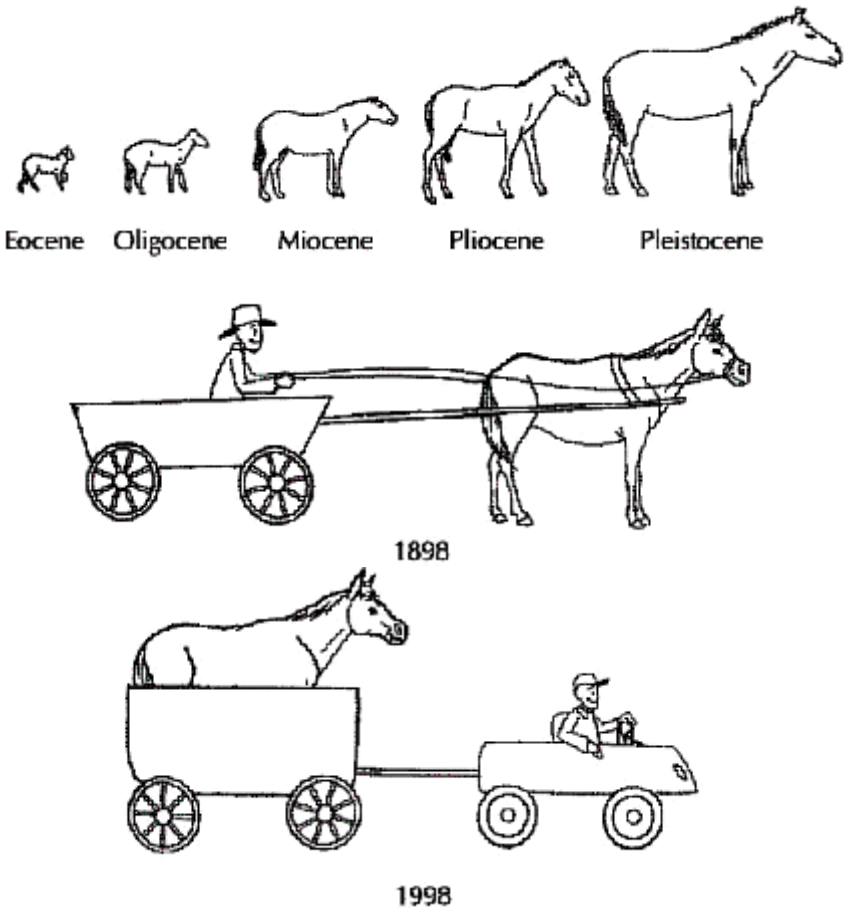
VERTEBRATE ZOOLOGY



"The Horse – an outstanding example of evolution".

Saskia Raevouri. Urantia Book. 1998

BIOS2061
2018

CONTENTS **Page No.**

1. Information about the Course 3
2. Staff Involved in the Course 3
3. Course Details 4
4. Rationale and Strategies Underpinning the Course 5
5. Course Schedule 6
6. Assessment Tasks and Feedback 7
7. Additional Resources and Support 9
8. Required Equipment, Training and Enabling Skills 10
9. Course Evaluation and Development 10
10. Administration Matters 11
11. UNSW Academic Honesty and Plagiarism 15
12. Scientific Writing 16

RESEARCH ASSIGNMENT 25

PRACTICALS

Practical 1 29
Introduction to Chordates 30
Amphioxus 32
Dissection of Cunjevoi 38
Practical 2
Dissection of a Shark – part 1 49
Practical 3
Dissection of a Shark – part 2 59
Practical 4
Vertebrate Jaws and Lungs 67
Practical 5
The Tetrapod Skull and Skeleton 87

Practical 6

Lab Quiz 103

Amphibians and Amniotes 104

Practical 7

Turtles, Crocodiles and Birds 135

Practical 8

Birds in their Habitat 157

Practical 9

Mammal Skeletons 1 171

Dentition 172

Monotremes 178

Marsupials 181

Practical 10

Mammal Skeletons 2 189

Placentals 190

Practical 11

Practical Exam 211

Vertebrate Zoology Glossary 212

Faculty of Science - Course Outline

1. Information about the Course

NB: Some of this information is available on the UNSW Handbook[1]

Year of Delivery	2018
Course Code	BIOS2061
Course Name	Vertebrate Zoology
Academic Unit	School of Biological, Earth and Environmental Sciences
Level of Course	2nd UG
Units of Credit	6UOC
Session(s) Offered	S1
Assumed Knowledge or Prerequisites	Assumed knowledge: BIOS1101 or equivalent
Hours per Week	5 HPW
Number of Weeks	12 weeks
Commencement Date	5 March 2018

Summary of Course Structure (for details see 'Course Schedule')

Component	HPW	Time	Day	Location
Lectures	2			
Lecture 1		11 – 12 pm	Monday	Mathews D
Lecture 2		4 – 5 pm	Thursday	Mathews D
Laboratory	3			
Lab – Option 1		10 – 1 pm	Tuesday	E26 Teaching lab 3
Lab – Option 2		2 – 5 pm	Tuesday	E26 Teaching lab 3
TOTAL				

Special Details	Week 10 is a fieldtrip to Centennial Park. This is held during normal practical class times.

2. Staff Involved in the Course

Staff	Role	Name	Contact Details – room and email	Consultation Times
Course Conveners		Prof Sue Hand	Biolink 557 s.hand@unsw.edu.au	Email for appointment
		Prof Mike Archer	Biolink 563 m.archer@unsw.edu.au	Email for appointment
Other Teaching Staff	Lecturers & Facilitators	Prof Iain Suthers	E26 Level 4 i.suthers@unsw.edu.au	Email for appointment
		Prof Richard Kingsford	E26 Level 5 richard.kingsford@unsw.edu.au	Email for appointment
		Dr Daniel Noble	E26 Level 5 daniel.noble@unsw.edu.au	Email for appointment
	Tutors & Demonstrators	Claudia Ford Dr Matt McCurry		
	Snr Technical Officer	TBA	E26 Level LG	

[1] UNSW Online Handbook: http://www.handbook.unsw.edu.au

3. Course Details

Course Description[2] (Handbook Entry)	Australia has a high diversity of vertebrate species (e.g. kangaroos, tree frogs, parrots, snakes). This course examines the evolution, diversity and natural history of these animals with a special emphasis on how they cope with Australia's environment. It covers the evolutionary origins and relationships between the major vertebrate groups and explores their diversity of form, function and behavior. There is a detailed investigation of fish, amphibians, reptiles, birds and mammals, particularly their ecology, life history and emerging conservation issues. Practical work involves examining living and preserved specimens (including dissections) and an excursion near UNSW studying vertebrates in the wild.
Course Aims[3]	1. To impart a fundamental understanding of the evolution and diversity of organisms classified as vertebrates (Phylum Chordata) 2. To teach students the origins of the major features of vertebrates. 3. To introduce the principles of taxonomy in the classification of living organisms 4. To demonstrate the major conservation issues facing vertebrate life with an emphasis on Australian fauna methods to synthesise biological and other information to produce adaptive action plans.
Student Learning Outcomes[4]	At the end of this course, students should 1. Have an understanding of the evolutionary interrelationships between the major groups within the Phylum Chordata 2. Be able to identify and distinguish among different vertebrate taxa 3. Understand current thinking on the origins of the major features defining the major lineages 4. Understand the major issues in the conservation of Australia's vertebrates

Graduate Attributes Developed in this Course[5]

Science Graduate Attributes[5]	**Select the level of FOCUS** *0 = NO FOCUS* *1 = MINIMAL* *2 = MINOR* *3 = MAJOR*	**Activities / Assessment**
Research, inquiry and analytical thinking abilities	2	All activities and assessments require and enhance ability to synthesise and act on biological and other information
Capability and motivation for intellectual development	1	Presentation of conflicts between different biological information. Students have many opportunities to develop and express these skills through lecture discussion, assignments, and in interpretation for final exam
Ethical, social and professional understanding	**0**	
Communication	1	Written reports and group work during lab classes
Teamwork, collaborative and management skills	**2**	Students will collaborate in lab classes over dissections and are encouraged to discuss what they see
Information literacy	**2**	Students will gain experience in finding and citing information from primary, secondary and web-based literature

[2] UNSW Handbook
[3] Learning and Teaching Unit: Course Outlines
[4] Learning and Teaching Unit: Learning Outcomes
[5] Contextualised Science Graduate Attributes

Major Topics (Syllabus Outline)	• Introduction, taxonomy and the evolution of early vertebrates • Evolution of fish to amphibians • Evolution and origin of "reptiles" • The birds • Evolution and origins of mammals
Relationship to Other Courses within the Program	In line with school policy, there are no formal pre-requisites. This course allows students to draw on material that they have learned in various 1st-year biological subjects and apply this to understanding Vertebrate Life. In 2nd year, useful companion subjects are BIOS 2011 (Evolutionary and Physiological Ecology), BIOS 2031 (Biology of Invertebrates), BIOS 2051 (Flowering Plants) and GEOS2071 (Life Through Time). This course is assumed knowledge for BIOS3601 (Advanced Field Biology).

4. Rationale and Strategies Underpinning the Course

Teaching Strategies	Teaching includes lectures and practicals, with continuous assessment. As well as being introduced to theories currently used in our understanding of the origin of vertebrates and their traits, students will be challenged to continually evaluate the basis and evidence for these theories.
Rationale for learning and teaching in this course[6],	**Suggested approaches to learning in the course, and resource materials** Students should approach each component of the course with the aim of evaluating whether particular aspects of biology are relevant to management decisions in the context of the particular conservation issue presented. As this is a fundamental knowledge course, memory work will be a necessary component. There is also a large volume of material which student will encounter so students are strongly encouraged to study as they go. **Relying solely upon last minute preparation for the final prac exam is NOT advised.** You are expected to attend all your scheduled classes. Since this subject is **NOT** offered in distance mode, if you miss classes, your progress will be significantly hindered. After attending lectures and pracs much of the material can be studied independently, with the aid the textbook, lecture outlines (on the web), and the references contained in the lecture notes. Some of the practical exercises are to be completed independently. However, it is advised that students should plan to stay for the duration of 3 hour lab classes. There is a strong correlation between how long students stay in a lab and their final lab assessment grade. The demonstrators are casual staff, and are therefore difficult to contact outside prac times – use them while they are in prac. Each assessment appears in the schedule with the code of the class to which it relates most strongly. However, this course aims to develop the ability to integrate different strands of information, so a student might use information from any of the classes in any of the assessments, especially in more general exercises such as the research assignment.

[6] Reflecting on your teaching

5. Course Schedule

Some of this information is available on the Online Handbook[7] and the UNSW Timetable[8].

[7] UNSW Virtual Handbook: http://www.handbook.unsw.edu.au
[8] UNSW Timetable: http://www.timetable.unsw.edu.au/

WEEK	LECTURE Mathews D Mon 11-12 pm	LECTURE Mathews D Thursday 4-5 pm	LAB E26Teaching lab 3 Tues 10-1 pm; 2-5 pm
2 Mar 5	Introduction/ Early Vertebrates Mike Archer	Classification, Taxonomy & Cladistics Sue Hand	Amphioxus/Cunjevoi
3 Mar 12	Fish 1. Jaws & sharks Iain Suthers	Fish 2. Rays & teleosts Iain Suthers	Shark Dissection I
4 Mar 19	Fish 3. Modern fish Iain Suthers	Fish 4. Lobe fins Iain Suthers	Shark Dissection II
5 Mar 26	Frogs 1 Dan Noble	Frogs 2 Dan Noble	Fish: Jaws and Lungs
	EASTER/MID SESSION BREAK	30 March - 8 April	
6 Apr 9	Reptiles 1 Dan Noble	Reptiles 2 Dan Noble	Tetrapod Skull and Skeleton
7 Apr 16	Birds 1 Richard Kingsford	Birds 2 Richard Kingsford	Lab Quiz *and* Amphibians & Amniotes
8 Apr 23	No lecture	No lecture	No practical class
9 April 30	Birds 3 Richard Kingsford	Birds 4 Richard Kingsford	ZOOMOBILE *and* Turtles, Crocodiles & Birds
10 May 7	Birds 5 Richard Kingsford	Origins of Mammals Mike Archer	Birds in their Habitat **Centennial Park**
11 May 14	Monotremes Mike Archer	Marsupials 1 Mike Archer	Mammal Skeletons 1
12 May 21	Marsupials 2 Mike Archer	Placentals Sue Hand	Mammal Skeletons 2
13 May 28	Humans as Vertebrates Darren Curnoe	Australian Mammal Extinctions Mike Archer	Practical Exam

6. Assessment Tasks and Feedback

Task	% of total mark	Assessment Criteria	Date of		Feedback		
			Release	Submission	WHO	WHEN	HOW
Prac Class drawings	10	Thoroughness and precision of drawing and labels	Wks 2-5	End of class	Tutors	Week following submission	Written comments on drawings
Research Assignment	15	Articulation of topic, synthesis and depth of background material, development of arguments, accurate summary of taxonomy	Wk 2	Wk 8 26 April 15	All lecturers	Wk 11	Written comments on assignment
Bird Survey of Centennial Park	5		Wk 10	End of class	Tutors	Wk 12	Written comments on report
Lab Quiz	10	Accuracy of answers based on lab materials from Wks 2-6	Wk 7	End of quiz	Sue Hand	Wk 7	Mark
Practical Exam	20	Accuracy of answers based on lab materials from Wks 2-12, emphasis on Wks 6-12	Wk13	End of class	Mike Archer		With final results
Final Exam	40	Accuracy of answers based on interpretation of lecture material and recommended readings	Exam period	End of exam	All lecturers		With final results

The website for BIOS2061 Vertebrate Zoology can be accessed via Moodle.
The username is your student number and the password is your unipass. Lecture notes as PDF files will be posted at this site soon after the lecture.

Lab quiz – is an on-line multiple choice exam. No materials can be taken into the quiz.

Practical exam - is of the "musical chairs" type where you have 1.5 minutes at each question and then move on to the next. You may only take writing materials into the exam.

The final theory exam - will be of two hours duration and will be held during the normal UNSW exam period at the end of Session 1 as scheduled by the registrar. No notes, books or examination aids of any kind will be allowed. The University expects that all students (domestic and international) to be present and available until the end of the examination period. Exchange and study abroad students are required to sign a declaration to this effect-- but many seem to forget this. There are also cases of local students who book holidays during the exam period. While we can of course take medical and misadventure considerations into account, other matters are not grounds for rescheduling exams or giving additional exams before or after the scheduled exam.

Submitting your Practical Drawings

Your practical drawings for Weeks 2 to 5 must be submitted before you leave the lab in each of those weeks. Late submissions will have marks deducted (10% per day). If you have a problem that affects your work, you should immediately apply for special consideration and contact the appropriate lecturer if you need an extension.

Guidelines for Practical Drawings

Each drawing should be made on ONE side of an unlined sheet of white A4 paper.

Each drawing should include a TITLE, LABELS and a SCALE BAR.

All drawings, the title and the labels should be done in pencil ONLY (preferably soft lead that will not smudge). And, the pencil should be SHARP!

Drawings should be neat, clean and large (fill about 2/3 of the page so as to leave enough space for clear labelling).

Labels should be written horizontally, and must be accurate and spelled correctly.

Each label indicator line must be straight (use a ruler) and should not cross over other label lines. Do not use arrow heads!

The scale bar should represent a 'rounded' number such as 500μm or 20mm NOT 133.7mm!

