Biol 515: Marine Invertebrate Biology
Laboratory Manual

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Introduction

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Overview of the Biol 515 Laboratory Manual

This lab manual provides a guide to the activities and specimens available during Biol 515 labs. Exposing students to the diversity of marine invertebrates is a major learning goal of Biol 515. Therefore, *many species* will be available each day; students should recognize that seeing some of the animals is a once-in-a-lifetime opportunity! Students should pay close attention to activities and specimens listed as *"Required"* and devote time to *"Optional"* activities and specimens only when time permits. Because the majority of specimens for Biol 515 are alive — and collecting certain species in nature cannot always be guaranteed — some specimens listed in this manual might not be available as anticipated. Conversely, some rare and unusual specimens that happen to be collected unexpectedly might be available even though they are not listed in the manual. Each day, Dr. Hentschel will point out species that are additions or deletions to the prepared manual.

Many, but not all, of the activities and specimens in this manual are based on those of Dexter (2000). Dr. Dexter taught Biol 515 at SDSU for 34 yr. During that time she developed SDSU's collection of preserved invertebrates as a unique and valuable teaching resource. Over the years, the collection has been enhanced by contributions from many individuals including SDSU's present Marine Collector, Constance Gramlich. Dr. Dexter also developed a variety of innovative lab activities that proved to be appropriate and effective for invertebrate-biology students at SDSU. Students presently enrolled in Biol 515 should recognize, therefore, that Dr. Hentschel expects little more of them than has been expected of previous students at SDSU.

This lab manual is a guide, not a stand-alone manual. To enhance their learning, students are expected to use multiple resources in combination with this manual. The two most useful resources will be the texts by Pechenik (2005) and Pearse et al (1987). *Within this lab manual, parenthetical citations of figures refer to numbered figures in Pechenik (2005), and cited page numbers refer to items in Pearse et al. (1987).* Students should bring both textbooks to class every day. On many occasions, each of these texts will offer a similar but slightly different perspective that, in combination, might help a student identify some structures. In addition, figures from various other sources will be available to assist with some dissections that cannot be guided adequately by figures in either Pechenik (2005) or Pearse et al. (1987). To avoid unnecessary confusion or frustration, students must recognize that some structures can be identified by synonymous terms (e.g., a worm's intestine might be labeled as the "intestine", the "hindgut", or the "gut" depending on the source of the figure and the context in which it is presented). Simply trying to memorize *the* name of a structure is much less scholarly than achieving a broader understanding of the structure and recognizing its various possible names.

Students also are advised that some of the structures that are recommended for identification during dissections might not be easy to recognize in a single specimen. Students should not be overwhelmed by frustration if structures mentioned in the lab manual are difficult (or impossible) to see! When adequate numbers of specimens are available, groups of students should dissect multiple specimens; perhaps one will reveal an elusive structure. Dr. Hentschel will observe the dissections of all groups and will alert the entire class if one specimen provides a textbook example of a structure that was difficult to see in most other dissected specimens.

Laboratory Notebook

Each student will compile his/her own laboratory notebook(s) that will include line drawings of slides, live and preserved animals, and dissections. Observations of animals’ behaviors also should be included in the notebook where appropriate. *All material in a student’s lab notebook must be the student’s original work*. A pencil should be used; colored pencils are acceptable. All pages must be numbered. Entries in the notebook must be dated. Diagrams should be labeled appropriately and clearly. A Table of Contents must be included at the front of the notebook, with entries for each major taxon (Phylum, Class, or Order). The Table of Contents should be updated daily with appropriate taxa and page numbers. Students are advised to leave at least 6 blank pages at the front of their notebooks for the Table of Contents.

The *required* notebook for Biol 515 is the “Green Lab Book” sold at Aztec Shops: #53-108 (10 1/8 × 7 7/8 inches, 5 × 5 grid). Students should purchase at least two of these notebooks so they can divide their lab notebooks into Part 1 (material prior to Lab Exams 1 and 2) and Part 2 (material prior to Lab Exams 3 and 4).

After the first three lab exams, students will turn in their lab notebooks for evaluation (up to 25 pts each time). Lab notebooks will be graded for the clarity and completeness of their organization and content. Lab notebooks will not be collected or graded after Lab Exam 4.

At the end of each day’s lab activities, Dr. Hentschel will sign each student’s lab notebook. Along with a signature, Dr. Hentschel will write the date and time the student completed that day’s activities. This allows Dr. Hentschel to quantify how much time was required for students to complete each day’s activities. It also assists Dr. Hentschel in helping some students improve their study habits and learning (i.e., it will be obvious why a student is performing poorly on lab exams if he/she regularly leaves lab 30 min earlier than most of the students). *It is each student’s responsibility to get Dr. Hentschel’s signature before leaving the room*. When lab notebooks are graded after Lab Exams 1-3, Dr. Hentschel will deduct –1 point for each day’s lab that does not have his signature.

Laboratory Tools

A complete dissection kit is not required, but can be very helpful. Although some dissection tools will be provided in lab, each student *must* purchase some tools for dissection. Most of the following are available at Aztec Shops, as well as other locations (sometimes at better prices):

- a pair of fine forceps (watchmaker’s forceps)
- a package of single-edge razor blades
- 2 needle pointers

Lab #1: Intro to Microscopes & Body Plans. Monday, 28 August 2006

The following activities are modified extensively from those of Dexter (2000). Diagrams of and discussion about *Planaria*, *Ascaris*, and *Lumbricus* cross sections are available in almost every invertebrate-biology text (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994) in addition to those required for Biol 515 and referenced below (Pechenik 2005 and Pearse et al. 1987). In addition to those texts, general diagrams of acoelomate, pseudocoelomate, and coelomate cross sections are described in most introductory biology texts (e.g. Campbell et al. 1999, 2002; Purves et al. 2001). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

During this brief laboratory period, students will gain experience using their compound microscopes to examine several prepared slides that depict the three main body plans among bilateral invertebrates (Acoelomate, Pseudocoelomate, Coelomate) and the major tissue types.

Required Activities

Students should draw each of the available slides in their notebook (If lab notebooks have not been purchased yet, drawings made on blank paper during the lab period should be added to notebooks later). Identify and label all of the structures mentioned for each specimen.

- Acoelomate: *Planaria* (double mount and cross section "c.s.") is a platyhelminth. Note the branched digestive system (Fig. 8.7, 8.16; p. 208), ectoderm, mesoderm, and endoderm (Fig. 8.4; p. 206, 212).
- Pseudocoelomate: *Ascaris* (male c.s. & female c.s.) is a nematode. Note the intestine, ovaries & testes, uterus with fertilized eggs, longitudinal muscles, cuticle, epidermis, nerve cords, and pseudocoelom (Fig. 16.4; p. 277).
- Coelomate: *Lumbricus* (c.s., Fig. 13.18; p. 406) is an oligochaete annelid. Note the coelom that's lined completely by a mesodermal peritoneum, circular & longitudinal muscles, epidermis, intestine, dorsal & ventral blood vessels, ventral nerve cord.

Reminder:

Don't forget to have Dr. Hentschel, Henry Carson, or Constance Gramlich sign your lab-notebook entry for today's lab before you leave the classroom. Clean up your table! Check to make sure that you returned all microscope slides!

Lab #2: Review of Major Invertebrate Taxa. Wednesday, 30 August 2006

An introductory course on organismal biology that covers the major groups of invertebrates (e.g., Biol 201, now 201B, at SDSU) is a required prerequisite to enroll in Biol 515. Dr. Hentschel has noticed that most Biol 515 students retain little of the introductory knowledge they were taught in a course like Biol 201. This lab is designed to quickly refresh the memories of students so they are prepared to master the more advanced aspects of invertebrate biology covered in Biol 515.

There are approximately 35 major phyla of "invertebrate" animals. Some of the phyla are very diverse and are subdivided into multiple taxonomic subgroups (e.g., "classes") that themselves each have many commonly known species. Other phyla are not very common and often are not studied during introductory courses. Some phyla have only a few living species! During Biol 515, students will study approximately 26 of the animal phyla and many of the major subgroups within each phylum. Throughout the course it is not necessary for students to remember the Linnaean rank of each taxon (i.e., Phylum, Class, Order, Family, etc), but students should learn and understand the relevant hierarchical groupings and evolutionary relationships among taxa (e.g., Gastropoda and Bivalvia are sister subgroups within the Mollusca).

During this lab, each group of 4 students will have a wide variety of specimens belonging to the most common marine invertebrate taxa (below). A representative of each of these taxa might not be present at every table, and some of the taxa might be represented by more than one specimen.

- Phylum **Porifera**
- Phylum **Cnidaria**: Class **Hydrozoa**
- Phylum **Cnidaria**: Class **Scyphozoa**
- Phylum **Cnidaria**: Class **Anthozoa**
- Phylum **Ctenophora**
- Phylum **Mollusca**: Class **Gastropoda**
- Phylum **Mollusca**: Class **Bivalvia**
- Phylum **Mollusca**: Class **Polyplacophora**
- Phylum **Mollusca**: Class **Cephalopoda**
- Phylum **Annelida**: Class **Polychaeta**
- Phylum **Arthropoda**: Subphylum **Crustacea**
- Phylum **Arthropoda**: Subphylum **Chelicerata**
- Phylum **Echinodermata**: Class **Asteroidea**
- Phylum **Echinodermata**: Class **Ophiuroidea**
- Phylum **Echinodermata**: Class **Echinoidea**
- Phylum **Echinodermata**: Class **Holothuroidea**
- Phylum **Chordata**: Subphylum **Urochordata**
- Phylum **Chordata**: Subph. **Cephalochordata**

Each group of 4 students should do all of the following activities:

1) Identify which major taxon each specimen belongs to. Write a label for each bowl.

2) Write a brief description (1-3 sentences) of where in the marine environment the general taxon typically lives. If the taxon is very diverse, students might focus their answer on the individual specimen, rather than generalizing to the broader taxon.

3) Write a brief description of how the general taxon (or the specimen) typically moves.

4) Write a brief description of how the general taxon (or the specimen) typically feeds.

5) Write a brief description of how the general taxon (or specimen) typically reproduces.

6) Write a brief description of how the taxon (or specimen) defends itself against predators.

7) Describe how the taxon (or specimen) exchanges O_2 and CO_2 with the environment.

8) Describe how the taxon (or specimen) maintains its water-salt balance (osmoregulation).

Students should work as a collaborative team and use a variety of resources.

Divide the various taxa and duties among the 4 group members and discuss your questions, answers, and possible confusion. Use Pechenik (2005), Pearse et al. (1987), and the Biol 515 Lab Manual as resources to help you identify the specimens to major taxon (i.e., the list above) and answer the 7 additional questions about where the taxa live and how they function physiologically and ecologically. Students also might find it useful to bring their introductory biology textbook to class (If you sold your intro biology text and want to continue as a Biology Major, Dr. Hentschel strongly encourages you to invest in the purchase of an intro biology text and keep it for many years to come; the 2002 edition of Campbell et al. is recommended as an especially useful general biology reference).

A major goal of the activities in today's lab is to encourage students to use several written resources. Dr. Hentschel is happy to discuss students' ideas, but he will not answer general questions (e.g., What is this?) until it is clear that students have first tried to answer the basic questions using the written resources.

Each team of students should compile written answers for each taxon associated with every specimen on their table. During the last 30 min of class, Dr. Hentschel will lead a class discussion in which students will share their team's answers to some of the questions for some of the taxa. By the end of the lab period, every member of the team should be prepared to answer all of the questions for all of the specimens examined by the team. Initially students can use scratch paper to write their answers, but eventually *answers to the 7 questions for each taxon should be written neatly into each student's laboratory notebook*. Neatly written, final notebook entries can be completed individually at home. Dr. Hentschel suggests that students might organize their notebook entries by including a drawing of each specimen and writing the answers to the 7 questions on a single notebook page below each drawing of the representative of that major taxon.

Reminder:

Don't forget to have Dr. Hentschel, Henry Carson, or Constance Gramlich sign your lab-notebook entry for today's lab before you leave the classroom. Clean up your table! All glass bowls should be rinsed and scrubbed with freshwater and returned to the front counter.

Lab #3: Protozoa. Wednesday, 6 September 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy follows Pechenik (2005). Descriptions of the various protozoans can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Protozoa

The distinction between plant-like and animal-like unicellular eukaryotes is not always clear or easy. For many years all unicellular eukaryotes were grouped into a single kingdom "Protista". The general term "protist" is commonly used. More recent classification schemes have elevated various protistan groups to kingdoms. In this lab, we will focus on the most animal-like protists, members of what is now considered the Kingdom Protozoa.

All protozoans are eukaryotes that lack collagen, which is present in animals, and chitinous cell walls, which are present in plants. Most protozoa are unicellular, but some are colonial and bridge the gap between unicellular and multicellular organisms. The lack of specialized differentiation among colonial cells generally distinguishes colonial protozoans from true metazoans. Colonial protist cells do not organize into functional tissues, as is the case in true metazoan animals.

Although protozoans definitely are not animals, there is considerable evidence that the earliest animals (early metazoans) evolved from protozoan ancestors. Theories focus especially on certain flagellated protozoans, but recent ideas suggest that early metazoans may have evolved multiple times from several different protozoan ancestors (see Chp. 2 in Pechenik 2005; p. 66-68 in Pearse et al. 1987).

Feeding, reproduction, and locomotion are extremely varied among the Protozoa. Modes of locomotion are the features that most easily distinguish among the major protozoan groups.

Biol 515 will examine three groups of protozoans: the flagellates (several phyla), the sarcodinids (phyla Amoebozoa, Foraminifera, Radiozoa), and the ciliates (phylum Ciliophora).

Required Activities

Students should observe and draw all of the specimens mentioned below.

Flagellates

- Flagellates are divided into the phytoflagellates and the zooflagellates. They move by lashing one or more flagella. A variety of live flagellates should be available in the plankton-tow samples. The most common will be dinoflagellates (Fig. 3.23; p. 21, 22).

Sarcodinids

Several groups were formerly classified in the Phylum Sarcodina. More recent classification schemes suggest several distinct phyla (e.g., Amoebozoa, Foraminifera, Radiozoa, Heliozoa). Sarcodinids move and feed by temporary extensions of the cytoplasm called pseudopodia.

- Observe a live *Amoeba* (Fig. 3.26; p. 26-31) from the culture in lab by placing a few drops on a microscope slide and adding cover slip. Observe and describe the locomotion. Draw a specimen and label the following structures: endoplasm, ectoplasm, food vacuole, pseudopodia, and nucleus.
- Examine and draw slides of Radiozoa (radiolarians, Fig. 3.29; p. 39-41).
- Examine and draw slides of Foraminifera (Fig. 3.28; p. 36-37). Several live planktonic and benthic "forams" also should be available for observation.

