

BIOL. 515
Marine Invertebrate Laboratory Manual
Spring 2000
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© 2000.4

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MARINE INVERTEBRATE BIOLOGY
Biology 515
Fall 2000

Course description: Structure and function, ecology, behavior, physiology, and phyletic relationships of marine invertebrate animals.

Marine Invertebrate Biology is an upper division elective course with two lectures and two three hour laboratory periods weekly. Students will examine the invertebrate phyla which live in the marine environment, study their functional morphology and adaptations, their ecology, their evolutionary relationships, and their diversity

Specific course goals

- To present a comprehensive course on marine invertebrate diversity
- To involve students in an atmosphere where they take the responsibility for independent learning, so that they develop lifelong learning skills
- To provide appropriate laboratory and field skills (dissection techniques, observation skills, taxonomic identification, etc.) so students develop technical competence in marine invertebrate biology
- To improve active reading skills
- To improve writing skills
- To support group interaction and teamwork skills and to create a cooperative rather than competitive environment

Overview

Approximately 95% of all living animals are invertebrates, which belong to approximately 40 phyla. Given the diversity of marine invertebrates, it is not feasible to discuss all subjects for all taxa. Key topics within specific phyla will be emphasized to develop a broad overview and understanding of invertebrate biology. A phyletic approach will be used, because it provides the necessary framework for an understanding and appreciation of this diversity. The course will focus on structure and function, ecology, behavior, and physiology. These aspects will be presented in an evolutionary context with a comparative emphasis.

The emphasis will concentrate on the following subjects:

- General morphology: structure and function, the basic body plan
In all groups basic functional anatomy forms the initial focus. This includes such aspects as cellularity (unicellular versus multicellular); integration among cellular components (from independent cell level through tissue level to organ system level); body symmetry (evolution from asymmetrical to radial to bilateral symmetry and its modifications); contributions of germ layers (diploplastic versus triploblastic); and the role of body cavities (acoelomate versus pseudocoelomate versus coelomate).

- Nutrient acquisition and feeding behavior (morphology of structures, types of feeding mechanisms, processing food material)
- Reproduction and life history strategies
Advantages and disadvantages of asexual versus sexual reproduction, dioecious versus monocious strategies, frequency and seasonality in reproduction, embryology, determinant versus indeterminate cleavage patterns, presence or absence of larval stages.
- Physiology or functional responses (systems)
Within each major taxonomic group locomotory systems (from amoeboid, ciliary, and flagellar locomotion to the use of body wall musculature), skeletons (endoskeletons, exoskeletons, hydroskeletons) and appendages are considered. Other discussion topics include gas exchange and circulatory transport of metabolic products, methods of excretion, integration of nervous system and sense organs). Other aspects of organismal biology will be stressed in those groups where it is uniquely important or where it is the first appearance of a particular structure or system.
- Ecology
Topics will include environmental adaptations, habitat, general life history strategy, trophic roles, interspecific interactions, and adaptations to specific habitats (i.e. pelagic versus benthic, soft sediments versus hard substrate, sessile versus active, accommodating versus physiologically stressful, intertidal versus subtidal, etc.).
- Evolutionary relationships
Relationships between and within groups, with evidence from developmental patterns and larval forms, from comparative morphology, and/or from fossil records.

Textbook

The text for this course is *Living Invertebrates* by V. Pearse, J. Pearse, T. Buchsbaum, and M. Buchsbaum, 1987. Blackwell Scientific Pub. It will also serve as a reference in laboratory and must be brought to class daily.

Laboratory

The lab experience teaches the student to focus on significant characteristics of different invertebrate phyla. It allows students to develop their dissection skills to discover for themselves the important structures. Through microscopic examination students learn to recognize histological characteristics of major cell types and organs. Behavioral observations on feeding, locomotion, and reproduction (in almost all organisms examined), and other aspects develop observational skills and knowledge. Associated field trips to local marine habitats present proper methods for field collecting, provide the opportunity to see the organisms in their natural habitat, and to introduce ecological aspects such as zonation and distribution, which are more easily assimilated with visual acquisition from the field experience, rather than from lecture material.

Laboratory manual

A detailed laboratory guide is provided. Laboratory exercises will include examining the diversity of marine organisms, recognition of major features, development of dissection skills with frequent dissections of important representative taxa, histological identification of structures and behavioral observations.

Laboratory exams

There will be four lab exams (50-75 points) on the structure, function, identification of taxa, and other pertinent questions. Most of the questions will ask you to identify the taxa (Phylum, Class, or whatever level your are responsible for), identify the structure under the pointer or pin, state the function of the structure, or other direct questions with short answers (2-4 words). These exams will be closed book. At the end of the exam, you will be able to refer to your lab notebook for 10 minutes. There will be 2-4 short answer questions at each station. Stations will include slides, entire organisms (either live or preserved), dissections, and occasionally video footage. Usually there will be 2 minutes at each station. You will **not** be able to return to any stations.

Laboratory notebook

Each student will compile their own laboratory notebook which includes line drawings of slides, live and preserved animals, dissections, behavioral observations, etc. The lab notebook should normally be done with a lead pencil. Pages must be numbered, and the date the organisms were examined should be placed underneath the page number. Diagrams should be labeled (classification, type, structures, etc.) clearly. All material in the lab manual will be done by the author. A table of contents should be included for each major taxa (Phylum or Class). Aztec Shops sells a green Lab Book (10 1/8 x 7 7/8 inches # 53-108) which is the required notebook.

The lab notebook may be used at the end of each lab exam to check spelling, add information, identification, etc. It will be turned in immediately after each lab exam for evaluation. The lab notebook will be worth a total of 100 points.

Laboratory tools

Some personal tools are needed, but you need not purchase a complete dissection kit. You must have a pair of fine tip forceps (watchmaker's forceps), a packet of single edged razor blades, and 2 needle pointers. Aztec Shops sells all of these items but their watchmaker's forceps are overpriced. I recommend that you purchase the forceps from Harbor Freight Tools (1196 East Main Street El Cajon 441-3771) which sells a set of 5 forceps (3 of which are useful). The catalog number is 32279, and the set costs between \$5-6. These are not made of stainless steel, but with care with last several years.

Disclaimer

This course requires students to participate in field trips, research, or studies that include course work that will be performed off-campus. Participation in such activities may result in accidents or personal injury. Students participating in the event are aware of these risks, and agree to hold harmless San Diego State University, the State of California, the Trustees of the California State University and Colleges and its officers, employees, and agents against all claims, demands, suits, judgements, expenses and costs of any kind on account of their participation in the activities.

Other safety issues

Students are responsible for their own health and safety during classroom, laboratory, and field exercises. The student health insurance policy at SDSU does not cover injuries received on or off campus, unless the injury is minor and can be treated at the SDSU Student Health Services.

Students may neither snorkel nor scuba dive in relation to SDSU course activities without certification and approval of the SDSU Diving Safety Officer.

Grading policy

The grades will be determine by scores in two major performance areas: individual performance and group performance (as modified by peer evaluations). Individual performance (67%) will be based on quizzes, short assignments (from text, dissections, field work, etc.), 4 laboratory exams, and the laboratory notebook.

Group performance (33%) will be based on group quizzes, reports, etc. On all group work, each group will turn in only one paper and all group members will receive the same score. The grading structure is deliberately designed to reward students for providing assistance to other members of their group. Peer evaluation is a factor that will modify the group grade for each individual.

Although 1/3 of the grade will be group based, peer evaluations will be used to modify individual group grades. Each individual (anonymously, except to the instructor) will rate all of the other members of their group at the end of the course {see peer evaluation form}. Individual peer evaluation scores will be the average of the points they receive from the members of their group. The instructor reserves the right to overrule the peer evaluation score if it appears that there will be a miscarriage of justice.

An example of how peer modification works

Assume that the final group grade was 90%, and that there were 4 members of the group.

Student 1 was rated highest by the individual team members because of she/he was always present, almost always knew the correct answer to the quizzes, discussed the dissections and histology with team members, helped with other problems which arose during lab work, and was always ready to answer questions. The average peer evaluation was 10.8, which translates into 108 % of the group grade (90), and therefore this student received a peer evaluated final group grade of 97.2%.

Student 2 was consistently prepared, interacted well with teammates, worked hard, had great attendance, and basically did an excellent job. The average peer evaluation was 10 , with 100% of the group grade or a peer evaluated final group grade of 90

Student 3 tried hard, but was not prepared each day for the quizzes or lab work, had good attendance but did not work as hard as other members of the team. The average peer evaluation was 9.5, which translates into 95 % of the group grade (90), and therefore this student received a peer evaluated final group grade of 85.5%.

T 9.5

Student 4 was absent from lecture and lab on several occasions, and therefore did not contribute as much to group quizzes, routinely left lab early and did not interact very much with team members, did not communicate by email with team, and basically seemed disinterested in teamwork. The average peer evaluation was 8.0, 80% of 90 resulted in a per evaluated final group grade of 72%.

The S.D.S.U. Senate grading policy will be followed which defines an A as available for only the highest accomplishment and for outstanding achievement; B as praiseworthy performance, definitely above average; and C as the average undergraduate grade. Any student earning 90% or more of the total points will earn an A, 80% a B, etc. The best student in the class will earn an A, and the curve is flexible in a downward direction accordingly. Any student receiving less than 50% of the total points earned by the top student in the class earns a grade of F. The final grade will be based on the cumulative points earned. Plus and minus grading will be used on the final class grades. {For example, a B+ grade would be assigned for grades between 87-89%, a B between 83-86%, and a B- between 80-82%}.

Any student who will be absent from an lab exam due to illness or other major emergency, must notify the instructor prior to the exam. Telephone Dr. Dexter at 594-6379 and leave a message, or email her at ddexter@sunstroke.sdsu.edu. Because of the use of living material, and the time needed to set up laboratory exams, no makeups will be available for missed lab examinations, but an excused absence will allow averaging of lab exam grades in lieu of a makeup. There will be no makeup on quizzes or other short assignments.

Cheating CHEATING WILL NOT BE TOLERATED.

Cheating includes (but is not limited to):

- The receiving of any specific information about a specific quiz, exam, or assignment prior to taking it. This precludes using someone else's lab notebook from a previous semester.
- The giving of any specific information about a specific quiz, exam, or assignment prior to someone else taking it or during the quiz.
- Using any unauthorized information during an exam. Do not look at a neighbor's lab exam or quiz. Keep your lab answer sheet folded in half when not writing on it.
- Plagiarism. Submitting, as your own, work that was written by another person.

If you are caught cheating, or I even suspect it, I will report you to the Academic Judiciary Committee and the minimum result will be a grade of 0 on the specific quiz, exam, or assignment.

Responsibilities of the professor

I will provide clear, organized, and scientifically accurate information and laboratory experiences. I will keep my posted office hours. I appreciate questions and suggestions, I will treat all students equitably and with respect, and will evaluate student performance as objectively as possible.

Responsibilities of the students

The students are expected to attend and be attentive during class, ask questions when material is not clear, be prepared by completing the required reading from the text and lab manual before the class, and cooperate effectively with their teammates. Notes from reading, discussions, and laboratory should be integrated to obtain a synthesis of the information. The average study time for this course (outside the classroom) should be at least 6 hours weekly.

Why team learning, problem solving, and student centered learning rather than a traditional lecture course?

- Educational advantages

In student centered learning students work in small groups, tutor one another, learn to depend on one another rather than depending exclusively on the authority of the teacher. They learn to construct knowledge as it is constructed in the academic disciplines, and they learn the craft of interdependence.

At present there is too much passive learning experience (lectures) and few opportunities for active learning. In teacher centered learning the teacher is solely responsible for what the student is expected to learn. The teacher's usual role is to dispense information in lectures, assign readings, and provide demonstrations. The student is a passive recipient.

Active learning is not something that is done for students; it is something that learners do for themselves. This is student centered learning where the student 'learns to learn'. In active learning students take responsibility for their own learning. It fosters a cooperative rather than competitive learning environment. It should foster intellectual curiosity in students. Faculty should be viewed as facilitators of learning rather than disseminators of knowledge.

- This process helps meet the stated goals of CSU system (Spring 1997) which listed the following specific abilities expected of CSU graduates:
 - a. Communicate effectively, through a variety of means
 - b. Read analytically and think critically at a high level
 - c. Write clearly
 - d. Acquire substantive in-depth command over one or more fields of study

- e. Locate, analyze, evaluate, and synthesize information
- f. Integrate knowledge across discipline boundaries
- g. Make both qualitative and quantitative assessments
- h. Participate effectively in a democratic society
- i. Work effectively in group settings with people different from oneself

- The CSU statement also included the following remarks:

"We will assure that our graduates possess a certain breadth and depth of knowledge together with a certain level of skills. CSU will facilitate other techniques of active learning such as collaborative learning, problem solving, and use of interactive technology. We will require that each student be responsible for creating an academic plan, one which will encourage students to take a more active role in their own learning, including self-paced and self-directed study".