Tips for preparing your Research Assignment (p. 25)

This assignment is a major part of the Vertebrate Zoology course and is worth 15% of the total mark.

Make sure it is submitted on or before the due date. Late assignments lose 10% of the assignment mark per day.

Scientific reporting depends on data. Such data are first presented in PRIMARY SOURCES of literature, that is from material actually written by the people who did the research. Secondary resources are those written by people who did not do the work but gathered the data from primary sources. This includes review type articles. In your bibliography at least FOUR primary sources must be used (of at least SEVEN sources listed). These primary sources will usually be from scientific journals.

Web pages are (in general) not primary literature sources; they have not been peer reviewed so their information cannot be trusted as scientifically rigorous.

Sources of information must be acknowledged for two reasons: to give credit where it is due and to allow the reader to check the source. The reader may need to look up your sources to get further information about some aspect to which you refer. You will no doubt do this yourself by using the reference lists at the end of some papers to find more information about the topic. A reader may also want to check the actual meaning of something taken out of context. To facilitate these uses of source citation, most Australian scientific writers follow the guidelines for citation recommended by the Australian Academy of Science and as used by CSIRO journals.

You are required to follow this, and the main requirements are:

1. In the text, cite the author(s) by surname and the year of publication; e.g. Glutz (1978) or Smith and Jones (1989). If there are more than two authors, only the surname of the first is given and the others are represented by the notation et al. (note that *et al*. may be in italics in some journals, although this practice is declining); e.g. Wilson et al. (1956).

All authors will be given in a list at the end of the assignment. If several sentences or even an entire paragraph rely on the same source of information, it is not necessary to repeat the citation at the end of each sentence. It is sufficient to make the citation at the end of the 'block' as long as it does not include more than one paragraph. If in doubt, read the text you have written carefully and ensure that it is absolutely clear what the source of all information is. You can check on how this works by looking at the introduction to any recent Australian scientific paper. The source of all tables and figures must be cited in the legend of **each** and **every** one. If you have modified them in some way, the form of citation is 'Modified from Smith and Wesson (1989)'.

2. A reference list at the end of the assignment includes ALL works cited in the text. However it does not include other sources you used for background but did not actually cite in the text. This is NOT a bibliography but a listing of citations. We assume you have read wider and covered more sources than you actually used in the final draft.

The form of the reference list is that of any recent CSIRO journal (see details in the Research Assignment p. 25).

Reports submitted which do not follow these guides for listing of sources will be returned without marking.

Submitting your Research Assignment

You must submit your assignment through ***Turnitin*** via the BIOS2061 Vertebrate Zoology interface on Moodle. A hard copy of your assignment must **ALSO** be submitted with a cover sheet, before 4 pm on the due date, to the BSB Undergraduate Office (G27) Ground Floor, Biological Sciences Building (see also Administrative Matters).

7. Additional Resources and Support

Text Books	Suggested Text: Pough, F.H., Janis, C.M. and Heiser, J.B. (2012). *Vertebrate Life*. 9th Edition. Prentice Hall International. The text book is an integral part of this course. Be sure to get the latest edition as it is completely revised from earlier editions (e.g. 5th). Recommended Reading: Van De Graaff, K.M. and Crawley, J.L. (2009). *A Photographic Atlas for the Biology Laboratory*. 7th Edition. Morton Publishing Company, Englewood, Colorado. Shubin, N. (2008). *Your Inner Fish: A Journey into the 3.5-Billion-Year History of the Human Body*. Vintage Books, New York.
Course Manual	Course manual will be available to purchase from the UNSW Bookshop; it will also be posted on Moodle.
Required Readings	Because this course is designed to develop and evaluate students' ability to select and criticize material, students make their own choices of reading matter from the material presented in classes and course manual.
Additional Readings	Other references will be given in individual lectures, using citations of electronically available material Demonstrators and tutors. They can help you integrate the lecture and practical material. Note however, that they are casual staff NOT paid outside class hours, so use them during class!! Lecturers: As the ultimate source of help, for each lecture or prac, the lecturer responsible is indicated by their name in the schedule. Enquiries about the contents of this class, or requests for appointments, should be directed to this lecturer's email address. It will be much easier for the lecturer to help you rapidly if you come with a written attempt at a problem, or a page of notes on which you have identified your FIRST point of difficulty.
Recommended Internet Sites	Online material Lecturers put notes for their lectures onto Moodle Lectures are available as iLectures This Manual is available on Moodle UNSW Library. One starting point for assistance is: info.library.unsw.edu.au/web/services/services.html From the library website, the Sirius Database is useful for accessing scientific databases such as current contents and science citation index.
Societies	Royal Zoological Society of NSW: www.rzsnsw.org.au
Computer Laboratories or Study Spaces	See BSB Student Office (located Biolink Ground Floor G27) for access.

8. Required Equipment, Training and Enabling Skills

Equipment Required	<u>For Labs</u>: 1. Your dissecting instruments from First Year Biology. From this kit the only instruments you will use are **nurses' scissors** (=one blunt blade and one sharp blade) and **blunt probe**. 2. Note plain (un-lined) paper/pencils/eraser for drawings of dissections and lab material. A "Visual Diary" which is a blank notebook is a good idea. 3. **LAB COAT** and **CLOSED TOED SHOES**. University-wide requirements mean that we need to ensure that all students are wearing the appropriate safety clothing in these labs. You must bring these items to every lab class otherwise you will not be allowed to attend. If you forget your lab coat, disposal lab coats are available for purchase at the BSB student office (Biolink G27). <u>For Field Trip</u>: Closed toed shoes, rain gear, sunscreen, drinking water

9. Course Evaluation and Development

Student feedback is gathered periodically by various means. Such feedback is considered carefully with a view to acting on it constructively wherever possible. This course outline conveys how feedback has helped to shape and develop this course.

Mechanisms of Review	Last Review Date	Comments or Changes Resulting from Reviews
Major Course Review		This course has been progressively modified over the years, as student numbers have grown, so that more intensive teaching methods are inappropriate.

CATEI **myExperience**	2015-2016 2017	Student feedback on the course is gathered periodically, using various means, including the Course and Teaching Evaluation and Improvement (CATEI) Process and in 2017 myExperience. This feedback is generally positive, and written comments show that any aspect of the course which one student disliked was usually well-liked by another student. Nevertheless, all suggestions for improvement are considered carefully with a view to acting on them constructively where possible. For example the dissections are seen by some students as most useful because they are hands-on, while other students feel they needed strong direction in the labs with exact questions about what they should learn from each lab. Therefore we have reduced the scope of some exercises, and have added more direction to the lab notes where there are especially large numbers of specimens.
myExperience	2018	In 2018, myExperience will be open to students in Week 11 of the semester and close prior to the exam period.

10. Administration Matters

Expectations of Students	You are expected to attend all your scheduled classes. **Field trips are compulsory.** Since this subject is **NOT** offered in distance mode, if you miss classes, your progress will be significantly hindered. Any alterations to the schedule will be announced in a preceding class. If you miss a class, it is your responsibility to (i) catch up on the course material, and (ii) find out the details of any announcements. Students whose attendance at classes or assessment is affected by obligatory religious ceremonies should discuss ways of dealing with this clash with one of the convenors prior to, or at the commencement of, the course; you may be required to show proof of the nature of the ceremony and your obligation to attend. **Suggested approaches to learning in the course, and resource materials** Students should approach each component of the course with the aim of evaluating whether particular aspects of biology are relevant to management decisions in the context of the particular conservation issue presented. As this is a fundamental knowledge course, memory work will be a necessary component. There is also a large volume of material which student will encounter so students are strongly encouraged to study as they go. **Relying solely upon last minute preparation for the lab quiz and final prac exam is NOT advised.** You are expected to attend all your scheduled classes. Since this subject is **NOT** offered in distance mode, if you miss classes, your progress will be significantly hindered. After attending lectures and pracs much of the material can be studied independently, with the aid the textbook, lecture outlines (on the web), and the references contained in the lecture notes. Some of the practical exercises are to be completed independently. However, it is advised that students should plan to stay for the duration of 3 hour lab classes. There is a strong correlation between how long students stay in a lab and their final lab assessment grade. The demonstrators are casual staff, and are therefore difficult to contact outside prac times – use them while they are in the prac.
Assignment Submission	Due dates, word-lengths, percentages, and the staff member responsible are shown in the schedule. Assignments are due on the date shown in the schedule. Practical reports must be submitted before leaving the laboratory (Weeks 2-5) or the field excursion (Week 10). Assignments should be submitted via Blackboard through **Turnitin**. A **hard copy must ALSO be submitted**, by 4 pm on the due date, in the BEES assignment box, at the Student Office (G27), BioLink building. Assignments must have a cover sheet firmly attached; cover sheets are available from the school office. **You must keep a photocopy of all work handed in**. Late assignments will have marks deducted as outlined in the schedule above. If you have a problem that affects your work, you should immediately apply for special consideration and contact the appropriate lecturer if you need an extension for a particular report or assignment. If you need a long extension, tell the lecturer well before the deadline. BEES cover sheet and related information are at http://www.bees.unsw.edu.au/biosciences-student-office
Work Health and Safety[9]	The School of BEES values the health and safety of all persons associated with its activities. The School is committed to the expectation, as outlined in the UNSW WHS Policy, that no one will come to harm whilst engaging in research, teaching or learning, or any other activity undertaken by BEES workers, students or others. To achieved this expectation everyone must ensure they take all reasonable care for their own health

[9] UNSW Health & Safety

and safety, and also take all reasonable care that the health and safety of others is not adversely affected either by their acts or omissions. In addition, it is a legal requirement that all workers, students and others comply with any reasonable instruction given by UNSW with regards to health and safety to ensure UNSW is in compliance with the NSW WHS Act and Regulation 2011.

The School of BEES follows the UNSW chain of HS responsibility and accountability for all persons in the workplace, extending down from the Head of School through to the students undertaking BEES courses. Within this chain of responsibility and accountability, the Course Convener is responsible for ensuring all activities associated with their course are safe. The Course Convener has identified all potential hazards associated with course activities and documented risk control measures to ensure your health and safety. For each activity, clear written instructions are given and appropriate hazard warnings or risk minimisation procedures included for your protection. It is the student's responsibility to prepare for all practical work. Students should be familiar with the written procedures scheduled for the practical class and follow all personal protection requirements specified to complete the exercise in a safe manner. Provided it is safe to do so, students must comply with all safety instructions given by the Course Convener and/or Laboratory / Field Demonstrator, and observe the safety Information located outside or within teaching rooms. If you are unsure of any safe work procedures or written instruction regarding safety, you should seek further information from the Course Convener and/or Laboratory / Field Demonstrator before attempting the task.
In addition, if you observe any unsafe work environment, procedure or equipment you have a duty to ensure that the hazard is reported and appropriate steps are taken to prevent harm. You should be aware of your responsibilities (http://www.safety.unsw.edu.au/). Your colleagues will be grateful that you have helped ensure the continued enjoyment of their day without any nasty surprises.

General conduct

A laboratory is for serious work not horseplay. Eating, drinking or smoking in laboratories is not allowed. Students must read the instructions to their laboratories carefully beforehand and be aware of all possible hazards.
No undergraduate students will be allowed to work in the laboratories outside class hours without permission and some supervision.
All accidents and injuries must be reported to the lecturer or demonstrator in charge of the practical class for treatment if necessary. A 'Hazard/Incident' report should be filled in if an accident or incident occurs without causing an injury. With injury, an additional 'Injury/Loss of Time' report is also required.
Never dispose of broken glass or other dangerous rubbish in waste paper baskets. Put broken glass into bins marked 'broken glass' and other sharp objects into bins labeled 'sharps' or 'contaminated sharps'.

Laboratory and protective clothing

Clothes should protect your body and not be highly inflammable. Laboratory coats are essential in all laboratories. You will be asked to leave if a supervisor feels your attire puts you at risk. Where necessary, safety equipment will be provided and should be used as directed.
Closed-in shoes are compulsory so they can give adequate protection against corrosive liquids and cuts. Persons wearing thongs or arriving in bare feet will not be allowed into practical classes.

Fire hazards

Students with long hair should tie it up while working in the laboratory, since long, loose-hanging hair can be a nuisance and a serious fire hazard.

Use of fire extinguishers

Electrical fires must not be fought with liquid-foam extinguishers dry powder, CO_2 or BCF (Bromochlorodifluoromethane) types are more suitable. Fires caused by **sodium** should not be fought with liquid-foam or CO_2. Use solid powder or BCF. Report any use of a fire extinguisher so that the cylinder can be refilled. After using BCF or CO_2 extinguishers, ventilate the area thoroughly to remove vapours.

	If clothes catch fire *1. If your own clothing catches fire* **Do not run**. If there is no one to help you, promptly lie on the floor and roll over and over to smother the flames. *2. If another person's clothing catches fire* Force the person to lie down on the floor immediately. This prevents the flames from reaching the eyes and entering the nose. Roll the person over and over on the floor to smother the flames. A fire blanket or laboratory coat may be used to smother the flames. **Never** use a chemical fire extinguisher. ***Evacuation*** If there is a fire, explosion or other major calamity an alarm will sound. Follow the instructions from your lecturer or demonstrator. Close all the doors and windows if possible. Quickly check to see that everyone is out of the room. Move steadily to the nearest stair well and out of the building. **Do not use the lifts.** Assemble in the grassy area in front of the Biological Science Building. Supervisors should bring the class roll and check that everyone has left the building. ***Accidents*** ***Fire or serious injury*** Telephone 56666 and then describe carefully: • The location of the emergency, giving the name of the building, the floor and the room number. • The type of emergency. • Your name and extension number. ***Minor injuries*** Telephone the University Health Service on 55425 or 55426 or 55427. ***First Aid*** First Aid may be obtained by phoning: Ms Rosa Ascencio on 9385 2016 Mr Frank Hemmings on 9385 3274 Ms Rochelle Johnston on 9385 8054 Ms Mira Van der Ley on 9385 8031 In case of an electric shock, shout for help. Disconnect the current or remove the person from the current using some **insulated** material. If there is no pulse and no breathing, start external cardiac compression and mouth to mouth artificial respiration. When the pulse and breathing have been restored get medical aid immediately. If high voltage current is involved, **do not** attempt to assist the person until the current has been disconnected at the mains. **(FOR ADDITIONAL INFORMATION SEE THE COPY OF THE UNIVERSITY'S SAFETY MANUAL IN THE LECTERN IN EACH LABORATORY)**
Assessment Procedures **UNSW Assessment Policy**[10]	Assignment procedures are described above in "Assignment Submission". If you have a problem that affects your work, you should immediately apply for special consideration and see the appropriate lecturer if you need an extension for a particular assignment. If you need a long extension, tell the lecturer well before the deadline. The final examination will be scheduled by the examinations branch. Students should be available for examination throughout the entire UNSW mid-year examination period. Supplementary examinations will only be granted to students who miss the final examination due to illness or other unexpected reasons outside their control. A student who wishes to apply for a supplementary examination should contact one of the course convenors as soon as the problem becomes apparent, as well as applying for special consideration through the student office. If a supplementary examination is granted, it will be held before the beginning of session 2. Until then, you should maintain a current address with SIS, and be available for contact and assessment.

