side where they are mixed with mucus and transported to the food grooves by cilia.

**Labial Palps**

The long narrow **labial palp** on each side of the mouth is an anterior extension of the gill (Figs 8). Each palp consists of a **lateral** and a **medial lamella.** The lateral demibranch of the gill connects with the lateral lamella of the palp and the medial demibranch with the medial lamella. Each lamella bears a **sorting field** of ciliated ridges and grooves on one surface. The fields are arranged so that when
the lamellae lie together, the sorting fields face each other. A ciliated oral groove lies between the two sorting fields and leads to the mouth.

Mucus and food particles from the gills move along the food grooves to the labial palps where the sorting fields separate desirable organic matter (food) from indigestible mineral particles. Organic particles and mucus move via the ciliated oral groove to the mouth whereas mineral particles, also bound in mucus, move to the tip of the palp from which they are dropped into the inhalant chamber. This mixture of discarded mineral particles and mucus is known as pseudofeces and it is periodically expelled through the inhalant siphon by sudden contractions of the adductor muscles.

**Internal Anatomy**

*Hemal System*

The bivalve hemal system consists of heart, arteries, blood, and an extensive hemocoel. Only the heart will be studied in this exercise.

The heart lies in the **pericardial cavity** located dorsally just below the hinge (Figs 8, 9, 12). It is surrounded by the thin membranous **pericardium**. The body wall in this area is very thin and the pericardium is close to the surface. The pericardial cavity is a remnant of the coelom and the pericardium is peritoneum. The dark reddish brown **nephridium**, or kidney, can be seen on the walls of the pericardial cavity, especially posteriorly. Paler, greenish brown tissue situated farther anterior is the **digestive cecum**.

With fine scissors, make a shallow, longitudinal, middorsal incision in the thin dorsal body wall and pericardium paralleling and extending the length of the hinge ligament. This cut opens the pericardial cavity to reveal the **heart** within. The heart consists of a single large **ventricle** into which the paired right and left **atria** empty (Fig 12). The ventricle lies on the midline and is a long, soft, ovoid organ. It is penetrated by the posterior intestine, or **rectum**, which runs the length of its lumen (Fig 12). The intestine can be seen faintly through the walls of the ventricle.

![Figure 12](image)

Figure 12. Dissection of the left side of **Mercenaria mercenaria**. The left side of the visceral mass has been dissected. The left mantle skirt and most of the kidney and left gill have been removed.

With a blunt probe, carefully lift the edge of the ventricle and find the **left atrium** attached to its left side (Fig 12). The atrium is a thin-walled, transparent, truncated triangle extending from the ventrolateral pericardial wall to the ventrolateral wall of the ventricle. The truncated apex of the atrium
attaches to the ventricle and its broad base extends along the length of the central axis of the gill. Oxygenated blood from the gills drains into the atria and from there enters the ventricle. Anteriorly, the ventricle narrows to become the wide, transparent anterior aorta which may be visible beside the base of the anterior pedal retractor muscle. The anterior aorta is dorsal to the intestine. The intestine emerges from the visceral mass at the end of the aorta and bends almost 90° to enter the lumen of the ventricle (Fig 12).

Posteriorly, the ventricle constricts to become the posterior aorta which then immediately expands to form the large swollen bulbus arteriosus. The size of the bulbus varies depending on the amount of blood it contains. The posterior aorta then narrows and continues posteriorly, ventral to the rectum.

Exhalant Chamber
The ventrolateral floor of the pericardial cavity is the roof of the exhalant chambers (Fig 12). Insert the blunt probe into the exhalent aperture and into the exhalant chamber. The transparent roof of the chamber extends anteriorly from the exhalent siphon but may have been cut when you severed the posterior adductor muscle. The visceral ganglion of the nervous system is in the tissue between the roof of the chamber and the adductor muscle. In living clams the ganglion is orange (neuroglobin). Be careful that you do not destroy it.

Excretory System
The two nephridia, or kidneys, are large metanephridia, one on each side on the floor and walls of the pericardial cavity at the dorsal margin of the visceral mass (Figs 12). They are brown or reddish-brown (in life) and are easily seen without dissection although their structure is not apparent. The nephridia are elaborate ducts extending from the pericardial cavity to nephridiopores in the exhalant chamber. Urine is released from this pore into the exhalant water stream.