Ciliophora

Ciliates show the most specialization among the Protozoa. Solitary and colonial forms are common. The presence of external ciliation is the most conspicuous feature. The coordinated, rhythmic beating of cilia provides locomotion. Cilia also are important for feeding. Most ciliates feed by ingesting particulate food. Some even hunt living prey. All ciliates have two types of nuclei: macronuclei, which regulate the cell's metabolism, and micronuclei, which function in ciliates' "sexual" reproduction. Reproduction can occur by fission (p. 52) or by conjugation (p. 53). Conjugation involves the exchange and recombination of haploid pronuclei (diploid micronuclei that have undergone meiosis) between two individuals, but conjugation is not true sexual reproduction because gametes are never formed. Students should understand conjugation in *Paramecium* (Fig. 3.17; p. 53)

- Several live ciliates should be available for observation: *Stentor* (Fig. 3.22a; p. 63), *Vorticella* (Fig. 3.22f; p. 62), *Euplotes* (p. 65), and *Paramecium* (Fig. 3.22e; p. 47-53). Observe the ciliates by adding a drop of culture and a drop to methylcellulose, which slows down the ciliates' movement, to a microscope slide and cover slip. Students should draw and identify at least one of these ciliates. Yeast particles can be added to observe feeding.
- Whole-mount slides of *Paramecium* (Fig. 3.22e; p. 47-53) should be drawn in detail. The following structures should be easy to identify in most specimens: micronuclei, macronuclei, and the oral groove. The following should be visible in a few, but not most specimens: cilia, contractile vacuole, food vacuoles, and cytoproct. Know the function of each structure.
- Examine the plankton-tow samples for tintinnids (Fig. 3.20; p. 64)
- live *Zoothamnium* (p. 56), a colonial ciliate, also should be available for observation.
- live *Ephelota*, a suctorian (see Fig. 3.22h,i; p. 60, 61) might be available. Mature stages lack ciliation, but immature bud stages are ciliated.

Reminder:

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes!

Lab #4: Porifera & Cnidaria I. Monday, 11 September 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005) and Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Porifera

Unlike true animals, sponges lack tissues. Their cells are, however, differentiated and specialized to carry out functions in a cooperative division of labor. Students must understand the cell types (Fig. 4.5; p. 76-78) and the differences between the ascon, sycon, and leucon types of construction (Fig. 4.7; p. 79).

Required Activities

A variety of live sponges will be available for observation. Be sure to look at the diagrams of the ascon, sycon, and leucon types of construction and draw an example of each in your notebook.

- Pipet fluorescein dye along the side of a live sponge. Note the pattern of the water current.
- An alternative way to observe the pattern of water flow through a sponge is to submerge a live sponge in a bucket containing fluorescein for 1 h and then transfer the dye-filled sponge to a bowl of clean seawater.
- Identify and draw the various types of spicules (Fig. 4.2; p. 84, 85, 90).
- Cross-section slides of *Euspongia* illustrate a species that has spongin fibers and no spicules.

Phylum Cnidaria

There are three classes within Cnidaria: Hydrozoa, Scyphozoa, and Anthozoa. In this lab we will examine the Hydrozoa.

Class Hydrozoa

Required Activities

Order Hydroida

- *Gonionemus* is a common example, often grouped within the Suborder Limnomedusae. Draw and identify the features of the medusa: radial canal, ring canal, manubrium, velum, tentacles, and gonad (p. 102, 103, 105, 107). Students should understand the life cycle of *Gonionemus* (p. 109-110).

- *Obelia* (Fig. 6.14; p. 130, 131) is a common example, usually grouped within the Suborder Leptomedusae. The life cycle of this species completely alternates between asexual polyps and sexual medusae. The medusae are usually small and rather flat. The polyps are specialized for either feeding (gastrozooids) or reproduction (gonozooids). The feeding-end (hydranth) of the gastrozooids is surrounded by a chitin theca. Understand the life cycle of *Obelia* (p. 130, 131).
- *Tubularia* is a member of the Suborder Anthomedusae. Their hydranths are athecate. Draw a colony and compare the *Tubularia* life cycle (p. 137) to that of *Obelia*. Study feeding behavior of *Tubularia* or *Corymorpha* by adding some *Artemia* nauplii.
- *Hydractinia* (Fig. 6.15; p. 136, 137) is another anthomedusan (athecate hydranths). This polymorphic, colonial hydroid has gonozooids, gastrozooids, and dactylozooids (stinging, defensive polyps). Draw a colony and identify each type of zooid. Study the life cycle of *Hydractinia* in Pearse et al. (1987, p. 145) and compare it to the life cycles of other hydrozoans (p. 144-145).

Order Siphonophora

Siphonophores take colonial organization and polymorphism to an extreme! (Fig. 6.16; p. 148-151).

- *Physalia*, the Portuguese man-of-war is the most common example. Study the preserved specimens of *Physalia* and other siphonophores on display (e.g., *Praya*). Identify the various morphs of polyps and medusae, including pneumatophores (gas-filled floats), nectophores (swimming medusae: note *Physalia* does not have nectophores), bracts (defensive, leaf-like structures), gastrozooids (and their nematocyst-bearing tentillae), gonozooids, and dactylozooids.

Optional Activities & Observations

- Observe the examples of hydrocorals (p. 142, 143), *Allopora* and *Millepora* ("fire coral") colonial hydroids that have a calcium-carbonate skeleton.
- *Velella* (p. 146, 147, 806), Suborder Chondrophora, appear to be a single large, inverted, floating polyp. Some researchers have, however, suggested that they are complex polymorphic colonies (p. 146).
- *Polyorchis* (p. 141) is another anthomedusan. Unlike the flat medusae of leptomedusans, these are tall and bell shaped. *Polyorchis* has one of the larger medusae of the Hydrozoa.

Reminder:

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes!

Lab #5: Cnidaria II & Ctenophora. Wednesday, 13 September 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005) and Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Cnidaria

Class Scyphozoa

Scyphozoans are often called the true jellyfish. Their mesoglea tends to be rather thick and gelatinous. In scyphozoans, the medusa stage is the dominant form. The polyp is usually absent or greatly reduced. Students should be able to list all of the differences between scyphozoan medusae and hydrozoan medusae.

Required Activities

- *Aurelia* (Fig. 6.7, 6.9; p. 153-155) is the most common example. Preserved and live specimens should both be available. Draw and label the radial canals, mouth, mouth lobes, rhopalium, gonads, gastric cavity, and gastric filaments. Understand the function of these structures.
- Life cycle of *Aurelia* (Fig. 6.9; p. 154, 155). Examine the slides of planula, strobila, scyphistoma (Pechenik 2005 and Pearse et al. 1987 use the term "strobilating scyphistoma"), and ephyrae. Draw each life stage and understand that strobilation is the key characteristic that distinguishes Scyphozoa from the other two classes of Cnidaria. Live scyphistoma might be available for observation, as well.

Optional Activities & Observations

- live *Haliclystus*, a scyphozoan, might be available for observation.

Class Anthozoa

Anthozoans are the sea anemones, corals, soft corals, sea whips, and sea pens and sea pansies. These cnidarians have only a polyp form: there's no medusa stage. The class is divided into two subclasses: Octocorallia and Hexacorallia.

Subclass Octocorallia

Octocorallians have 8 pinnate (branched) tentacles and 8 septa. Most species (all of the common ones) in this subclass are colonial. Polyps live embedded in a structural endoskeleton composed of either calcium-carbonate tubes (pipe-organ corals: Order Stolonifera), thick and fibrous mesoglea (soft corals: Order Alcyonacea), proteinaceous material called "gorgonin" (sea whips & sea fans: Order Gorgonacea), or fleshy bodies that are supported somewhat by calcareous spicules (sea pens & sea pansies: Order Pennatulacea).

Required Activities

- Gorgonacea: Observe and draw some of the assorted gorgonians (p. 181-183). Live specimens of *Muricea* and *Lophogorgia* might be available.

- Observe and draw the whole-mount slide of an alcyonacean soft coral. Label the axial rod, polyps, calcareous spicules, and endodermal canals (p. 181).

- Pennatulacea: Observe and draw *Renilla* (p. 184). Note that the polyps are polymorphic. Identify the autozooids, siphonozooids, and axial polyp. What is the function of each kind of polyp? Some *Renilla* that have been kept in the dark will be disturbed to demonstrate their bioluminescence (students should all say "Ohhhhhh" when the fireworks go off!).

Optional Activities & Observations

- Alcyonacea: Observe and draw some of the assorted soft corals (p. 179, 180).
- Stolonifera: Observe and draw the organ-pipe coral (p. 178, 820).
- Pennatulacea: Observe and draw the sea pen *Acanthoptilum*.

Subclass Hexacorallia

Hexacorallians have more than 8 tentacles and septa, often arranged in multiples of 6. Tentacles are usually not pinnate. Polyps may be either colonial or solitary.

Required Activities

Order Actiniaria: the sea anemones.

- Examine the preserved *Metridium* (Fig. 6.18, 6.21; p. 165). Identify and label the following structures in your drawings: mouth, pharynx, siphonoglyph (the ciliated groove along the pharynx), gastrovascular cavity, muscular septa, septal filaments containing nematocysts (acontia), and gonads. A live *Metridium* might be available for observation.

- Observe the feeding behavior of live *Epiactis*, *Tealia (= Urticina)*, or *Anthopleura* (Fig. 6.19; p. 166) by providing the anemones with pieces of mussel.

- Order Corallimorpharia: Remove a piece of a tentacle from a live *Corynactis* (p. 169, 808). Place the portion of the tentacle on a glass microscope slide. Add methylene blue and smash the tentacle. Add a cover slip and use a microscope to see the nematocysts in action! Adding acetic acid will trigger nematocysts. Identify and draw both discharged and undischarged nematocysts (p. 116).

- Order Ceriantheria: Observe and draw *Pachycerianthus* (p. 177), a burrowing tube anemone that is common in Mission Bay.

- Order Scleractinia are the stony corals, which are anemone-like polyps that secrete calcium-carbonate cups (Fig. 6.22; p. 170, 172, 174). Observe and draw several of the dried corals, noting the various morphologies of their external skeletons. Several live specimens should be available: *Balanophyllia, Astrangia, Coenocyathus, Paracyathus*.

Optional Activities & Observations

- Order Antipatharia: Observe and draw some of the black, thorny coral (p. 176).

Phylum Ctenophora

Superficially, ctenophores look like cnidarian medusae, but about all these phyla really share in common is diploblastic tissue layers and what is generally radial body symmetry.

Required Activities

- Observe and draw the preserved ctenophore specimens (Fig. 7.1, 7.4; p. 189, 190, 195). identify the following: mouth, tentacle, gastrovascular canals, and ctene. Note that ctenophore tentacles do not have stinging nematocysts; they have adhesive colloblast cells.
- If live *Pleurobrachia* are available, observe and describe their locomotion.

Reminder:

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes!

Lab #6: Platyhelminthes, Nemertea, Rotifera, & Nematoda.

Monday, 18 September 2006

Most, but not all, of the activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Platyhelminthes

This phylum includes three classes of parasites (Cestoda, Monogenea, Trematoda) and one class of predominantly free-living flatworms (Turbellaria). Because Dr. Hentschel is grossed out by parasitic flatworms, lab activities will focus on turbellarians.

Class Turbellaria

Most turbellarians are marine (this, of course, is the real reason why Biol 515 focuses on them!).

Required Activities

- Order Tricladida: *Planaria*, which lives in freshwater, is a common example (p. 208-212). Whole mount and cross-section sides of *Planaria* were studied during Lab #1; review your drawings. A few slides will be available for a second look. Cultures of live *Planaria* should be available for observation, as well.
- Order Rhabdocoela: *Syndesmis* lives in a sea urchin's gut (p. 227). It is not clear whether this symbiosis is parasitic, commensal, or mutualistic.
- Order Polycladida: Several live marine specimens should be available for observation: *Pseudoceros*, *Prostheceraeus* (the "Halloween" flatworm), and *Hoploplana*.

Class Trematoda

- Preserved trematode parasites of fishes and dolphins are available for observation.

Phylum Nemertea

Nemerteans resemble acoelomate flatworms, with one key exception: nemerteans' eversible proboscis resides in a cavity (the rhynchocoel) that forms by the splitting of mesodermal tissue (mesenchyme). This is similar to schizocoely in protostome coelomates. Whether the rhynchocoel is truly homologous to the coelom of annelids and other protostomes is under scientific debate.

Required Activities

- live *Cerebratulus* & *Emplectonema* should be available. Note the proboscis (Fig. 11.4, 11.5; p. 261, 263).
- Examine and draw the slide of the pilidium larva (Fig. 11.7; p. 267).
- Examine several of the cross-sectional slides of nemerteans ("Rhynchocoela"). Each slide shows some structures better than others. Draw a composite and label the epidermis, intestine, mesenchyme, longitudinal & circular muscles, lateral nerve cords, lateral blood vessels, and the rhynchocoel (Fig. 11.1; p. 264).
- Preserved specimens of a pelagic nemertean show an everted proboscis clearly.
- A rare nemertean from Antarctica also is available for observation.

Phylum Nematoda

Nematodes have a pseudocoelomate body plan. The phylum is extremely diverse and lives in every habitat. Most species are free living and very small in size. Some are endoparasites.

Required Activities

- *Turbatrix* are available in culture. Study and describe their locomotion (Fig. 16.3). Note that males can be identified by the curl in their posterior end (Fig. 16.5; p. 275).
- Many marine nematodes live between sand grains and terrestrial forms live in soil (p. 275). In these habitats, nematodes play extremely important ecological roles!

Dissection of *Ascaris* (p. 277)

- External morphology: Be sure to divide male and female specimens within each lab group so all students can see one individual of each sex. Males are usually smaller and have a tight curl in their posterior end that has two penile spicules (for copulation). Using a dissecting microscope, draw and label the following structures: mouth, lips, penile spicules (male), genital pore (female), and the anus.
- Internal morphology: Pin the specimen with its ventral side down and make a full length incision along the dorsal surface. Identify and draw the following: pharynx, intestine, ventral nerve cord, and excretory canals. In males, identify the testis, vas deferens (sperm duct from testis), seminal vesicle (sperm storage), and ejaculatory duct (located posterior). In females, identify the ovary, oviducts, uteri, vagina, and genital pore (located anterior). *Note:* the various reproductive structures can be difficult to distinguish; use the textbook diagrams to help identify the major reproductive structures.
- Cross-section slides: These slides were examined during Lab #1. Review your drawings. A few slides will be available for a second look.

Phylum Rotifera

Rotifers are among the smallest metazoans. Like nematodes, they have a pseudocoelomate body plan. Rotifer life cycles are extremely unusual (Fig. 10.15; p. 307).

Required Activities

- Use the live specimens and slides to identify and draw the following general morphological structures: corona, jaws, toe, cement glands, digestive system (Fig. 10.4, 10.11; p. 305).
- Study and describe the locomotion of the live rotifers.

Reminder: **Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Lab #7: Chaetognatha, Lophophorates, & Kamptozoa
Wednesday, 20 September 2006

Most, but not all, of the activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005) and Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Chaetognatha

Chaetognaths are semi-transparent planktonic carnivores. They have a series of curved, chitinous spines on both sides of the head that are used for grasping prey. Chaetognaths also have lateral fins that provide stabilization during their rapid bursts of swimming. Chaetognaths do not have any specialized gas-exchange or excretory structures; these key physiological functions seem to be provided by diffusion across the body wall. Chaetognaths do, however, have a fairly complex nervous system (Fig. 18.5).

- Examine the preserved specimens and slides that are available. Identify the fins, grasping spines, head, eyes, digestive tract, and gonads (Fig. 18.6, 18.7, 18.8, 18.9; p. 654, 655).
- If live specimens are available, be sure to observe their swimming behavior.

Phylum Phoronida (Fig. 19.2, 19.3; p. 656-661)

All phoronids are marine. There are only 12 described species. Like bryozoans and brachiopods (both discussed below), phoronids feed with a ciliated, tentacular lophophore. Most phoronids live in permanent tube made of chitin or mucus-sediment. One of Dr. Hentschel's PhD students, Amy Larson, has found that at least one species, *Phoronopsis viridis*, produces chemicals that are distasteful to at least some predators. These defensive chemicals are most concentrated in the lophophore, which is normally the only portion of the worm that is exposed out of the tube.

- Place a live phoronid under low magnification of a compound microscope and add carmine powder to observe its feeding and water circulation.
- Observe the video of the actinotroch larva (Fig. 19.16a; p. 661).