[10] UNSW Assessment Policy

Equity and Diversity[11]	Those students who have a disability that requires some adjustment in their teaching or learning environment are encouraged to discuss their study needs with the course Convenor prior to, or at the commencement of, their course, or with the Equity Officer (Disability) in the Equity and Diversity Unit (9385 4734 or http://www.studentequity.unsw.edu.au/). Issues to be discussed may include access to materials, signers or note-takers, the provision of services and additional exam and assessment arrangements. Early notification is essential to enable any necessary adjustments to be made.		
Student Complaint Procedure[12]	**School Contact**	**Faculty Contact**	**University Contact**
	BEES Grievance Officer A/Prof. Scott Mooney s.mooney@unsw.edu.au Tel: 9385 8063 School Student Ethics Officer A/Prof. Stephen Bonser s.bonser@unsw.edu.au Tel: 9385 3863	The Science Student Centre Tel: 9385 6125 sso@unsw.edu.au	The Student Conduct and Integrity Unit can provide information about the complaints process Telephone 02 9385 8515, email studentcomplaints@unsw.edu.au University Counselling and Psychological Services[13] Tel: 9385 5418

[11] UNSW Equity & Diversity
[12] UNSW Student Complaint Procedure
[13] University Counselling and Psychological Services

12. A sampler of things for BIOS2061 students to consider when writing essays

In what follows, we have given you guidelines for improving your writing for essays and later research theses, publications etcetera. That said, some scientific journals have specific requirements such as how references should be formatted in the reference list or cited in the body of your paper. But for general essays (as in this course) and most scientific writing, the following guidelines should be followed.

GENERAL ADVICE

1. Read the instructions for any essay you are asked to write very carefully--and follow them. If you do not understand all of the instructions, ask for clarification. If you skim the instructions and fail to do what you have been asked to do, you will lose marks.
2. Make certain that you understand what aspects of the topic you are expected to address.
3. Normal scientific papers have the following: Title, Author, Abstract, Introduction, Methods, Results, Discussion, Conclusion, Acknowledgements, References, Appendix. Student essays, however, may only have: Title, Author, Abstract, Introduction (or Background), Discussion, Conclusion, Acknowledgements, References.
4. Outline your essay first. Make a list of dot points to remind you about the main topics you intend to cover. Then go back and start to flesh them out. Keep the length of each section under control so the length of the whole essay doesn't 'blow out'. It's much harder to condense an essay that has become too long than it is to write up to the limit allowed.
5. Before you start fleshing out the dot points, read what you need (publications that will provide the information you require) and take notes associated with the dot points. Be sure you take careful notes about the reference and page number from which you obtained any particular bit of information you are likely to use in your essay.
6. Write simple, short sentences. It is called the 'KISS' principle: 'Keep it simple stupid!' If your sentences become too long or entangled, they will become increasingly impossible to decipher. Examiners then begin to doubt your understanding or ability to communicate and may give up trying to make sense of your writing. This is a dreadfully common but easily avoided trap.
7. After you write something, read it out aloud. If you find you have to pause or stop and think about what you have said or meant, rewrite it until it is easy to say smoothly, quickly and clearly.

8. Writing IS rewriting. Never stop with your first draft. It can always be improved whether you are 18 or 180 or improved with rewriting even if you have already done this 10 times. Sometimes it is best when you have finished to leave the draft alone for a day and then revisit it after you have done other things.
9. Don't fall in love with the sentences or sections you have written or you won't be able to trim them down, revise them or, if necessary in the end, discard them.
10. Don't pad your writing out with bullshit because it only ends up annoying the reader and losing you marks. Say what you need to say to make the points you need to make with an economic use of carefully chosen words—and then stop.

OVERALL STRUCTURE

11. All complete sentences (the only kind you should write) should have a noun or pronoun (i.e., 'subject' of the sentence) and a verb ('action' word). For example, 'Dogs exist.' is a complete sentence. In contrast, 'Dogs throwing up inside.' is not a complete sentence because it's missing a verb.
12. Don't be guilty of creating '*non sequiturs*' (something that 'does not follow') in your writing. Make sure that the sense of what you are saying or arguing flows naturally from start to finish. A *non sequitur* is something that appears in a case being made without any logical reason for it being there. For example, 'There are many kinds of dogs based on facial shape and body form. Cat canines are ugly.' The second statement has no relation to, and does not build from (or on), the first statement. It causes the reader to screw up their face and say 'What's that got to do with anything?' or 'How did we get to that conclusion?' In pure logic, a *non sequitur* is a conclusion that does not follow from the statements that went before. For example, 'My dog has fleas. Fleas love my dog.' The second statement is not a justifiable conclusion based solely on the first statement. *Non sequiturs* are far too common in student essays!
13. In terms of the logic of your arguments, make sure your conclusions *do* follow from the statements or arguments that precede them. If your premises are flawed, your conclusion will be invalid.
14. Use punctuation to say exactly what you mean. Recall the outcome of the following sentence being given to a class of students who were asked to punctuate it to clarify its meaning: 'A woman without her man is nothing'. The males punctuated it as follows: 'A woman, without her man, is nothing'. The females, however, responded with: 'A woman; without her, man is nothing.' Punctuation is powerful so use it to say exactly what you mean.
15. In general, please try NOT to right and left justify your writing. You should only left justify text. If you do justify the right and left sides, not only is it harder to read, the spacing between words

visually screws up which makes it hard for a reader to know if the actual spacing has errors.

16. In general, try to use a font that is *sans serif*—one that does not have 'tails' at the tops & bottoms of the letters. The *sans serif* font used here is Arial. It is easier than (e.g.) to read in essays, PowerPoint, etcetera. '*Serif*' fonts (such as Times New Roman) are just that much less crisp because the bases of the letters tend to approximate one another.
17. In general, do not use coloured letters in your text or diagrams unless it is necessary. Use black letters. Similarly, do not use bold format unless it too is necessary for some technical reason.

FIGURES

18. Use figures to complement the text and vice versa. Do not use the text to explain the figure if it is self-explanatory; if you do, you are wasting words.
19. Make sure you use a scale if there is an object in the figure.
20. Make the figure just large enough so what needs to be visible is clearly visible. Keep extraneous, irrelevant material out of figures.
21. Make sure the caption clearly explains what the figure is depicting.
22. The caption does not need to be a complete sentence although a complete sentence may be more easily understood.
23. Be careful to cite the source of the figure as part of the caption. For example: 'Comparison of the number of species of macropodids in each habitat type (after Dawson 1975)'.

STOPS

24. Never put a full stop after a phrase. For example, the title of the essay 'Behaviour in Sugar Gliders' should not have a full stop after 'Gliders' because it is not a complete sentence.
25. Never put a full stop at the end of part of a sentence *inside* parentheses. For example, 'The fox is a canid (which in turn is a carnivoran).' Include a full stop only if the whole sentence is inside parentheses. (The fox is a canid, which in turn is a carnivoran.)
26. If you are quoting someone else's statement and use a whole sentence as it was originally published, put quotes around it and, in the reference to the quote, note the page on which the quote appeared. For example, 'Clinker (1987, p. 33) said "I did not mix either blood sample with peanuts." '
27. But if you are lifting part of a quote out of a longer statement, use three (3) stops to represent the missing bits of the original sentence. For example, 'Clinker (1987, p. 42) said "…but it was not the outcome we expected." '

28. Abbreviations should get a full stop as appropriate particularly in situations where the last letter of the abbreviation is *not* the last letter of the word being abbreviated: e.g., et al., *viz*., etc., etcetera. Conversely, where the last letter of the abbreviation *is* the last letter of the word being abbreviated, you should *not* use a full stop: e.g., Dr, St (for Street), Mr, Ms etcetera.

29. Do not use abbreviations at the beginning or ends of sentences. For example, '*Petaurus australis* has many attributes including odour, colour etcetera'. [Not good form: '*P. australis* has many attributes including odour, colour etc.']

COMMAS

30. Use commas to set off what are parts of a sentence that require you to pause when you read the whole thing. For example, 'There were no vampires, black or white, visible anywhere in the cave.'

31. Normally you would never put a comma before the word 'and'. For example, 'It was a dark, stormy night and he had no idea where he was.'

32. The word 'however' should *almost* always be set off with commas. E.g., 'It was indeed a dark and stormy night, however, he was too wasted to care.' Always consider whether the word 'but' might be more succinctly used. E.g., 'It was indeed a dark and stormy night, but he was too wasted to care.'

SEMICOLONS & COLONS

33. If in your writing you want to tie closely together what are in fact two complete sentences, do it with a semicolon. For example, 'Pasteur realised there was only one way to stop the infection; he had to bite his own leg off below the knee.'

34. Use a colon if you are trying to follow a statement with an appropriate action that is not in the format of a complete sentence. For example, 'Pasteur realised there was only one way to stop the infection: bite off his own leg below the knee.

35. If you make a statement followed by a series of points, separate the statement and the points with a colon. For example, 'The dog had lost too many things: its ear, its hearing and its toy duck.'

36. Alternatively, you can use a double dash instead of a colon in situations of the two kinds of statements just noted above: 'Pasteur realised there was only one way to stop the infection—bite off his own leg below the knee.'

CONTRACTIONS and ABBREVIATIONS

37. Contractions should not be used in scientific writing. Break them up and use the two words separately. For example, use ‘do not’ (not don’t), cannot (not can’t), will not (not won’t), that is (not that’s) etcetera.

38. If you are going to use abbreviations in an essay or scientific paper, make certain that these are explained either in the Introduction or the first time they are introduced in the text. For example, ‘The Indian Ocean Dipole (IOD) appears to be related to droughts in Australia. If the IOD is in fact the cause of these, monitoring changes in the IOD may provide a predictive tool to anticipate droughts.’

ITALICS

39. Latin/Greek words should normally be italicised: e.g., *et al.* (which is a Latin abbreviation for *et alia* which means ‘and others’).

40. Other normally italicised words include scientific names (e.g., *Petaurus australis*) and sometimes muscle or other formal anatomical names (e.g., *Gluteus maximus*).

41. Other words normally put in italics include: *ibid*, when you are noting a reference to a publication that you previously just noted and don’t want to keep repeating the details of the reference. For example, ‘Dogs are not adverse to eating anything with food value (Gobble 2003). It has been noted in Mexico that rabid dogs have even been seen to consume cats (*ibid*).’

42. That said, some journals no longer require some foreign words to be presented in italics such as ‘et alia’. But in essays in UNSW, you should use *et al.* when referring to other things or persons implied to be included but not spelled out. For example, ‘There are nine species of singing whales (Flipper *et al.* 2004).’

43. While discussing *et al.*, it should be used when you are referring in the body of your essay to a single publication by three or more authors. If there are one or two authors, both names should be given in the reference in the text. For example, ‘The Golem was known to eat putrid fish (Gandarth & Wogwort 1735).’

44. Most scientific journals use italics for journal names in the reference list at the end of the paper.

45. Do not use italics to emphasize a word in a quotation from someone else just because you want to draw attention to it—unless you indicate after the quote that the emphasis is yours.

UNDERLINING

46. Underlining is an alternative to italics and shouldn't be used if italics are available. For example, 'The Eastern Grey Kangaroo (Macropus giganteus) is relatively uncommon in western Victoria.'

47. Underlining for emphasis is not a normal thing to do in scientific writing. The words used should be sufficient to communicate the meaning without the need to exaggerate this meaning using italics, bold or underlining.

SCIENTIFIC NAMES—FORMAL AND INFORMAL FORMATS

48. Terminology is as follows

    a. genus (singular); genera (plural)

    b. species (singular and plural)

    c. abbreviations: gen. for genus; sp. for species; spp. for more than one species

    d. *Macropus giganteus* (caps for generic names; lower case for species)

    e. Never start a sentence with an abbreviated generic name. For example, DO NOT say: '*M. giganteus* is big.' You must say '*Macropus giganteus* is big', even if you have just used the full name in the previous sentence. But if it is *not* at the beginning of a sentence and you have already indicated above this what the '*M.*' stands for, you can use the abbreviation.

    f. *Formal taxonomic* terms that need to have the first letter capitalised: the names of a genus (e.g. *Macropus*), subgenus (e.g., *Prionotemnus*), subfamily (e.g., Macropodinae), family (e.g., Macropodidae), superfamily (e.g., Macropodoidea), suborder (e.g., Phalangerida), order (e.g., Diprotodontia), etc. on up the line. For example, 'There are two Suborders, Phalangerida and Macropodiformes, in the Order Diprotodontia.'

    g. *Formal use of the taxonomic rank* involves capitalising the rank name: e.g., Subgenus *Prionotemnus*, Genus *Macropus*, Subfamily Macropodinae, Family Macropodidae, etcetera.

    h. *Informal taxonomic* terms from subfamily on up are not capitalised (unless at the start of a sentence) and have different endings than the above. For example: subfamily (e.g., macropodine; or macropodines if it is more than one species you are referring to), family (e.g., macropodid), superfamily (e.g., macropodoid), suborder (e.g., phalangeridan) and order (e.g., diprotodontian). Incidentally: 'macropod' is not a scientific word; it is an abomination used only by the scientifically illiterate!

i. When referring to attributes of species of a genus, you should not imply that these are attributes of the generic name. For example, you should say ‘All species of *Macropus* exhibit an enlarged fourth metatarsal and use embryonic diapause.’ You should NOT say ‘*Macropus* has an enlarged fourth metatarsal and uses embryonic diapause’ because it does not—it has species. The *genus* does not have feet or a reproductive tract. The *species* have enlarged fourth metatarsals and reproductive tracts.

WHEN TO USE WHICH OR THAT

49. When trying to decide whether you should use the word ‘which’ or ‘that’ you use ‘which’ if what follows that point in the sentence is not essential to the meaning of the sentence and could have been separated by a comma. For example, ‘The boy picked the black dog which was sitting in the corner’.

50. If what follows the which/that in the sentence is essential to the meaning of the sentence, you should use the word ‘that’. For example, ‘The boy picked the black dog that had watched him from the moment he walked in the door.’

51. In the first sentence above, ‘black dog’ is the significant bit hence ‘which’ is the correct word to use in linking the two parts of the sentence. In the second sentence, the fact that the dog was watching him becomes the key issue hence ‘that’ is the correct word to use to link the two parts of the sentence.

WHEN THERE IS AN ERROR IN A QUOTATION AND IT’S NOT YOURS

52. If you are quoting someone else’s statement and know it to be wrong in some detail (e.g., a word is misspelled), you need to put the term ‘sic’ in square brackets immediately after the word in the quotation that is incorrect. For example, ‘The resercher [sic] was determined to be a perfectionist’ (Dreadful 1999, p. 10).

REFERENCES AND REFERENCE LISTS

53. When citing references to back up what you are saying, it is always better if you can to use a primary reference than a textbook or other ‘secondary’ reference.

54. Do not cite or quote from a reference that you yourself have not actually seen. If you want to refer to a statement made by someone noted by someone else, and you have only seen the latter, then you need to come clean and say so. For example, you could say: ‘There are known cases of dog vampires (Bloodlusty 1867 *fide* Donabelievhim 1959).’ The Latin expression *fide* means ‘by faith’ and indicates that you are trusting Donabelievhim to have correctly reported what Bloodlusty actually said. Another way of expressing this is:

‘There are known cases of dog vampires (Bloodlusty 1867 as cited in Donabelievhim 1959).’

55. The main things to watch in compiling reference lists are accuracy and consistency. Make sure your references are word and punctuation perfect. Do not add or subtract words from the title of the paper or change the punctuation, even if it is in your opinion wrong.

56. In terms of consistency, make sure that whatever format rules you use, you use them consistently. For example, don’t capitalise some of the words in a book title and not others. If you capitalise words in one book in the list, make sure you do the same thing for all other books cited in the list.