Digestive System
The bivalve gut consists of a mouth, esophagus, stomach, digestive caeca, midgut, rectum, and anus. A complex stomach with style and style sac are present but bivalves have no buccal cavity, radula, radular sac, or odontophore. Most of the gut is within the visceral mass and cannot be seen without dissection. If you plan to study the nervous system, refer to the nervous system section and find the cerebropleural ganglia at this time as they are usually destroyed during the dissection of the anterior gut.

_remove the left gill and left labial palp so you have unobstructed access to the left side of the visceral mass. Relocate the mouth on the anterior midline between the upper and lower lips of the labial palps (Fig 12). The mouth opens directly into the esophagus. The short esophagus passes through the greenish digestive caecum to join the stomach (Fig 12). The anterior end of the stomach, which is otherwise embedded in the visceral mass, lies very close to the surface of the antero-dorsal corner of the visceral mass and can sometimes be seen without cutting.

Insert a blunt probe through the mouth into the esophagus to the stomach. The probe will follow the gut lumen and you can see it (the probe) through the gut wall. The esophagus extends obliquely dorso-posteriorly between the bases of the two anterior pedal retractor muscles (Fig 12). The esophagus more or less parallels the edge of the dental shelf in the vicinity of the cardinal teeth. The walls of the esophagus bear fine, longitudinal folds, or rugae.

Open the stomach by inserting a blade of your fine scissors into the mouth and cut along the esophagus, following the probe to the stomach. Once you have entered the stomach, cut posteriorly through the lateral wall of the visceral mass and digestive caecum, opening the stomach as you go (Fig 12). Continue this cut posteriorly, paralleling the dorsal border of the visceral mass. The incision should follow and open the intestine (= midgut) which extends posteriorly from the stomach. Continue this cut, following the intestine, around the posterior curve of the visceral mass to the foot.
Two openings to the digestive caeca are located on the floor of the stomach just posterior to the opening of the esophagus. A branching network of tubules extends from these openings throughout the caeca.

On the right of the esophageal opening, and extending dorsally to the left side, is a large, ciliated sorting field. The field is composed of numerous fine ridges and grooves. A thick shelf on the right side of the stomach marks the posterior right border of the sorting field and separates the dorsal and ventral portions of the stomach from each other.

The roof and much of the left wall of the stomach are covered by a thin, chitinous gastric shield but it is difficult to see. Although the shield itself is nearly invisible, the wall of the stomach under it is smooth and can thereby be distinguished from the surrounding walls.

The intestine extends from stomach to anus (Fig 12). Its anterior end is the midgut whereas the rectum is its posterior end. The midgut consists of a descending intestine and ascending intestine. The descending intestine exits the posterior end of the stomach and parallels the dorsal and posterior edges of the visceral mass. It is divided into two parallel tubes by two longitudinal ridges of tissue that approach each other in the middle of the midgut lumen (Fig 12). These two ridges are typhlosoles. The typhlosoles are ciliated ridges that transport particulate material.

The major typhlosole is on the lower right side of the midgut and is the larger of the two. It begins in the anterior stomach and its edge is thin and sharp. The minor typhlosole begins at the posterior end of the stomach, lies on the dorsal left wall of the midgut, and has a broad, bilobed edge.

The two side by side tubes of this region of the gut are the dorsal style sac and the ventral intestine. The style sac of your specimen may or may not contain a crystalline style. The style is produced only when needed and if your animal has been maintained without food, it probably will not have a style. The style is a very long, narrow, flexible, pellucid, gelatinous rod that occupies the length of the style sac and protrudes from the sac into the stomach lumen. It is composed of hydrolytic enzymes (amylase, cellulase, lipase) secreted by the glandular walls of the sac. It stirs the stomach contents, serves as a windlass to help pull mucus/food strings from the labial palps into the stomach, and is a source of digestive enzymes for the extracellular hydrolysis of carbohydrates and lipids in the stomach. Protein digestion occurs intracellularly in the digestive caeca.

The intestine extends posteriorly from the stomach, curves around the posterior edge of the visceral mass to the foot where it changes direction and turns anteriorly as the ascending intestine (Fig 12). It soon changes direction again and heads dorsally. Only the intestine, and not the style sac or the style, continues past this point.