Phylum Brachiopoda (Fig. 19.4, 19.6, 19.7, 19.8; p. 661-666)

These lophophorates are enclosed within a two-valved shell. In contrast to bivalved molluscs, however, the shells of a brachiopod are dorsal and ventral (not right and left). There are ~ 350 living species, but over 30,000 species of brachiopods are known from the fossil record (If you put your ear close to a brachiopod, you might hear it reminiscing about "the good old days"!).

There are two classes of brachiopods: the Inarticulata and the Articulata. The Articulata have hinged shells that, together with adductor muscles, allow opening and closing without lateral sliding of the shells. The Inarticulata have similar adductor muscles, but the shells are not hinged. The shells of Articulata are composed mainly of calcium carbonate with very little organic material in the shell matrix. The shells of Inarticulata are, on the other hand, composed of calcium phosphate and have a relatively high amount of chitin and protein.

- Find the lophophore of a live articulate brachiopod by separating the valves of its shell. Add carmine powder and observe feeding.
- Dissected specimens of an inarticulate brachiopod and an articulate brachiopod are available. In both specimens, locate the lophophore, digestive glands, muscles, and gonads (Fig. 19.6, 19.7, 19.8; p. 664, 665). Identify the branching mantle canals, which provide circulation and discharge of gametes.

Phylum Bryozoa (Fig. 19.9, 19.10, 19.12, 19.13, 19.14, 19.15; p. 667-677: "Ectoprocta")

These lophophorates are commonly called the "moss animals." They are the most diverse of the three "lophophorate phyla." Bryozoans form colonies by asexual reproduction. Bryozoans are either gelatinous, encrusting, or erect.

The lophophore of bryozoans can be retracted into the body. The bryozoan body plan includes some odd terminology because, in the 19th century, the gut and lophophore were thought to be a distinct body residing within a second protective layer. All bryozoans secrete a "house" around their body. The gut, lophophore, nervous tissue, and most of the musculature are called the **polypide**. The house and the body wall that secretes it are usually called the **cystid**. The non-living part of the house (i.e., the "exoskeleton") is often called the **zooecium**. The body wall is attached to the zooecium; the bryozoan is glued to its house! An individual (polypide plus cystid) is called a **zooid**.

Like many hydrozoans, bryozoan colonies often are polymorphic. **Autozooids** are specialized for feeding. **Avicularia** are protective zooids.**Vibracula** are zooids that have specialized sensory functions. **Kenozooids** are long tubular zooids that provide attachment for some colonies. **Kleistozooids** provide nutrient storage for some colonies. **Gonozooids** are specialized for reproduction in some colonies. **Ovicells** are specialized for brooding embryos in some colonies.

- Observe the feeding of a gelatinous bryozoan *Zoobotryon*.
- Observe the feeding of an encrusting bryozoan *Membranipora*.
- Observe the feeding of an erect bryozoan *Bugula* (Fig. 19.15).
- Several other live bryozoans might be available for observation.
- Look closely for polymorphic individuals on the erect and encrusting bryozoans. Preserved slides of *Bugula* contain some avicularia, vibracula, and ovicells (Fig. 19.15).
- *Thalamoporella* and Hippodiplosia have especially prominent ovicells.
- Study the slides of bryozoans to learn their internal anatomy (p. 670).
- Examine slides of the coronate and cyphonautes larvae (Fig. 19.16c,d; p. 675).

Phylum Kamptozoa (Fig. 19.18; p. 678-682: "Entoprocta")

Approximately 150 species of these benthic marine invertebrates have been described. Like lophophorates, kamptozoans feed with a ciliated anterior organ. Unlike the lophophorates, however, the anus of a kamptozoan lies within the ring of tentacles (thus, they are often called "Entoprocts" in contrast to the bryozoans that are often called "Ectoprocts"). Water flow is also different than that of lophophorates. In kamptozoans, water flows between the tentacles into the center of the tentacular crown and then travels upward and out the center of the tentacular crown.

- Observe live specimens of *Barentsia*. Note their distinctive nodding motions of their anterior end. Pretty cute, huh?

Reminder: **Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Reminders:

Lab Exam #1: Monday, 25 September 2006 (covering Labs #1-7).

Lab #8: Invertebrate Community Associated with *Macrocystis* Hold Fasts.

Wednesday, 27 September 2006

This activity was suggested by Constance Gramlich.

This lab is a little more wet and messy than most; students are advised to dress appropriately!

Each table will have a mass of kelp hold fast. Dig in and try to recover as many animals as possible. As you sort through the hold fast, try to observe where among the hold fast various organisms are found. A variety of books will be available to help students identify what they find. Members of the community should be noted in students' lab notebooks.

Reminder: **Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Lab #9: Gastropod Molluscs I. Monday, 2 October 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005) and Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Mollusca

Class Gastropoda

Gastropods are the most diverse group of molluscs. 75-80% of all living molluscs are gastropods! The typical gastropod has a few obvious features: the visceral mass (all of the internal organs), the muscular foot, columellar muscles ("shell muscles") that attach the foot to the shell, the operculum (a tough proteinaceous "door" on the dorsal, posterior portion of the foot), and an asymmetrically coiled shell (which can be reduced or lost in some taxa). A key characteristic of the gastropods is torsion (Fig. 12.13a; p. 330): the 90-180˚ twisting of the visceral mass during development (Do not confuse torsion with the separate process that creates the helical coiling of the shell: Fig. 12.12).

Gastropoda is divided into three subclasses: Prosobranchia, Opisthobranchia, and Pulmonata. Lab #8 will focus exclusively on two of the three orders of prosobranchs.

Subclass Prosobranchia.

Prosobranchs generally have an anterior mantle cavity, gills, and anus. Prosobranchs display the most obvious torsion. For each order, it is important to understand how reproduction, water circulation & gas exchange, and feeding are accomplished.

Required Activities

Order Archaeogastropoda

Reproduction:

The archeogastropods are the only gastropods that have a free-swimming trochophore larva (Fig. 12.46; p. 330). All species are dioecious (have separate sexes). There is no copulation; fertilization is external.

Water Circulation and Gas Exchange:

The more primitive archaeogastropods have two bipectinate ctenidia (gills), two kidneys, two auricles, and one osphradium (a chemical-sensing organ: Fig. 12.2) at the base of each gill.

- The abalone *Haliotis* (Fig. 12.17e; p. 332), keyhole limpet *Megathura* (Fig. 12.13d; p. 331), and volcano limpet *Fissurella* (p. 331) have cleft or perforated shells. This might represent a primitive solution to a big problem caused by torsion: having the anus and exhalent water stream located over the head (Yuck!).

The more derived archaeogastropods, posses only the left ctenidium and have non-perforated shells. Water enters the mantle cavity on the left side of the head and exits on the right side. The anus also opens to the right of the head; the exhalent current disperses wastes.

- *Tegula* (p. 332), the wavy-top snail *Astraea*, the kelp snail *Norrisia*, and the limpets *Collisella* & *Lottia* (p. 333) have only the left ctenidium and the circular ventilation pattern described above.

Feeding:

Archaeogastropods can be divided into two feeding types: browsers/grazers and raspers.

- Browsers/grazers use a rhipidoglossate radula to collect small algal particles from the substrate. Examples include *Haliotis, Megathura, Fissurella, Tegula, Norrisia,* and *Astraea*.
- Dissect either *Megathura* or *Astraea* by removing the shell. Identify and draw: the tentacles with eyes, foot, mantle, head, and ctenidia. Next, expose the digestive system. Identify and draw: the radula, the mouth musculature, digestive gland, and intestine. Remove the rhipidoglossate radula and examine it under the compound microscope. Understand the function of this radula. Find the gonad and try to determine the specimen's sex.
- Raspers scrape algae off rocks using a docoglossate radula that has fewer teeth that are very stout. Examples include *Collisella* and *Lottia*. Examine a docoglossate radula and be able to distinguish it from other radula types.

Order Mesogastropoda

Water Circulation and Gas Exchange:

Mesogastropods have one monopectinate ctenidium, one kidney, one auricle, and only one osphradium (Fig. 12.14). The monopectinate gill is of particular importance. It is attached directly to the mantle wall and is less susceptible to fouling than is a more filamentous bipectinate ctenidium. Unlike, the archeogastropods that tend to live in cleaner waters such as the rocky shore, mesogastropods are more common in turbid sedimentary habitats.

Feeding:

Mesogastropods all have one type of radula: the taenioglossate radula. The mesogastropods do, however, display a variety of feeding methods.

- *Littorina* (Fig. 12.10, 12.16; p. 329) rasp fine algal particles off rocks.
- The purple snail *Janthina (= Ianthina)* (p. 335) drifts on a raft of air bubbles and feeds on *Velella* (p. 806) when it happens to encounter them. *Janthina* excretes a purple dye to anesthetize *Velella*.
- Heteropods (p. 334) are active swimmers that hunt prey in the plankton. They have large eyes to locate prey and can extend their radula to capture prey.
- *Serpulorbis* (p. 334) secretes strands of mucus, like a net, to capture suspended particles.

- *Crepidula* (p. 332) collects suspended food particles on its mucous, enlarged ctenidium. Observe a live *Crepidula* under a dissecting microscope. Add carmine dye to observe its mucus-string feeding activity. Note how it everts the radula to collect the food mass from the ctenidial mucus. Also identify the osphradium (directly above the ctenidium), the mouth, eyes, and foot of *Crepidula*.
- The moon snail *Polinices* (p. 335) attacks bivalves by boring a hole through the shell and rasping out soft tissue with its radula. The proboscis of *Polinices* contains a gland that secretes an acid to dissolve a hole.
- The cowrie *Cypraea* is another carnivore, feeding on soft animals (e.g., anemones, sponges)

Reproduction:

Almost all mesogastropods are dioecious. Copulation between males and females occurs. The trochophore stage is suppressed, occurring within the egg. Eggs are usually deposited in jelly masses or capsules. Eggs usually hatch to free-swimming veliger larvae. Some species have direct development: eggs hatch to crawl-away juveniles.

Some mesogastropods are, however, hermaphrodites. *Crepidula* (p. 332), the slipper snail, is a protandric hermaphrodite. Initially, individuals are always males. Males can be identified by the presence of the penis near the side of the head. Following the initial male phase, the male reproductive tract degenerates, and the individual develops into either a female or another male. The individual's sex is influenced by the sex ratio of neighbors, which apparently secrete pheromones. A scarcity of females will lead some males to develop into females. Once an individual becomes female, it never reverts back to the male condition.

- Each lab group will have an *Astrea* with several attached *Crepidula adunca*. Map the location of all *Crepidula*, giving each *Crepidula* a number and indicating the spacing between individuals (use mm ruler). Remove each *Crepidula* and measure it with calipers (to nearest 0.1 mm. Examine each individual under the microscope to determine its sex. Collect the data needed to answer the following questions in your lab notebook:
- What is the male:female ratio of individuals in *Crepidula* mating stacks?
- What is the male:female ratio among all of the single (non-stacked) individuals?
- What percentage of all *Crepidula* were located singly?
- *At home*, construct a table listing the sex of each single *Crepidula* individual, each individual in a pair, each individual in a stack of three, each individual in a stack of four, etc.
- *At home*, construct a bar chart to display the size of each individual male and the size of each individual female measured.
- *Crepidula adunca* broods its eggs until they hatch as juveniles. Examine the brooded eggs of several females and note their developmental stages.

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes!

Lab #10: Gastropod Molluscs II. Wednesday, 4 October 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005) and Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Mollusca

Class Gastropoda

Subclass Prosobranchia.

The previous lab focused on the orders Archeogastropoda and Mesogastropoda. Today's lab concludes the prosobranchs with the order Neogastropoda.

Required Activities

Order Neogastropoda

Neogastropods have the same general features as mesogastropods, with a few differences:

- Most species are carnivores and have a specialized osphradium to sense prey.
- The nervous system of neogastropods is also more developed than that of mesogastropods.
- Most species have an eversible proboscis.
- Most species have a shell with a siphonal notch or canal.
- Most neogastropod eggs develop directly, hatching as juveniles. Veliger larvae are rare.

The feeding habits and structures of neogastropods are especially interesting.

- *Nassarius* is a scavenger on the surface of muds and sands. It has a rachiglossate radula for rasping, tearing, and pulling. Examine the feeding behavior of *Nassarius* by exposing it to pieces of meat. Also locate the siphon and siphonal canal.
- *Acanthina* and *Pteropurpura*, as well as most neogastropods, are hunters that drill into the shells of bivalves, barnacles, snails, etc. The "drilling" process is both physical and chemical. The snail alternates between scraping with its rachiglossate radula and secreting acid from its eversible "boring gland" (located in the snail's foot). Examine and draw the rachiglossate radula. Examine the photo of a feeding *Acanthina*. Identify and draw its eyes, mouth, proboscis, radula, and boring hole.
- *Conus* (p. 337) uses a very specialized toxoglossate radula to kill its prey. Examine this type of radula and understand the venomous capture of prey by *Conus*.

Additional Observations

- Examine *Kelletia*.
- Neogastropod egg capsules might be available for observation.

Subclass Opisthobranchia.

Opisthobranchs are distinguished from prosobranchs in several ways. Generally, opisthobranchs tend to display reductions or loss of many features. Specifically the shell, mantle cavity, and operculum tend to be reduced or lost. Ctenidia are replaced by secondary gills. During embryological development, torsion is reduced and often followed by varying degrees of detorsion. All opisthobranchs are hermaphrodites, either simultaneous or protandric.

Required Activities

Opisthobranchs from six orders will be examined. Focus on feeding structures and habits.

Order Cephalaspidea: the bubble snails.

- *Bulla*. This snail is an algal grazer. Most species are carnivores and have a specialized osphradium (Fig. 12.19).
- *Navanax* is a benthic hunter that commonly feeds on *Bulla*.

Order Sacoglossa: Snails that suck! (radula has a single row of teeth to slit open algal cells and slurp up the contents).

- The chloroplasts of algae can be incorporated into special cells in the digestive gland where they continue to photosynthesize and provide some (but not much) nutrition to species such as *Tridachia* (p. 341, 799).

Order Thecosomata: Shelled pteropods (Fig. 12.20).

- The majority of pteropods ("sea butterflies"; p. 341) are shelled and feed on suspended particles. Their feeding organs are ciliated lobes, which are derived from the muscular foot.

Order Gymnosomata: Naked pteropods (Fig. 12.20).

- The naked pteropods are fast-swimming predators, often preying on shelled pteropods.

Order Nudibranchia: Sea slugs (Fig. 12.18).

Nudibranchs have completely lost their shell and mantle cavity and have secondary bilateral symmetry. They also have "naked" secondary gills.

- Eolid nudibranchs (p. 326, 342, 343) have dorsal gills called cerata that also contain cnidosacs. Eolid nudibranchs usually feed on cnidarians and store nematocysts in the cnidosacs for defense.
- Dorid nudibranchs (p. 343) have gills surrounding their anus. They usually feed on sponges, tunicates, or bryozoans.
- *Tritonia* and *Melibe* (p. 343, suborder Dendronotina) are planktonic hunters that swallows their prey whole.

Order Anaspidea: Sea hares.

Sea hares have a reduced shell that they use to cut large pieces of algae.

Aplysia (p. 340) might be available for dissection. If so...

- The nervous system is especially prominent. Locate the conspicuous, paired cerebral ganglia (often orange in color). Also try to locate the pedal, pleural, and visceral ganglia (Fig. 12.49)
- Also find the shell, ctenidium, buccal mass with the odontophore, crop, gizzard, stomach, digestive gland, purple gland, ovotestis, and spermatic groove.

Subclass Pulmonata (mostly terrestrial and freshwater snails/slugs; Fig. 12.21, 12.22).

Pulmonates lack ctenidia and an operculum. The mantle cavity is highly vascularized and functions as a primitive lung. The small opening on the right side is called the pneumostome. All pulmonates reproduce as simultaneous hermaphrodites.