57. Also, make sure that every reference you have noted in the essay is in fact detailed in the reference list at the end. Conversely, make sure all references given in the reference list are in fact cited in the essay and, if not, remove them from the reference list.

SPELL CHECKERS

58. ALWAYS use a spell-checker set for English (Australian) if it is available. But beware of the following problems.

    a. Spell-checkers will not know weather the whether is fine for the girls or there high-cut dresses over their are wear they where them when it reigns. Hence YOU must read your essay very carefully, word by word.

    b. If you are not careful, spell-checkers will try, inappropriately, to change words in quotes that you have used from other sources, or words in references listed in your reference list—and this must not happen.

THE PLAGUE KNOWN AS PLAGIARISM

59. Under no circumstances should you ever be guilty of plagiarism. Academics get fired if they plagiarise. All your work must be your own; if it is not and you have not acknowledged where something you have used has come from, you can expect a ‘0’ for a grade, or worse. Hence, please make absolutely certain that when you take notes from other works you have read that you carefully note where your notes came from—so you do not make the mistake of thinking further down the track that they were your words: an honest but fatal mistake.

Prof Mike Archer
Prof Suzanne Hand
BIOS2061 Vertebrate Zoology, 2018

NOTES

BIOS2061 Vertebrate Zoology Research Assignment

Assessment: 15% of course mark

Choose one (1) species from the list below and answer the following eight (8) questions about that species using the most up-to-date references you can access through UNSW Library and other sources. Make sure you cite in the text all references listed in your reference list (Question 9; see also 'Tips for preparing your Research Assignment' pp.7-8). Answers should be typed (e.g. Arial 12 pt) with 1.5 spacing. Assignments should be printed on one side only.

[fish] Mosquitofish or eastern Gambusia; African Lungfish; any stingray or stingaree (Dasyatidae or Urolophidae); Australian Sawtail *Prionurus* (or any other Australian surgeonfish-acanthurid)

[frogs] Peron's Tree Frog; Desert Tree Frog; Desert Froglet; Gastric Brooding Frog; Rocket Frog

[reptiles] Leaf-tailed Gecko; Perentie; Death Adder; Flatback Sea Turtle; Eastern Water Skink

[birds] Yellow-tailed Black Cockatoo; Eurasian Coot; Channel-billed Cuckoo; Osprey; Bush Stone Curlew; Little Penguin

[mammals] Thylacine; Western Quoll; Musky Rat-kangaroo; Grey-headed Flying-fox; Mountain Pygmy-possum

Name of your chosen species_____

Question 1: Taxonomy

For your chosen species, provide the following scientific names, and where possible the author and date of that taxonomic name. Note that the author and date should be separated by a comma (refer also to your lecture and lab notes about binomial nomenclature from Week 2).

Class_____ _____, _____

Order_____ _____, _____

Family_____ _____, _____

Genus_____ _____, _____

Species_____ _____, _____

Binomial name

_____ _____ _____, _____

(genus) (species) (author) (date)

Example:	Orange Leaf-nosed Bat	
Class	Mammalia	Linnaeus, 1758
Order	Chiroptera	Blumenbach, 1779
Family	Hipposideridae	Lydekker, 1891
Genus	*Rhinonicteris*	Gray, 1847
Species	*aurantia*	Gray, 1845

Binomial name

Rhinonicteris aurantia (Gray, 1845)

Note that in this case (Gray, 1845) is in parentheses to indicate that this is not the original combination of names. When Gray first described the species *aurantia*, he placed it in the existing genus *Rhinolophus* Lacépède, 1799. Later he erected the new genus *Rhinonicteris* for this species.

Question 2: Morphology

Describe the morphological features uniquely distinguishing your chosen species (half page)

Question 3: Evolution/phylogeny

Outline the evolutionary origins/relationships of your chosen species (half page)

Question 4: Distribution and habitat

Give the distribution and describe the habitat of your chosen species (half page)

Question 5: Reproduction (not behaviour)

Outline the reproductive method of your chosen species (half page)

Question 6: Behaviour (including reproductive behaviour)

Describe the behaviour/aspect of the behaviour of your chosen species (half page)

Question 7: Feeding ecology

Outline the ecology/aspect of the ecology of your chosen species (half page)

Question 8: Conservation status

Describe the conservation status and most significant threats to this species (half page)

Question 9

Using the guide given below as an example of the style you should follow here, list all references (at least 7) you have used to answer the questions above. At least four (4) references should be primary (journal) papers.

REFERENCE STYLE USED BY CSIRO JOURNALS

- *Journal article*
  Morton, S. R., and Baynes, A. (1985). Small mammal assemblages in arid Australia: a reappraisal. *Australian Mammalogy* **8**, 159-169.

- *Book chapter*
  Kirsch, J. A. W., and Calaby, J. H. (1977). The species of living marsupials: an annotated list. In ´The Biology of Marsupials´. (Eds B. Stonehouse and D. Gilmore.) Pp. 9-26. (Macmillan: London.)
- *Book*
  Breed, W., and Ford, F. (2007). ´Native Rats and Mice.´ (CSIRO Publishing: Melbourne.)
- *Thesis*
  Harding, H. R. (1977). Reproduction in male marsupials. A critique on sperm development and structure. PhD Thesis, University of New South Wales, Sydney.

  Harrison, A. J. (1961). Annual reproductive cycles in the Tasmanian scallop *Notovola meridionalis*. BSc (Hons) Thesis, University of Tasmania, Hobart.
- *Report or Bulletin*
  Chippendale, G. M., and Wolf, L. (1981). The natural distribution of *Eucalyptus* in Australia. Australian National Parks and Wildlife Service, Special Publication No. 6, Canberra, Australia.
- *Conference Proceedings*
  Driessen, M. M. (1999). Effects of fire on the broad-toothed mouse, *Mastacomys fuscus*, and other small mammals in buttongrass moorlands of western Tasmania - preliminary findings. In ´Bushfire99. Proceedings of the Australian Bushfire Conference, Albury, Australia, 7-9 July 1999´. Available at http://www.csu.edu.au/special/bushfire99/papers/ [accessed 1 May 2007].

  Web-based material

  Goudet, J. (2001). ´FSTAT, a Program to Estimate and Test Gene Diversities and Fixation Indices (Version 2.9.3).´ Available at http://www2.unil.ch/popgen/softwares/fstat.htm [accessed 15 November 2007].

PRACTICAL 1

INTRODUCTION TO CHORDATES

Cephalochordates

Amphioxus

Urochordates

Ascidians

Thaliaceans

Larvaceans

Dissection of Cunjevoi

THE CHORDATES

This large and well known group of animals share three fundamental characters:

♦ **notochord**

definition: a longitudinal rod, midline and dorsal. The main skeletal element in many chordates; becomes incorporated into the vertebral column of vertebrates. Flexible but not compressible, formed of connective tissue.

♦ **dorsal hollow nerve cord**

definition: single, hollow, longitudinal nerve cord that lies beneath the dorsal surface, dorsal to the notochord. In vertebrates differentiates into the brain and spinal cord.

♦ **pharyngeal slits**

definition: Slits in the pharyngeal wall that connect the lumen of the pharynx with the atrium (in urochordates and cephalochorates) or the outside (vertebrates, where present). Also called gill slits because gills evolve within these slits in the pharynx in fish, agnathans and larval amphibians. In other vertebrates this character is present only in the embryo, visible as a series of pharyngeal pouches.

One other character is also characteristic of chordates.

♦ **post-anal tail**

definition: muscular tail that extends posteriorly from the anus. This feature is linked to the presence of the notochord. In some vertebrates, such as humans, this feature has become vestigial.

Not all characters may be visible in adult animals and knowledge of the biology of a given species may be required to find them. For example, humans clearly have a dorsal hollow nerve cord (the spinal cord), but the pharyngeal slits are present only in the embryo, the notochord has become incorporated into the vertebral column, and the post-anal tail has become vestigial.

If any one of the three fundamental characters is present in a species, the other three are also represented. Therefore they serve to define a group, which in the traditional Linnaean taxonomy has been known as the **PHYLUM CHORDATA**. None of these characters are found outside this group and therefore CHORDATA is a true clade, definable by major apomorphic characters.

Three major lineages (clades) within the CHORDATA are defined by modifications to the notochord. These are classified as the following subphyla in the Linnaean taxonomy:

• **Subphylum: CEPHALOCHORDATA** - in which the notochord runs the length of the body.

• **Subphylum: UROCHORDATA** (also known as Tunicata) - notochord is in the posterior, or tail, region only.
• **Subphylum: VERTEBRATA** - in which the notochord is incorporated into the vertebral column.

We will examine the basic body plan of these three groups and the relationships between them. In so doing we will discover several major problems with the traditional taxonomy as listed above. Meanwhile it is sufficient to simply consider them as groups of animals which can be defined by observable characters and continue to use the traditional group names without worrying about the Linnaean hierarchy. Thus we can speak of ‘chordates’ and ‘vertebrates’ without ambiguity as long as we understand the characters that define each group. Whether they are a phylum, subphylum or whatever need not concern us at this point.

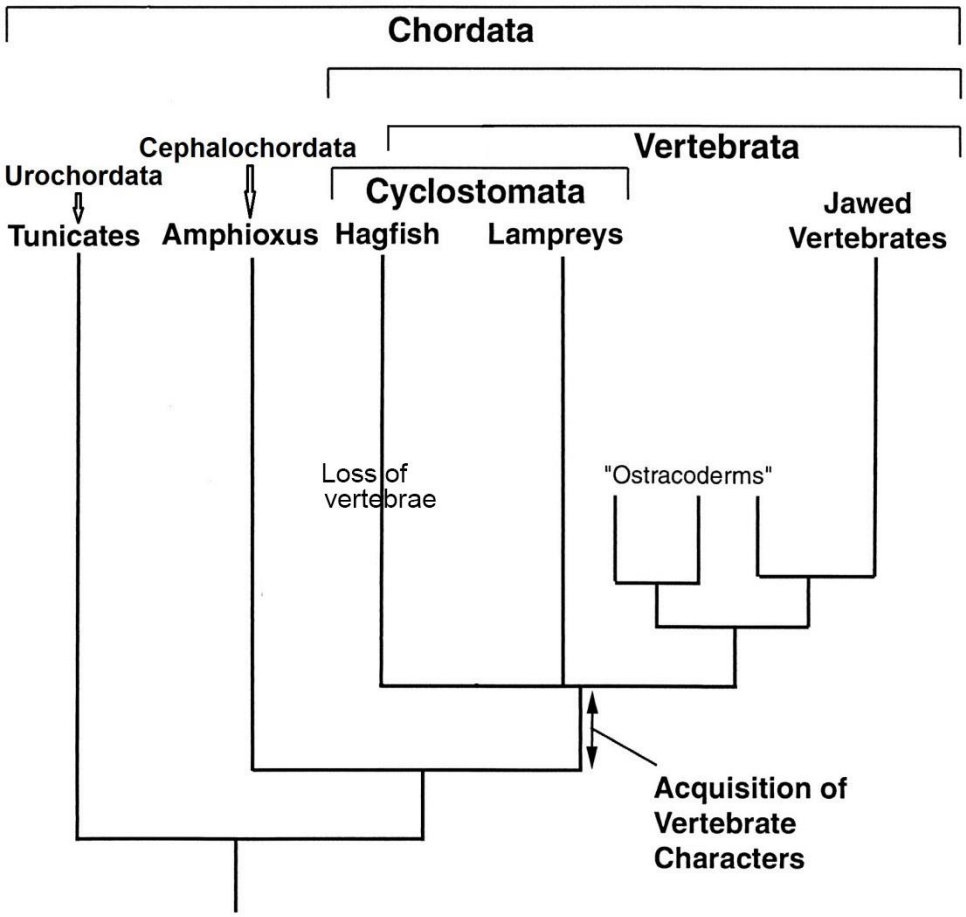


Figure 1. Proposed phylogenetic relationship of the three subphyla of the Phylum Chordata. Whether the sister clade to the Vertebrata is the Cephalochordata or Urochordata is not completely resolved, but most scientists believe it is the former with Urochordates being the most primitive chordates. (Also note the uncertainty about the position of the Hagfish with respect to the Subphylum Vertebrata.)

(Modified from Shimeld and Holland (2000). PNAS 97: 4449-4452)

AMPHIOXUS

Subphylum: CEPHALOCHORDATA

The chordate 'ground plan' - amphioxus as an example

Basic chordate anatomy can best be seen in one of the most primitive animals in the clade, the cephalochordate known as amphioxus or the lancelet. This small animal inhabits tropical and temperate sea coasts. It usually burrows in clean, shifting sand in shallow shore waters, leaving only the anterior end protruding (see Figure 2). At times amphioxus emerges to swim with rapid lateral movements of the body. The animal lacks appendages. Amphioxus is a filter feeder; water brought in through the mouth is filtered as it passes out through the pharyngeal gill slits and food particles are trapped in mucus secreted by the **ENDOSTYLE** located in the floor of the pharynx.

Endostyle: a ciliated groove running along the floor of the pharynx. Secretes copious amounts of mucus necessary for filter feeding (food particles become entrapped in mucus). Becomes the thyroid gland in some vertebrates.

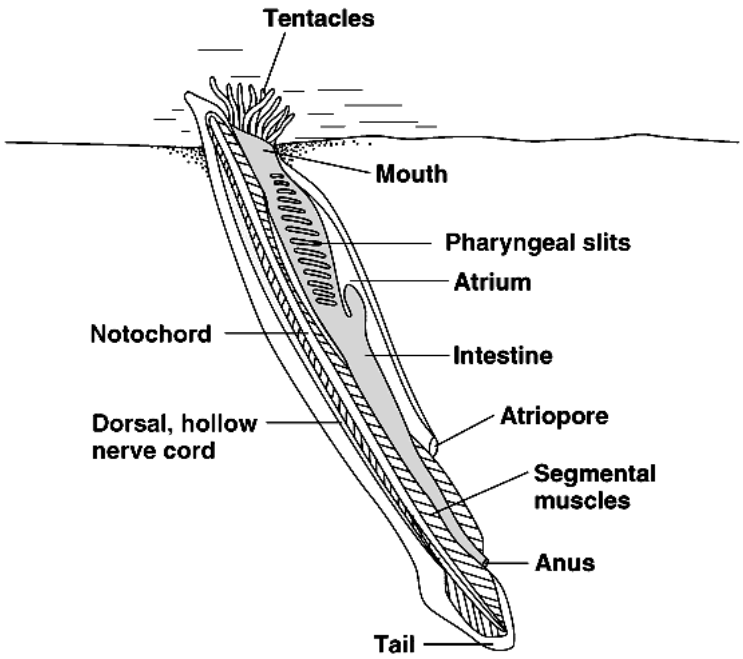


Figure 2. Amphioxus buried in sand with only anterior end protruding. The tentacles act to trap food particles and as the first filtering stage.
(Copyright Pearson Education Inc. Publishing as Benjamin Cummings)

Amphioxus (pronounced *am-fee-ox-us*) means 'both ends sharp' and was originally a genus name for a group of about two dozen species, but this same group had been

given the name *Branchiostoma* two years earlier (1834), so by the rules of zoological nomenclature the earlier name must stand. As these poorly known animals had no common name, at least in European languages, amphioxus came to be used as the common name for this group of species. The specimens we have in the Vertebrate Zoology Lab are probably the Californian Amphioxus (*Branchiostoma californiense*), which lives on the coast of Southern California and Northern Baja California.