The intestine loops in a characteristic pattern through the visceral mass, and emerges at the base of the anterior aorta (Fig 12). Here it makes a right angle turn to extend posteriorly through the center of the pericardial cavity and ventricle as the rectum. Beginning at the point where the style sac ends, the intestine is characterized by the presence of a single, large, rounded typhlosole that occupies most of its lumen (Fig 12). Continue tracing the intestine a little beyond the point where the typhlosole begins so you can get a good look at this part of the gut. The gut is easiest to trace by opening it and following the typhlosole. Trace the intestine as far as you wish into the visceral mass. If you have the time you may follow it all the way to the heart but the procedure is tedious and time-consuming.

Locate the rectum where it exits the heart and trace it posteriorly. It passes between the bases of the two posterior pedal retractor muscles and then curves over the top of the posterior adductor muscle and part of the way around its posterior margin. It ends in the exhalant chamber at the anus on the posterior edge of the adductor muscle. The anus is dorsal to the inner aperture of the exhalent siphon. Fecal pellets released from the anus are caught in the exhalant current and swept out the siphon. (In Tapes, the rectum flares trumpetlike to end at the anus.)

**Nervous System**

The bivalve nervous system is relatively simple and consists of four major pairs of ganglia (cerebral, pleural, pedal, and visceral), connectives and commissures between them, and the nerves radiating from them.
Despite its simplicity, the system is not easily studied. The ganglia can usually be found but tracing the connectives and nerves is difficult. In living animals the ganglia are orange or yellow with neuroglobin, making them easier to recognize. The bivalve sensory system is weakly developed. Most sensory receptors are in the middle fold of the mantle margin.

The cerebral and pleural ganglia are coalesced and the resulting two cerebropleural ganglia are close to each other atop the anterior end of the esophagus, very close to the mouth (Fig 12). They are embedded in connective tissue on the posterior dorsal edge of the anterior adductor muscle. The two cerebropleural ganglia are connected to each other via a short transverse cerebral commissure across the top of the esophagus and nerves extend from them to the labial palps, anterior adductor muscle, anterior mantle, and anterior pedal retractor muscle.

From the cerebropleural ganglia a pair of visceral nerves (= cerebrovisceral connectives) runs posteriorly through the dorsal visceral mass to the visceral ganglia. The visceral ganglia are located on the anterior face of the posterior adductor muscle between the origins of the two posterior pedal retractor muscles (Fig 12). They are fused with each other on the midline. The visceral ganglia send nerves to the siphons, posterior adductor muscle, posterior pedal retractor muscle, posterior mantle, nephridium, gill, and heart.

A pair of cerebropedal connectives extends ventrally and posteriorly from the cerebropleural ganglia to the pedal ganglia in the foot. The two pedal ganglia are fused with each other and lie on the midline in the visceral mass, very near the muscles of the foot (Figs 12). The pedal ganglia innervate the musculature of the foot. Look for them on the border between the foot and the visceral mass ventral and anterior to the point at which the midgut makes its sharp turn dorsally.

Reproductive System

Like most bivalves, Mercenaria is gonochoric and the two gonads, either ovaries or testes, fill most of the space in the visceral mass (Figs 12). The size of the gonads depends on the degree of development. Although there are two of them, they cannot usually be distinguished from each other.

The gonads occupy remnants of the embryonic coelomic cavity but that will not be apparent in gross dissection. Each gonad empties into the exhalant chamber via a gonoduct that opens at a gonopore at the tip of a small genital papilla just anterior to the nephridiopore. The genital papilla is located at about the level of the posterior end of the ventricle in the medial exhalant chamber but is difficult to locate.

Table 1. Comparison of Mytilus edulis and Mercenaria mercenaria. Complete the following table describing how each characteristic differs for the two bivalve species dissected.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mytilus edulis</th>
<th>Mercenaria mercenaria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Foot (size) and function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Byssus (pres/abs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Gill (size)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Number of adductor muscles and term describing condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Habitat type</td>
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<tr>
<td>6. Feeding</td>
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<td>---</td>
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</tr>
<tr>
<td>7.</td>
<td>Siphons</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Mantle margins fused or unfused</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Hinge teeth</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Lunule (pres/abs)</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Escutcheon (pres/abs)</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Denticles (pres/abs)</td>
<td></td>
</tr>
</tbody>
</table>