Most pulmonates live on land or in freshwater, but there are a few marine species. Marine pulmonates usually live high in the intertidal zone. Unlike the terrestrial and freshwater pulmonates, which lack a larval stage, the marine pulmonates usually have a veliger larva, suggesting that the marine habitat is ancestral.

Required Activities

Two species of marine pulmonates should be examined.

- *Melampus* lives in the high intertidal regions of saltmarshes.
- *Siphonaria* is abundant in the high intertidal regions of tropical rocky shores.

Reminder:

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.

Lab #11: Bivalve Molluscs. Monday, 9 October 2006

The activities and specimens in this lab are based on a combination of two labs in Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005) and Rupert and Barnes (1994). Descriptions of the various taxa and morphological features can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Mollusca

Class Bivalvia

Bivalves are two-valved, laterally compressed molluscs. The two shells enclose right and left sides, joined by a dorsal hinge. Most bivalves are filter feeders; some are deposit feeders. Unlike gastropods, bivalves do not have a distinct head; there's just a mouth and two feeding palps. Bivalves also lack a radula. Most bivalves live a fairly sessile or slow-moving existence, either attached to hard substrates or burrowed in soft sediments. Scallops are the only bivalves capable of short-burst swimming by clapping the valves of their shell.

Bivalve taxonomy varies among different texts. Members of the subclass Protobranchia are the most primitive bivalves. They have small, simple, bipectinate gills like those of archaeogastropods. Most of the other subclasses are informally grouped as the "lamellibranchs" (several subclasses distinguished by the intricacies of their gills, their shell structure, and hinge teeth). Rather than studying such features in detail for the sake of understanding the taxonomic distinctions, Biol 515 will focus on the functional aspects of bivalves' diverse morphologies.

The Shell

The dorsal edge of each valve has a prominent bulge (the umbo) next to the hinge. The umbo is the oldest part of the shell. Concentric growth lines radiate outward from the umbo. In primitive bivalves, the shells are equal in size. More derived species have modifications in shell symmetry, shape, and size. Species that attach by cementation typically have shell valves that differ in size.

Musculature

The shell's valves are pulled together by two adductor muscles. In primitive bivalves, the adductor muscles are equal in size (isomyarian condition). In most bivalves, however, the anterior adductor muscle is reduced in size relative to the posterior adductor muscle (anisomyarian condition). In some bivalves, the anterior adductor muscle is absent, and the posterior adductor muscle is located more centrally between the valves (monomyarian condition).

The Mantle, Mantle Cavity, and Siphons

Bivalves have an extensive mantle and mantle cavity. Water enters through the inhalant opening at the ventral, posterior end. The water then makes a U-turn through the gills and then out the exhalent opening, which is located at the dorsal, posterior end.

The mantle is specialized to each bivalve's habitat. Mantles display varying degrees of fusion (sealing the edges). Fusion reduces fouling and creates a more functional mantle cavity. Bivalves that live on hard substrates and are less susceptible to fouling show no fusion of the mantle, but some species have a mantle fold that separates the incurrent and excurrent openings. Species that burrow into mud or sand usually develop siphons, which are gaps between fused portions of the mantle. Some species have well developed, long siphons. When bivalves burrow into mud or sand, their anterior end points downward, leaving the inhalant and exhalent siphons to extend upward above the sediment-water interface. Some siphons, as well as other portions of the mantle, have sensory structures, such as tactile papillae and light receptors. Species that burrow deeply display fusion of the mantle at the ventral, anterior end. This creates an aperture through which a strong, sucker-like foot can protrude.

The Foot

The bivalve foot is highly modified depending on the mode of locomotion. The foot can be used for digging, swimming, even boring into wood or rock. In settling larvae and the adult forms of some species, a byssal gland resides in the anterior portion of the foot. It secretes byssus threads that anchor the bivalve to its substrate. Juvenile mussels have a very long foot that can be used to clean the outside of the shell. In some species, the foot of a larva secretes an organic adhesive that provides very firm attachment. In most species that attach by cementation, the foot is often reduced or completely absent in adults (the mantle secretes the adhesive for the adults).

Students should compare the structures of several species, with an eye toward function.

- Compare *Mytilus*, *Hinnites*, and boring bivalves (e.g. pholadids: *Zirfaea* and teredinids: *Teredo;* Fig. 12.33, 12.34) for differences in musculature.
- Compare *Mytilus*, *Hinnites*, *Musculista*, and boring bivalves for differences in attachment.
- Compare *Mytilus*, *Hinnites*, and boring bivalves (e.g. *Teredo, Zirfaea*) for differences in mantle fusion and sensory structures.
- Compare the siphons (including presence/absence) of *Hinnites*, *Chione*, *Mercenaria*, *Saxidomus*, *Protothaca*, *Nuttalia*, and *Tagelus*. The comparison of the relatively short siphons of *Mercenaria* with the medium siphons of *Saxidomus* is especially important.
- Compare the size of the foot of a scallop, a mussel, a boring bivalve, *Chione*, and *Tagelus*.
- Compare the external shells of *Mytilus*, *Hinnites*, *Chione*, *Mercenaria*, *Sanguinolaria*, and *Tagelus*.
- Examine the protobranch bivalve *Nucula*, (and *Yoldia*, and *Solemya*, if available). Use the various diagrams to identify the palp appendages (Fig. 12.25, 12.26; p. 348) and compare the gill structure to that of lamellibranchs (Fig. 12.24, 12.25, 12.26, 12.28, 12.29, 12.31).
- Examine at least one species that attaches by cementation: *Hinnites*, *Chama*, or *Crassostrea*.

***Mytilus* Dissection** (Fig. 12.29, 12.32)

- Remove one valve by inserting a knife between the shell and the tissue. Submerge the opened mussel in seawater.
- Add carmine powder. Note the flow of water. It enters between the filaments of the ctenidium in the ventral edge of the shell, moves anteriorly, and then exits through the ctenidium posteriorly and dorsally. Also note the string of carmine powder as it moves down the food groove to the labial palps and mouth.
- Remove a piece of ctenidium and place it under the compound microscope to examine the cilia (Fig. 12.29).
- Find the two pairs of labial palps and the mouth at the center of the palps.
- On the ventral surface, find the foot and byssal threads.
- Identify the kidney (a long, brown organ) and the anus (on the posterior surface of the posterior adductor muscle).
- Remove the thin membrane on the visceral mass to expose the digestive gland (pale green) and stomach. Open the stomach to find the intestine and crystalline style.

***Hinnites* Dissection** (Fig. 10-79 of Rupert & Barnes 1994 will be available in lab)

- Remove one valve by inserting a knife between the shells and cutting the large adductor muscle near the center, posterior region of the shell. Scallops display the monomyarian condition in which the anterior adductor muscle is absent.
- *Hinnites* is a hermaphrodite. Identify the testis and ovary regions of large gonad.
- The gill should be obvious.
- Try to identify the major components of the digestive tract: the stomach, intestine, and anus.
- The heart might be visible in some specimens.

The clams *Mercenaria* or *Saxidomus* will also be available for Dissection (Fig. 12.32)

- Remove one valve by inserting a knife between the shells and cutting both the anterior and posterior adductor muscles.
- Identify the incurrent and excurrent siphons.
- Identify the gill and remove it to expose the digestive organs.
- Be sure that you can identify the left and right shells of a clam, as well as the dorsal, ventral, anterior, and posterior regions of each shell (Fig. 12.23).

***Reminder:* Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Lab #12: Remaining Molluscs. Wednesday, 11 October 2006

Most, but not all, of the activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Mollusca

Class Scaphopoda

There are only about 350 species of scaphopods; all are marine. They resemble bivalves more closely than any other group of molluscs. The animals have a long, tubular shell. They live burrowed in sand, usually in the deep sea. Scaphopods feed with numerous tentacles called captacula. Scaphopods do not have gills, but do have a specialized respiratory area of the mantle.

- Examine the shells of scaphopods (Fig. 12.36; p. 363).
- On the dissected specimens, identify the foot, tentacles (captacula), gonad, digestive gland, and retractor muscle (Fig. 12.36; p. 363).

Class Aplacophora

This class includes the most primitive living molluscs. All of the ~ 300 species are marine; most live in the deep sea. These worm-shaped molluscs lack a head and true shell. The unsegmented body has numerous calcareous spicules embedded in the outer mantle. Like typical molluscs, however, aplacophorans have a radula (often used for grasping rather than rasping), ctenidia, and a trochophore larva.

- Examine the demonstration specimen (Fig. 12.7; p. 382).

Class Monoplacophora

This class was only known from the fossil record until a live specimen was discovered in 1952 (In the 1890s, some live specimens were collected and mis-classified as gastropods). Since 1952, about 20 living deep-sea species have been described.

Monoplacophorans have a single limpet-like shell. Their head does not have any sensory structures. Curiously, the internal organs of monoplacophorans display serial repetition (their gills, pedal retractor muscles, metanephridia, gonads, and auricles and ventricles of the heart are arranged in multiple copies), but monoplacophorans are not considered to have segmented bodies. Both a radula and crystalline style are present.

- Examine the photo of *Neopilina* (Fig. 12.9; p. 383).

Class Polyplacophora

Polyplacophorans, the chitons, have a distinct 8-plate shell. The mantle cavity of chitons is divided into two lateral grooves. Numerous (up to 80) bipectinate ctenidia hang down from each lateral groove to create incurrent and excurrent chambers. The foot extends along the entire ventral surface. Chitons can create a powerful suction anchor with its foot. The mouth and anus are at opposite ends of the linear digestive tract. The radula is a scraping organ. Usually chitons feed on algae, but some species are carnivores.

- Examine the live chitons: *Mopalia, Nuttallina,* and/or *Cyanoplax*.
- Examine *Placiphorella* (p, 325), a carnivorous chiton.
- Also be sure to examine *Cryptochiton*.

Stenoplax conspicua Dissection (Fig. 12.6; p. 320, 321, 322)

- On the dorsal surface, identify the 8 shell plates and calcareous spicules in the mantle edge.
- On ventral surface, identify foot, mantle cavity or grooves, rows of ctenidia, mouth, anus.
- Cut ventrally all around the edges of the shell to remove the animal from the shell. The space surrounding the viscera is the hemocoel. Find the heart at the posterior end of the visceral mass. Identify the gonad in the middle of the dorsal region.
- Beneath the heart and gonad is a long, coiled intestine. Expose the entire digestive tract and find the mouth, digestive glands, and stomach.
- Examine the radula.

Class Cephalopoda

Cephalopods are the most highly organized molluscs. Like gastropods, some cephalopods have shells (*Nautilus*), and others have only vestigial shells (squid, cuttles). Unlike other molluscs, cephalopods have a closed circulatory system. Ganglia form to fuse a complex brain. The foot is modified to form flexible arms and siphons (funnel). The radula has a beak-like modification.

Nautilus (Fig. 12.37, 12.38; p. 381).

- Examine the shell, noticing the siphuncle ("tissue strand").
- Also examine the preserved dissection, noting the mouth, beaks, radula, digestive tract, two pairs of ctenidia, the funnel, and the siphuncle.

Sepia (Fig. 12.40; p. 376, 377)

- Examine the cuttlefish specimens.

Octopus (p. 373)

- Examine the live *Octopus*. Note the chromatophore changes and feeding behavior.
- If developing eggs are available, examine them.
- Examine the slides of the eye (Fig. 12.44; p. 369).
- Examine the preserved dissections of *Octopus*, locating the following external structures: eyes, funnel, arms.
- Locate the following internal structures: gills, branchial hearts (gill hearts), stellate ganglia (one in each side of mantle wall), esophagus, crop, stomach, digestive gland, and ink sac.
- In the female, identify the ovaries, oviducts, and egg capsules.
- In the male, identify the testis, penis, spermatophore sac, and hectocotylus arm (Fig. 12.45).

Dissection of *Loligo* and/or *Dosidicus* (Fig. 12.39; p. 367, 368)

Either or both squids might be available for dissection.

- The squid's original dorsal surface is now, functionally, its posterior end, while the ventral surface is its anterior end. The foot is modified into 5 pairs of tentacles; one pair in males is modified to be the hectocotylus arms.
- Locate the mouth and chitinous beak.
- Identify the funnel, lateral fins, and the mantle.
- Cut the mantle slightly along the mid-ventral line. Note the funnel and its valve-like projections. Identify the gills and the branchial hearts.
- Find the stellate ganglia on the inner, dorsal surface of the mantle near the tip of the gills.
- Identify the rectum/anus just behind the funnel.
- Locate the ink sac (just behind rectum) and carefully remove it.
- Locate the paired kidneys. They are light orange and usually easier to find in females.
- In *Dosidicus*, note the very large liver.
- If the specimen is a female, find the large paired nidamental glands (they secrete a gelatinous coating around each egg). Look for eggs in the ovaries (in the posterior "cone").
- In males, find the penis (left of the rectum). The testis runs alongside the digestive caecum. Sperm passes from the testis through the vas deferens to the spermatophoric gland that secretes a covering around the spermatophores. Spermatophores exit via the penis and are transferred to females by the hectocotylus arms.
- Examine the slides of the spermatophore (p. 371)
- Open the head along the midline and find the buccal bulb, beaks, and radula.
- Note the eyes. It is analogous to the vertebrate eye, having a cornea, iris, pupil, and lens.

Lab #13: Annelida I. Monday, 16 October 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Detailed descriptions of the various errant polychaete families can be found in Fauchald (1977), Fauchald and Jumars (1979), Banse and Hobson (1974), the two required texts (Pechenik 2005 and Pearse et al. 1987), and most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Annelida

There are over 12,000 described species of annelids. All annelids are segmented worms and display one or more pairs of chitinous setae per segment. The phylum is divided into three main classes: Polychaeta, Oligochaeta, and Hirudinea.

Class Polychaeta

Polychaetes are the most diverse annelids and the most common in marine habitats. Their most prominent characteristic is their bi-lobed parapodia, which are specialized to function in gas exchange and locomotion. The dorsal lobe is called the notopodium; the ventral lobe is the neuropodium. Differences among the detailed morphologies of parapodia are important for distinguishing among the many polychaete families (over 80!).

In addition to the parapodia, three other regions of the body are important to recognize. The anterior most region of polychaetes is called the prostomium ("in front of the mouth"). The prostomium usually has sensory eyes, antennae, and palps. The region adjacent to the prostomium is the peristomium ("around the mouth"). The peristomium often has sensory tentacles (or cirri) and feeding tentacles (or palps). The posterior most region of polychaetes is called the pygidium. Sensory cirri are often found on the pygidium. The segments bearing numerous setae lie between the peristomium and pygidium. Identifying polychaetes to species often requires close examination of the setae and their arrangement.

Polychaetes have a wide range of life histories. The class is operationally divided into the errant (mobile) and sedentary polychaetes. This lab focuses on the errant polychaetes.

Nereis Dissection

- Specimens narcotized in $MgCl_2$ usually show most structures clearly and colorfully!
- Identify the following structures on the head of *Nereis*: prostomium, peristomium, palps, antennae (prostomial tentacles), peristomial tentacles (cirri), eyes (Fig. 13.3; p. 390, 393).
- Note the obvious segmentation and identify the bi-lobed parapodia.
- Dissect *Nereis* by making a mid-dorsal incision down the entire length. Identify the aciculum (chitinous rods within parapodia), septa, longitudinal muscles, circular muscle layer, parapodial muscle, ventral blood vessel, lateral blood vessels, ventral nerve cord, segmental ganglia, esophagus, esophageal sac, intestine, pharynx/proboscis, and the jaws (Fig. 13.3; p. 390, 394, 395).