The general features of the anatomy of amphioxus are shown in Figure 4.

We first need to define some terms routinely used in describing animal anatomy:

- ♦ **dorsal**: the 'upper surface' of an animal. In chordates this is defined as the surface above the notochord and associated nerve cord. From the Latin word dorsum meaning 'back'.
- ♦ **ventral**: the 'lower surface' of an animal, opposite to the dorsal.
- ♦ **posterior (aka caudal)**: towards the 'rear end' of an animal's body.
- ♦ **anterior (aka cranial)**: towards the 'front end' of an animal's body.
- ♦ **lateral**: towards the 'side' of an animal's body.
- ♦ **medial**: towards the 'midline' of an animal's body.

These terms can be combined to more accurately describe the location of a structure on an animal's body. For example, ventrolateral means to the side of the lower surface of the animal.

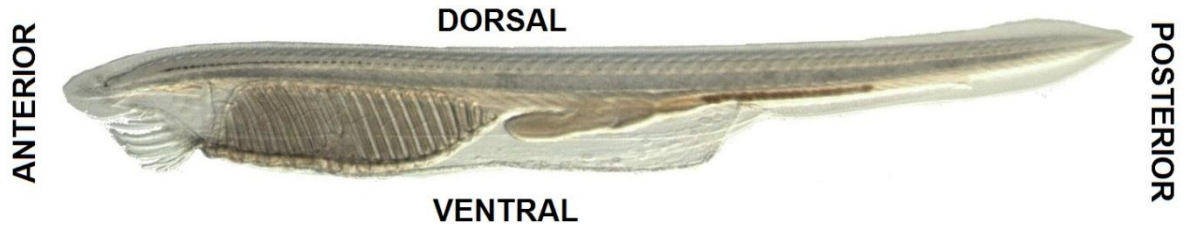


Figure 3. Dorsal and ventral surfaces and anterior and posterior ends of Amphioxus (*Branchistoma lanceolatum*)

(Photo: Manuel Irimo, Pascual and Juan Maesco, Universitat De Barcelona http://www2.ub.edu/comunicacions/cgi/principal.pl?fitxer=noticies/noticia004617.htm)

TASK: Examine a whole amphioxus

Using the teaspoon provided, remove one preserved amphioxus from the stock bottle on the side bench and place it in a watch glass. Examine the specimen using the binocular microscope. You will of course not be able to see most internal structures, but you should be able to identify:

♦ **Myomeres** (=myotomes)
definition: segmented bundles of muscle tissue that attach to the notochord and are responsible for the swimming action. In amphioxus they run the length of the body and are shaped like sergeant's stripes (chevrons).

♦ **Anus** (not always visible)

♦ **Buccal cirri** (tentacles)
definition: Buccal - oral. Refers to structures found in or around the mouth.
Cirri - a cluster of cilia or tentacles. In the case of the buccal cirri they are small, thin tentacles which form a sieve around the opening into the mouth. They are provided with receptor cells.

♦ **Dorsal fin**

♦ **Mouth**

♦ **Metapleural folds (lateral fins)**
definition: two folds (not true fins) that run on either side of the ventral surface in the region of the pharyngeal slits. They do not run back beyond the atriopore.

♦ **Gonads**
definition: organ that produces gametes; can produce either male gametes (sperm) in which case it is termed a testis, or female gametes (eggs) in which case it is termed an ovary. It is a useful term for an animal like amphioxus in which we humans cannot tell a female from a male (unless we examine the tissues under high power with a microscope).

♦ **Tail fin**

♦ **Atriopore**
definition: the exterior opening from the atrium. Anterior to anus.

See Figure 4 for an illustration of the external and internal anatomy of Amphioxus.

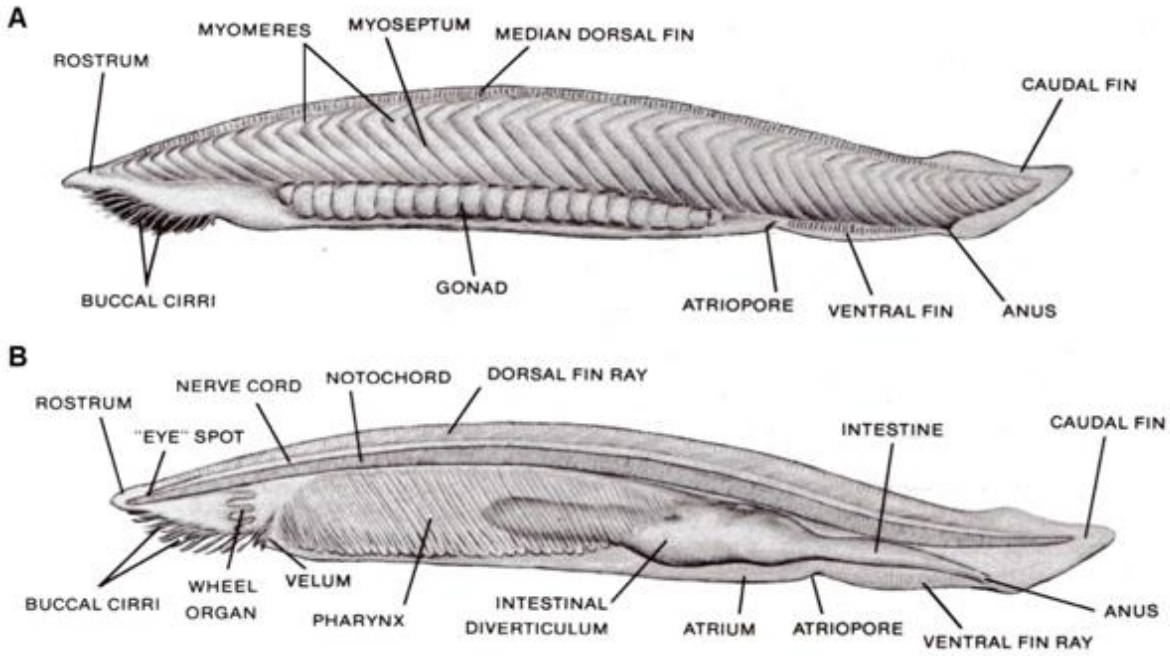


Figure 4. Lateral view of external (A) and internal (B) anatomy of Amphioxus. Note that in (B) the myomeres and gonads have been removed to illustrate the underlying structures.
(Source: University of Florida Vertebrate Zoology lab manual)

The pharyngeal slits, which in most aquatic vertebrates open from the pharynx directly to the outside of the body, are NOT visible externally. This is because in cephalochordates (and urochordates) there is a second body cavity (the **ATRIUM**) surrounding the pharynx. The gill slits open into the atrium and the connection to the outside is through the single, ventral opening called the **ATRIOPORE**.

As soon as you have finished,
PLEASE RETURN THE SPECIMEN TO THE STOCK BOTTLE.
Do not let it dry out.

TASK: Draw a labelled diagram of a transverse section through the region of the pharynx

*****HAND IT IN AT THE END OF THE LAB*****

NOTE: all drawings should be on BLANK paper, in PENCIL and on ONE SIDE of the page only.

A transverse section is also called a cross section and is taken at right angles to the long axis of the body. On your bench you will find glass slides of transverse sections of amphioxus that have been stained in order to see the different tissues.

Examine a slide labelled “Pharynx” under the binocular microscope. First determine which surface is the dorsal surface of the animal and orient the slide accordingly.

By referring to Figure 4 determine the physical relationship between the pharynx and the atrium. Once you understand the general anatomy of the region, make a drawing in pencil on an unlined white sheet of paper, then identify and label (in pencil, with neat straight lines as in Figure 4) the following:

- ♦ Dorsal fin (possibly with supporting fin ray)
- ♦ Myomeres
- ♦ Notochord
- ♦ Nerve cord (is it hollow? _____)
- ♦ Epipharyngeal groove
- ♦ Pharynx (lumen and wall)
- ♦ Pharyngeal slits
- ♦ Atrium (note: this is a space not a solid structure)
- ♦ Endostyle
- ♦ Metapleural folds (lateral fins)

Epipharyngeal groove: groove that runs along the top of the pharyngeal wall. Ciliated. Moves mucus with entrapped food particles towards the intestine.

Lumen: the space within a long, hollow structure (e.g. blood passes through the lumen of an artery).

Two additional structures, both protruding into the atrium, might be visible depending on the level at which your section was made. They are:

- ♦ Gonads
- ♦ Diverticulum

If your section lacks these structures, be sure to examine one of the demonstration microscopes on the side bench that show them.

Diverticulum: blind pouch connected to any long, hollow tube (e.g. digestive tract). In amphioxus there is only one, which is sometimes called the hepatic diverticulum, hepatic caecum or digestive caecum.

Lastly, on Figure 4 indicate which region of the body the transverse section on your slide was made.

TASK: Draw a labelled diagram of a transverse section through the region of the intestine

*****KEEP THIS FOR THE PRAC EXAM*****

Return your slide of the transverse section of the pharynx to the tray and select a slide labelled “intestine” or “gut”.

For most slides, the section has been cut posterior to the atriopore. Examine the section under the binocular microscope and determine the relationship between the different structures.
Is the atrium present? _____

Why is there so much empty space around? Are living animals full of empty space?

_____

Draw a labelled diagram of the section, then identify and label as many structures from the above list (pharyngeal section) as can be found plus:

- ♦ Intestine
- ♦ Ventral fin

In Figure 4 identify the region of the body that your transverse section was made.

GLOSSARY OF TERMS INTRODUCED IN THIS SECTION

Apomorphic = derived. Apomorphic characters have arisen in only one lineage of evolution and are therefore characteristic of the taxon that is comprised of that lineage.

Fin = a flattened structure that gives stability in water. Please note that not all fins are true appendages. Only those with an internal skeleton connected to the vertebral column are appendages. The flipper of a seal is an example of a fin that is a true appendage. The fins of amphioxus are not.

Fin ray = an internal support for a fin. In amphioxus this takes the form of a solid arch of connective tissue lying at right angles to the long axis of the fin.

TUNICATES

Subphylum: UROCHORDATA

Tunicates are a group of filter-feeders that possess the three fundamental characteristics that define the chordates. However, the notochord only occurs in the tail region (and usually only in the larval form), which has lead to the name 'Urochordata' for them. Their outer covering is a living material (NOT a shell) which contains a molecule very similar to cellulose and is often called a **tunic**. Because of this prominent feature the common name for the group is Tunicates. There are three types of tunicate, all marine:

- **Ascidians** - sessile adult form, common on beaches and in low water; also known as sea-squirts.
- **Thaliaceans** - transparent pelagic animals common in all oceans, also known as salps.
- **Larvaceans** - tiny pelagic animals.

The ascidians are the best known tunicates, especially the **CUNJEVOI**, which can be seen on Sydney rock platforms, attached to rocks in the intertidal zone. It is commonly used as bait by surf fishermen. Other ascidians are on display on the side bench.

Thaliaceans are not so well known, but they are a significant component of the plankton (and hence an important part of the marine food chain) in some areas. We have a few preserved specimens in the laboratory which are displayed on the side bench.

Unfortunately, we do not have any specimens of larvaceans, which are a poorly known group that is considerably different from the other tunicates.

SUMMARY OF TASKS

1. Dissect an adult cunjevoi
2. Label a diagram of a dissected cunjevoi
3. Understand the movement of food and water through the internal structures of the cunjevoi

1. ASCIDIANS

Ascidians have a remarkable metamorphosis from the larval stage (sometimes known as the ascidian tadpole) to the adult stage (see Figure 5). The adults are sessile filter-feeders, often mistaken by the uninformed as some sort of marine plant on the intertidal rocks. However, like many sessile marine animals, the larval form is free-swimming in the plankton. The larva has a notochord, dorsal hollow nerve cord and gill slits. Only the latter can be observed in the adult. Indeed for many centuries these two life forms of the same species were classified as different and unrelated species.

The specimens of Ascidians we have in the Vertebrate zoology collection are displayed on the side bench and include:

Ciona intestinalis - solitary ascidian which is notorious for fouling boats

Pyura pachydermatina - the solitary sea tulip; around Sydney coast the tunic is usually orange. Attaches to the bottom by a stalk of the tunic.

Sarcobotrylloides and *Polyclinum* sp. are colonial ascidians with a number of individuals (zooids) in a common tunic.

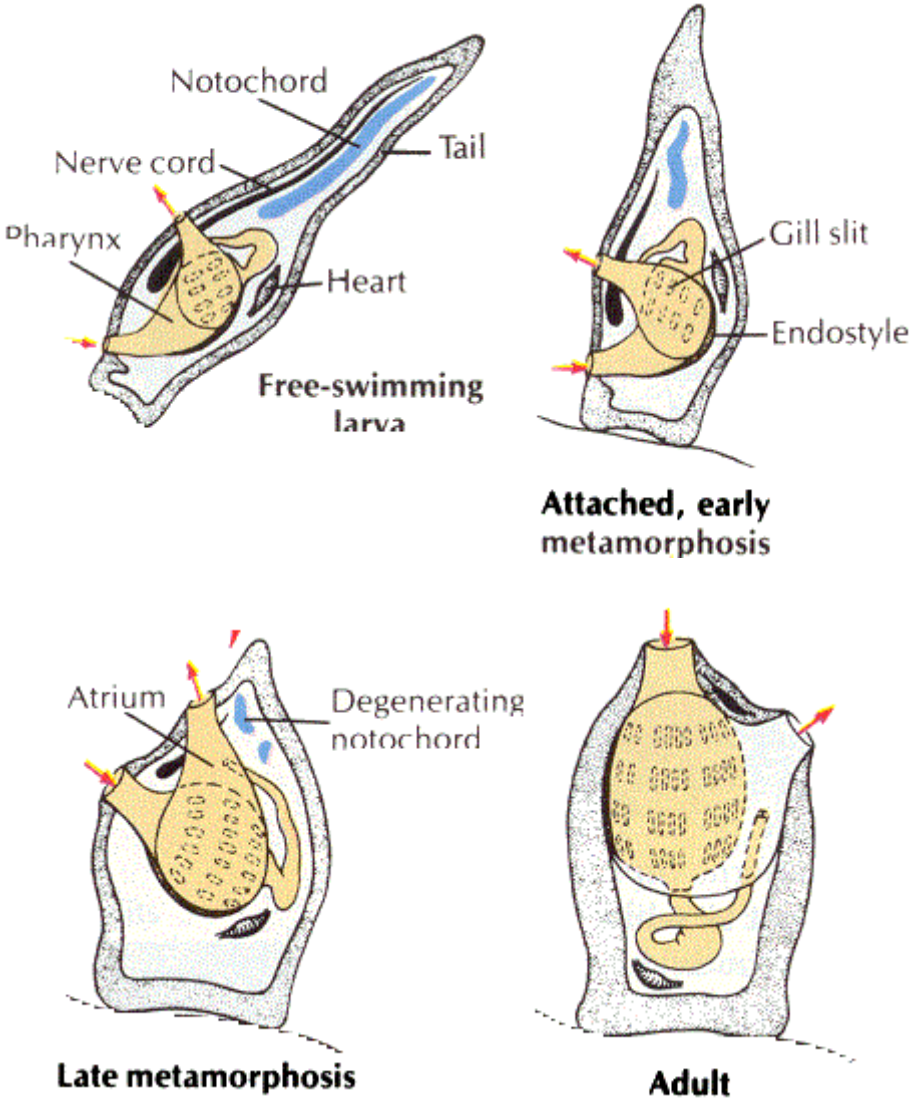


Figure 5. Metamorphosis in a urochordate. Note that the interal anatomy of this species differs from that of *Pyura praeputialis* that you will be dissecting.
(Source: Hickman, Roberts and Larson (1993). Integrated Principles of Zoology. 9th Edition. St Louis: Mosby)

TASK: Dissection of the adult cunjevoi, *Pyura praeputialis*

DISSECTION PROCEDURE

First, note the external features: there are two siphons. Usually one is higher than the other and located in the middle of the upper surface. This is the EXCURRENT SIPHON. The INCURRENT SIPHON is towards the side and lower.