- These skills also meet the goals of SDSU College of Sciences (Spring 1997) which identified the main attributes that any Bachelor's Degree holder should possess:
 - a. Mental maturity and critical thinking
 - b. Solid background in the fundamental principles of the discipline
 - c. Sense of self, community, and the environment
 - d. Ability to communicate
 - e. Ability to work on a team

"As students progress into their junior year they should learn to accept more responsibility for their own education. Students must have basic technological skills (word processing, spreadsheets, web browsing, library searches, and e-mail). Almost without exception, corporations approach a problem with a team of people bringing different and appropriate skills to the solution. University graduates must have the skills necessary to work successfully on such project teams. Individual competence must be complemented by strong cooperative skills".

Class Schedule

Date	Lecture and Laboratory	Required Reading
Aug. 28	Introduction Lab: Microscopes, tissues	Chpt. 1, Chpt. 30
Aug. 30	Protozoa: flagellates, ameba, ciliates	Chpt. 2 p. 11-12, 21-22, 25-31, 36-41 47-54, 58-65
Sept. 6	Porifera Cnidaria: general Hydrozoa	Chpt. 3 Chpt. 5 p. 99-102, 107-110, 116 128-132; Chpt. 6 p. 133-151
Sept. 11	Scyphozoa Anthozoa Ctenophora	152-157, 162 163-184 Chpt. 7 p. 187-199
Sept. 13	Platyhelminthes Nemertea Pseudocoelomates, Nematoda Rotifera	Chpt. 8, Chpt. 9 p. 222-232 Chpt. 11 Chpt. 12 p. 268-278 Chpt. 13 p. 301-307

Sept. 18	Deuterostomes Lophophorates Kamptozoa Chaetognatha	Chpt. 27 p. 695, Chpt. 30 p. 756-760 677; Phoronida 656-665 Brachiopoda 662-666 Bryozoa 667-675 Chpt. 26 p.678-682 Chpt. 25
Sept. 20	Echinodermata, Asteroidea Ophiuroidea, Crinoidea	Chpt. 27 p. 683-697 p. 698-703, p. 721-724
Sept. 25	Echinoidea, Holothuroidea	p. 704-720
Sept. 27	Laboratory exam 1 Protozoa through Holothuroidea	Field trip to fouling community
Oct. 2	Hemichordata Urochordata Cephalochordata	Chpt. 28 p. 731-734 Chpt. 29 p. 737-746 p. 747-751
Oct. 4	Protostomia Mollusca Gastropoda	p. 396, 756-750 Chpt. 14 p. 327-335
Oct. 9	Gastropoda	p. 336-346
Oct. 11	Bivalvia	p. 347-361
Oct. 16	Bivalvia, Scaphopoda	p. 347-364
Oct. 18	Polyplacophora Cephalopoda	Chpt. 14 p. 319-325 p. 365-381
Oct. 23	Minor Protostomes Echiuroidea, Sipunculida Pogonophora	Chpt. 18 p. 438-445 Community lab Comparison of the fauna associated with two benthic organisms.
Oct. 25	Laboratory exam 2 Hemichordata through Mollusca tide 0.0 feet at 2:59 pm	Field trip to Mission Beach and Mariner's Basin
Oct. 30	Introduction to Annelida Errant polychaetes	Chpt. 16 p. 387-398 Chpt. 16 p. 387-398, p. 411-417
Nov. 1	Sedentary polychaetes	p. 417-427
Nov. 6	Sedentary polychaetes Oligochaeta Hirudinea	p. 399-410, 428-430 p. 431-435

Nov. 8	Onychophora Tardigrada Introduction to Arthropoda Uniramia Chelicerata. Arachnida	Chpt. 19 Chpt. 13 p. 316-318 Chpt. 20 p. 455, 458-477 Chpt. 23 p. 565-570, 573-583 Chpt. 22 p. 534-544
Nov. 13	Chelicerata Merostomata Pycnogonida ----- Introduction to Crustacea	Chpt. 22 p. 529-533 p. 559-563 Chpt. 21 p. 482-491

Please note that during the crustacean section the discussion will focus on crustacean systems while the laboratory will examine the crustacean taxa.

Nov. 15	Laboratory exam 3 Minor protostomes through Chelicerata Community lab	Comparison of the fauna associated with two benthic organisms.
Nov. 20	Crustacea 1 Feeding Reading for lab General characteristics	p. 508-510, 524, 527
Nov. 22	Crustacea 2 Other systems Reproduction Reading for lab	p. 462-463, 467-473 lab manual for information p. 511-512, 514-516, 526
Nov. 27	- 0.5 feet at 4:19 pm Bird Rock or Mar del Vista or Mariner's Basin or Sail Bay	
Nov. 29	Crustacea 3 Growth Development Reading for lab	p. 512-513, 517-520
Dec. 4	Crustacea 4 Molting Burgess Shale fauna Reading for lab	p. 458-462 p. 521-523, 494-499
Dec. 6	Laboratory exam 4 Crustacea	

Final Dec. 11 1-3 pm

It is likely that there will **not** be a final examination. However, class will meet Dec. 11th from 1 to 3 or 2 to 4 pm. One possibility is an intertidal field trip to the rocky shore. The tide is -1,5 feet at 3:32 pm, the best tide of the semester.! Students absent for part or all of this period will have 25 points subtracted from their total individual grade.

Marine Invertebrate Laboratory Instructions (pagination in Pearse and Buchsbaum, 1987)

This laboratory dissection guide has benefitted from editorial review by Dr. Alistair Hobday. All starred (*) items must be included in your lab notebook, additional diagrams will be useful.

Introduction to major tissue types and cells

* The purpose is to examine assorted cross sections of invertebrates to recognize and identify the following structures: epithelial cells, circular versus longitudinal muscles, nervous tissue, blood vessels, digestive structures (gastrovascular cavity, intestine), reproductive tissue: ovary versus testis and body plan (acoelomate, pseudocoelomate, coelomate).

The examples available will include nemertean, nematods, polychaetes, oligochaetes, and cephalocordates.

Protozoa

Protozoans demonstrate a wide range of feeding types, locomotory structures, and reproductive patterns.

Mastigophora is subdivided into two groups, the phytoflagellates and the zooflagellates.

- A variety of living flagellates may be available for viewing. But the *dinoflagellates found in the live plankton tow should be emphasized (21, 22).

Sarcodina

- The sarcodines move by means of sol-gel reactions of the cytoplasm. The temporary projections are generally known as pseudopodia.
- Place a living amoeba on a glass slide on which you have made clay feet which support the cover slip and prevent crushing of the amoeba. Note the general body shape and how it changes as the pseudopodia are formed. Study pseudopodial movement and locomotion. Carefully note the flowing of the endoplasm into the pseudopodia. *Locate the following structures: ectoplasm, endoplasm, food vacuole, pseudopodia, and nucleus (26-31). *What is the function of each of these structures? *Describe locomotion in an amoeba.
- Examine the slides of *Radiolaria (39-41) and *Foraminifera, as well as live examples from the plankton (36-37). Be able to recognize any foram or radiolarian to this taxonomic level.

Ciliophora

- A variety of living ciliates may be available for examination, including *Stentor* (63), *Vorticella* (62), *Euplotes* (65), and *Paramecium* (*illustrate one of these ciliates). Place a drop of methyl cellulose (restraining solution) on the slide, and add a drop of culture before adding the cover slip. Suctorians (60,61) may be available from the fouling community. Observe locomotion in the assorted ciliates. Add yeast particles and watch feeding.
- The whole mount slides of **Paramecium* (47-50) can be used to see the micro and macronucleus. Locate the following structures: oral groove, cilia, contractile vacuole, food vacuoles, cytoproct, micronucleus and macronucleus. Food vacuoles pinch off from the end of the gullet. Digestion occurs as the food vacuoles move about the inside of the animal. Waste materials are ejected through the cytoproct at the cell margin just posterior to the gullet (50, 51)
- Use your textbook to help you understand binary fission (52) and conjugation (53) in *Paramecium*.
- Examine the plankton tow for living *tintinnid ciliates (64).

Phylum Porifera

A variety of living sponges are provided for examination. Look for examples of ascon, sycon, and leucon sponges. Pipette fluorescein dye along the surface of the sponge. *What can you tell about the water current of sponge? Cut apart some of the living sponges to see the differences between ascon, sycon, and leucon morphologies. Study the text to understand the major differences between ascon, sycon, and leucon sponges (79).

- Use bleach to dissolve tissues to see *spicules. What spicule types (85,90) are present in these sponges?
- A variety of dried sponges are also provided for examination, including bath sponges, glass sponges, and sclerosponges.
- There are no slides of ascon or leucon sponges. For the sycon level see *Grantia* in which the level of organization can be seen.

Phylum Cnidaria

Class Hydrozoa

Diversity

Trachylines The trachyline medusae are the most primitive group of cnidarians.

- *Gonionemus* * Find the typical features seen in a medusa: radial canal, ring canal, manubrium, velum, tentacles, and gonad (102,103,105,107). You are responsible for the *life cycle a trachyline medusa.

Hydroids

● **Obelia* Both living colonies and slides of colonies and medusae are available for study (130-131). This species is polymorphic and has complete alternation between polyp and medusa stages. The feeding polyps (gastrozooids) possess tentacles with nematocysts for capturing prey. The reproductive polyps (gonozooids) have neither a mouth nor tentacles. In the medusa a ring canal connects the 4 radial canals to manubrium, which projects downward with the mouth at its tip. Ectodermal gonads are located beneath the radial canals. You are responsible for the life cycle of *Obelia*.

- **Tubularia* Living colonies and slides. Study feeding behavior using carmine powder or small *Artemia* (if available). Both large feeding individuals with basal and oral whorls of tentacles, and reproductive individuals should be located (137). *How does the life cycle of *Tubularia* differ from *Obelia*?
- **Hydractinia* *This polymorphic form is a colonial hydroid with gonozooids (male and female), dactylozooids (defensive polyps), and gastrozooids (136,137). Identify each morph type. Slides are available if living specimens are not.
- Verify the life cycles of these hydrozoans by comparing your observations with the text (144-145).

Hydrocorals

- There are two groups of colonial hydroids with a calcium carbonate skeleton.
- Examine the dried skeleton of *Allopora* with its star-shaped openings. Living specimens may also be present (143).
- The fire corals (*Millipora*) have massive calcareous skeletons (142,142).

Chondrophora

- Scientists classify these as either polymorphic polyp colonies or solitary polyps which float upside down. *Verella* (146-147, 806).

Siphonophora

- *The siphonophores (148,149) are colonies with advanced polymorphism. Preserved specimens of *Physalia* (150,151, 818) as well as unidentified siphonophores are available. Study the preserved specimens, slides, and figures to identify the various morphs. *Morphs include pneumatophore (sail or float), gastrozooids, gonozooids, dactylozooids (defense), bracts, and swimming bells (nectophores).

Class Scyphozoa

The medusa stage is dominant in this class. *List all the differences between the hydrozoan medusae and the scyphozoan medusae. Examine the demonstration specimens of assorted species of medusae, including the stalked medusae *Haliclystus* (162, 785).

- **Aurelia* Study the adult anatomy of the preserved *Aurelia* (153). The rhopalium is sensory in nature, containing an eyespot, a statocyst for balance, and two chemoreceptors. It is located between 8 equally spaced notches along the periphery of the medusa. Find the many radial canals. The mouth has long oral arms which bear nematocysts. The gastric pouches have nematocysts on the gastric filaments. Find the gonads and note they are of endodermal origin.
- *Life cycle of *Aurelia* Examine the slides (Wards) of planula, strobila, scyphistoma (text uses the term strobilating scyphistoma), and ephyrae (154,155).

Class Anthozoa

Subclass Octocorallia (Alcyonaria)

The subclass consists of colonial species in which there are eight bipinnate tentacles. The endoskeleton consists of either calcium carbonate or a horny material known as gorgonin.

Diversity

- Examine the whole mount section slide of an alcyonarian (181).
- Stolonifera: organ pipe corals (178,820)
- Alcyonacea: soft corals (179,180)
- Gorgonacea: horny corals (182, 183) assorted gorgonians, sea fans
- Pennatulacea: *Stylatula* (sea pens) and **Renilla kollikeri* (sea pansy) (184)
Some specimens of *Renilla* kept in the dark will be excited to demonstrate bioluminescence. Note the polymorphism on the sea pansy finding the gastrozooids, the siphonozooids (function for water movement), and the axial polyp (or stem){ used for attachment to the sandy substrate}. Why are polyps lacking from the ventral surface?