Behaviors of Errant Polychaetes

- Describe the feeding behavior of the carnivorous glycerid polychaete.
- Describe the locomotion of live phyllodocid and nereidid polychaetes.
- Observe the burrowing behavior of live glycerid or nereidids by placing them in sand.

Structure of Parapodia

- Examine the cross sections of nereidid parapodia and whole-body cross sections (p. 389). Identify the notopodium and neuropodium, aciculum, ventral and dorsal cirri, ventral and dorsal blood vessels, ventral nerve cord, longitudinal muscle, the thin layer of circular muscle, intestine, and coelom.
- Also examine and draw the cross sections of parapodia from nephtyid and phyllodocid polychaetes. The structure of parapodia is important for distinguishing among many of the polychaete families.

Errant Polychaete Families

A range of specimens is available. Students should be able to recognize the following errant polychaete families:

- **Alciopidae** - These are planktonic polychaetes with transparent bodies and two large eyes.
- **Amphinomidae** - The "fire worms" have long glass-like setae and a pair of branched gills on most segments.
- **Aphroditidae** (p. 415) - The "sea mouse". The dorsal surface is covered with scales (elytra) that are concealed by a felt-like mat.
- **Eunicidae** (p. 413) - The prostomium has 1-5 pairs of antennae, an eversible proboscis, and distinctive jaws.
- **Glyceridae** - The prostomium is annulated with 4 antennae. The long, eversible proboscis has 4 jaws. The parapodia are very small.
- **Hesionidae** - These worms have a relatively short body, 2-3 antennae, and 2-8 pairs of tentacular cirri. The parapodia have long dorsal cirri.
- **Nephtyidae** - These worms have well developed parapodia with interramal cirri between most parapodial lobes. They move with rapid undulations. The eversible proboscis has papillae, but lacks jaws. The prostomium has 2 pairs of small antennae.
- **Nereididae** (Fig. 13.4a; p. 389) - The prostomium has two large palps, 2 antennae, and 4 eyes. The peristomium has 3-4 pairs of tentacular cirri. The eversible proboscis has 2 jaws. The parapodia are fairly large.
- **Phyllodocidae** (Fig. 13.4d; p. 416) - Distinctive, leaf-like dorsal cirri on parapodia.
- **Polynoidae** (Fig. 13.4b; p. 415) - The "scale worms" display simple, exposed elytra.
- **Syllidae** (Fig. 13.10; p. 412-413) - These worms have long dorsal cirri that often look like a string of beads. They have 3 long antennae and a barrel-shaped proboscis.
- **Tomopteridae** (p. 417) - These are planktonic, transparent polychaetes with very large parapodia and membranous pinnules instead of setae.

Lab #14: Annelida II. Wednesday, 18 October 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Detailed descriptions of the various sedentary polychaete families can be found in Fauchald (1977), Fauchald and Jumars (1979), Hobson and Banse (1981), the two required texts (Pechenik 2005 and Pearse et al. 1987), and most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Annelida, Class Polychaeta (continued)

As introduced in the previous lab, polychaetes have a wide range of life histories. This lab focuses on some of the sedentary polychaetes. The remaining sedentary polychaetes, as well as the other classes of annelids (Oligochaeta and Hirudinea) will be examined in the next lab.

Sedentary Polychaete Families (Part 1 of 2)

A range of specimens is available. Students should be able to recognize the following sedentary polychaete families:

- **Chaetopteridae** (Fig. 13.7a; p. 422) - These large worms have very distinct, leathery or chitinous tubes. Chaetopterids have one pair of palps that are used for some feeding activities and for depositing fecal pellets. The body is differentiated into 2-3 distinct regions, which can be distinguished by obvious modifications of the parapodial lobes.

- **Cirratulidae** (Fig. 13.7d; p. 423) - The "hairy-gill worms." Cirratulids have long, threadlike gills extending from many of their segments. Most cirratulids also have one or more pairs of anterior feeding palps.

- **Sabellariidae** (Fig. 13.7c; p. 423) - These worms construct tubes (and reefs!) by cementing sand grains together. The worm's anterior end functions as an operculum with 2-3 concentric rows of paleae (broad, flat setae that have a metallic appearance). Feeding tentacles are simple and usually short.

- **Sabellidae** (Fig. 13.8, 13.9; p. 418-420) - "Feather-duster worms." These worms have a distinct crown of pinnate feeding tentacles. Sabellids do not have an operculum. They construct non-calcareous tubes — usually of membranous parchment — but some build mucus-sand tubes.

- **Serpulidae** (p. 421) - These "feather-duster" or "Christmas-tree" worms build calcareous tubes that are rather straight. Most serpulids have one tentacle modified to form an operculum; an exception is *Salmacina*.

- **Spirorbidae** (p. 421) - These "feather-duster" or "Christmas-tree" worms build spiral-coiled calcareous tubes. Like serpulids, spirorbids have one tentacle modified as an operculum that seals the tube. The operculum is also used to brood embryos. Spirorbids are hermaphrodites.

- **Terebellidae** (p. 417) - These worms burrow in sediment, usually constructing mucus-sediment tubes. The prostomium contains many non-retractable feeding tentacles. The anterior few segments contain gills (usually branched and bright blood red).

Observations of Feeding

- Observe *Chaetopterus* in plexiglas tubes. These worms produce mucus nets to trap suspended particles that are pumped by the action of fan-shaped notopodia.

- Add carmine powder to observe suspension feeding of serpulids, sabellids, and spirorbids.

- Observe surface-deposit feeding of cirratulids and terebellids. Add small pieces of *Mytilus* meat as large food particles and yeast as small particles.

Reproduction in Polychaetes

- Examine the tubes of spirorbids on algal fronds for the presence of brooded larvae (p. 396-398).
- Draw a trochophore and a later-stage polychaete larva (Fig. 13.11)
- Examine the plankton tow for free-swimming polychaete larvae.
- Examine heteronereids (the pelagic, reproductive epitokes of nereidids). Understand the process of epitoky (Fig. 13. 10).

Reminders:

Field Trip #1: Sunday, 22 October 2006
(Mariner's Basin, 3-4:40pm, low tide @16:21)

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.

Lab #15: Annelida III. Monday, 23 October 2006

Many, but not all, of the activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Detailed descriptions of the various sedentary polychaete families can be found in Fauchald (1977), Fauchald and Jumars (1979), Hobson and Banse (1981), the two required texts (Pechenik 2005 and Pearse et al. 1987), and most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Annelida, Class Polychaeta (continued)

As introduced in the previous two labs, polychaetes have a wide range of life histories. This lab begins by concluding the sedentary polychaetes.

Additional Sedentary Polychaete Families (Part 2 of 2)

Students should be able to recognize the following sedentary polychaete families:

- **Arenicolidae** (Fig. 13.7b; p. 418) - "Lug worms" have broadly shaped bodies. The anterior segments are prominently annulated. The middle segments bear branched, dorsal branchiae (gills). Lug worms reside in fairly stable L-shaped burrows that they irrigate.
- **Capitellidae** - These are probably the most common polychaetes. They are usually long and slender and resemble earthworms more than most polychaetes. Capitellids are usually pink or red in color. The thoracic and abdominal regions can usually be distinguished. The anterior end lacks appendages. Identification of genera requires a close examination of the setae, and species often cannot be distinguished without direct genetic analyses.
- **Flabelligeridae** - Flabelligerids have distinctive long, anterior-pointing setae on their first few anterior segments; these form a "cephalic cage." In addition, their prostomium and peristomium can be retracted within the anterior segments. A pair of grooved palps extend from the prostomium and several gills extend from the peristomium. Flabelligerids are surface deposit feeders. Some species are commensals and have an unusual sort of "deposit feeding." *Flabelligera commensalis*, for example, lives in the spines of a sea urchin and eats the urchin's fecal matter (This bit of trivia should seem so bizarre to students that it should be easy for those who read this handout to remember it on a quiz or exam. *Hint, Hint!*).
- **Maldanidae** - "Bamboo worms" live head-down in a sediment tube. Their segments are very long and distinct relative to those of most polychaetes.
- **Onuphidae** (p. 424) - These worms construct tubes that are often decorated with shell and algal material. One of Dr. Hentschel's worm mentors, Dr. Sally Woodin (U. of So. Carolina) finds the tubes of one onuphid, *Diopatra*, so beautifully decorated that she makes earings out of the tubes! Onuphids have 7 antennae, 5 of which are usually large and annulated, and one pair of palps. Their jaws are used for scavenging any living or detrital food within reach.
- **Opheliidae** - These worms lack anterior appendages. Both the anterior and posterior ends are rather pointed. Usually, opheliids have a prominent ventral groove. They burrow in sands and mud and are fairly non-selective deposit feeders.
- **Orbiniidae** - These burrowing worms have a pointed head and ragged-appearing abdominal region in which the parapodia are located dorsally.

- **Pectinariidae** (Fig. 13.7e; p. 424) - "Ice-cream-cone worms" construct very distinctive sediment tubes. They live head down and deposit feed with many tentacles. Their fifth setigerous segment bears paleae (broad metallic setae). The Paleae are used for digging.
- **Spionidae** (p. 422) - The most distinctive feature of these worms is their pair of prostomial feeding palps. Spionids usually live in sediment tubes and feed at the sediment-water interface, using their palps to collect deposited particles or those suspended by near-bottom currents. Dorsal gills may be present on some or many segments.

Observations of Feeding

- Observe deposit feeding by members of several polychaete families.

Class Oligochaeta

Oligochaetes lack parapodia and have fewer setae than polychaetes. The anterior region of oligochaetes lacks the conspicuous sensory and feeding structures of most polychaetes. Unlike polychaetes, which typically have separate sexes, most oligochaetes are hermaphrodites. Oligochaetes also have distinct gonads. The most conspicuous feature of oligochaetes is the clitellum, a specialized region of the epidermis that secretes a cocoon in which embryos develop. Oligochaetes are most common in terrestrial and freshwater habitats, but there are several marine species.

Dissection of ***Lumbricus*** (Fig. 13.18, 13.31; p. 403, 404, 406, 408)

- Identify the clitellum.
- Make a mid-dorsal incision and observe the following internal structures: dorsal hearts, segmental coelomic compartments, circular and longitudinal muscles, crop, gizzard, intestine, testis, seminal vesicle, ventral nerve cord, and metanephridia.
- Examine cross-sectional slides and locate the intestine, typhlosole, circular and longitudinal muscles, ventral nerve cord, and ventral and dorsal blood vessels (Fig. 13.32).

Class Hirudinea

Recently, Oligochaeta and Hirudinea have been considered to be subclasses within the class Clitellata. Like Oligochaetes, leeches lack parapodia and are hermaphrodites with a clitellum. Leeches, however, usually do not have any setae. They also lack internal septa, and the coelomic space is greatly reduced. Leeches, therefore, move in ways that are very different from other annelids. Most leeches live in freshwater or moist-terrestrial environments. Although most leeches are blood-sucking ectoparasites, some are predators.

- Observe and describe the locomotion of live leeches.
- Identify the posterior and anterior suckers of a preserved specimen.
- Pin open a dissected specimen and locate the mouth, esophagus, and intestine. Note the lack of septa and the reduction of the coelomic space (Fig. 13.22; p. 432).

Reminder: **Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Lab #16: Pogonophora, Echiura, Sipuncula, & Priapulida
Wednesday, 25 October 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Annelida

Class Pogonophora (Fig. 13.12, 13.13, 13.14, 13.15, 13.16; p. 443-445)

This is a small, but very interesting group. Recent texts consider this group to be a family of polychaetes: the family **Siboglinidae** (Pechenik 2005). Regardless of their phylogenetic position and taxonomic nomenclature du jour, Biol-515 students should recognize that these are a very curious group of worms! These worms do not have a mouth or digestive tract. Small pogonophorans might obtain nutrition from dissolved organic matter. Larger ones definitely rely on a vascularized portion of tissue called the trophosome, which harbors chemoautotrophic endosymbiotic bacteria. The rear portion of a pogonophoran is called the opisthosoma. This region of the body is segmented, suggesting that pogonophorans might form a class within the phylum Annelida. The most famous and charismatic pogonophorans are the giant vestimentiferan tube worms living at deep-sea hydrothermal vents (first discovered in 1977).

- Examine the photos of *Riftia*.
- Examine the dissected *Riftia* specimen. Identify the obturaculum, vestimental region, trunk, trophosome, and opisthosoma.

Class Echiura (Fig. 13.26, 13.27, 13.28, 13.29; p. 438-440)

Echiurans have long been considered a distinct phylum of unsegmented worms, but recent evidence of short-lived segmentation during their embryonic development suggests that they might form a class within the phylum Annelida. There are ~ 140 described species. Echiurans burrow in sand or mud. They feed with a distinct proboscis. The edges of this proboscis curl to form a ciliated gutter. Most echiurans are deposit feeders, but some (e.g., *Urechis*) suspension feed by trapping particles in a mucous net that lines their burrow.

- Examine the peristaltic movements of live *Urechis* (Fig. 13.27, 13.28; p. 438, 442) and understand how this functions in feeding.
- Dissect a specimen of *Urechis* by making a dorsal incision (p. 439). Identify the ventral nerve cords, genital sacs (metanephridia), esophagus, intestine, anal sac (excretory organ), and gonad (if present). Although most echiurans have a closed circulatory system, *Urechis* does not; hemoglobin-rich blood circulates within the coelom.

Phylum Sipuncula (Fig. 13.34, 13.35; p. 441, 442)

Like priapulids, sipunculans are peanut-shaped worms that have an eversible introvert used for burrowing in mud. They are unsegmented and have a free-swimming trochophore larva. Most of the ~ 350 species are deposit feeders, some have tentacles surrounding the mouth that function in both feeding and gas exchange.

- Examine the live sipunculans, paying special attention to their feeding.
- Dissect a preserved sipunculan (Fig. 13.35; p. 442). Make a lengthwise incision slightly off the mid-dorsal line. Find the ventral nerve cord, retractor muscles, metanephridia, esophagus, intestine, anus, gonad (if present).

Phylum Priapulida (Fig. 17.2; p. 447)

There are only about 15 species of priapulids. These peanut-shaped worms inhabit muddy sediment. They were once thought to be most closely related to echiurans and sipunculans, but their chitinous cuticle, which is molted during growth, suggests priapulids may share a common ancestor with nematodes and arthropods. The anterior portion of the body is a retractable introvert (or proboscis) that can be retracted into the posterior trunk. The introvert is used for burrowing. It usually bears rows of spines.

- Examine the preserved specimen. Identify the introvert, trunk, caudal appendages.

Reminders:

Lab Exam #2: Monday, 30 October 2006 (covering Labs #8-16).

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.

Lab #17: Onychophora, Tardigrada, & Intro to Arthropoda
Wednesday, 1 November 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994) and introductory biology texts (e.g., Campbell et al. 1999, 2002; Purves et al. 2001). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Onychophora (Fig. 15.5; p. 452, 453)

All onychophorans are free-living protostome coelomates. All living onychophorans (~ 100 species) are found in moist terrestrial habitats, but many marine specimens are known from the fossil record.

Onychophorans possess some features that are similar to those of annelids and some that are similar to arthropods. The annelid-like characteristics include their body-wall musculature, a lack of jointed appendages, a pair of nephridia in most body segments, a hydrostatic skeleton involved in locomotion, simple eyes, and sperm that resemble those of oligochaetes and leeches. The arthropod-like characteristics include a chitinous cuticle, a hemocoel as the body cavity, a tracheal respiratory system, an open circulatory system, and a pair of appendages modified as feeding jaws. Several characteristics are unique to onychophorans: unusual walking legs, oral papillae as the third pair of appendages, dorsal slime glands, and two ventral nerve cords that lack ganglia.