The actual shape of the tunic is influenced by physical pressure of waves and other cunjevoi, but usually the main body has a bit of a 'collar' where the upper part flattens out (see Figure 6). Make an incision into the collar with the point of the bone-cutters and carefully enlarge the nick until you can see the dark red of the inner organs.

Carefully run one point of the bone-cutters along the collar just under the tunic and make a cut by forcing the other point through the tough tunic. To avoid cutting the internal tissues angle the blade that is inside the tunic towards the outside of the animal. Continue with much care all around the collar (see Figure 3). It is worth taking your time and making careful cuts!

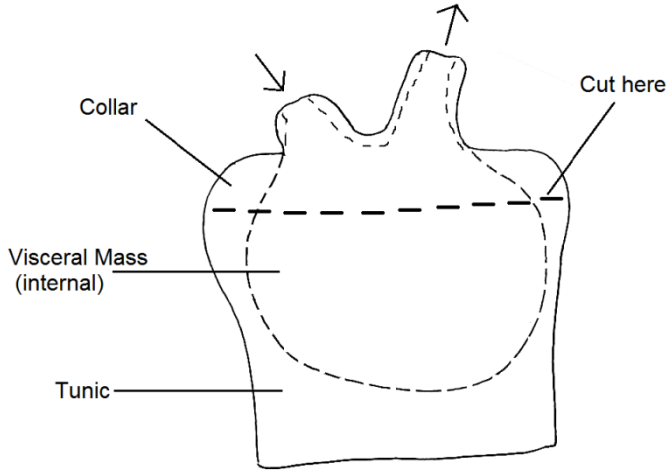


Figure 6. First step in dissection of cunjevoi
(Source: UNSW)

When completed run your finger or a blunt instrument around the VISCERAL MASS (the large dark red 'sac' inside the tunic) to detach the fibres joining the visceral mass to the tunic. You can then lift out the visceral mass attached to the upper part of the tunic.

Note the blood vessels on the inside of the tunic. Why is the tunic considered to be neither shell nor test nor skin?

_____

_____

Examine the red visceral mass. Sometimes the pulse of the ‘HEART’ can be seen at the bottom. The ‘heart’ is a simple U shaped tube in the cunjevoi. The gonads (if the animal you have is reproductively mature) may be seen as lighter structures in the MANTLE, or wall of the visceral mass.

The VISCERAL MASS is basically two sacs; one inside the other. The inside sac, which you cannot see yet, is the pharynx (also called the ‘pharyngeal basket’ or ‘pharyngeal sac’) and it is connected to the incurrent siphon. The outer sac is comprised of the mantle, which is the thick dark-red part you can see, and the included digestive organs and gonads. The space between the two sacs is the ATRIUM and it connects to the excurrent siphon.

The next step is to identify the gut, which can sometimes be seen as a pale tube inside the mantle wall, otherwise it appears as a slight bulge along one side of the bottom of the visceral mass. Once you find the gut turn the visceral mass over. Using scissors, carefully cut along and just to the side of the greater curvature of the visceral mass (see Figure 7). Again, point the blade inside the visceral mass away from the animal to avoid cutting the internal structures we wish to examine. Once you have completed the cut the two halves can be opened like a book. Note: if you have cut into the pharynx (the inner, orange sac) it will be opened into two halves (Figure 8); If you have not cut the pharynx, it will be on one side only (Figure 8).

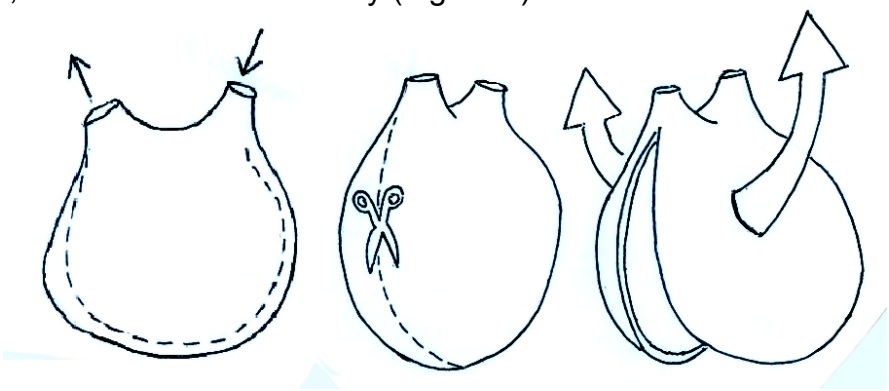


Figure 7. Final steps in dissection of cunjevoi. From left to right: cut along the dotted line; visceral mass has been rotated to a different angle from the image on the left to show where to cut; once the cut has been completed reflect both halves to expose internal cavity.
(Source: UNSW)

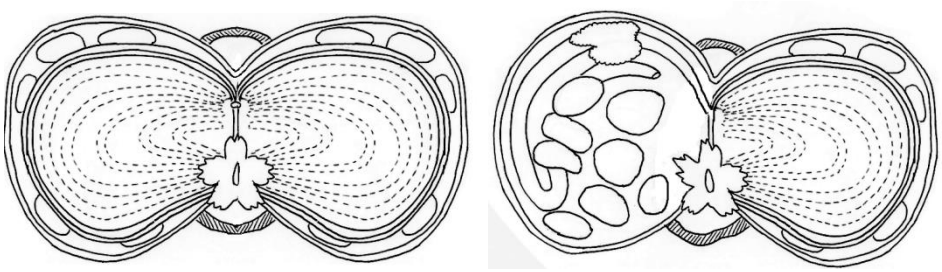


Figure 8. Open halves of cunvejoi. Left image shows a dissection where the pharynx has also been cut in half, right image shows a dissection where the pharynx has been left intact.
(Source: UNSW)

Examine the pharynx. Note the large, fleshy PURPLE TENTACLES inside the aperture of the incurrent siphon that guard the entrance to the pharynx. Where the two halves of the pharyngeal sac meet, along the greater curvature, is the trough-like ENDOSTYLE which produces mucus to entrap food particles. Strands of trapped particles are then carried upwards via cilia on the pharyngeal wall and channelled into the gut opening. The lips of the trough are thick and can be located by feel. The endostyle is on the ventral wall of the pharynx.

The walls of the PHARYNGEAL SAC have six folds, all of which can be followed around to the entrance into the gut. If you look carefully you can see small slits in the walls known as stigmata. However, these are not the final filter as cunjevois can filter out particles of 2 μm diameter.

If the pharyngeal sac of your cunjevoi has been cut in half and appears on both halves. You will need to remove the pharyngeal wall overlying the gut in order to examine this structure. The GUT begins where the folds of the pharynx join.

_____

The gut has little regional differentiation and proceeds along the ventrolateral wall of the mantle until it does a U-turn and runs parallel along almost the full length until terminating into an ANUS. It can be difficult to follow the path of the gut after the U-turn as it becomes embedded within the parietal bodies and gonads (described below). Note it is neither accurate nor worthwhile to label one part stomach, small intestine, etc. The digestive enzymes are produced by an obvious gland, called the DIGESTIVE GLAND, which is made up of many tiny, grape-like lobules joining to one duct that empties into the gut. This is located within the first section of the gut.

Into what space does the gut empty?

_____

When the animal was intact, what was the physical relationship between the opening into and the opening out of the gut?

_____

Which siphon does the anus open towards?

_____

Most of the lining of the inside wall of the visceral mass is taken up with gonadal tissue. Cunjevois are monoecious (i.e. hermaphrodite – with both male and female reproductive organs). Immature gonad tissue (reddish in colour) can differentiate into either ovary (greenish) or testis (white). Because the immature tissue also acts as a storage body holding large amounts of a glycogen-like substance, the lobules that have no differentiated ovary or testis are called PARIETAL BODIES.

TASK: Label the diagrams of the cunjevoi *Pyura praeputialis*

Figure 9 is a diagram of the anatomy of *Pyura praeputialis*. Figure 10 depicts the 'open book' dissection of a cunjevoi with pharynx divided in half and partially removed on one side to expose the gut. Figure 11 is a drawing of a transverse section made across the middle of the visceral mass.

Using neat straight lines clearly identify and label the following structures (not all will be visible in both diagrams):

- ♦ Incurrent siphon
- ♦ Excurrent siphon
- ♦ Mantle
- ♦ Pharyngeal sac (i.e. pharynx)
- ♦ Epipharyngeal groove
- ♦ Endostyle
- ♦ Tentacles
- ♦ Gut
- ♦ Atrium (a space not a solid structure)
- ♦ Digestive gland
- ♦ Entrance to gut
- ♦ Tunic
- ♦ Anus
- ♦ Parietal body/Ovary/Testis (differentiated gonad tissue will only be present if the animal is reproductively mature)

Refer to your dissected cunjevoi to identify the structures in the Figures 9, 10 and 11.

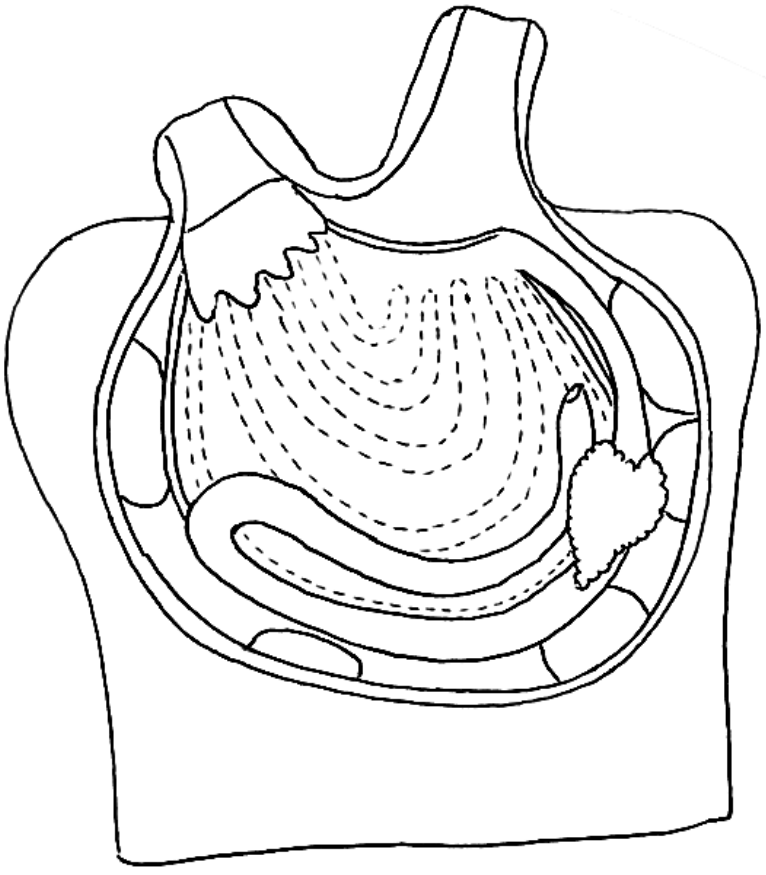


Figure 9. Anatomy of cunjevoi *Pyura praeputialis*
(Source: UNSW)

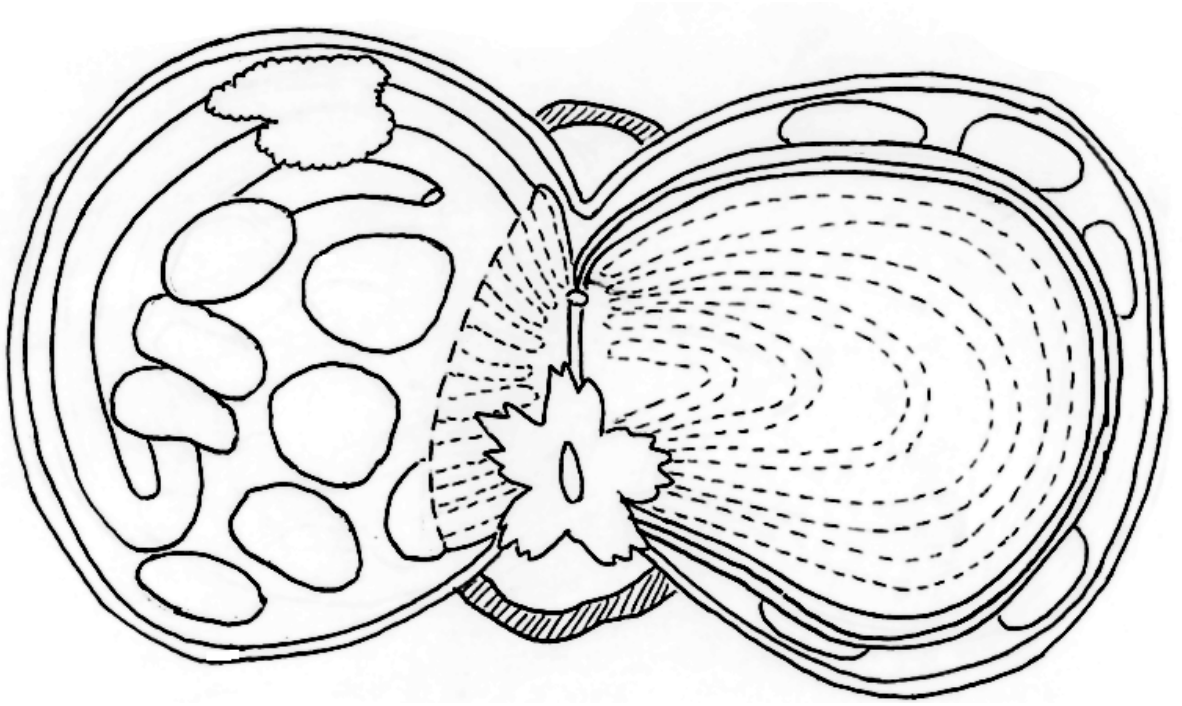


Figure 10. ‘Open-book dissection of cunjevoi exposing all internal structures.
(Source: UNSW)

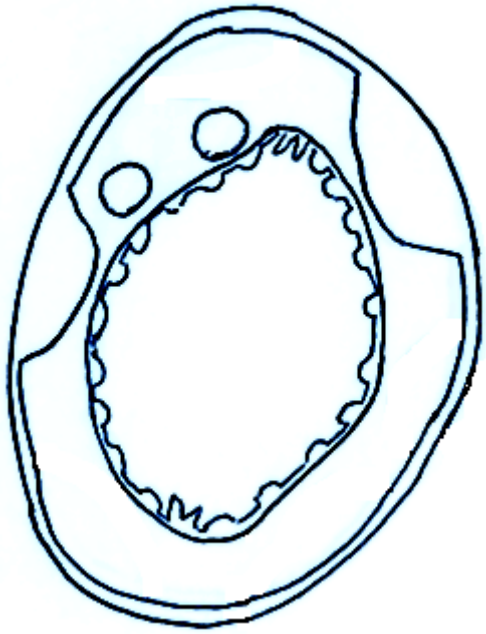


Figure 11. Transverse section through the middle of cunjevoi. Compare this to your transverse sections of Amphioxus.
(Source: UNSW)

Now that you have dissected your tunicate and observed the internal structures, you need to understand the relationship between these structures and how the cunjevoi feeds.