Subclass Hexacorallia (Zooantharia)

Diversity

- Cerianthidea: The tube anemone *Cerianthus* (177) is a common burrowing anemone in muddy sands in Mission Bay. The tube is built from nematocysts extruded by the anemone along the column.
- Madreporaria (Scleractinia): stony corals (170, 172, 174)
Examine the dried corals noting the variation in the exoskeleton morphology. In San Diego the solitary corals *Balanophyllia* and *Astrangia* are found on rocky ledges at 10 m and deeper.
- Antipatharia: black thorny corals (176)
- Actiniaria: sea anemones

Feeding

Live *Anthopleura* or *Epiactis* (166-167). *Describe the feeding behavior using fragments of mussels for food.

Corynactis (169,808) occurs on rocky ledges from 10m depth off San Diego and has the largest nematocysts of any local species. Remove a piece of tentacle and place it on a glass slide. Add methylene blue and smash the tentacle. Add a cover slip and examine under the microscope to see the nematocysts (116). *You should be able to find both uncharged and discharged nematocysts. Use acetic acid (vinegar) to trigger nematocysts.

General morphology

Examine the preserved **Metridium*. There is a ciliated groove at the end of the mouth which leads into the gastrovascular cavity. The dissected specimens show the muscular septa which divide the gastrovascular cavity. These septa have perforations for water circulation. Both septal filaments with nematocysts (acontia) and gonads are located on the septa (165). Slides of cross sections and longitudinal sections of an anemone show many of the same structures.

Phylum Ctenophora

Preserved *ctenophores will be available for an introduction to their general anatomy (190,195). Find the mouth, tentacles, gastrovascular canals, and ctenes. *Describe locomotion in living specimens or from video.

Phylum Platyhelminthes

Class Turbellaria

Behavior

Watch feeding behavior and general locomotion in living marine turbellarians. * How does the organism respond to light, touch? How does it right itself?

General morphology

- *Whole mounts of *Planaria* (208-212). Study the general anatomy. What structures are associated with the anterior end? What structures are associated with the posterior end? Locate eyes, pharynx, and branches of digestive tract.
- *Cross section of *Planaria* (206) (Wards). The animal is solid without a body cavity. Find the epidermis (ectoderm) which is ciliated on the ventral surface. Identify the digestive cells of the endoderm. The circular and longitudinal muscle layers, and the reproductive system are not easily visible on these slides.

Phylum Nemertea

- Examine the living and preserved specimens for general external anatomy. The proboscis is the most distinctive external feature (261,263).
- *Examine the cross sections of Rhynchocoela (Nemertea). These cross sectional slides are quite diverse with each slide showing different structures (264). Find the ectodermal (epidermis), endodermal (gut), and mesodermal layers. The only cavity present is the rhynchocoel or proboscis cavity. Circular and longitudinal muscle layers are well developed. Locate the lateral blood vessels, lateral nerve cord, proboscis, and the gut with its lumen.
- Examine the slide of the *polidium larva (early development; 267).

The Pseudocoelomates

Phylum Rotifera

- Living freshwater and/or marine specimens will be available to study locomotion by cilia and body wall muscles. *Describe locomotion in rotifers. Cement glands in the foot are used to anchor rotifers to the substrate.
- Examine the rotifer slide (Kaston) and living rotifers to understand the *general anatomy of a rotifer (305). Find the corona (crown of cilia), jaws (304), toe, cement glands, and digestive system. Learn the life cycle of rotifers (307).

Phylum Nematoda

Nematodes are everywhere, but most are tiny. In order to understand the internal anatomy of this important group, the pig parasite *Ascaris* will be studied.

Locomotion

Live *Turbatrix* (vinegar 'eels') will be available for observations of locomotion. Males are distinguished by the curl at the posterior end of the body (275). Living marine nematodes can be found between grains of sand or between the branches of coralline algae.

* Dissection of *Ascaris* (277)

- * External morphology Students should alternate the specimens for dissection so that male and female *Ascaris* can be seen by all. Males are generally smaller and have a tight curl in the posterior end with two penial spicules used in copulation. Females are larger and lack the posterior curl. The following external features can usually be seen under a dissecting scope: mouth, lips, male penial setae, female genital pore, excretory system, dorsal and ventral nerve cords, and anus.
- * Internal morphology Pin the specimen with its ventral side down and make a full length surface incision along the dorsal surface, slightly lateral to the dorsal line. Find the pharynx, intestine, anus, and lateral lines/excretory canals. Find the ventral nerve cord. In females find the ovary, oviducts, uteri, vagina and gonopore (anterior). In males find the testis, vas deferens, seminal vesicle, and ejaculatory duct (posterior).
- * Cross section slides (277). Find the cuticle, epidermis, longitudinal muscle bands, dorsal and ventral (nearer digestive system) nerve cords, lateral nerve cord, excretory canal, intestine, pseudocoelom, testis, ovary, and uterus.

Phylum *Kamptozoa

There are both marine and brackish water species of kamptozoans. Colonies of *Barentsia* are found attached to rocks in the San Diego area. Their 'nodding head' behavior makes for easy recognition (679).

The Lophophorate Phyla

Phylum *Phoronida

- Place a live phoronid under low magnification of the compound microscope (659). With the use of carmine powder, examine the process of feeding and study circulation. Red blood cells within the lophophore.
- The larval form is an actinotroch (661).

Phylum Brachiopoda

- This phylum has two classes, the Inarticulata and the Articulata (662,663).
- Separate the valves of a living articulate brachiopod and examine the lophophore. Use carmine powder to examine the process of feeding.

- Dissected specimens of an *inarticulate brachiopod and an *articulate brachiopod are available for study, as is a cross sectional slide through a brachiopod. Study the internal anatomy of these organisms locating particularly the lophophore, digestive glands, muscles, and gonads (664,665). The branching mantle canals function as the main circulatory system of brachiopods. Gametes are also discharged into these canals.
- A slide of the 'larval' form of an inarticulate brachiopod is available (665)

Phylum Bryozoa (Ectoprocta)

- This is the most diverse phylum of lophophorates in terms of numbers of species. These small encrusting, erect, and gelatinous species are very abundant in the fouling community and on rocky surfaces in shallow water.
- Living specimens of *gelatinous (*Zoobotryon*), *erect (*Bugula*), and encrusting (such as **Membranipora*) species will be available for study (669). Use carmine powder to study the feeding behavior.
- Look carefully for polymorphic individuals on both erect and encrusting species. Avicularia (670) and vibracula are also present on the slides of *Bugula*. Also look for ovicells on *Bugula*.
- Slides are available for a view of internal anatomy (670) and of the cyphonautes larva (675).

Phylum *Chaetognatha

- Preserved specimens and slides are available of these carnivorous planktonic organisms. Examine their general structure locating these external features: fins, grasping spines, head, eyes and these internal features: gut, ovaries, testes (654,655).
- If living chaetognaths are available describe their swimming behavior.

Phylum Echinodermata

Class Asteroidea

A variety of living species from along the San Diego coastline will be available for study, as well as some unusual preserved asteroids.

Behavior

- Turn over a sea star and watch its return to the normal position (righting behavior). *Is there a difference in speed and agility among the various species? Why? Describe and explain the results.
- *What is the function of the tube feet, skin gills (papulas), and the pedicellaria? Make your observations using the dissecting scope.

Dissection of sea star (687,688,692)

- *External morphology

Examine the general external anatomy (687) locating the 5 radial arms and central disc. On the aboral surface find spines, papulas (skin gills) (684), pedicellaria (686), anus (687), and madreporite (688). On the oral surface find the mouth, the ambulacral grooves, and the tube feet.

- * Internal morphology

Cut along the edges of each arm and remove the surface of at least one arm and the entire central disc. Locate the stomach, digestive glands (or pyloric caeca), and anus (817). Find the water vascular system consisting of the ring canal, 5 radial canals, lateral canals, and tube feet (688). The gonads (ovaries or testes) are only conspicuous during the reproductive season (692).

The structure of tube foot can be seen in more detail on the cross section slides (Wards). Locate the digestive glands, ossicles, coelom, ampulla, radial canal, lateral canal, tube foot, and sucker (687).

Developmental stages of echinoderms.

- Composite slides are available which show radial cleavage, blastula stage, gastrula stage, and the formation of the blastopore, archenteron, and enterocoelous coelom formation (696).
- Examine the slides of the bipinnaria larva (697), the brachiolaria larva (697), and newly metamorphosed seastar (831E), and diagrams of starfish metamorphosis (697).

Class Ophiuroidea

General morphology and behavior

- A variety of living and dried specimens will be available for examination of local species of brittle stars and the basket star (703).
- * In the living brittle stars watch locomotion and righting behavior. Tube feet are reduced and without suckers, and are largely sensory in function. Locomotion depends mainly on the well developed skeleton of the arms and its associated musculature.
- Watch movement of the bursal pouches which function in respiration in all ophiuroids (and also for brooding of young in some species).
- *Examine the oral surface of an ophiuroid locating the madreporite, spines, jaws, teeth, bursal slits, and tube feet (700).
- * Examine the exceptional cross sectional slides through the disc of a brittle star to find the internal organs. Digestive glands, muscles, teeth, and skeletal plates are easily seen (700,701). Five teeth surround the mouth. Tube feet (in cross section) are visible in the arms and around the mouth. The muscles and endoskeleton are visible in the arms. In the soft tissue of the bursal pouches are infoldings of the stomach or digestive glands. The gonad (testis) is also visible.
- Slides of ophiopluteus larva (702) are available for examination.

Class Crinoidea

- Dried and preserved specimens of crinoids are available.
- *Note the cup-shaped central disc or calyx and the 5 arms which branch into 10. The arms have branching pinnules that bear the tube feet (721,723,724). Locate the mouth, and if possible, the anus.
- *Note the differences in orientation between this class of echinoderms and all other living classes.

Class Holothuroidea

*There are three groups of holothuroids.

1. Filter feeders with highly branched dendritic tentacles (Dendrochirates) such as *Cucumaria*
2. Deposit feeders with long tentacles with suckers at the end (Aspidochirates) such as *Parastichopus*
3. Deposit feeders with pinnate tentacles, no tube feet (Apods), and ossicles as anchors which stick to substrate such as *Leptosynapta*.

Behavior

*Observe feeding behavior (716) in a live representative of each group. *Watch cloacal breathing.

*Dissection of a holothuroid

- On the external surface find the crown of tentacles, the rows of warts or papillae, and tube feet which are the remnants of the pentamerous water vascular system.
- Make a longitudinal ventral incision along the entire length of the animal to expose the organs within the coelom.
- The digestive system consists of mouth, intestine, and cloaca.
- The water vascular system consists of ring canal, stone canal, polian vessicles, radial canals, ampulla of oral tube feet, and an internal madreporite.
- Locate the longitudinal body wall muscles and the circular body wall muscles.
- The respiratory trees are unique to this class.
- A single gonad is present during the reproductive season (719).
- Slides of ossicles show the endoskeleton of holothuroids (717). Try polarizing lenses to see crystalline structures; in a single crystal all light rotates in the same direction.

Class Echinoidea

This class is subdivided into two main groups, the regular and the irregular urchins. The perfect symmetry found in sea urchins makes them regular.

The irregular urchins are the sand dollars (713), heart urchins (712), and cake urchins (712), represented in San Diego fauna by the local heart urchin *Lovenia cordiformis*, and the sand dollar *Dendraster excentricus*.

A variety of living and dried specimens of echinoids will be available for examination.

*General morphology and behavior

- Study the skeleton of a sea urchin (706) finding on the aboral surface the madreporite, apical plates with pores, and the ambulacral region. On the oral surface locate the mouth, 5 ambulacral regions, and Aristotle's lantern.
- Live specimens of *Strongylocentrotus* will be available for observation. Observe the righting behavior of the urchin. Are spines or tube feet or both used righting?
- On the aboral surface study the moveable spines and the tube feet in the ambulacral region.
- On the oral surface find the oral tube feet, the 3-jawed pedicellaria, the peristome (a soft membranous area surrounding the mouth), and 5 pairs of dermal gills (707).

*Dissection of *Strongylocentrotus*

- Remove an area around the center (midway between aboral and oral ends) of the test of all its spines, parallel with the oral/aboral surface. Cut the urchin in half.
- Locate Aristotle's lantern and its associated endoskeletal structures and muscles (709). This lantern serves to scrape algae and other food.
- Find the mouth, intestine, and the anus.
- Locate the water vascular system which consists of the ring canal, radial canals, lateral canals, and ampullae of tube feet.
- Find the reproductive system which consists of 5 gonads.
- Examine the slides of echinopluteus larvae (711).

Irregular urchins

The irregular urchins (sand dollars and heart urchins) show a strong tendency toward bilateral symmetry. Both mouth and anus are on the oral surface, and they move with the anterior end first.