- Watch the video of *Peripatus*. Note its behaviors associated with feeding, defense, and reproduction.
- Examine the preserved specimens to identify the key external features of onychophorans.
- Examine cross-sectional slides and identify the circular and longitudinal muscles, intestine, ventral nerve cords, dorsal slime glands.
- Examine longitudinal sections to identify the brain, mouth, intestine, dorsal tubular heart.

Phylum Tardigrada (Fig. 15.2, 15.3; p. 316, 317)

Tardigrades are extremely small (most are < 0.5 mm). Most of the ~ 800 described species inhabit freshwater films on terrestrial plants (especially mosses and lichens), but several marine species are known (usually living interstitially between sand grains). Tardigrades' most unique characteristic is their piercing oral stylets (used to pierce plant or animal foods). Some other features, such as the chitinous cuticle that is molted and the nervous system, are similar to arthropods. Tardigrades' stubby appendages are not, however, jointed. Undoubtedly, the most interesting thing about tardigrades is their ability to undergo cryptobiosis — dehydrating and reducing metabolism to withstand periods of extreme environmental conditions such as low temperature and desiccation.

- Examine live tardigrades using a compound microscope. In particular, note the pumping action of the pharynx and the oral stylets.

Phylum Arthropoda

Arthropods are the most diverse group of animals (period!). At least 75% of all animal species belong to this phylum, and arthropods are abundant in terrestrial, freshwater, and marine systems. Arthropods all have a hardened exoskeleton that is jointed and must be molted during growth. Unlike annelids, which use a coelom in part to facilitate locomotion, the arthropod coelom is reduced (jointed appendages require a different sort of musculature and locomotion), and the main body cavity is a hemocoel: a feature inherent in an open circulatory system. Rather than the simple, serial segmentation displayed by most annelids, the arthropod body plan displays tagmatization: a fusion of segments into distinct body regions (some polychaete families display rather simple tagmatization).

Arthropod phylogeny is especially controversial. Biol 515 will consider four major groups (subphyla) of arthropods: Uniramia, Trilobitomorpha, Chelicerata, and Crustacea. This lab will briefly introduce the uniramians and trilobites, focusing on marine chelicerates. The next four labs will be devoted to marine crustaceans.

Subphylum Uniramia

Uniramians have jointed appendages that have unbranched tips (uniramous). They have a pair of anterior antennae and a pair of mandibles. Respiration is facilitated by tracheal tubes. Excretion is accomplished by malpighian tubules.

There are two major groups of uniramians: the Myriapoda (centipedes and millipedes: Fig. 14.14) and Insecta. Centipedes (Chilopoda: p. 566-568) have one pair of jointed walking legs on each segment. Millipedes (Diplopoda: p. 569-571) have two pairs of jointed walking legs on each segment. Insects (Fig. 14.15; p. 573-583) have a body divided into three regions (head, thorax, abdomen) and have three pairs of jointed thoracic appendages.

Because Biol 515 focuses on marine invertebrates and other courses focus on insects and other terrestrial arthropods (e.g., Biol 462, Biol 526), students will be expected to understand only the most general features of uniramian arthropods.

Required Activities

- Observe the preserved *Halobates* (p. 634), which strides along the surface waters of the ocean.

Optional Activities

- If time permits, observe any of the uniramians that are on display.

Subphylum Trilobitomorpha (Fig. 14.9)

Trilobites were very common in marine environments ~ 500 million years ago, but became extinct by ~ 275 m.y.a. Evidence suggests that Chelicerates descended from trilobites.

- Observe the trilobite fossils on display.

Subphylum Chelicerata

The chelicerates are the only arthropods that lack antennae. The second anterior segment bears clawed chelicerae for grabbing and shredding food. Unlike other arthropods, chelicerates also lack mandibles. Unlike uniramians, chelicerates have branched, biramous appendages. The tagmatization of chelicerates consists of two regions: a cephalothorax and abdomen.

There are three groups of chelicerates: the Arachnida, Merostomata, and Pycnogonida.

Class Arachnida

Although the earliest arachnids (scorpions and spiders) were marine, all living species are either terrestrial or derived from terrestrial species. Therefore, Biol 515 will not emphasize the arachnids.

Class Merostomata

Most of the Merostomata are extinct. Only four species are alive today. The "horseshoe crab" *Limulus* (Fig. 14.10; p. 530) is very common in some regions.

- If a living *Limulus* is available in lab, observe its movement.

External anatomy of preserved *Limulus*.

- Identify the cephalothorax, chelicerae, five pairs of walking legs, and telson.
- Identify the pedipalps of males and females. The pedipalps are the first pair of walking legs. They are chelate in immature individuals and adult females, but adult males have pedipalps modified into a curved claw for grasping the female during mating.
- Note that the last pair of walking legs is modified for digging (p. 531).
- Note the gnathobases at the base of the first four pairs of walking legs. Understand their function in the feeding process (p. 530).
- Identify the genital operculum (the first abdominal appendage) that protects the gonopores.
- Identify the five pairs of book gills.

Internal anatomy of preserved *Limulus*.

- Identify the mouth, esophagus, gizzard, intestine, and digestive gland.
- Identify the carapace attachment muscles, dorsal heart, and book gills.

Larvae and juveniles of *Limulus*.

- Be sure to examine the preserved larval and juveniles stages of *Limulus*.

Class Pycnogonida

There are ~ 1000 species of pycnogonids ("sea spiders"); all are marine. Their most conspicuous feature is their extremely long legs relative to the rest of the body. The legs of some deep-sea and Antarctic species can exceed 10 cm in length. Most species have 8 legs, but a few have 10 or 12 legs. Most of the body consists of the cephalothorax region; the abdomen is extremely reduced. In contrast to the true spiders (arachnids), pycnogonids do not have specialized respiratory or excretory systems (these are very important on land, but not in the sea!). Considering that most of a pycnogonid's body consists of its legs, it's not surprising that the branched digestive system and the gonads extend inside the legs.

In addition to the 8-12 walking legs, pycnogonids usually have up to three other pairs of anterior appendages. The first are the chelicerae, which grasp or shred prey. The second appendages are sensory palps. The third are ovigers. Both males and females use the ovigers to groom their walking legs. Males also use the ovigers to brood fertilized eggs ("Mr. Mom"!).

- Study the locomotion of live pycnogonids.
- In addition to the live specimens, study preserved specimens and slides to understand the basic anatomy of pycnogonids (Fig. 14.13; p. 559-561).
- Identify the ovigerous legs of a male.
- Developing ovaries can be seen inside the legs of some females.

Reminders: **Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Field Trip #2: Monday, 6 November 2006, 2:00-4:30
Camino de la Costa Rocky Tidepools, low tide @16:01

Lab #18: Crustacea I. Wednesday, 8 November 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Arthropoda

Subphylum Crustacea

Crustaceans are very diverse and abundant in marine habitats. Crustacean tagmatization varies somewhat within the group, but all crustaceans have a head region with five pairs of appendages. The first two are antennae. The third pair are the mandibles. The fourth and fifth pair are the first and second maxillae. All crustaceans also have a nauplius larva, although sometimes this developmental stage occurs within the egg. Appendages are usually biramous.

The general anatomy of crustaceans will be introduced by examining crabs and crayfish. Specimens of several species will be available, including *Cambarus*, *Cancer*, *Loxorhynchus*, and *Portunus*.

External anatomy of crabs and crayfish

- Remove all appendages from all body regions and identify them (Fig. 14.24; p. 485).
- Draw at least 2 head appendages, 2 thoracic appendages, (a maxilliped and a walking leg), and 1 abdominal appendage.
- Identify the gill bailers associated with the 2nd and 3rd maxillipeds. These are modifications of the exopods (see p. 483) that draw in water over the gills (p. 487).
- Identify the five pairs of thoracic legs. The first pair is chelate (a pincer).
- Gills are modified epipods (p. 483) attached to the thoracic legs. Examine the phyllobranchiate gills (p. 487).
- The abdomen has five pairs of pleopods. Females have all five pairs. They function to brood developing eggs. Males might have only the first two pairs of pleopods. These are used for copulation. The pleopods of some decapod crustaceans are used for swimming.
- Identify the uropods, which form a tail fan with the crab's telson.

Internal anatomy of crabs

- Remove the carapace covering the cephalothorax by gently cutting the posterior edge and taking care to not disturb the fragile connective tissue.
- Locate the following structures (p. 487, 488, 493): stomach, digestive gland, intestine, heart, gills and gill bailer, testes or ovaries.

Class Branchiopoda

These small crustaceans have leaf-like phyllopodous appendages on their trunk. Gnathobases on these appendages are used to crush food particles.

Order Anostraca

These are commonly called brine shrimp and fairy shrimp.

- Study the differences between male and female *Artemia* (Fig. 14.27d; p. 509).
- Observe the feeding and swimming behaviors of *Artemia*.
- Remove one of the phyllopodous trunk appendages and examine it using a microscope.
- Examine the nauplius larva of *Artemia*.

Order Cladocera

These are commonly called water fleas. Their trunk, but not the head, is covered by a bivalved carapace.

- Study the swimming behavior of *Daphnia* (Fig. 14.27a; p. 510).
- Notice that the young are brooded within the female's carapace. Understand other aspects of *Daphnia*'s life history (p. 510).

Order Notostraca

- Specimens of *Triops* (p. 509) might be available. These tadpole shrimps have a thorax covered by a carapace. They have thoracic appendages, but no abdominal appendages.

Class Ostracoda (Fig. 14.28; p. 527)

These small crustaceans have hinged, bivalved carapace that covers the entire body. The carapace is usually hardened with calcium carbonate (though not as hard as most clam shells). The well developed antennae are often used for locomotion.

- Observe the locomotion of live ostracods.

Class Maxillopoda

This group has only 6 pairs of trunk appendages. The first pair are modified as accessory jaws or maxillipeds. Members of the group also have 5 abdominal segments that do not bear appendages and a forked telson.

Subclass Copepoda

Copepods are the most abundant marine crustaceans. Students must distinguish among calanoid, cyclopoid, and harpacticoid copepods.

- live copepods will be available in plankton-tow samples. Observe swimming behavior.
- Slides of preserved copepods are also available.

- **Calanoid copepods** (Fig. 14.29a,b; p. 524) are the most abundant marine copepods. Most feed on phytoplankton. The head and thorax are distinct from the abdomen. The first antennae are usually very long, having 22-25 articles (segments). The second antennae are biramous. Eggs are carried in egg sacs.
- **Cyclopoid copepods** (Fig. 14.29d, 14.30; p. 524) have shorter first antennae (10-16 articles) and uniramous second antennae. Most cyclopoids are predatory carnivores.
- **Harpacticoid copepods** (Fig. 14.29c; p. 524) are primarily benthic detritivores. The body is more linear than that of calanoids and cyclopoids, and there is less distinction between body regions. The first antennae have no more than 10 articles, and the 2nd antennae are biramous.

Subclass Cirripedia, Order Thoracica

Barnacles have a bivalved carapace, a mantle that secretes several calcareous plates. Until ~ 150 years ago barnacles were misclassified as molluscs. The discovery of their nauplius larva proved key. Much of the systematic study of barnacles was conducted by Charles Darwin.

The adult body is highly modified for sessile life. The head is attached to the substrate. Six pairs of cirri (thoracic appendages) are divided into two functional groups: maxillipeds (usually the first 2 pairs, sometimes the third) and the feeding legs (remaining 4 pairs) that are extended from the shell.

Most barnacles are simultaneous, cross fertilizing hermaphrodites. Their mating behavior is unique (and kinda kinky!: p. 505). Eggs hatch to nauplii which then metamorphose to cyprid larvae. The cyprids superficially resemble ostracods. Cyprids are non-feeding larvae specialized for habitat selection; they swim in rapid short bursts and have an adhesive gland for attachment to surfaces.

Acorn barnacles (Fig. 14.33a,b; p. 500)

- Acorn barnacles do not have a stalk. Observe feeding behavior of live acorn barnacles. If you get lucky, you might see some mating.
- Examine slides of barnacle nauplii and cyprid larvae (p. 502, 503). Students must be able to distinguish barnacle nauplii from the nauplii of other crustaceans and understand the life cycle of acorn barnacles (p. 502).

Pedunculate "stalked" barnacles (Fig. 14.33c; p. 504)

- Examine *Lepas* and *Pollicipes*.
- Dissect *Pollicipes* and locate the following structures: cirri, maxillipeds, mandibles, maxillae, mouth, stomach, penis, testes (whitish finger-like structures), ovaries (usually orange in color), and the adductor muscle (p. 504).

Reminder: **Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and scopes!**

Lab #19: Crustacea II. Wednesday, 15 November 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Arthropoda

Subphylum Crustacea

Class Malacostraca

With a few exceptions, these crustaceans have a trunk composed of 14 segments that all bear appendages. The first 8 segments form the thorax, the last 6 (rarely 7) form the abdomen. Female gonopores open on the sixth segment; male gonopores open on the eighth segment.

Subclass Phyllocarida, Order Leptostraca (p. 511)

These crustaceans have an unhinged bivalved carapace covering the thorax. They have phyllopodous legs and 7 abdominal segments; the seventh segment lacks appendages.

• Examine *Epinebalia*.

Subclass Hoplocarida, Order Stomatopoda (p. 511)

These are the mantis shrimps. A short carapace does not cover the last two thoracic segments. The second thoracic appendage is specialized for raptorial feeding. The jack-knife like appendages can be modified for spearing or clubbing prey (or foolish divers who poke at a stomatopod).

• Examine *Hemisquilla* and the preserved pseudozoea and antezoea larvae of a stomatopod.

The remaining malacostracans are sometimes grouped as the Eumalacostraca because they always have only 6 abdominal segments.

Subclass Syncarida

This is a rather uncommon group. These malacostracans lack a carapace and have biramous thoracic appendages. They include the anaspids that inhabit freshwater in Australia, New Zealand, and South America.

• Examine the preserved anaspid.

Subclass Peracarida (part 1 of 2)

This is an extremely diverse taxon that is commonly divided into 5 orders: Mysidacea, Cumacea, Tanaidacea, Isopoda, and Amphipoda. All of these orders share the following characteristics:

- The eggs are brooded in a ventral-thoracic marsupium. Oostegites (shelf-like plates) are attached to the coxae of thoracic legs to form the brood pouch.
- Peracarids have direct development (i.e., no free-living larvae).
- The first thoracic segment is fused with the head, and the first thoracic appendages are maxillipeds.

Order Mysidacea (p. 512)

The opossum shrimp have a carapace that is unfused with the posterior four thoracic segments. They have seven pairs of biramous thoracic appendages that appear unspecialized. The abdomen is rather long with five pairs of biramous pleopods and a pair of uropods (tail fan). The uropodal endopods of mysids have a statocyst that provides geotaxis. Primitive mysids, such as *Gnathophausia*, have epipods on each side of the thoracic legs that function in respiration.

- Examine live mysids, if available.
- Examine large Antarctic mysids and deep-sea *Gnathophausia*. Locate the statocysts.

Order Cumacea (p. 516)

The body shape is distinctive. The thoracic shield is fused to the first three segments of the thorax. Determining the sex of a cumacean is usually rather easy: males have well developed abdominal pleopods, while females have either no pleopods or those that are very reduced in size.

- If live cumaceans are available, examine them.

Order Tanaidacea (p. 516)

The thoracic shield is fused to the first two segments of the thorax. The second pair of thoracic legs (gnathopods) are chelate. In some species, females can change into males.

- Examine live *Leptochelia*.

Order Isopoda (Fig. 14.25i; p. 514-516)

Isopods are diverse peracaridans with a dorsoventrally flattened body and no carapace. The thorax has one pair of maxillipeds and seven pairs of pereopods. Isopods also have five pairs of flattened pleopods. The uropods are usually fused to form a pleotelson. Isopods are the only crustaceans that have some completely terrestrial species.