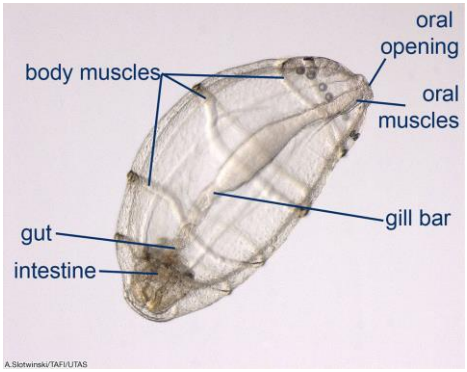
In the blank spaces of the following paragraph, insert the following terms: pharynx, endostyle, tentacles, pharyngeal wall, atrium, gut, excurrent siphon, incurrent siphon, digestive gland, epipharyngeal groove, anus. Note that some terms will be used more than once.

Food particles, suspended in sea water, are drawn through the _____ into the lumen of the _____. The _____ prevent large particles, such as sand which can damage the delicate walls of the _____, being drawn in with the sea water. The _____, which runs along the bottom of the _____, secretes mucus which traps food particles that cannot pass through the _____. Sea water passes through the sieve-like walls of the _____ into the _____. The food particles, trapped in mucus, are moved by cilia on the _____ and along the _____ (which runs along the top of the _____ towards the opening of the _____. After travelling a short distance along the _____ digestive enzymes are added by the _____ to aid digestion. Nutrients are absorbed from the ingested food through the walls of the _____ which loops back on itself. Undigested material empties into the _____ by passing through the _____, where it mixes with sea water before being expelled to the outside through the _____.

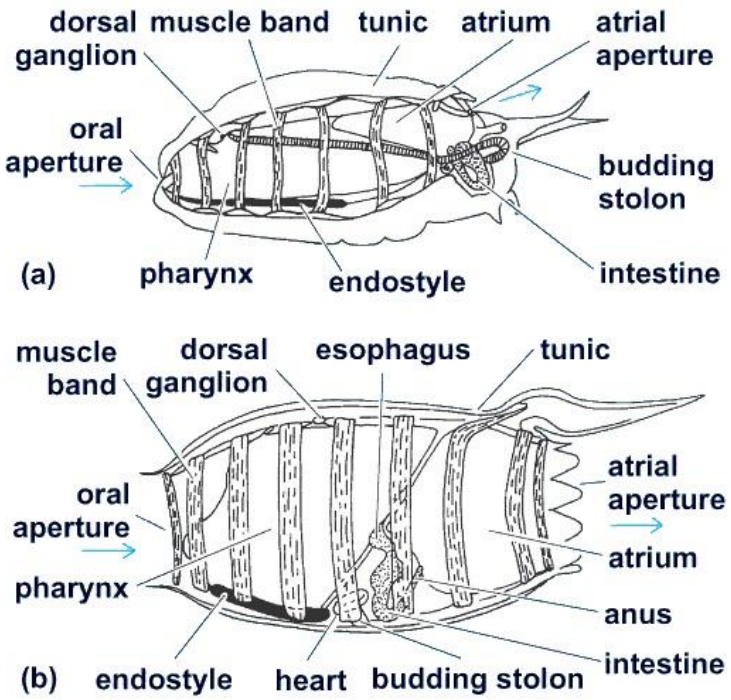
2. THALIACEANS

Example specimens are on the side bench. These are the salps, transparent pelagic animals. They are barrel shaped with incomplete bands of muscle visible in the walls of some species. The overall shape is that of a jet engine, with the oral and atrial openings at opposite ends. The pharynx and atrium are almost continuous.
How does this compare to the amphioxus and cunjevoi?

There are a couple of specimens of *Pyrosoma* spp. in the collection. This is a colonial salp shaped like a glove finger (a hollow cylinder open at one end). The individual zooids have their incurrent apertures on the outside and their excurrent apertures on the inside of the cylinder. This genus is often phosphorescent and occasionally huge. It is difficult to see much structural detail in these simple animals.



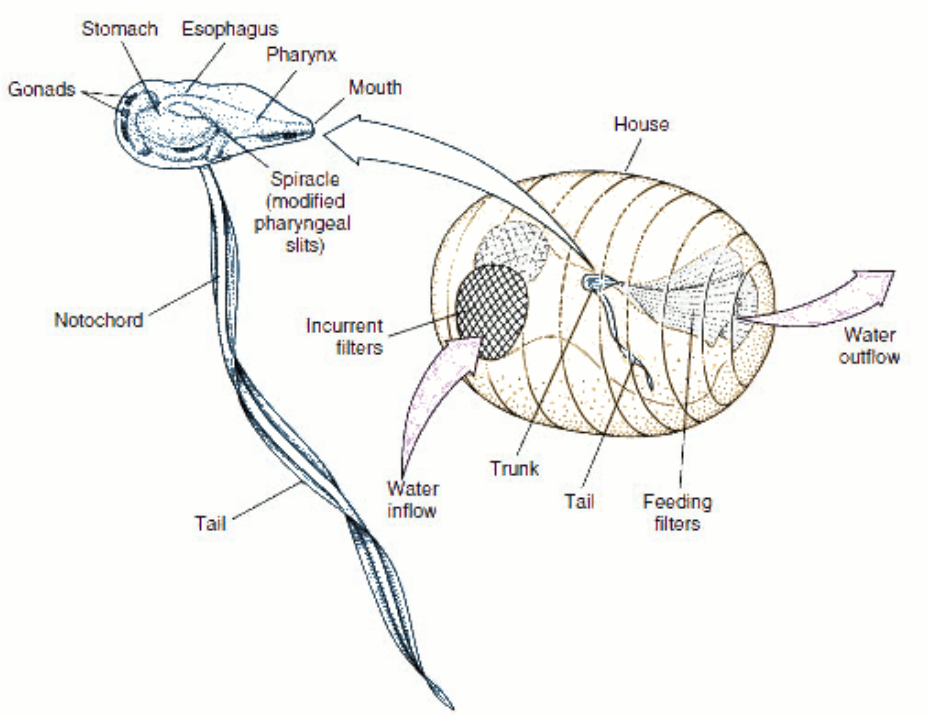
(Source: Tasmanian Aquaculture and Fisheries Institute)



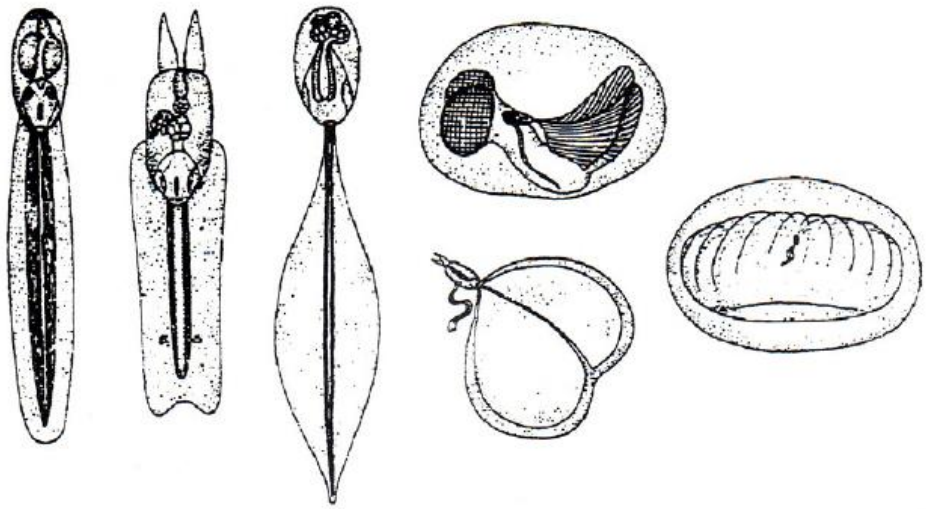
(Source: www.accessscience.com)

3. LARVACEANS

We have no specimens of these tunicates. Like the salps they are pelagic, but they have two extraordinary features. Firstly, the tunic is in the form of a delicate, gelatinous 'house' which is much larger than the tiny animal itself. The animal may shed the 'house' and secrete another. Water carrying food particles (like all tunicates, these are filter feeders) is drawn through a channel in the 'house' by movements of the animal's tail. And that is part of the second peculiarity of these tunicates - they have a tail with a notochord. In fact they remain in the larval form throughout their life and never metamorphose, hence the name 'Larvacea' for the group. This phenomenon, where the gonads develop in what is clearly a larval body form, is called PAEDOMORPHOSIS.



(Source: www.biocyclopedia.com/index/general_zoology/subphylum_urochordata_tunicata.php)



(Source: Unknown)

NOTES

PRACTICAL 2

Dissection of Dogfish (shark)

Part 1

External anatomy

Internal organs

Eye musculature

Dogfish are found in all the world's oceans. *Squalus acanthias,* the species you will be dissecting, is caught off the coast of the United States. It is commonly known as the spiny dogfish, and is much the same as *S. megalops*, the bluntnose spiny dogfish or shortnose spurdog, which can be found off the Australian coast.

TASK: Sketch and label the following external features of your spiny dogfish

♦ **claspers** (male only)
definition: extension of the pelvic fin of male sharks and rays that serves as a copulatory organ to inseminate the female (i.e. internal fertilisation). See Fig. 3.

♦ **cloaca**
definition: the chamber into which the digestive, urinary and reproductive tracts empty. In Latin means 'sewer' or 'drain'.

♦ **gill slits**
How many does *Squalus* have? _____

♦ **spiracle**
definition: respiratory aperture, located behind the eye.
Examine this in your shark (use a probe). Where does it lead?

_____

♦ **lateral line**
definition: a series of sensory pores along the head and sides of fish that detect pressure changes and vibrations.

♦ **pores of ampules of lorenzini system**
definition: a network of gelatinous-filled canals containing electroreceptors round the head (especially the ventral surface and snout).

What is the function of this sensory system?

_____

♦ **stabilising fins:**
anterior dorsal fin
posterior dorsal fin
caudal fin (dorsal and ventral lobes)

♦ **true fins:**
pelvic fins
pectoral fins

♦ **spines**
With what fins are these associated? _____

Gently run your finger along the skin of the shark from anterior to posterior, and then in reverse from posterior to anterior. Can you feel a difference? Examine the piece of skin under the microscope on the side bench to explain this difference. Make sure you can identify which edge of the piece of skin is anterior and which is posterior!

TASK: Make an 'expanded' sketch of a dissected dogfish, labelling the internal organs and tissues.

***** Hand it in before leaving the lab *****

Dissection procedure

Place the animal on its dorsum (i.e. its back). This will require you to cut off the spines and dorsal fins.

Using scissors, open the peritoneal cavity with a mid-ventral incision.

Cut forward to the pectoral girdle and back to the cloaca, as shown in Figure 1.

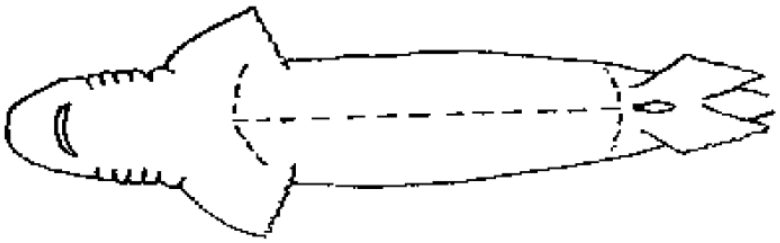


Figure 1. Diagram of cuts to be made on the ventral surface of the shark to expose the peritoneal cavity. (Source: UNSW)

Extend the anterior end of the incision laterally by cutting in an arc along the posterior edge of the pectoral girdle toward the pectoral fins. Repeat this at the posterior end of the incision, anterior to the cloaca. The result will be two 'flaps' that can be opened to expose the contents of the peritoneal cavity. You can either pin the flaps back or remove them altogether.

Notice that the peritoneal cavity is lined with a shiny, cellophane-like tissue. This is the peritoneum and the same tissue extends from the dorsal body wall to suspend and enclose the organs within the peritoneal cavity. The sheet-like portions of this tissue that actually suspend the organs from the dorsal midline are called mesenteries. Locate the:

- **Mesogaster** - suspends the stomach
- **Intestinal mesentery** – suspends the intestine, it is much folded
- **Mesorectum** - suspends the rectal gland
- **Mesorchium** - suspends the testis (male only)
- **Mesovarium** - suspends the ovary (female only)
- **Mesotubarium** - suspends the oviduct (female only)

You do not need to include these in your drawing but you are expected to understand their anatomy.

In the very young embryo the organs in the peritoneal cavity were also attached to the ventral midline by sheets of peritoneum known as ligaments (a most unfortunate name as they are quite different from true ligaments which bind bone to bone). In the adult, all but two remnants of these ligaments are lost. Both are important landmarks and should be located:

- ♦ **FALCIFORM LIGAMENT** - connects the liver to the ventral body wall at the absolute front of the peritoneal cavity. (In the female this ligament contains the **ostium**.)

- ♦ **GASTROSPLENIC LIGAMENT** - is a remnant of the gastric ligament. While the stomach has lost all ventral connection, the spleen (which in development lays ventral to the greater curvature of the stomach) remains attached to the stomach by this ligament. It may also extend across to the small intestine and include at least part of the pancreas. This is an important landmark which in ANY vertebrate will allow you to find the spleen.

Include and ***label*** these two ligaments in your drawing.

Identify and label the following organs shown ***in capital letters***.

Digestive tract

- ♦ **ESOPHAGUS**

  The short esophagus connects the pharynx to the stomach. The differentiation between pharynx, esophagus and stomach can be made by examining the mucosal linings of these organs. The esophagus is lined with **papillae** (small conical projections) that contain the shark's taste buds. The cardiac stomach is lined with **rugae** (longitudinal folds) that serve to increase the surface area.

- ♦ **STOMACH**

  Open the stomach and place the contents on the tray. Examine what your dogfish has eaten.

- ♦ **SMALL INTESTINE**

  Make a longitudinal incision to expose the **spiral valve** (see Figure 2).

  What is the function of the spiral valve? _____

  _____

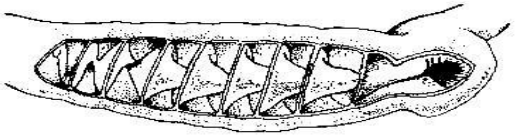


Figure 2. Spiral valve inside intestine of shark
(Source: http://library.thinkquest.org/26153/marine/chordata.htm)

- ♦ **LARGE INTESTINE** (this is very short!)

- ♦ **CLOACA**

Accessory digestive organs

- **LIVER**
  How many lobes does the shark liver have? _____
- **GALL BLADDER**
- **BILE DUCT**
  Where does this lead to and from? _____
- **PANCREAS**
  The pancreas is absent in some individuals. Suggest a possible reason for this.

  _____

- **SPLEEN** - part of the circulatory system. No digestive function.