- Heart urchins (*Lovenia*) Examine living or preserved heart urchins to verify the secondary bilateral symmetry (712). If a live animal is available, watch it burrow and move through sand with its spines. Look for the long respiratory tube feet which project from the aboral surface, and the smaller oral tube feet for feeding. Heart urchins feed on diatoms, detritus, and other organic matter associated with sand grains, and lack an Aristotle's lantern.
- *Sand dollars *Dendraster* (713). Examine the oral and aboral surfaces to differences in spine mobility and tube feet. Note the petaloid ambulacral region and the reduced Aristotle's lantern. How does its righting behavior differ in the presence of sand versus its absence?
- *Sand dollar test Locate the madreporite, ambulacral regions, mouth, anus, and food grooves. How does the skeleton of a sand dollar differ from that of a regular urchin?

Phylum Hemichordata (Class Enteropneusta)

Acorn worms are often difficult to find. Concentric rings of faecal pellets surrounding a burrow provides a good clue of their presence.

Behavior

If live specimens are available, watch feeding behavior.

General morphology.

- On live and preserved hemichordates, locate these external features: proboscis, collar, and trunk.
- *Examine a saggital section to understand both external and internal anatomy (732,733).
Find the following structures: mouth, collar, proboscis, trunk, pharynx and pharyngeal gill slits with their skeletal support.
- Acorn worms have a tornaria larva (734).

Phylum Chordata

Subphylum Urochordata (Tunicata)

Class Ascidiacea

General morphology

- Look at examples of solitary ascidian species common to the San Diego region.
- Study the slides of tadpole larva (743). They possess a dorsal nerve cord, notochord, gill slits, and post anal tail.
- *Examine a colonial ascidians finding the individuals within the colony and locate the common excurrent siphon.

Dissection of **Ciona intestinalis*

- Remove the tunic with a razor blade.
- *Locate and diagram all the major internal structures (739) including oral (incurrent) and excurrent siphon, pharyngeal gill slits, nerve ganglion, endostyle, stomach, intestine, anus, heart, testis, vas deferens, ovary, and oviduct. Note the reversing heart beat.
- * Describe the pathway for the transport and processing of food.

Class Thaliacea

Pyrosomida

- Study a preserved specimen finding the individuals, colony, and common atrial chamber (746).

Salpida

- Specimens of the solitary asexual oozoid for a variety of salp species (745) are available.

Class Appendicularia (Class Larvacea)

- *Study the slide of *Oikopleura* (744).
- Examine the live plankton tow to see if any *Oikopleura* and/or ascidian tadpole larvae are present.

Subphylum CephalochordataGeneral morphology

- * Identify the following structures on the preserved specimens of *Branchiostoma* (*Amphioxus*): caudal fin, myotomes, metapleural fold, and gonads.
- *Examine the saggital section slide of *Branchiostoma* and locate oral tentacles, mouth, velar tentacles, pharynx, gill slits, intestine, midgut caecum. Locate the notochord, dorsal nerve cord, and the myotomes (748).
- *On the cross sectional slides (Ann Arbor) find the following: dorsal nerve cord, notochord, myotomes, gut, pharyngeal gill slits, and gonads. Male and female gonads are easily distinguished (749).
- *If living specimens are available, describe swimming and burrowing behavior (747).
- Examine the larval slides.

Phylum Mollusca

Laboratory 1: Archeogastropoda, Mesogastropoda

Class Gastropoda

It is important to understand the evolution of water circulation and gas exchange in gastropods.

Subclass Prosobranchia (anterior gills): 3 orders Archeogastropoda, Mesogastropoda, Neogastropoda.

Order ArcheogastropodaReproduction

- The archeogastropods are the most primitive living gastropods and are the only ones which have free swimming trochophore larvae. All are dioecious.

Water circulation and gas exchange

- The most primitive members of this order have two ctenidia, two kidneys, and one osphradium for each gill. In the abalone (*Haliotis*; 332), keyhole limpets (*Megathura*; 331), and volcano limpets (*Fissurella*) (331), the shells are cleft or perforated because these all possess two bipectinate ctenidia.
- In *Tegula* (332), wavytop snails (*Astrea*), kelp snails (*Norrisia*), and the limpets (*Collisella*, *Lottia* (333), a single bipectinate ctenidium remains (the left one).

Feeding

The archeogastropods can be divided into two feeding types:

- Browsers and grazers on algae with rhypidoglossan radula. *Haliotis*, *Megathura*, *Fissurella*, *Tegula*, *Norrisia*, *Astrea*

- * Dissect either *Megathura* or *Astrea* by first removing the shell (use vice for *Astrea*). Locate: tentacles with eyes, foot, mantle, head, and ctenidia/ctenidium. Expose the digestive system finding the radula and mouth musculature, digestive gland, and intestine. Examine the radula under the compound microscope. Understand radular structure and use. Find the gonad and see if you can determine the sex of the animal.
- Some gastropods have a protective covering or operculum on the bottom of the foot. Usually the operculum is thin, but turbinid gastropods have a heavy calcareous operculum.
 - When foreign material invades the area between the mantle and the shell, the mantle will secrete nacreous material around the object. Examine blister formation in the demonstration abalone shell.
 - Examine the cross section of the shell of *Tegula* to see shell layers.
- * Raspers of algae off rock surfaces with docoglossan radula. *Collisella* (333), *Lottia*
 - Examine a docoglossan radula.

Order Mesogastropoda

Water circulation and gas exchange

The mesogastropods have a single auricle, a single kidney, a single ctenidium and a single osphradium. The mesogastropods and neogastropods exploit other habitats beside the rocky shore, and the single gill has been modified to prevent fouling by sediments. The gill becomes monopectinate and the gill axis is attached directly to the mantle wall.

Feeding

*The mesogastropods all have one type of radula, a taenioglossan radula, but have very diverse feeding methods. Examine the taenioglossan radula.

- Raspers of algae off the rock surfaces.
Littorina (329) Littorinid snails directly rasp fine algal particles from the surface of the rocks.
- *Planktonic hunters
The purple snail *Ianthina* (334) drifts on its raft of air bubbles and by chance bumps into *Veleva* (806). It excretes a purple dye which may act as an anaesthetic, and then feeds on *Veleva*.
- *Heteropods (334) are active swimmers, swimming with the ventral surface upwards. They actively hunt prey using their large eyes, and extend their radula to grab their prey.
- Collectors of plankton
Plankton collectors using an enlarged ctenidium include the slipper shell *Crepidula* (332) and the tube snail *Serpulorbis* (334).
- * The monopectinate ctenidium is very large and serves for both respiration and for the collection of food material. Watch a live *Crepidula* under the dissecting scope to see the eversion of the radula which is used to grab the food mass trapped in mucus produced by the ctenidium. Also locate the osphradium(directly above the ctenidium), mouth, eyes, and foot.
- Benthic hunters
The moon snail *Polinices* (325) attacks bivalves by boring a hole through the shell and rasping out the soft parts with its radula. There is a boring gland on the ventral surface of the proboscis.
Cypraea (cowries) are also carnivorous and their prey includes anemones, sponges, and ascidians.

Reproduction

- Almost all mesogastropods are dioecious. The trochophore stage is suppressed; free swimming veligers are released. Development may also be direct, with juveniles crawling out of the egg capsules.
- However, *Crepidula* is a protandric hermaphrodite. The initial male phase is followed by a period of transition in which the male reproductive tract degenerates and then the animal develops into a female. Males can be recognized by the presence of the penis at the side of the head.

- * Each group will have an *Astrea* on which are located several *Crepidula adunca*. Each group will write a short report on their findings regarding the distribution and size of the *Crepidula* on their *Astrea*. The report may be submitted at the end of the lab period or at the beginning of the next class.

Diagram the location of all *Crepidula* on the *Astrea*, giving each *Crepidula* a number, and roughly indicating the space between the individuals and/or stacks using a mm ruler. Remove each *Crepidula*, examining it under the microscope. Measure the length of the animals with calipers to the nearest 0.1 mm. Identify the sex of each individual. What is the ratio of females:males for individuals located in stacks? What is the ratio of females:males for individuals that occur singly? What percent of all individuals were located singly versus those in stacks? Make a table showing the number of each sex found singly, in stacks of two, in stacks of three, etc. Draw a histogram showing the relationship between size and sex.

Crepidula adunca broods its eggs until they crawl away as small individuals. Each member of the team should select one female that is brooding and examine the developmental stage of the young. Collin (2000; Veliger 43:24-33) found that *C. adunca* produced an average of 65 eggs in 7 capsules with an 9 eggs/capsule). The young hatched at shell lengths of 1.5 to 2.7 mm.

Class Gastropoda

Laboratory 2: Neogastropoda and Opisthobranchia

Subclass Prosobranchia

Order Neogastropoda

Neogastropods have the same general features as the mesogastropods with the following changes:

- Most species are carnivorous and the osphradium has become highly developed.
- Most have a proboscis.
- Most have a shell with a siphonal notch or canal.
- The nervous system is more highly developed.
- Most hatch as miniature snails; veliger larvae are rare.

Feeding

Neogastropods are characterized by carnivorous feeding habits and two radular types.

- Scavengers using a rachiglossan radula .

Nassarius species are active scavengers on sandy and muddy substrates. Locate the siphon and the siphonal notch. Examine the feeding behavior of *Nassarius* as it is exposed to pieces of *Mytilus* meat.

- Marine benthic hunters
 - Drillers using a rachiglossan radula.

Most of the neogastropods are drilling snails (336)) which bore into bivalves, snails, barnacles, etc. The proboscis is everted, the shell of the prey explored, and the radula used to clear a specific site. After a few minutes, the drilling stops, and the accessory boring organ of the foot is pressed against the site of drilling. Examine the *rachiglossan radula under the compound microscope. Look at the photo of the head of *Acathina* in feeding position in which the eyes, mouth, proboscis, radula, and boring hole are easily visible.
 - Dart poison using a *toxoglossan radula

All species of *Conus* use this specialized radula to kill their prey (337). An individual tooth with its associated poison sac is passed up to the proboscis and inserted into the prey (polychaetes, snails, and fish). Examine the radula.

Subclass Opisthobranchia

General Morphology

The primitive opisthobranchs are asymmetrical and possess the more or less typical coiled gastropod shell. But there is a tendency toward shell reduction, a reduced mantle cavity, loss of the original ctenidium, development of secondary gills, and bilateral symmetry.

Reproduction

All are hermaphroditic, either simultaneous or protandric.

Feeding

Modes of feeding include:

- Browsers and grazers on algae *Bulla* (complete shell)
- *Benthic hunters *Navanax* feeds on *Bulla* which are swallowed intact; the shell is later extruded through the mouth.
- *Cutters of algae *Aplysia* with its reduced shell and bilateral symmetry; feeds on comparatively large pieces of seaweed (340).
- Plankton suspension feeders Pteropods (341) The majority of pteropods (sea butterflies) are shelled and feed on particles suspended in the water. The feeding organs are ciliated lobes derived from the foot.
- Feeders on colonial animal growth

Most of the *dorid nudibranchs feed on sponges, tunicates or bryozoans (343). The *eolid nudibranchs (326, 342) feed on hydroids or other cnidarians and store the nematocysts for passive defense against their own predators.
- Feeders on algae and incorporation of chloroplasts

**Elysia* (a sacoglossan, 341) has reduced the radula to a single row of teeth which are used to slit open the algal cells. The contents of the cells are then sucked out. *Elysia* also incorporates some of the chloroplasts into their cells where they continue photosynthesizing until required by *Elysia* for food.

Tridachia (another sacoglossan, 799) also incorporates individual chloroplasts into its epithelium.
- * Planktonic hunters The naked pteropods are fast swimming predators on the shelled pteropods (341).

The nudibranch *Melibe* (343) is a planktonic hunter which swallows its prey whole.

Dissection of Aplysia

*Dissect *Aplysia*. The nervous system is usually very conspicuous as the ganglia are quite large, and often orange in color. Locate the paired cerebral ganglia, and perhaps the pedal, pleural, and visceral ganglia. Find the shell, ctenidium, buccal mass with the odontophore, crop, gizzard, stomach, digestive gland, intestine, purple gland, ovotestis and spermatid groove.

Subclass Pulmonata (mostly land and freshwater snails and slugs)

There are no ctenidia in the pulmonates. The mantle cavity on the right side is highly vascularized and converted into a lung. The pneumostome (a small opening) connects the lung to the external environment. All pulmonates are simultaneous hermaphrodites.

There are marine pulmonates. In San Diego the pulmonate snail *Melampus* lives high in the salt marsh. The most primitive living genus of pulmonate is the limpet *Siphonaria*. It has a veliger larva. This genus is abundant in the high intertidal zone of rocky shores along tropical shorelines.