- Examine the live isopods that are available: *Ligia, Paracerceis, Idotea, Cirolana*.
- Distinguish male and female *Ligia*.

Lab #20: Crustacea III. Monday, 20 November 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Arthropoda

Subphylum Crustacea

Class Malacostraca

Subclass Peracarida (continued, part 2 of 2)

This is an extremely diverse taxon that is commonly divided into 5 orders: Mysidacea, Cumacea, Tanaidacea, Isopoda, and Amphipoda. The previous lab included the first 4 orders; today's lab concludes the Subclass Peracarida by focusing on the amphipods.

Order Amphipoda

Amphipods are laterally compressed peracaridans that lack a carapace. The thorax has one pair of maxillipeds and seven pairs of legs. The first two pairs are gnathopods, the last five are pereopods. The abdomen has three pairs of swimming pleopods and three pairs of backwardly directed uropods. Amphipods are the only crustaceans that have three pairs of uropods!

Amphipods are divided into three suborders: Caprellidea, Hyperiidea, and Gammaridea.

Suborder Caprellidea (Fig. 14.25n; p. 513)

These are the skeleton shrimp. They have a long, thin, tubular thorax and almost no abdomen. The second thoracic appendage is partially fused with the head so that the first gnathopod acts as a mouth part. The third and fourth pereopods are reduced; the fifth, sixth, and seventh are used for grasping.

• Examine the behavior of live caprellids.

• Study preserved caprellids to understand their anatomy.

Suborder Hyperiidea (Fig. 14.25k,l; p. 513)

These are pelagic amphipods. They have a very large head and large eyes. The abdomen is prominent, and pleopods are powerful. Many hyperiideans live commensally on gelatinous pelagic animals.

• Examine preserved hyperiideans.

Suborder Gammaridea (Fig. 14.25m; p. 512)

This is the most diverse group of amphipods (over 4,700 species). The head of gammarids is not fused with the second thoracic segment. They usually have small eyes. The pleopods and uropods are well developed. Gammarids' diverse life histories include species that swim freely, burrow in sediment, build tubes, cling to substrates, and infect fish as parasites.

• Examine the behavior of live gammarids.

• Study preserved gammarids to better understand their anatomy.

Subclass Eucarida

The eucarids are an extremely diverse group that includes two orders: Euphausiacea and Decapoda. All eucarids have a cephalothorax: a complete fusion of the carapace to all thoracic segments. The eyes are usually on movable stalks. Life cycles are usually complex (multiple larval stages). Today's lab will include the Euphausiacea and the "shrimp-like" decapods; the next lab will focus on "crab-like" decapods.

Order Euphausiacea (Fig. 14.25g; p. 517)

Euphausiaceans are commonly called krill. They have eight pairs of thoracic appendages that are all very similar and biramous. The epipods function as gills. The longer endopods are for feeding. Most euphausiaceans filter vast quantities of phytoplankton and *Euphausia superba* is a key component of Antarctic food webs.

• Study preserved euphausiids. Locate the 8 thoracic limbs, the setae-rich endopods, the epipodal gills, and the location where eggs are brooded (p. 517).

Order Decapoda (part 1 of 2)

Decapods have eight pairs of thoracic appendages: the first three pairs of thoracic appendages are maxillipeds, the last five pairs of thoracic appendages — 10 total — are walking legs. Decapod classification is very complicated. The first subdivision is usually between the suborders Dendrobranchiata and Pleocyemata.

Suborder Dendrobranchiata

This group includes shrimp that have dendrobranchiate gills (gills with branched filaments). These shrimp also have their first, second and third walking legs chelate for grasping and manipulating food (but the chelae are not very large). This group includes the common commercial penaeid shrimp (*e.g., Penaeus*) and the sergestid shrimp (*e.g., Lucifer*). Females release eggs into the water where they hatch as nauplii. Nauplii metamorphose to protozoea larvae, which then metamorphose as juveniles.

• Examine several of the penaeid shrimp that are available (p. 517).

• Note their chelate first three walking legs and their dendrobranchiate gills.

Suborder Pleocyemata

All the rest of the decapods (most of the shrimps, crabs, lobsters) belong to this group. They all brood their eggs on the female's pleopods. The nauplius stage of development occurs within the egg. The first larval stage after hatching is the zoea. Gills are either phyllobranchiate (plate-like filaments) or trichobranchiate (highly branched, long filaments).

Most decapods belong to this group, which is divided into several infraorders.

Infraorder Caridea (p. 518)

The caridean shrimps have phyllobranchiate gills. The first two pairs of legs are chelate and enlarged for feeding. The last three pairs of legs provide locomotion. Carideans tend to have stronger legs than penaeids, and the pleopods are relatively reduced in size. The second abdominal segment overlaps the first and third segments, giving these shrimp the name "broken-back shrimp." This structure can function in rapid escape from predators. Most of the decapod shrimp belong to this group.

- Observe the "broken back" feature of the freshwater shrimp *Macrobrachium*.
- Examine the anatomy and swimming behavior of live carideans: *Lysmata* (cleaner shrimp), *Alpheus* (snapping shrimp), *Crangon, Pandalus, Betaeus, Hippolyte, and Heptacarpus*.
- Examine preserved specimens of *Pandalopsis*.

Infraorder Astacidea (p. 519)

This group includes the crayfish (**family Astracidae**) and the clawed lobsters (**family Homaridae**). These families have the first pair of legs modified as large, defensive chelipeds. These claws are oriented forward and cannot be bent toward the mouth; they are not used for feeding! The remaining four legs are for locomotion. Astacideans can walk forward, backward, and sideways. This range of motion is unusual for decapods. Yeah, but can they dance? Of these four pairs of legs, the second and third pairs are chelate and used for feeding. In addition, the third pair of maxillipeds is somewhat elongated and leg like. Gills are trichobranchiate (very branched and filamentous).

Distinguishing the sexes is easy: males have two pairs of enlarged pleopods for mating, while females have five pairs of pleopods for brooding eggs. Larval development is largely direct. The egg hatches to an advanced, juvenile-like mysis larva.

- Examine the trichobranchiate gills of crayfish, *Cambarus*, and Maine lobster *Homarus*.
- Review the appendages (from lab 17).

Infraorder Palinura (p. 520)

This group includes the spiny lobsters (**family Palinuridae**) and the slipper lobsters (**family Scyllaridae**). Members of this group have modified second antennae for protection. These antennae are very long in spiny lobsters and spatulate in slipper lobsters. The third maxilliped is very strong and is used to grasp prey.

- Examine the California spiny lobster *Panulirus*.
- Identify the gonopore. In males it's at the base of the eighth thoracic segment (near the fifth legs), while in females it's near the fifth thoracic segment (near the third legs).
- Also notice in males that the pleopods are reduced. They are not used in mating. Spermatophores exit the gonopore and are placed on the ventral thorax of the female.
- A female who has attached spermatophores is called a "plastered female." She discharges her eggs and uses her last pair of legs, which are chelate, to break up the spermatophores so sperm can fertilize the eggs. Once eggs are fertilized, the females attaches them to her pleopods. She is now called a "berried female."
- *Panulirus* eggs hatch as phyllosome larvae (there are 9 phyllosome stages) that metamorphose to a puerulus larva (2 stages). The planktonic larval period lasts for 1 yr before the second puerulus swims toward shore and settles to the bottom.

- Examine the slipper lobster *Scyllaris*.

Infraorder Thalassinidea (p. 520)

The mud shrimps and ghost shrimps have a symmetrical, flattened abdomen. The first two pairs of thoracic legs are chelate; the first pair is very large. The third maxillipeds look very leg like.

- Examine the ghost shrimp *Neotrypaea (= Callianassa),* which builds extensive burrows in sand and mud.
- The second and third legs have conspicuous setae; they and the maxillipeds are used for digging and sorting organic-rich particles from the sediment.
- Males have one chela much larger than the other. Females carry fertilized eggs in their pleopods. Eggs hatch as zoea larvae.

***Reminder:* Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Lab #21: Crustacea IV. Wednesday, 22 November 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Arthropoda

Subphylum Crustacea

Class Malacostraca

Subclass Eucarida

The Eucarida include the orders Euphausiacea and Decapoda. The previous lab focused on the "shrimp-like" decapods. This lab concludes the decapods by focusing on the diverse crabs.

Order Decapoda (continued, part 2 of 2)

Infraorder Anomura (p. 521)

The anomura, or "false crabs", have a well developed cephalothorax in which the fifth pair of legs is reduced or turned upward and are not used for locomotion. The second antennae are usually very long. The first cheliped extends forward and is used for defense. The abdomen is reduced, asymmetrical, and soft. The five pairs of pleopods are reduced, and the uropods are vestigial.

Anomurans are divided into three superfamilies: Paguroidea, Galatheoidea, and Hippoidea

The **Superfamily Paguroidea** (Fig. 14.25e,f; p. 521, 522) is characterized by its very asymmetrical abdomen.

This group includes the hermit crabs (**families Paguridae** and **Diogenidae**) and the lithode crabs (**family Lithodidae**).

• Examine *Pagurus* (**family Paguridae**) and *Paguristes* (**family Diogenidae**), which has claws of equal size. Note how the abdomen in these species is soft to fit inside a gastropod shell. Pleopods are present only on the left side. The first pair of legs is chelate. The second and third pairs of legs are not chelate; they are used for locomotion. The fourth and fifth legs are short and turned upward; they are used to clean the abdomen and attach to the shell. Most hermit crabs use the first chelipeds to feed on mud. Some filter feed by creating a current with the exopods of the second and third maxillipeds and filtering particles with setae on the mouthparts.

• Lithode crabs include the commercial king crab *Paralithodes*. They have a very heavy exoskeleton, an asymmetrical abdomen, and a fifth pair of thoracic legs that are very short.

The **Superfamily Galatheoidea** (p. 521, 522) has a fifth leg folded along side the carapace.

This group includes the squat lobsters, such as the pelagic tuna crab, (**family Galatheidae**) and the porcelain crabs (**family Porcellanidae**).

• Examine the pelagic tuna crab *Pleuroncodes* (p. 522).

• Examine *Pachycheles* and *Petrolisthes* (p. 523). The chelipeds are defensive. The fifth pair of legs is reduced. The third maxillipeds are very setose and used for filter feeding. In addition, setose pads on the chelipeds can function for sweeping up detritus.

Superfamily Hippoidea (p. 522)

This group includes the mole crabs, *Emerita* (**family Hippidae**). These crabs have the most reduced abdomens of all anomurans.

• Examine *Emerita*. Notice the long second antennae, which are used for filter feeding, and the reduced abdomen.

Infraorder Brachyura

Brachyurans are the “true crabs.” Their carapace is broader than it is long. The abdomen is always reduced and flexed beneath the thorax. The chelipeds (first pair of thoracic legs) of brachyurans are jointed in such a way that they can be used for bringing food to the mouth. No other legs are chelate. Eggs hatch as zoea, followed by megalops postlarvae.

Brachyurans are usually divided into six groups: Dromiacea, Archeobrachyura (not in lab), Oxystomata, Oxyrhyncha, Cancridea, and Brachyrhyncha.

Dromiacea (p. 499)

These are the most primitive crabs. A common genus is *Dromia*.

Oxystomata

Oxystomatans have a spiny mouth. The male reproductive openings are on the sternum. The most common families are the **families Calappidae** and **Leucosiidae**.

• Examine *Calappa* and *Randallia*.

Oxyrhyncha

Oxyrhyncans are the spider crabs that have a spiny, pointed rostrum (**family Majidae**). They have long legs adapted to fairly rapid walking along soft sediments. Many species decorate themselves by using their chelae to attach pieces of algae, sponge, and detritus to their carapace and legs.

• Examine *Loxorhynchus, Pugettia,* and *Taliepus* (p. 523).

Cancridea

This group has an elongated, oval, or hexagonal carapace and eyes that are very close together. This group includes the **family Cancridae**.

• Examine cancrid species in the genus *Cancer (p. 495)*.

Brachyrhyncha

These are the short-snouted crabs and include most brachyuran crab species. The carapace is not narrowed anteriorly, and eyes are fairly wide apart. The Cancridea were once included in this group, but are now usually separated (above). Brachyrhychan families include the swimming crabs (**family Portunidae**), the ghost crabs and fiddler crabs (**family Ocypodidae**), the mud crabs and stone crabs (**family Xanthidae**) and the shore crabs (**family Grapsidae**).

• Examine the portunid *Portunus* (p. 495) and the ocypodid fiddler crab *Uca* (p. 498).

• Examine the grapsid crabs *Pachygrapsus* and *Hemigrapsus*.

• Examine the xanthid crabs *Cycloxanthops* and *Pilumnus* (the "hairy crab").

• Examine slides of zoea and megalops (p. 496, 497).

Reminders:

Lab Exam #3 Monday, 27 November 2006 (covering Labs #17-21).

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.

Lab #22: Echinodermata I. Wednesday, 29 November 2006

Many, but not all, of the activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Most introductory biology texts (e.g., Campbell et al. 1999, 2002; Purves et al. 2001) include diagrams of the external and internal anatomy of asteroid sea stars. Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Echinodermata

There are ~ 6,500 living species of echinoderms. A few are estuarine, but all the rest are marine; there are no freshwater echinoderms. Echinoderms are deuterostome coelomates, undergoing radial, indeterminate cleavage and enterocoely as embryos. Echinoderm larvae are bilaterally symmetrical. Adult forms, on the other hand, typically have a pentamerous radial symmetry. Adults usually do not have an anterior and posterior end; they have an oral end (bearing the mouth) and an aboral end (opposite the mouth). The most unifying feature of all echinoderms is their water vascular system: a system of fluid-filled canals that end in structures called tube feet. The tube feet serve a variety of functions, including locomotion, feeding, and gas exchange. Another feature common to most echinoderms is the presence of an endoskeleton composed of calcareous ossicles, which are derived from mesodermal tissue. The collagen fibers within the connective tissue of echinoderms also contain calcium. Echinoderms are able to control the stiffness of their body by altering the amount of calcium in the connective tissue between ossicles.

The Phylum Echinodermata has historically been divided into 6 classes: Asteroidea, Ophiuroidea, Crinoidea, Echinoidea, Holothuroidea, and Concentricycloidea. The first specimen belonging to the Class Concentricycloidea was discovered in wood dredged from the deep sea in 1986, and Biol 515 does not have specimens to examine (Unless Constance dives much deeper than her safety warrants!).

Class Asteroidea

Several live and preserved sea stars will be available.

Dissection of *Asterina (= Patiria)* and *Pisaster*

Begin by examining the external anatomy of *Asterina* and *Pisaster*.

- Locate the 5 radial arms and the central disc.
- On the aboral side, identify the papulae (skin gills: Fig. 20.7, 20.8; p. 687), pedicellariae (Fig. 20.7, 20.11; p. 686), anus (Fig. 20.6, 20.8; p. 687), and madreporite (Fig. 20.1, 20.6; p. 688). Understand the function of these structures.
- On the oral side, identify the mouth, ambulacral grooves, and tube feet (Fig. 20.1, 20.2, 20.6, 20.8).

Examine the internal anatomy of *Asterina* and *Pisaster* (Fig. 20.8; p. 692).

- To examine the internal anatomy (Fig. 20.8; p. 692), cut along the edges of at least one arm (you've got 5 chances to do it well!) and the central-disc region. Remove the epidermis to expose the internal structures.
- Identify the stomach, digestive glands (pyloric caeca), and anus.
- Identify the water vascular system, including the ring canal, 5 radial canals, lateral canals, tube feet, and polian vesicles (usually visible in *Asterina*). (Fig. 20.1)
- Identify gonads if they are present (Fig. 20.8; p. 692).