Class Bivalvia

Laboratory 1 Introduction to bivalve morphology and diversity of rocky shore bivalves

The division of bivalves into subclasses is highly variable depending on the taxonomic reference. The most primitive bivalves are the 'protobranchs' which have small simple gills, no crystalline style, and a flattened sole on the foot. Most bivalves have large lamellibranch gills, with the filaments elongated and folded. These may be divided into subclasses based on the intricate structure of the gills, shell structure, and hinge teeth. A small group of bivalves have septibranch gills.

MAJOR GOAL: TO UNDERSTAND DIVERSITY AND FORM IN BIVALVES

- **Shell:** Bivalve shells are found in a great variety of shapes, sizes, colors, and surface sculpturings. The dorsal margin of each valve has a prominent point, the beak, which is the oldest part of the shell, and around which are the concentric growth lines. In the primitive bivalves the two shells are symmetrical and equal in size. As bivalves become specialized for various habitats there are modifications both in symmetry and in the size of the two valves. In some genera the two valves are of unequal size and of different shapes. Some boring bivalves have abrasive serrations on the shell for drilling or stability or for protection against predators. One of the valves may be permanently attached to the substrate.
- **Muscles:** The valves of the shell are pulled together by two large dorsal muscles called adductors. Primitively the two adductor muscles are equal in size (isomyarian condition), but in many bivalves, there has been a tendency for the anterior adductor to become reduced compare to the posterior adductor (anisomyarian condition). In other bivalves the anterior adductor has completely disappeared, and only the posterior adductor muscle is present and has shifted its position to a more central location between the valves (monomyarian condition).
- **Mantle** Bivalves have an extensive mantle and mantle cavity which provides a new pathway for water circulation. Water enters through the inhalent chamber at the ventral posterior end, makes a U-turn through the gills, and passes out the exhalent chamber posteriorly and dorsally. This enables the animal to burrow with the anterior end first into the mud or sand, leaving the inhalent posterior end (or siphons) projecting just above the surface of the bottom.

The mantle has undergone specialization in relation to habitat. In bivalves which live on hard substrates there is no fusion to produce siphons, but inhalent and exhalent currents may be separated by a fold in the mantle.

Burrowing species usually develop siphons by extension of the mantle tissue. Some clams have mantles with completely free borders, but there is a strong tendency to define more clearly the incurrent and excurrent channels by partial union of the mantle margins. The second joining occurs below the incurrent siphon, separating a pedal opening from the two completely defined siphonal apertures. By more posterior closure behind the foot, and more intimate joining of the mantle in the region of the siphons, well developed protruding siphons can be formed. Siphons make the only effective contact with the external environment and they may require sense organs (such as tactile papillae, light sensitive spots, and even clusters of eyes). In some cases the incurrent and excurrent siphons are surrounded by a muscular sheath. Sometimes there is a fourth mantle opening for the byssus.

Study the amount of mantle fusion in each specimen observed noting the presence of sensory elements, the condition of the siphons, special features of the inhalent siphon, and the surface of the siphons. The mantle also becomes specialized in active forms with many sensory tentacles and photoreceptor structures or ocelli.

- Foot The foot in bivalves is highly modified depending on the mode of locomotion, the use of the foot for digging, swimming, boring, etc. The foot has different shapes, varies in relative size and may be rudimentary or absent. A byssal apparatus is typical for recruiting bivalves, but has limited distribution in adults.

At the end of the two bivalve labs, you should be able to discuss the structural and functional adaptations of bivalves in relation to habitat. You should synthesize the following information in your lab notebook.

- Compare *Mytilus*, *Hinnites* and a pholad or *Tresus* for differences in muscle condition.
- Compare *Mytilus*, *Hinnites*, and a pholad for method of attachment to substrate.
- Compare mantle fusion and sensory structures on mantle edge in: *Mytilus*, *Hinnites*, and a pholad.
- Compare presence or absence of siphons in *Hinnites*, the surface dweller *Chione*, moderate depth (*Macoma* or *Sanguinolaria*), rapid burrower *Tagelus*, and deep living *Tresus*.
- Compare foot size in a scallop, mussel, pholad, the surface dweller *Chione*, *Tagelus*, and *Tresus*.
- Measure the length of foot and the length of shell. What is the ratio between shell length:foot length for each species? Rank in order of smallest foot to largest foot.
- Compare external shell features of *Mytilus*, *Hinnites*, a pholad, *Chione*, *Sanguinolaria*, and *Tagelus*.

Dissection: * *Mytilus* (351-355)

- Remove one valve by inserting a knife between the shell and the underlying tissue. Submerge the animal in sea water. Add carmine powder. Note the flow of water. It enters between the filaments of the ctenidia in the ventral edge of the shell moves anteriorly and then exits through the ctenidium posteriorly and dorsally. Note the carmine powder food chain as it moves down the food groove to the labial palps and the mouth.
- Remove a piece of ctenidium and place it under the compound scope to examine the ciliation.
- Find the two pairs of labial palps (accessory feeding structures) which pass food from the ctenidia to the mouth. At the center of the palps is the mouth.
- On the ventral surface find the foot and associated byssal threads.
- Remove one ctenidium.

- In the space between the viscera and the muscle tissue you should be able to identify the urogenital papilla (a tiny 'pimple' near the posterior dorsal surface of the animal). Find the elongated brown renal organ (kidney) and the anus on the posterior surface of the posterior adductor muscle.
- Remove the thin skin on the dorsolateral surface of the visceral mass to expose the pale green digestive gland and the stomach. Open the stomach to find the intestine. Be very careful not to damage the delicate thin tissue which covers the pericardial sac. Carefully open the pericardium to expose the heart. If the heart is not seen in *Mytilus*, try to locate it in a dissection of another bivalve.
- Dissect into the digestive gland, below the heart and anterior to it, to find the crystalline style, which is inside a thin tube. The crystalline style may also be found in pholads and scallops.

Adaptive radiation in rocky shore bivalves

Byssal bearing forms *Mytilus*

Cementation: *Hinnites*
Chama or *Anomia* (rock jingles) (demonstration: shells only)
Ostrea (oysters; 358) (demonstration: shells only)

Boring forms *Teredo* wood borer (361) (live demonstration)

Lithophaga, *Adula* rock boring nestlers (demonstration preserved specimens)

Pholadidae rock boring by deep burrowing (361) (preserved specimens)

Epifauna: Free living *Aequipecten*; *Argopecten*, *Lima* (live demonstration)

Byssal gland and muscle attachment *Pododesmus* (live demonstration)

- Specimens of the above species will be distributed among the laboratory tables for general dissection and/or observations

Class Bivalvia

Laboratory 2: Diversity in soft bottom bivalves

Protobranchiate Bivalves (*Nucula*, *Yoldia*, *Solemya*)

Examine the demonstration dissection to obtain an idea of the anatomy of this group, identify particularly the palp proboscides (348).

Adaptive radiation in soft substrate lamellibranchiate bivalves

Re-read the previous material on diversity and form in bivalves. Continuing working on your comparisons summarizing pertinent bivalve species and their characteristics.

- Shallow burrowers: **Chione*, *Laevicardium*
- Moderately deep burrowers: **Sanguinaria*, *Macoma* (360)
- Active burrowers: **Tagelus*, (357)
- Deep burrowers: *Tresus* (357) (demonstration specimen)
Examine for shell, siphons, mantle fusion, and adductor muscle condition.
- Byssal bearing forms: *Pinna* (pen shell), *Placuna* (window pane oyster) (demonstration specimens)

- Specimens of the above species will be distributed among the laboratory tables for general dissection and/or observation.

- Dissect one of the *clams and find: shell, hinge, siphons, mantle, labial palps, ctenidia, foot, adductor muscles, gonads, mouth, stomach, crystalline style, and intestine.

Phylum Mollusca

Class Scaphopoda

Examine the shells of scaphopods (363). On the *dissected specimens find the foot, tentacles (captacula), gonad, digestive gland, and retractor muscle (363).

Class Aplacophora The Class Aplacophora is the most primitive living mollusc. These wormlike molluscs lack a head and a true shell (although they have calcareous spicules embedded in the mantle), but possess a radula, typical molluscan ctenidia, and a trochopore larva. Examine the demonstration specimen of an aplacophoran (382).

Class Monoplacophora The Class Monoplacophora was known from the fossil record only (350 million years ago), but was discovered living in 1952. Monoplacophorans have a single limpet-like shell, but their head does not have any sensory structures. The internal organs show serial repetition which is suggestive of segmentation (10 pairs of lateral pedal nerves, 6-7 pairs of metanephridia, 2 pairs of gonads, 2 pairs of auricles, 1 pair of ventricles), but they are not considered segmented animals. Examine the photo of the monoplacophoran *Neopilina*. (383).

Class Polyplacophora

- Observe behavior in living chitons.
- Almost all chitons are herbivorous, but the local chiton *Placiphorella* (325) is carnivorous.

*Dissection of *Stenoplax conspicua*

- External morphology. On the dorsal surface find 8 calcareous plates and the mantle edge with calcareous spicules. On the ventral surface identify the foot, mantle cavity or mantle groove, rows of ctenidia, head, mouth, and anus.
- Internal morphology (320,321,322). Cut ventrally at the edges of the shell all around the animal to remove the animal from the shells. The space in which the viscera lies is a hemocoel. Find the heart at the posterior end of the viscera. In the dorsal mid-line identify the unpaired gonad. Beneath the heart and gonad is a long coiled intestine (indicative of a herbivore). Expose the entire digestive system finding the mouth, intestine, and digestive glands. Examine the radula.

Class Cephalopoda

Nautilus Examine the shell, taking special notice of the siphuncle (381). Examine the preserved dissection locating the mouth, beaks, radula, crop, digestive gland, and gonad. Locate the 2 pairs of ctenidia, the funnel, and the siphuncle.

Octopus Examine the live octopus noting chromatophore changes and feeding behavior (376,377). If developing eggs are available examine them. Slides of the spermatophore (371) and the eye (369) are available for examination.

Octopus. Dissection of the octopus.

- External anatomy: Locate the eyes, funnel and arms of the octopus. The arm on the right side of the head (dorsal view) is R4, while the arm on the left side is L4. The arm nearest the siphon is R3 and is the hectocotylus arm in males and its tip lacks suckers.
- Internal anatomy: Cut the adductor muscles which divide the end of the mantle and fold the mantle back. The most conspicuous structures are the gills and the purple gill hearts (branchial hearts). Locate the stellate ganglion. The gut is best seen in dissections made

from the dorsal surface. The most conspicuous large structure is the digestive gland. Ventral to it is the ink sac, gonad ducts, and rectum, while the crop/caecum is dorsal to it. Anterior to the posterior salivary glands is a cartilagenous box that surrounds the brain and supports the eyes and optic lobes. Follow the gut anteriorly to find the beak and radula. If the animal is a female, locate ovaries, oviducts, and egg capsules. If it is a male, located the testis, penis, and spermatophore sac.

Sepia Additional demonstration specimens of cephalopods include a cuttlefish, its beaks, and some cuttlebones (373).

Squids. Dissection of the squid *Loligo pealeii* (367,368) or *Dosidicus*

- External anatomy: The original dorsal surface of the animal is now the functional posterior end, while the ventral surface is the anterior end. The foot is modified into 5 pairs of tentacles; one pair (the hectocotylus arms/tentacles) in males is different from the other four. Locate the mouth and the chitinous beaks. Identify the funnel, the lateral fins, and the mantle.
- Internal anatomy: Cut the adductor muscles which divide the end of the mantle and fold the mantle back. The most conspicuous structures are the gills and the purple gill hearts (branchial hearts). Locate the stellate ganglion. The gut is best seen in dissections made from the dorsal surface. The most conspicuous large structure is the digestive gland. Ventral to it is the ink sac, gonad ducts, and rectum, while the crop/caecum is dorsal to it. Anterior to the posterior salivary glands is a cartilagenous box that surrounds the brain and supports the eyes and optic lobes. Follow the gut anteriorly to find the beak and radula. If the animal is a female, locate ovaries, oviducts, and egg capsules. If it is a male, located the testis, penis, and spermatophore sac.

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- Internal anatomy: Cut the mantle slightly to one side of the midventral line. Study the funnel noting the valve-like projections which prevent escape of water. Find the stellate ganglia located on the inner dorsal surface of the mantle near the tip of the gills. Identify the rectum which opens via the anus just behind the funnel. Under the rectum is the ink sac (do not rupture) which you should carefully remove. The two gills are readily identifiable. At the base of each gill is a gill (branchial) heart.
- Study both male and female reproductive systems. If your specimen is a female, large paired nidamental glands will cover much of the anterior viscera, and in the cone there may be egg masses, lying within the ovary. The nidamental glands secrete the coverings for the egg capsules. The paired kidneys are generally light orange in color are located very close to the ink sac and are more easily seen in the females.

If your specimen is a male, the penis can be seen lying to the left of the rectum. The testis extends along side the gut caecum. Sperm pass from the testis through the vas deferens to the spermatophoric gland which secretes the cover for the spermatophores. The spermatophores exit via the muscular penis, and are transferred from the male to the female by the hectocotylized arm.

- Open the head along the median line and find the buccal bulb, the horny beaks, and pry them open to locate the radula (367). The eye of the squid is analogous to the vertebrate eye. It has a cornea, iris, pupil, and lens (369).

Minor Protostome Phyla

Phylum Priapulida

- Examine the preserved specimen. The body is divided into a proboscis (or introvert) which can be retracted into the trunk (447). Locate the proboscis, trunk, caudal appendages, and ventral nerve cord.

Phylum Sipuncula

- Look at the live sipunculids and examine the feeding process. The tentacles are extended when the introvert is protruded (441,442).
- *Dissect a preserved sipunculid by making an incision slightly off mid-dorsal down the length of the animal. Find these major internal structures: ventral nerve cord, retractor muscles, metanephridia, esophagus, ascending and descending intestine, anus, gonad (if present) (440).

Phylum Echiura

- Study the peristaltic movements of the echiuroid *Urechis* (438,442) and understand its importance in feeding.
- *Dissect a specimen of *Urechis* by making a dorsal incision and find these major internal structures (439): ventral nerve cord, metanephridium, esophagus, intestine, anal sac, setal sac, gonad (if present). While many echiuroids have a closed circulatory system, *Urechis* does not, but it does have hemoglobin circulating within its coelom.

Phylum Pogonophora

- Examine the photos of the Galapagos hydrothermal vent vestimentiferan *Riftia*
- *Look at the dissected preserved *Riftia* specimen. Locate the bilobed obtural region, and vestimental region (with heart and closed circulatory system), trunk (trophosome is packed with sulfur granules), and the opisthosoma (annulated with septa dividing coelomic compartments). A typical pogonophora is illustrated in the text (444,445).

Phylum Annelida

Class Polychaeta

Laboratory 1 Morphology, feeding and biodiversity of errant polychaetes

General morphology and dissection of *Nereis*

- *Study the external structure of the head of *Nereis*. Locate the following structures: prostomium, peristomium, palps, tentacles or cirri, eyes (390,393).
- Dissect *Nereis* by making a mid dorsal incision down the length of the animal.
- *Identify the major structures (390,394,395) including external segmentation, parapodia, aciculum, septa, longitudinal muscles, circular muscle layer, parapodial muscle, ventral blood vessel, lateral blood vessels, ventral nerve cord, segmentally arranged ganglia, lateral nerves, esophagus, esophageal sac, intestine, pharynx, and jaws.

Parapodial structure and its effect on the body wall musculature

- * Examine the cross section of nereid parapodia and cross section of nereids which show the disruption of the muscle layers by the parapodia (389). Find: ventral and dorsal blood vessel, ventral nerve cord, longitudinal muscles, coelom, intestine, and small regions of circular muscle. Locate the notopodium, neuropodium, ventral and dorsal cirrus, aciculum, and setae. (Do not use Triarch slides).

- *Examine the cross section through Arenicolidae (a sedentary polychaete) noting the relatively larger circular muscle layer, which is much more extensive than was seen in Nereidae. The longitudinal muscle layer is more continuous and not broken into ventral and dorsal blocks.
- The structure of the parapodia is one of the main diagnostic features for identifying polychaetes. Please examine a slide of parapodia from either Family Nephtyidae or Phyllodocidae, so that you can see parapodial variety. You will not be responsible for recognizing the parapodia to family.

Behavior

- *Describe feeding in the errant carnivorous glycerid polychaete.
- *Describe locomotion in live phyllodocid or nereid worms.
- *Place glycerid polychaetes (388) into sand for observations on burrowing behavior.

Biodiversity of errant polychaetes

- *Learn to recognize these errant families

Amphinomidae	Nephtyidae	Phyllodocidae (416)
Aphroditidae (415)	Nereidae (389)	Polynoidae (415)
Glyceridae		Tomopteridae (417)

Errant Polychaete Families

- Alciopidae: planktonic family with large eyes
- Amphinomidae: glass-like setae; largely tropical; fireworms
- Aphroditidae: dorsal surface is covered with scales which are concealed by a thick mat of felt; 'sea mouse'
- Eunicidae: prostomium with 1-5 occipital antennae, eversible pharynx, distinctive jaws, among the largest of polychaetes, branchiae
- Glyceridae: pharynx has 4 jaws; parapodia are small
- Hesionidae: 2-3 antennae, 2-8 pairs of tentacular cirri, long dorsal cirri; jaws complex; relatively short bodied
- Nephtyidae: eversible pharynx without jaws; two pairs of small antennae; distinctive shimmy motion; well developed parapodia
- Nereidae: 2 large palps, head tentacles or cirri, eyes; pharynx with 2 jaws, large parapodia
- Phyllodocidae: leaf-like parapodia; often iridescent; excellent for studying locomotion
- Polynoidae: simple exposed scales (elytra); scaleworms
- Syllidae: long dorsal cirri which are often beaded; barrel-shaped pharynx
- Tomopteridae: planktonic family with very large parapodia

Class Polychaeta

Laboratory 2. Morphology, feeding, and biodiversity of sedentary polychaetes

Feeding mechanisms in sedentary polychaetes

- *Compare and describe the methods used among the following families.
 1. Surface deposit feeders Cirratulidae and Terebellidae
Use *Mytilus* meat for large food, and powdered yeast for small food.
 2. Filter feeders Serpulidae (384D;397D), Sabellidae, and Spirorbidae
Use carmine powder to simulate food particles.

3. Mucus net feeders Chaetopteridae Observe *Chaetopterus* in the plexiglass tubes.

Biodiversity of sedentary polychaetes

- * Learn to recognize the following families of sedentary polychaetes:

Cirratulidae (423)

Serpulidae (421)

Chaetopteridae (422)

Spirorbidae (421)

Sabellidae (418,419,420)

Terebellidae (417)

Sabellaridae (423)

Sedentary Polychaete Families

- Arenicolidae: 'lug worms', 1-13 pairs of dorsal branchiae (gills) in the middle part of the body; heavy bodied
- Chaetopteridae: large worms in distinctive leathery or chitinous tubes; parapodia are complexly lobed; highly differentiated with distinct body regions
- Cirratulidae: filamentous outgrowths start at the back of the head and are also borne on several segments of the body; body not divisible into two distinct regions; 'hairy gilled worm'
- Flabelligeridae: a characteristic cephalic cage or hood formed by the setae of the first 4 segments
- Magelonidae: greatly prolonged paired palps that are conspicuously papillated; spatulate prostomium
- Maldanidae: cylindrical, long-jointed polychaete; 'bamboo worms'
- Onuphidae: tube with shells; tentacles with annulated bases; usually iridescent
- Opheliidae: more or less short bodied; pointed at both ends; parapodia reduced to bundles of setae
- Orbiniidae: long, posteriorly tapering body that appears ragged because of the segmented branchiae that arise from the dorsal side; pointed head, ragged body
- Pectinariidae: 'ice cream cone worms'; distinctive sand tubes
- Sabellaridae: tubes of sand, convoluted and solidly cemented onto rocks; operculum; simple tentacles
- Sabellidae: 'feather duster worms' without operculum; various concreted flexible tubes of parchment, sand, and mucus
- Serpulidae: 'feather duster worms' with operculum; one of tentacles modified to form a stalked operculum; always in calcareous tubes
- Spionidae: body segments similar in size and setae; body shows gradual transition but is not sharply divided into distinct regions; 2 palps
- Spirorbidae: 'feather duster worms' with operculum; hermaphroditic; brood young in their calcareous tubes.
- Terebellidae: body divided into different regions; prostomium covered by tentacles and gills; tentacles not retractile into mouth.; tube dwellers.

Phylum Annelida

Laboratory 3: Polychaeta, Oligochaeta, Hirudinea

Class Polychaeta

Feeding mechanisms in sedentary polychaetes

- *Compare and describe the methods used among the following families.

4. Direct deposit feeders Watch capitellid or other burrowers feeding. (Arenicolidae, Maldanidae, Opheliidae, Orbiniidae)

Biodiversity of sedentary polychaetes (continued)

- *Learn to recognize the following families of sedentary polychaetes:

Arenicolidae (418)
Maldanidae

Onuphidae (424)
Opheliidae

Pectinaridae (424)
Spionidae (422)

Reproduction in polychaetes

- The spirorhids on algal fronds often have trochophore larvae in all stages of development within their tubes. Carefully remove the polychaete tube and examine for larvae (396,397). *Draw a trochophore and a nectochaete larva.
- Examine the live plankton tow for larval polychaetes.
- Study the slides of polychaete nectochaete larvae (398).
- Examine heteronereids of *Neanthes succinea* from the Salton Sea.

Class Oligochaeta

- Examine the live and preserved specimens and locate the clitellum (407). *Describe locomotion in live oligochaetes.
- Pin open a dissected specimen (or carefully cut the worm along the mid dorsal line).
- *Locate the following internal features: segmentally arranged circulatory system with the dorsal hearts, segmental coelomic compartments, circular and longitudinal body wall muscles, crop, gizzard, intestine and its typhosole, testis, seminal vesicles, ventral nerve cords, and the segmentally arranged nephridia (403,404,408). What is the function of the typhosole?
- *Examine the cross section slides across the intestine and locate complete layers of circular and longitudinal muscles, ventral nerve cord, ventral blood vessel, dorsal blood vessel, intestine, typhosole, and coelom (406).
- Locate the ovary (in the cross section of the ovary) and the testis (in the cross section of the testis) (406).

Class Hirudinea

- *Describe locomotion in live leeches.
- Examine a preserved leech and identify the posterior and anterior suckers.
- Pin open a dorsally cut specimen and locate the mouth, crop, and intestine. Note lack of internal segmentation and loss of distinct coelom (432-434).
- Examine the whole mount slide (wards) and locate the intestine and testis (432).

Phylum Tardigrada

- Examine living tardigrades under a compound microscope noting their general anatomy (316,317) and behavior. Pharyngeal pumping action and buccal styles can be seen at medium power.

Phylum Onychophora

- This group of forest dwelling tropical and subtropical animals has both annelidan and arthropodan characteristics. The annelidan characteristics include the structure of the body wall musculature, a thin, flexible cuticle, non-jointed appendages, simple eyes, segmented

nephridia, and ciliated reproductive ducts. The arthropodan characteristics include a reduced coelom with the hemocoel as the chief body cavity, a chitinous cuticle, a pair of appendages modified for feeding as jaws, an open circulatory system with a dorsal tubular heart, a tracheal respiratory system, and the basic arthropodan embryology.

- The unique features of the onychophora include limited segmentation, peculiar legs which are lateroventral and terminate in claws, a nervous system with brain, ventral nerve cord but no ganglia, and ovoviviparous and viviparous development.
- Watch the film loop on *Peripatus*. Describe feeding behavior, defense against predators, and reproductive behavior.
- Examine the preserved specimens to see the major features of Onychophora.
- Using the cross sectional slides, identify the following structures: circular and longitudinal body wall musculature, intestine, widely separate ventral nerve cords, paired dorsal slime glands, and lateral appendages with claws (452,453).
- On the longitudinal sections, find the brain, mouth, intestine, and dorsal tubular heart.

Phylum Arthropoda

Subphylum Uniramia

Uniramians are characterized by unbranched legs (uniramous). The head is completely separated from the thorax, and has 4 pair of appendages: antennae, mandibles, 1st and 2nd maxillae. Tracheal air tubes are used for respiration. **Myriapoda** and **Insecta** are uniramians.

Introduction to Arthropoda

- Remove all organisms from the 'introduction to arthropod' bottle and place them in a fingerbowl with water. Identify them to major taxa.

Superclass Myriapoda

Centipede fossils are known from the Cambrian while millipedes appeared in the Silurian.

• Class Chilopoda

Centipedes (566,567,568) are carnivorous ground dwellers with elongated bodies which are flattened dorsoventrally. The first pair of trunk appendages is modified into large raptorial pinchers which are provided with poison glands for injecting venom through the terminal claw into the prey. Each of the trunk segments (except the last 2-3 segments) bears 1 pair of walking legs. The organ systems (trachea, malpighian tubules, circulatory and nervous systems) are similar to insects and millipedes. Examine the preserved specimens of centipedes.

If living specimens are available, observe and describe locomotion.

• Class Diplopoda

Millipedes (569,570,571) are adapted for burrowing. There are two pairs of legs on each segment; the double nature is also reflected in ventral nerve cord and circulatory system. Internal organs resemble those of insects and centipedes. Examine the preserved specimens of millipedes.

If living specimens are available, observe and describe locomotion.