Also examine the cross-sectional slides of sea-star arms to see the detailed structures of the water-vascular system (Fig. 20.7; p. 687).

- Locate the ampullae, radial canal, lateral canal, tube foot, sucker, coelom, ossicles, and digestive glands.

Asteroid Embryology and Larval Development

- Slides are available showing radial cleavage, the blastula, the gastrula, formation of the blastopore, formation of the archenteron, and enterocoely.
- Slides are also available to illustrate the bipinnaria larva (Fig. 20.22, 20.23; p. 697), brachiolaria larva (Fig. 20.22; p. 697), and newly metamorphosed juvenile sea star.

Observations of live Asteroids

- Observe small specimens of *Pisaster* and *Astrometis* using a dissecting microscope.
- Three species of *Pisaster* might be available: *P. brevispinus* (has short spines), *P. ochraceus* (often ochre in color, but not always!), and *P. giganteus* (white spines surrounded by blue knobs).
- Observe the simple eyes (p. 689) on the arm tips of *Asterina*.
- Observe the pointed tube feet and obvious madreporite of *Astropecten*.
- Observe the dermal podia and obvious madreporite of *Dermasterias*.
- *Linckia* is known to reproduce by autotomy (Fig. 20.9; p. 694).
- *Pycnopodia* is known for its fast movement and very large size.
- Additional asteroids, such as *Henricia* and *Orthasterias*, might also be available to illustrate the diversity within the class.

Class Ophiuroidea

In contrast to asteroids, ophiuroids have their madreporite on the oral side and have tube feet that lack suckers. The central disc of ophiuroids is also much more distinct than that of asteroids.

Several live and preserved brittle stars will be available, including *Ophiothrix, Ophionereis, Ophioplocus, Ophioderma, Ophiopteris, Amphiodia,* and *Ophiopsila*.

- Examine the oral surface of ophiuroids and identify the madreporite, spines, jaws, teeth, bursal slits, and tube feet (Fig. 20.5; p. 700). Understand the functions of these structures.
- Examine the cross-sectional slides of an ophiuroid disc. Identify the digestive glands, muscles, teeth, and ossicles (Fig. 20.5c; p. 700, 701).
- Examine slides of an ophiopluteus larva (Fig. 20.22; p. 702).
- Examine the basket star *Gorgonocephalus* (Fig. 20.5d).

Class Crinoidea

Crinoids are the oldest of the extant classes of echinoderms. The group is subdivided into the stalked crinoids (sea lilies) and the non-stalked, motile comatulid crinoids (feather stars).

- Examine the dried and preserved crinoid specimens.
- Identify the cup-shaped central disc or calyx and the branching arms. The arms have branching pinnules that contain the tube feet (Fig. 20.3, 20.4; p. 721, 723, 724).
- Note that crinoids are oriented oral-side up, in contrast to the other echinoderm classes.

***Reminder:* Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Lab #23: Echinodermata II. Monday, 4 December 2006

Many, but not all, of the activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Rupert and Barnes (1994). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Echinodermata

Class Echinoidea

This class includes sea urchins and sand dollars. The calcareous ossicles are fused to form a rigid test. Adults feed (usually on algae) with a unique calcified structure called Aristotle's lantern. The echinoids are divided into the regular urchins, which have almost perfect spherical symmetry ("sea urchins"), and the irregular urchins, which display varying degrees of secondary bilateral symmetry ("sand dollars"). Tube feet are confined to 5 rows of ambulacral plates. A variety of calcareous spines and pedicellariae are distributed throughout the test to provide protection.

Echinoid Diversity

- Examine several regular urchins, including *Strongylocentrotus franciscanus, S. purpuratus, Lytechinus, Centrostephanus, Arbacia,* and *Eucidaris* (a member of the order Cidaroida, which is thought to be ancestral to all other echinoids).
- Study the test of a sea urchin. Identify the madreporite, apical plates with gonopores, the ambulacral regions, the mouth, and Aristotle's lantern (Fig. 20.14; p. 706).
- Examine several irregular urchins, including the sand dollar *Dendraster* (p. 713) and the heart urchin *Lovenia* (p. 712).
- Observe the locomotion and burrowing of a live *Lovenia*. Identify its long, aboral tube feet that are used for respiration and its smaller, oral tube feet that are used for deposit feeding.
- Observe the locomotion of a live *Dendraster.* Notice differences in the spines and tube feet on its oral and aboral surfaces.
- Compare the spines of *Centrostephanus* and *S. franciscanus*.
- Examine slides of the various stages of *Arbacia* development and the echinopluteus larva (Fig. 20.22; p. 711).
- Live *Dendraster* embryos should be available.

Dissection of *Strongylocentrotus*

- Study the locomotory functions of spines and tube feet of live *Strongylocentrotus*.
- On the oral surface, identify the buccal (oral) tube feet, the pedicellariae, the peristomial membrane (the soft area around the mouth), and the peristomial gills (Fig. 20.14; p. 707).
- Remove all of the spines around an area circling the center of the test (halfway between the oral and aboral end) and cut the urchin in half.
- Identify Aristotle's lantern and the associated muscles (Fig. 20.16; p. 709).
- Locate the mouth, intestine, and anus.
- Identify the major components of the water vascular system in textbook drawings: the ring canal, radial canals, lateral canals, and leaf-like ampullae of the tube feet (Fig. 20.17; p. 709). *Note:* many of the features of the water vascular system will be difficult to see in most dissected specimens.
- Identify the 5 gonads.

Class Holothuroidea

Sea cucumbers belong to this class of echinoderms. Holothuroids (often incorrectly called "holothurians") are soft-bodied, bilaterally symmetrical echinoderms. The calcareous ossicles are greatly reduced in size and are embedded in the soft tissue of the body wall. In contrast to other echinoderms, the body wall of holothuroids has well developed circular and longitudinal muscles. Tube feet are confined to ambulacral strips (usually 5) that extend from the anterior to posterior end. Some tube feet can be modified and enlarged as feeding tentacles. Gas exchange is accomplished by a branched respiratory tree that extends from the cloaca into the coelom. To facilitate gas exchange, water is regularly flushed into the cloaca. In fact, certain fish are common inhabitants of holothuroid cloaca (Don't try this at home!).

Several live holothuroids will be available. There are four common groups (orders) of holothuroids that each feed in different ways:

Order Dendrochirotida

These are suspension feeders that have highly branched, dendritic tentacles.

- Examine *Cucumaria, Lissothuria,* and *Psolus*. Observe feeding and look for cloacal pumping.

Order Apodida

These are deposit feeders that have pinnate tentacles and lack tube feet.

- Examine *Leptosynapta*. Observe feeding and look for cloacal pumping.

Order Molpadiida

The "sea potato" is also a deposit feeder. They have 15 digitate tentacles and lack tube feet.

• Examine *Caudina*. Observe feeding and look for cloacal pumping.

• Students who watched a lot of Saturday-morning cartoons on TV as a kid are encouraged to sing the "Mr. Potato Head I love you..." song they probably knew by heart 15 years ago!

Order Aspidochirotida

These are deposit feeders that have long tentacles that have suckers at the end.

• Examine *Parastichopus*. Observe feeding and look for cloacal pumping.

Dissection of *Parastichopus* and *Caudina*

• Examine the external surface and identify the crown of tentacles, rows of papillae (warts), and rows of tube feet on the ventral side.

• Make an incision along the entire ventral surface to expose the internal organs.

• Identify the mouth, intestine, and cloaca (Fig. 20.20; p. 719).

• Identify the components of the water vascular system: the ring canal, stone canal, polian vesicles (which function either as pumps or expansion vessels), radial canals, ampullae of oral tube feet, and the internal madreporite (Fig. 20.20; p. 719). The internal madreporite and stone canal are very fragile and will not be visible in all specimens; if you find them, be sure to let Dr. Hentschel know so other students can see these structures on your specimen.

• Identify the circular and longitudinal muscles of the body wall.

• Identify the respiratory tree (Fig. 20.20; p. 719).

• Examine the slides of the calcareous ossicles removed from the body wall of a holothuroid (Fig. 20.19; p.717).

***Reminder:* Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.**

Lab #24: Hemichordata & Chordata. Wednesday, 6 December 2006

The activities and specimens in this lab are based on those of Dexter (2000) and on recommendations by Constance Gramlich. The taxonomy is based on that of Pechenik (2005). Descriptions of the various taxa can be found in Pechenik (2005) and Pearse et al. (1987), as well as most other invertebrate-biology texts (e.g., Barnes 1980, 1987; Brusca and Brusca 1990, 2003; Rupert and Barnes 1994). Numbered figures refer to those in Pechenik (2005), and page numbers refer to figures in Pearse et al. (1987).

Phylum Hemichordata

Hemichordates are a curious group that display some lophophorate-like, some echinoderm-like, and some chordate-like characteristics. Hemichordates are deuterostome coelomates. The coelom forms as three compartments: the protocoel, mesocoel, and metacoel. Like members of the phylum Chordata, most hemichordates have pharyngeal gill slits and a dorsal, hollow nerve cord. Unlike chordates, however, hemichordates do not have a notochord.

This phylum of ~ 100 species consists of two classes: Pterobranchia and Enteropneusta. Enteropneusts are far more common and will be the focus of Biol 515 lab.

Class Enteropneusta

Acorn worms burrow in sediment and deposit feed, typically producing coiled fecal mounds at the posterior opening of the burrow.

- Examine live specimens of *Saccoglossus*. Identify the major morphological features: the proboscis, collar, and trunk (Fig. 21.1; p. 733).
- Examine prepared slides and identify the mouth, collar, proboscis, trunk, pharynx, and pharyngeal gills slits (Fig. 21.4; p. 732, 733).
- Slides of the tornaria larva probably will not be available in lab, but students should be sure to look at pictures in their texts (Fig. 21.5; p. 734).

Phylum Chordata

Look at yourself in the mirror; you have examined one of the ~ 50,000 species of chordates. Most are vertebrates. ~ 1,400 of the chordate species are included in two invertebrate subphyla: Urochordata and Cephalochordata. All chordates have four defining features (at some point during their life cycle): a dorsal, hollow nerve cord; pharyngeal gill slits; a notochord; and a muscular, postanal tail.

Subphylum Urochordata (tunicates)

Tunicates are divided into three classes: Ascidiacea, Larvacea, and Thaliacea.

Class Ascidiacea

This class includes ~ 90% of all tunicates. Commonly known as "sea squirts", most ascidians live attached to surfaces. Most are solitary, but some produce colonies by asexual budding. Adults are suspension feeders, filtering particles through their slitted pharyngeal basket. Larvae are called tadpoles because they resemble the larvae of frogs. Ascidian tadpoles are nonfeeding. In addition to pharyngeal gills slits, their muscular tails contain the notocord and dorsal, hollow nerve cord.

- Examine several solitary ascidians such as *Ascidia, Ciona, Halocynthia,* and *Styela*.
- Dissect *Ciona* by removing the tunic with a razor blade. Identify the incurrent and excurrent siphons, pharyngeal gill slits, endostyle, stomach, intestine, anus, heart, testis, and ovary (Fig. 22.1; p. 739). Look for the occasional reversing of the heart beat.
- Examine several colonial ascidians such as *Botryllus, Botrylloides, Didemnum, Cystodytes, Polyclinum,* and *Archidistoma*. Identify individuals within the colony and locate the common excurrent siphon (Fig. 22.3; p. 741).
- Examine ascidian colonies in which the degree of association among individuals is less extreme: *Metandrocarpa, Clavelina, Euherdmania*.
- Study slides of the ascidian tadpole larva. Identify the pharyngeal gill slits, dorsal hollow nerve cord, notocord, and postanal tail (Fig. 22.4; p. 743).
- A plankton-tow sample might be available to find live ascidian tadpoles.

Class Larvacea (= Appendicularia)

Larvaceans are planktonic, tadpole-like animals living in a disposable gelatinous house.

- Examine slides of *Oikopleura* (Fig. 22.6; p. 744).
- A plankton-tow sample might be available to find live *Oikopleura*.

Class Thaliacea

Thaliaceans are planktonic tunicates that more closely resemble the adult form of ascidians. The major difference between adult ascidians and thaliaceans is that thaliaceans have their incurrent and excurrent siphons at opposite ends of the body.

- Examine a preserved *Pyrosoma* colony. Identify individuals within the colony. *Pyrosoma* colonies can grow extremely large (Fig. 22.7a; p. 746).
- Several salp species (Fig. 22.8; p. 745) will also be available, including *Thetys vagina*.
- Examine the oozooids and blastozooids of *Cyclosalpa*.
- Examine the blastozooid of *Pegea*.

Subphylum Cephalochordata (lancelets)

Lancelets are sometimes commonly referred to by a genus name that is no longer used, "amphioxus." They are small, laterally flattened invertebrates. Their notocord extends anteriorly past the dorsal, hollow nerve cord, hence the name "cephalochordata." Like the urochordates, cephalochordates are suspension feeders, trapping particles on mucus strings in the gill slits. The feeding current is created by pharyngeal cilia, not muscular pumping.

- Examine preserved specimens of *Branchiostoma (Amphioxus)* and identify the caudal fin, myotomes (muscle bands), and gonads (Fig. 22.11; p. 748).
- Examine sagittal-section slides of *Branchiostoma (Amphioxus)* and identify the oral tentacles, mouth, velar tentacles, pharynx, gill slits, intestine, midgut caecum, notocord, dorsal nerve cord, and the myotomes (Fig. 22.11; p. 748).
- Identify the above structures on cross-section slides of *Branchiostoma (Amphioxus)*, as well (Fig. 22.12; p. 749).
- Examine slides of larval cephalochordates.
- If live specimens are available, describe their swimming and burrowing behavior.

***Reminder:* Lab Exam #4 Monday 11 December 2006, 13:00-15:00 (covering Labs #22-24).**

Don't forget to have your lab-notebook entry for today's lab signed before you leave the classroom. Clean up your table and microscopes! All glass bowls and dissection pans should be rinsed and scrubbed with freshwater and returned to the front counter to dry.

Acknowledgements

Many, but not all, of the activities and specimens in this manual are based on those of Dexter (2000). Dr. Dexter taught Biol 515 at SDSU for 34 yr. During that time she developed SDSU's collection of preserved invertebrates as a unique and valuable teaching resource. Over the years, the collection has been enhanced by contributions from many individuals including SDSU's present Marine Collector, Constance Gramlich. Dr. Dexter also developed a variety of innovative lab activities that proved to be appropriate and effective for invertebrate-biology students at SDSU. Rather than reinventing the wheel, I have paraphrased some of the text of Dexter (2000). In developing this lab manual for Biol 515, I also am indebted to Constance Gramlich. In my opinion, her knowledge of local marine-invertebrate species, commitment to providing a high-quality undergraduate lab experience, and work ethic are unsurpassed. In addition to providing extensive advice on which specimens and activities to include and emphasize in this manual, Constance made many editorial suggestions on earlier versions of the manual; her discussions with me greatly improved the present text. Along similar lines, I have a policy of awarding students 1 point of extra credit for any typographical or substantial error they find in this lab manual. In previous years, several students have had especially keen editorial skills that helped me improve the quality of this manual: Brenda Herrick, Kimberly Wright, Michelle Evans, Elsa Cortes, Irene Li, Casey Larsen, Felix Beltran, Henry Carson, Cheryl Barnes, Shay Heaton, Mandy Hildebrand, Christine Hitz, and Kristian Palaoro who was instrumental in providing the correct spelling of "Mr. Potato Head". I'm sure there's still plenty of errors within the 60-plus pages so present Biol-515 students have opportunities to earn extra-credit points and assist me in improving future revisions of this manual!

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