Superclass Insecta (or Hexapoda)

The body tagmata consist of head, thorax, and abdomen. The mouthparts are variously modified and adapted for different feeding styles. There are 3 pairs of jointed legs associated with the thorax (574). There are often 1 or 2 pairs of wings on the 2nd and 3rd segment of thorax. The respiratory system consists of spiracles which lead into air-filled trachea which branch repeatedly. The excretory system consists of Malpighian tubules.

Cockroach dissection

*External anatomy (compare with grasshopper 627,628)

- Examine the frozen cockroach, locating the appendages associated with each tagmata. Break off the legs of the cockroach. Melt the paraffin in a small dissection pan and gently press the cockroach into the wax, ventral surface down. Allow the wax to set. Flood the pan with water.

*Internal anatomy (compare with grasshopper 577,578,581)

- Detach the elytra and wings. Carefully cut up along the right side, without penetrating soft tissue of the body, and across at the top and bottom. Pin the flap down. The heart is a chain of narrow chambers which should remain attached to the terga. Move aside any fatty tissue.
- Locate the digestive system (572A) finding the esophagus, crop, gizzard (proventriculus), midgut, digestive caeca, and intestine. The Malpighian tubules (excretory tubules) are very fine strands found at the junction of the midgut and hindgut. Carefully move the digestive system to one side.
- The tracheal beginning at the spiracles is very obvious.
- The nervous system consists of cerebral ganglia and a double ventral nerve cord with segmentally arranged ganglia and nerves (577A).
- The female reproductive system is in the posterior part of the abdomen and consists of paired ovaries (light yellow) with paired oviducts which join near genital opening. Also at this junction are paired spermathecae (not easily seen) which store spermatazoa received during copulation. Large collateral (accessory) glands which form the egg capsule are also present. The giant cockroach is ovoviparous, and its ootheca are filled with fertilized eggs or pupa which exit individually.
- The male reproductive system contains paired testes, a mushroom gland (accessory gland), paired vas deferens, and an ejaculatory duct (not easily seen).

Subphylum Trilobitomorpha

- The trilobite fossil record exists from Cambrian times. There is a fairly clear fossil record of the evolution of Trilobita to the Chelicerata which appeared in the late Cambrian-early Silurian (both *Limulus* and the marine scorpion Eurypterida) (765).
- Examine the fossil trilobites (764).

Subphylum Chelicerata

The chelicerates have biramous limbs. Their jaws develop as protrusions from base of limbs (gnathobase). The body tagmata are cephalothorax and abdomen. The first pair of appendages are the cheliceras. A digestive gland (or liver) is present in all groups and respiration is by book gills, book lungs, or trachea associated with the abdomen. **Classes: Merostomata, Pycnogonida, Arachnida**

Class Arachnida

- The Eurypterida (765) gave rise to the arachnid scorpions (548,549) which evolved to the rest of the arachnids.

External anatomy

In the arachnids, the cephalothorax appendages are the cheliceras (prehensile and concerned with food capture), the pedipalps (tactile sensory organs or enormous chela), and 4 pairs of walking legs. There are no mandibles or jaws. Arachnids have a suctorial alimentary canal and are liquid swallows. They predigest their food in the mouth and suck

the juices into the gut. On the abdomen are book lungs (more common in primitive forms) and/or trachea (advanced arachnids) for respiration.

- Remove the assorted arachnids from the 'Introduction to Arachnid' jar and place them in a fingerbowl with water.
- The most primitive arachnids are scorpions (548,549) characterized by large chelate pedipalps which are always kept in a forward position, an abdomen which is divided into two portions, and the caudal stinger. Examine the preserved specimen and if live scorpions are present, look at them as well.
- The Araneae (true spiders; 534-547) have chelicerae provided with poison fangs, spinnerets, the pedipalps in the male as the copulatory organ, and an unsegmented abdomen. Find these structures on the preserved specimen. Look at the available live spiders.
- The largest group, the Acari (mites and ticks; 550-553), have the body fused into one region. Examine the slides of these two groups.

Class Merostomata

- Examine the molt of *Limulus* (530).

*External anatomy

Using preserved specimens study the external anatomy, examining the cephalothorax with chelicerae and 5 pairs of walking legs. The first pair are the pedipalps which function as walking legs (530). These are chelate in all young animals and adult females, but in adult males the pedipalps end in a curved claw which is used for clinging to the back of the female during reproduction. Examine an adult male and adult female to see this difference in the pedipalps. The last pair of walking legs are modified for cleaning and digging (531). Examine the gnathobases on the legs. What is their function? The first abdominal appendage is the genital operculum which protects the gonopores. There are 5 pairs of book gills.

*Internal anatomy

To obtain some understanding of the internal anatomy examine the longitudinally bisected specimen identifying the mouth, esophagus, gizzard, intestine, digestive gland, dorsal heart and circulatory system. Examine the dorsal dissection and find the digestive gland, the gizzard, the heart and extensive the gizzard, circulatory system, the carapace attachment muscles, and the book gills.

- Examine the slides of the trilobite larvae (533).
- If a live *Limulus* is available examine general locomotory behavior.

Class Pycnogonida

- Study locomotory behavior in living specimens
 - Study preserved specimens and slides to understand general anatomy (559-561).
 - The males have ovigerous legs and carry the eggs.
 - Both deep sea and cold water species (from Antarctica) are exceptionally large.

Subphylum Crustacea

Introduction to Basic Crustacean Anatomy

The basic anatomy of crustaceans will be examined using a crab. While crustacean tagmata vary, all crustaceans have a head of 6 segments with the same 5 pairs of head appendages: 1st and 2nd antennae, mandibles, and 1st and 2nd maxillae.

*External anatomy of a crab

- In a crab (as in all decapods), 3 thoracic appendages are modified into mouth parts (1st, 2nd, 3rd maxillipeds). In decapods three pair of thoracic appendages (1st, 2nd and 3rd maxillipeds) are associated with the head. All mouth parts are biramous (485). Remove all appendages from each tagmata and identify them. Illustrate at least 2 head appendages, 2 thoracic appendages (a maxilliped and a leg), and 1 abdominal appendage.
- Respiration is associated with the cephalothorax. The exopods of the 2nd and 3rd maxillipeds are modified as a flattened plates, the gill bailer. The gill bailer vibrates to draw in a respiratory current from behind the carapace, over the gills, and out in front of the head (487). Locate the gill bailer associated with the 2nd and 3rd maxillipeds.
- Associated with the thorax are 5 pairs of walking legs; the first pair is chelate. There are 7 segments in a typical appendage. Gills are modified epipodites attached to the thoracic legs. Examine the phyllobranchiate (lamellar) gills (486).
- The abdomen has 5 pairs of pleopods which in some decapods are used in swimming. Many males only have 2 pair of pleopods, the first two pairs, which are as a copulatory structure. All 5 pairs of pleopods are present in the female as they function to hold the eggs during development. The uropods form a tail fan with the telson.

*Internal anatomy

Remove the carapace covering the cephalothorax and examine the internal anatomy. Locate the following structures: stomach, digestive gland, intestine, heart, gills and gill bailer, testes or ovaries (487,488,493).

Subphylum Crustacea – Laboratory 1

Class Branchiopoda The members of this class have leaf-like phyllopodous trunk limbs which perform a variety of functions. Gnathobases occur in the trunk limbs and are used to crush food into smaller particles.

Order Anostraca brine shrimp and fairy shrimp

Artemia (509) Most crustacea are sexually dimorphic. Study the obvious differences in the external anatomy of adult males and females. Watch the living adults for swimming and feeding behavior. Remove one of the trunk appendages and examine its phyllopodous structure under a microscope. Examine the nauplius larva, the basic larva form of the phylum Subphylum Crustacea.

Order Cladocera These are the water fleas, characterized by a carapace covering the trunk.

Examine living specimens for swimming behavior. Notice that the young are carried within the carapace of the females. Study the slide for details of anatomy (604E,F), especially filter feeding legs and gnathobases. Sexually resistant eggs are produced in an encapsulated brood chamber which will separate from the carapace and sink to the sediment (510).

Class Ostracoda In this group the carapace is developed into a bivalved shell. Locomotion and feeding are carried out principally by the head appendages. Study living ostracods for swimming behavior and the slides for basic anatomy (527).

Class Maxillopoda This group has only 6 pairs of trunk limbs. The first pair of trunk limbs are modified as accessory jaws or maxillipeds, and this is why they are called the maxillopoda. There are 5 abdominal segments with no appendages, and a telson with a caudal fork.

Subclass Copepoda The copepods are the most numerous animals in the marine environment. You must be able to distinguish between calanoid, cyclopoid, and harpacticoid copepods.

- Living copepods are available from assorted plankton tows. Compare swimming behavior in calanoid versus cyclopoid copepods. Representative slides of calanoids, cyclopoids, and harpacticoids are also available. The larval form is a nauplius.
- Calanoid copepods are the most numerous marine copepods. They are usually larger than the other copepods, and the head and thorax are distinctly separated from the abdomen. The 1st antenna is composed of 23-25 segments and the 2nd antenna is biramous. The eggs are carried in a single cluster or in paired but unequal egg sacs (524). The majority of calanoids are herbivorous and microphagous, feeding on phytoplankton and detritus.
- In cyclopoid copepods the head and thorax are distinct from the abdomen, and most have paired egg sacs. The 1st antenna has 8-20 segments, and the 2nd antenna is uniramous (524). The majority of cyclopoids are carnivorous.
- The harpacticoid copepods are mostly benthic and of minute size. The body is linear in shape. They lack the obvious division between main body regions. The 1st antenna has no more than 8 segments, and the 2nd antenna is biramous. The egg sacs are paired in most (524). The majority of harpacticoids feed on benthic detritus.

Subphylum Crustacea – Laboratory 2

Class Maxillopoda

Subclass Cirripedia, Order Thoracica The barnacles have a bivalved carapace, a mantle, a pair of chitinous valves, and a series of calcareous plates. The body is highly modified for sessile life. The head is attached to the substrate at metamorphosis. The 6 pairs of thoracic limbs, called cirri, are divided into two functional groups. Usually the first two pairs (sometimes the 3rd) function as maxillipeds and have different kinds of setae, while the other 4 pairs are extended as the food catching organs.

Barnacles are hermaphroditic, in contrast to most crustacea which are dioecious, and their mating behavior is unique (505).

- Acorn barnacles
 - Acorn barnacles have no stalk (500). Observe feeding behavior in small acorn barnacles. Examine slides of barnacle nauplii and cyprid larvae (502,503). You must know how to recognize a barnacle nauplius.
- Pedunculate barnacles
 - Lepadomorph barnacles, such as *Lepas* have 5 major calcareous plates while scalpellid barnacles such as *Pollicipes* have 6 major calcareous plates (504). Note these differences in the preserved specimens.
 - Dissect *Pollicipes* Locate the following structures: cirri, maxillipeds, mandibles, maxillae, mouth, stomach, penis, testes, ovaries (which are located in the peduncle), and adductor muscle (504).

Class Malacostraca This group is characterized by a carapace which envelops the thoracic region, stalked eyes, and thoracic appendages used for locomotion. In these, the head has 6 segments with the typical head appendages found in crustaceans. The thorax has 8 segments (up to 3 of which may become associated with the head; these appendages then become maxillipeds).

The Malacostraca are divided into 5 subclasses: Phyllocarida, Hoplocarida, Syncarida, Peracarida, and Eucarida.

- Subclass Phyllocarida **Order Leptostraca** These have an unhinged bivalve carapace. They have phyllopodous legs and are all detritus feeders. There are 8 abdominal segments. Development is direct. Study the leptostracan *Epinebalia* (511) which is found in our local *Zostera* beds or in plant detrital debris in submarine canyons. If living examples are unavailable, examine the preserved specimens and slides.
- Subclass Hoplocarida **Order Stomatopoda** These are the mantid shrimp which are dorsoventrally flattened and elongate in appearance. A shield-like short carapace covers the head and the first two thoracic segments only. The 2nd thoracic appendage is developed for raptorial feeding. The inner edge of the movable finger is provided with long spines or is shaped like the blade of a knife. Prey are speared by rapid extension and retraction of the movable finger. Thoracic appendages 6 through 8 are used for respiration, as are the pleopods. Examine preserved and living (if available) specimens of stomatopods (511). The larval form is an antezoea.
- **Eumalacostraca** In all the remaining crustacea, the abdomen always has 6 segments.
 - Subclass **Syncarida** This is a very specialized group found in freshwater habitats in remote places. It includes the anaspids which are found in freshwater streams of Tasmania, Australia. They have biramous thoracic appendages and are detritus feeders. The pleopods function mainly as swimming appendages while the thoracic epipodites function as gills. Examine the anaspids (optional).
 - Subclass **Peracarida** This is a large taxon which can be divided into 3 groups on the basis of their mode of respiration, and into 5 orders (Amphipoda, Cumacea, Isopoda, Mysidacea, and Tanaidacea). All of the orders share the following characteristics:
 - The young are carried in a ventral thoracic marsupium. Oostegites are attached to the coxa of thoracic legs to form a brood pouch.
 - Development is direct. There are no larval forms.
 - The 1st thoracic segment is a maxilliped.

Order Mysidacea The mysids have a cephalothoracic shield which covers all of the thorax, but it is fused only to the first 4 thoracic segments. The eyes are stalked. There are 7 pairs of biramous thoracic legs which show no specialization. The abdomen is long with 5 pairs of biramous pleopods, and a pair of uropods which forms a tail fan with the telson. A statocyst is found in the endopod of the uropods, a feature found only in mysids.

There are two groups of mysids, the more primitive ones such as *Gnathopausia* (characterized by epipodites on each of the thoracic legs for respiration), and the more typical mysids.

Examine the large Antarctic mysids, deep sea *Gnathopausia*, and mysids of typical size. Locate the statocysts on the uropods (512).

Order Cumacea The body shape is distinctive (516) as the cephalothoracic shield is fused to the first 3 segments of the thorax. Note sexual dimorphism in *Cumopsis* with males having well developed abdominal pleopods, while females either have reduced abdominal pleopods or none.

Order Tanaidacea The cephalothoracic shield is fused to the first 2 segments of the thorax. The 1st pair of thoracic legs are chelate (sometimes called gnathopods). The last segment of the pleon is fused with the telson to form the pleotelson (516).

Order Isopoda The isopods are dorsoventrally flattened animals without a carapace. All 7 pairs of thoracic legs are similar. All 5 pairs of pleopods are similar and they are modified for respiration (pleopodal respiration). The uropods are usually fused to form a pleotelson. Isopods are the only crustaceans which have evolved completely terrestrial species.

Examine the assorted species of isopods provided to see the diversity of form (514-516). You are responsible for recognizing any isopod, as an isopod. Specimens of *Ligia* will be available for distinguishing males and females.

Order Amphipoda The body in amphipods is laterally compressed and there is no carapace. There are 7 pairs of thoracic legs; the first 2 pairs are gnathopods, and the other 5 pairs are pereopods. Amphipods have epipodal respiration on the thoracic legs. The abdomen is modified so that there are 3 pairs of biramous pleopods and 3 pairs of uropods (amphipods are the only crustaceans with 3 pairs of uropods). The amphipods are divided into three suborders: Caprellidea, Hyperidea, and the Gammaridea.

- Suborder **Caprellidea** The caprellids are the skeleton shrimp (513). They are characterized by having a tubular body with a long, thin shape. The 2nd thoracic segment is coalesced with the head so that the 1st gnathopod acts as a mouth part. The 3rd and 4th pereopods are rudimentary, and the 5th, 6th, and 7th are used for grasping. The abdomen is reduced or absent. Study living caprellids for general anatomy and behavior, and slides for morphology.
- Suborder **Hyperidea** The hyperid amphipods are pelagic forms which have a very large head with very large eyes. Examine preserved hyperids (513) in order to recognize this group.
- Suborder **Gammaridea** The gammarids usually have small eyes, and are common benthic organisms in a variety of aquatic habitats. One scheme of classification divides the gammarids based on the morphology of the reproductive males. Males can be pelagic or benthic during mating. Some gammarids possess sexual dimorphism while others do not. Examine living specimens of gammaridean amphipods for general anatomy (512). Study preserved specimens to distinguish males from females (if large specimens are available).

Subclass Eucarida In eucarids (euphausiids and decapods) the carapace is fused to all the thoracic segments to form a cephalothorax. The eyes are typically on moveable stalks, and larval development is very complex.

Order Euphausiacea

- The euphausiids have 8 pairs of thoracic limbs which are all similar and biramous. On each thoracic leg there are naked gills (epipodites) used for respiration, and longer endopods used feeding (mostly are filter feeders).
- Euphausiids have a long larval life with 3 stages, beginning with a nauplius. {Other larval stages are the calyptopis, equivalent to a zoeal stage, and the furcillia, equivalent to a mysis stage.
- Study the preserved specimens. Locate the 8 pairs of biramous legs with the obvious setation on the endopods for filter feeding, the epipodal gills, and the thoracic location where eggs are brooded (517).

- **Order Decapoda** Decapods have 3 pairs of thoracic appendages modified as maxillipeds, so that there are 5 pairs of remaining thoracic legs. Classification of the decapods is complex; the first division is usually into the Suborders Dendrobranchiata and Pleocyemata.

- Suborder Dendrobranchiata

This group includes shrimp which have dendrobranchiate or dendritic gills (gills with branched filaments). These shrimp have the 1st, 2nd, and 3rd legs chelate for grasping and manipulating food. Females do not brood their eggs but shed them into the water where the eggs hatch as a nauplius larva. The nauplius is followed by the protozoa stage, then the mysis stage, and finally the post-larva stage.

Included in the dendrobranchiate shrimp are the commercial **penaeid** shrimp *Penaeus* (517), and the planktonic sergestid shrimp *Lucifer*. Examine the various representative penaeid shrimp and look at a dendrobranchiate gill.

- Suborder Pleocyemata All the rest of the decapods (shrimp, lobsters, crabs, etc.) brood their eggs on the pleopods of the female. The larval emerges not as a nauplius, in a much more developed stage. Most decapods belong to this group.

- Infraorder Caridea

The **carid** shrimp are characterized by phyllobranchiate gills, (the same type of gills are found in most brachyura. The first 2 pairs of legs are chelate and enlarged for feeding, while the last 3 pairs of legs function for locomotion. The legs are stronger than those of penaeid shrimp, and the pleopods are reduced. The second abdominal segment overlaps the 1st and 3rd (called 'broken back' shrimp), and in flexure is used for escape. The young hatch as protozoa or in the post-larval stage.

Examine the general anatomy and swimming behavior of living carid shrimps (518), including *Lysmata* (cleaning shrimp) and *Alpheus* (snapping shrimp 518). Look at the freshwater shrimp *Macrobrachium* and fins the enlarged second abdominal segment.

- Infraorder Astacidea

This group includes the **Family Astacidae** or freshwater crayfish (519) and the **Family Homaridae**, clawed or chelate marine lobsters, such as the Maine lobster. These families have the first pair of legs large, chelate and modified as a defensive structure. The orientation of the chelipeds is far forward and there is no way in which they can be brought back to the mouth for feeding. The other four pairs of legs are for locomotion (they can walk forwards, backwards, and sideways -- very unusual for a decapod). Of these 4 pairs of legs, the 2nd and 3rd are chelate and are used in feeding. The third pair of maxillipeds is very leg-like. Development is basically direct; the hatching juvenile of marine forms is sometimes called a mysis larva. Sexual distinction is obvious as males have 2 pairs of enlarged pleopods, while females have 5 pairs of pleopods for carrying the eggs. Examine the filamentous (trichobranchiae) gills of the freshwater crayfish or of *Homarus*.

Filamentous gills are also found in the stenopid and thalassinid shrimp.

- Infraorder Palinura

This group includes the **Family Palinuridae** (520), the spiny lobsters (such as the California lobster *Panulirus*) and the **Family Scyllaridae** or slipper lobsters (520). These have a modified second antenna for protection (long in spiny lobsters, spatulate in slipper lobsters). The 3rd maxilliped is very powerful and is used to grasp prey. All 5 pairs of legs are non-chelate and function in locomotion.

- In *Panulirus* the reproductive opening (gonopore) is on the base of the 8th thoracic segments (near the 5th legs) in males, and the base of the 5th thoracic

segment (near the 3rd legs) in females. The pleopods of *Panilurus* males are reduced, and are not used in mating. Spermatophores exit the gonopore and are placed on the ventral thorax of the female. She becomes a 'plastered' female.

- The female discharges eggs, and uses her last pair of legs which are chelate to break up the spermatophore for fertilization. She moves the fertilized eggs to the abdomen where they are attached to the pleopods. She is now a 'berried' female. The eggs hatch as phyllosome larvae (9 phyllosome stages) which is followed by a puerulus larva (2 stages). This long planktonic larval life lasts approximately 1 year, before the puerulus swims toward shore and settles to the bottom.

Subphylum Crustacea - Laboratory 4

- **Infraorder Thalassinidea**

The mud and ghost shrimps are characterized by having a symmetrical flattened abdomen, and the first 2 thoracic legs chelate. The third maxillipeds are very leg-like. The ghost shrimp (520) *Callinassa* lives in burrows in mud and sand. The sexually dimorphic males have one chela much larger than the other. The 2nd and 3rd legs are very setose and are used both for digging and for feeding (sifting organic particles from the sediment). The pleopods produce the respiratory current and carry the eggs. The young hatch as a zoea.

- **Infraorder Anomura**

The Anomura, or false crabs, have a well developed cephalothorax in which the 5th pair of legs are reduced, turned back and are not locomotory. The 2nd antenna is very long. The first cheliped extends forward in front of the head and its function is defensive rather than manipulative. The 2nd and 3rd legs are chelate and involved in feeding. Legs 1 to 4 are walking legs, while the 5th functions to clean the abdomen. The abdomen is reduced, asymmetrical, soft (associated with burrowing life), the 5 pairs of pleopods are reduced, and the uropods are vestigial.

- The Paguroidea (521,522) include the hermit crabs (Family Paguridae), such as *Pagurus*. The abdomen is soft and asymmetrical to fit the gastropod shell. Pleopods are present only on the left side. The 1st pair of legs is chelate, while the 2nd and 3rd are not; these legs are used in locomotion. The 4th and 5th pairs of legs are short, turned back, and are used to clean the abdomen and attach to the shell. Most hermit crabs use the 1st chelate legs to scrape up mud or sand. Some filter feed using exopods on the 2nd and 3rd maxillipeds to produce the current, and setae on mouthparts as the filter. The larval forms of hermit crabs are zoea and glaucothoe (equivalent to megalops).

- Also included in this group are the lithode crabs (Family Lithodidae), which have a very heavy exoskeleton. Their obvious differences from true crabs are an asymmetrical abdomen and a very short pair of 5th legs. Several species of lithode crabs are commercially harvested for food.

- The Galatheaidea are the squat lobsters which includes the pelagic tuna crab *Pleuroncodes* (522) (Family Galatheaidea) and the porcelain crabs *Petrolithes* (Family Porcellanidae) (523). The chelipeds are defensive in *Petrolithes* while legs 2 to 4 are used in locomotion; the 5th legs are reduced. They generally filter feed using setose 3rd maxillipeds and most are specialized surface deposit feeders. Setose pads on the chelae are used as brooms to sweep up detritus from the rock surface. The abdomen is symmetrical but flexed under about half way down its length.

- The Hippoidea are the mole crabs (522) including Family Hippidae (*Emerita*). These have a long cephalothorax and long 2nd antenna, and they have the greatest reduction of the abdomen found in the anomura.

- Examine the assorted anomurans noting the major features, especially the reduced 5th legs and the modified abdomen. You are responsible for recognizing any anomuran as belonging to that taxon. You are responsible for feeding behavior of *Callinassa*, *Emerita*, and *Pagurus*.

- Infraorder **Brachyura**

The Brachyura, or true crabs, have a carapace which is broader than long, and the abdomen is always reduced and flexed beneath the thorax. The chelipeds of brachyurans are jointed in such a way that they can be angled in and used as feeding limbs. No other legs are chelate. The larval forms are zoea and megalops (496,497). The Brachyura can be divided into 4 groups: the Dromiacea, the Oxystomata, the Oxyrhyncha, and the Brachyrhyncha.

- The Dromiacea are the most primitive crabs (499).

- The Oxystomata have a spiny mouth. These crabs are specialized to burrow by digging in backwards into the soft substrate so the 5th pair of legs are flattened as diggers. Included are the Family Calappidae (*Calappa*) and the Family Leucosiidae (*Randallia*).

- The Oxyrhyncha are the spider crabs with spiny noses (**Family Majiidae**). They are very mobile on soft sediments and have long legs adapted to walk on soft substrates. Many species camouflage themselves using the chelae to attach algae, sponge, etc. to the carapace and legs (523).

- The Brachyrhyncha, short snouted crabs, include most of the crabs. They have wide-set chelipeds with well developed legs for sideways locomotion. The eyes are widely set apart. These are the advanced crabs and tend to be fast moving surface dwellers. They show sexual dimorphism in the shape of the abdomen with females U shaped and males V shaped. Males possess enlarged 1st and 2nd pleopods used in reproduction, while females have all 5 pairs of pleopods with setae to hold the eggs.

- Included in the Brachyrhyncha are the **Family Portunidae** (swimming crabs 495), the **Family Cancridae** (cancer crabs; 495), the **Family Ocypodidae** (ghost crabs) and fiddler crabs (*Uca* , 498) and the **Family Grapsidae** (shore crabs such as *Pachygrapsis*).

- Examine the slides of zoea and megalops larvae (496,497).

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