Excretory organs

- **RECTAL GLAND** - connects by a duct to the large intestine. Secretes NaCl.
- **KIDNEYS** – the two long structures lying either side of the vertebral column. They are *retroperitoneal*, meaning that they are above and not in the peritoneal cavity.
- **URINARY** (female) or **UROGENITAL** (male) **PAPILLA** – protrudes into the cloaca and directs the urine flow through the cloaca.
- **URINARY SINUS** – a small sinus **inside** the urinary papilla. (A sinus is a bodily cavity or space.)
- **urinary duct** – small and thin walled, may be enlarged at the end. There is no true bladder. (Note: this structure is very difficult to identify and, since you should never draw something that you did not actually see, you are not required to include this in your drawing.)

The reproductive systems of both sexes are difficult to clearly display in your 'expanded dissection' drawing and so labelled diagrams have been provided (Figs 4 and 5). However, it is important that you are able to identify these structures, understand their relationships and be aware of their functions as they may appear in a practical exam.

MALE reproductive system

- **testis** – suspended by the mesorchium towards the anterior of the peritoneal cavity (the ovaries are in the same position in female sharks)
- **vas efferentia** - you will not be able to see these tiny ductules without a microscope. There are many and they pass through the substance of the kidney, joining to form the vas deferens.
- **vas deferens** - a coiled duct adhering to the surface of the kidney. Carries sperm.
- **seminal vesicle** - enlarged end of the vas deferens. Very obvious in mature males in the reproductive season.

♦ **sperm sac** - these lie at the end of each seminal vesicle but will only be visible in fully developed males. They produce and store components of the seminal fluid.

♦ **urogenital papilla** - another term for the urinary papilla, but it is a better term as sperm as well as urine pass through the opening in its tip in the male. See Fig. 3.

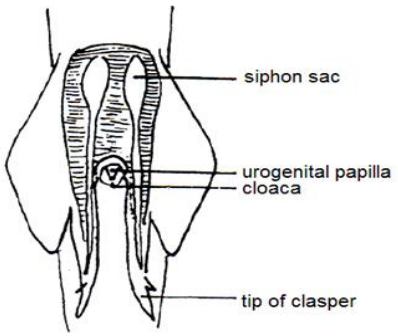


Figure 3. Internal anatomy of clasper
(Source: UNSW)

FEMALE reproductive system

NOTE: if your female shark is pregnant, the oviducts may be grossly enlarged with the yolk mass of the eggs. They may obscure the other organs; if so make a cut in the oviduct and remove the contents. Place the contents of the oviducts on the tray provided on the side bench of the lab.

♦ **ovary** - suspended by the mesovarium but NOT physically connected to the oviduct. Examine it closely to see that this is indeed the case.

♦ **ostium** - a funnel in the falciform ligament which forms the opening into the oviducts (which split into left and right just beyond the ostium). The egg must get from the ovary, through the ostium and into the oviduct.

♦ **oviduct** - in immature females a thin tube running from the ostium to the cloaca. Becomes considerably enlarged with maturity. NOTE: the distal portion of this tube, when expanded with developing young, is sometimes referred to as a "uterus". This is not technically correct as there is no true placenta and nourishment is almost entirely from the yolk in the species you dissect.

♦ **shell gland** - a thick-walled, tough portion of the oviduct near the anterior end. Produces much nutrient material.

After dissecting the reproductive system of your shark, be sure to examine a specimen of the other sex. Be prepared to demonstrate your animal to someone who has dissected the opposite sex.

Where does fertilization take place? Explain.

_____

_____

Is the dogfish oviparous, ovoviviparous or viviparous? What do these terms mean?

_____

_____

_____

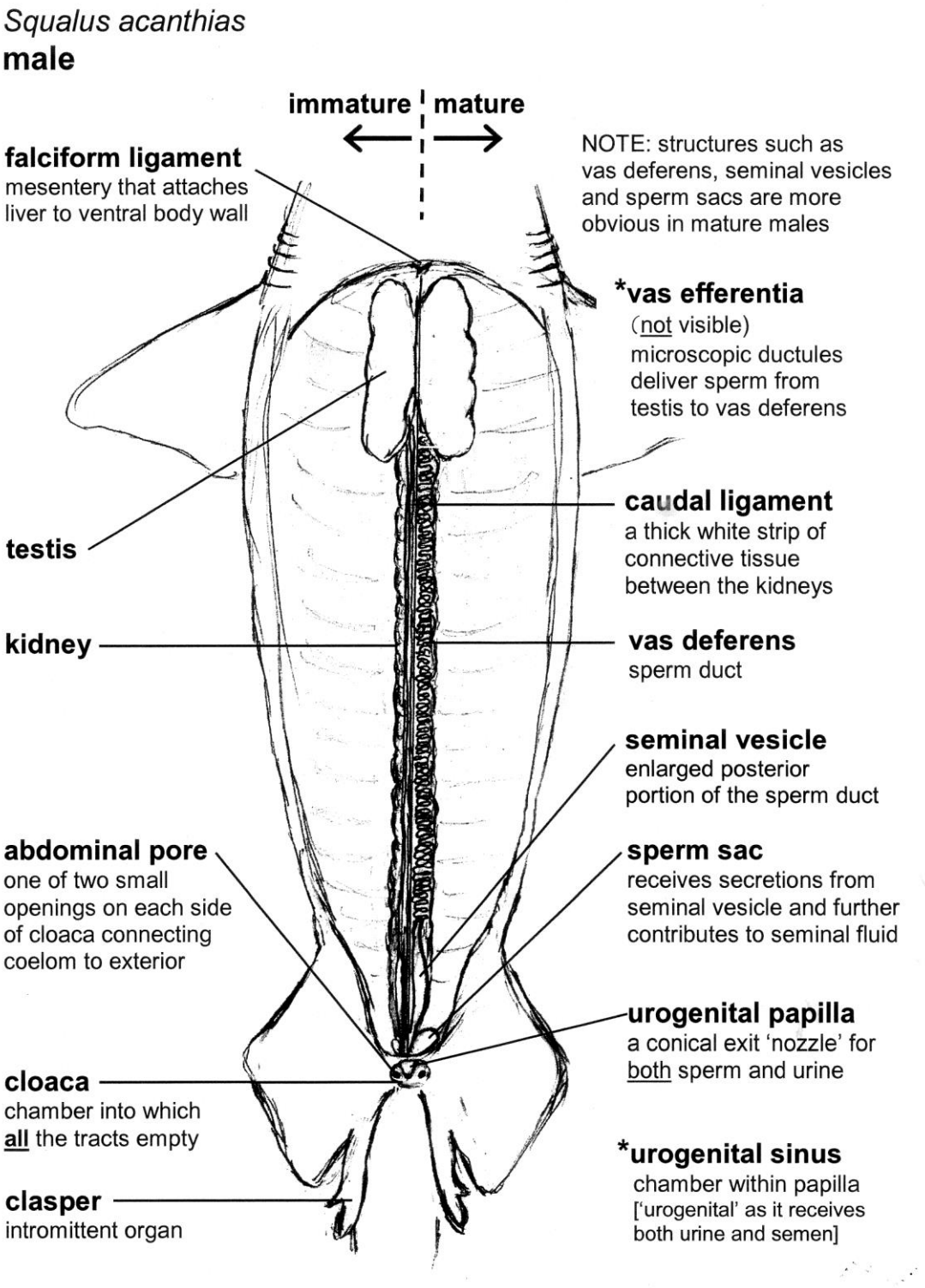


Figure 4. Reproductive system of a male *Squalus acanthias*

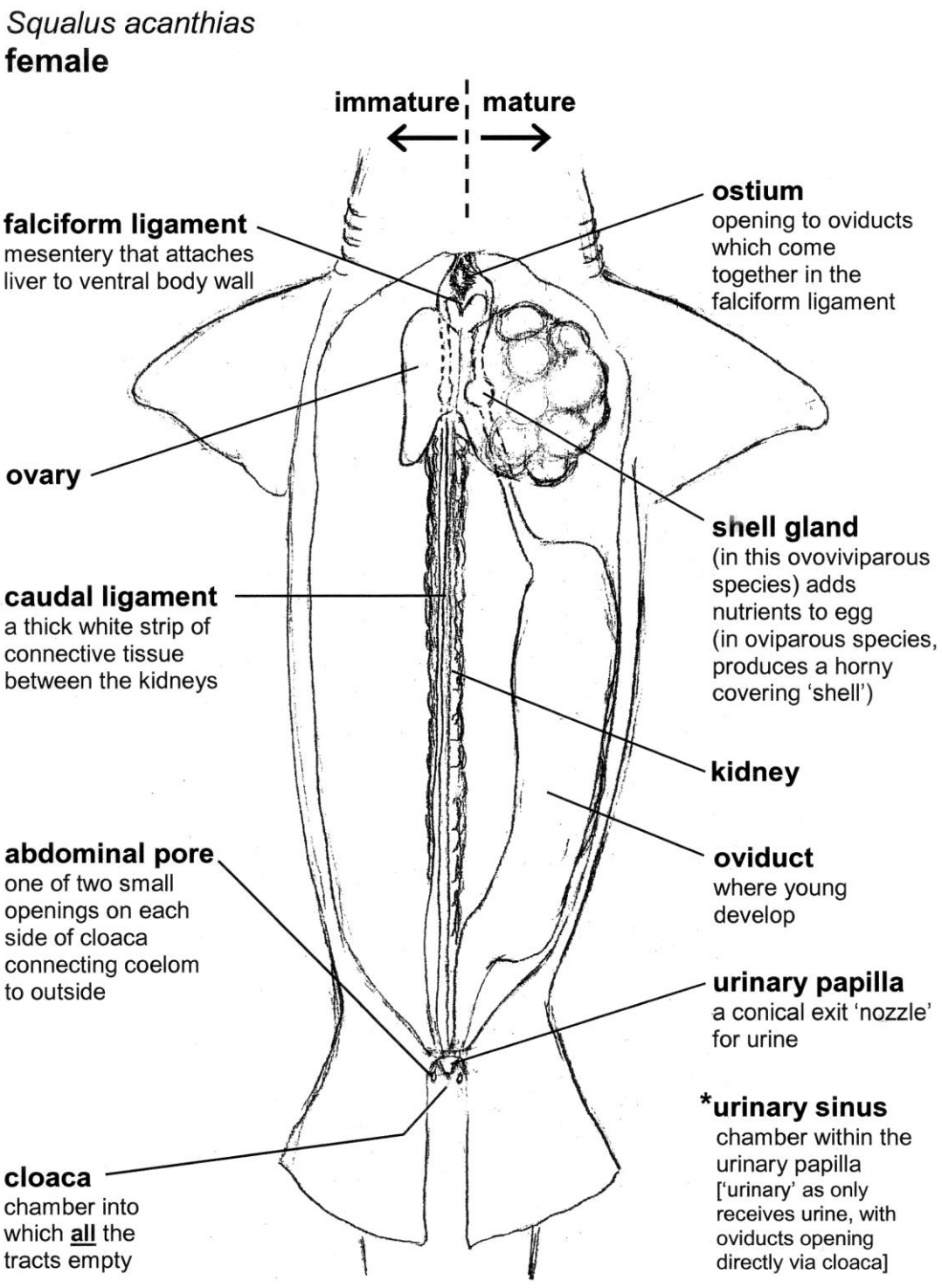


Figure 5. Reproductive system of a female *Squalus acanthias*

TASK: Dissect the orbit and examine the musculature of the eye and associated nerves.

You do not need to hand in a drawing of this exercise but it is recommended you make sketches for later revision.

The orbit is the socket in the chondrocranium in which the eyeball sits. The chondrocranium is the cartilaginous skull of chondrichthyans.

In order to study the contents of the orbit, cut away the skin around the margin of the orbit and free the eyeball. The orbit may contain a lot of gelatinous material that you will need to clean out, being careful not to break the muscles attaching the eyeball to the cranium.

Movement of the eye is very precise, involving a series of discrete, opposed muscles. They are attached to the chondrocranium (ORIGIN) and to the tough coat of the eyeball (INSERTION). There are six of them in two groups (see Figure 6):

OBLIQUE group - origin is the anterior wall of the orbit

- **Superior oblique muscle** - inserts on the anteriodorsal surface of the eyeball
- **Inferior oblique muscle** - inserts on the anterioventral surface of the eyeball

RECTUS group - origin is the posterior wall of the orbit

- **Superior rectus muscle** - inserts on the posteriodorsal surface of the eyeball
- **Inferior rectus muscle** - inserts on the posterioventral surface of the eyeball
- **Lateral rectus muscle** - inserts on the posteriomedial surface of the eyeball
- **Medial rectus muscle** - inserts on the anteriomedial surface of the eyeball, deep inside the orbit

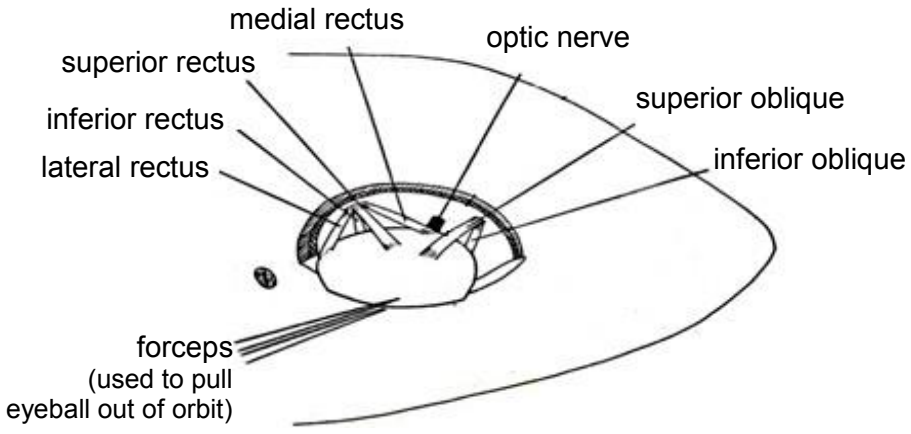


Figure 6. Dorsolateral view of muscles of the shark eye
(Source: Rowett (1957). Dissection Guides. 2. The dogfish. John Murray: London)

These muscles work in opposing pairs. Identify the opponent of the:

Superior oblique _____

Superior rectus _____

Lateral rectus _____

(Note: The same muscles operate the eyes of all gnathostomes including humans.)

Examine the other structures located in the orbit:

- **optic pedicel** - a remarkable structure shaped like a golf tee. It is in amongst the origins of the rectus muscles. It functions as a shock absorber for the eyeball.
- **orbital process** of the upper jaw - the upper jaw in sharks is not fused to the cranium and the orbital process is a supporting strut. Find it in the orbit and look at the dried jaws on the side bench to appreciate what it is in relation to the jaw.
- **optic nerve** - passes from the middle of the eyeball through a foramen (hole) in the cranium to the brain.
- **superficial ophthalmic nerve** - runs along the wall high in the orbit (from sense receptors in the snout).
- **deep ophthalmic nerve** - runs like a cord just below the superior rectus and the superior oblique muscles.
- **infraorbital nerve** - a massive nerve with several branches on the floor of the orbit. It is sensory from the skin of the lower snout and the lateral line.

Remove the eyeball and cut into it. Remove and examine the lens.

Why is it opaque? _____

WHEN YOU HAVE FINISHED

PUT YOUR SHARK INTO THE BAG PROVIDED AND WRITE YOUR NAME & CLASS (MORNING OR AFTERNOON) ON THE BAG.

YOU WILL CONTINUE DISSECTING YOUR SHARK IN THE NEXT LAB.

REMEMBER TO HAND IN YOUR DRAWING FOR ASSESSMENT BEFORE YOU LEAVE!

PRACTICAL 3

Dissection of Dogfish (shark)

Part 2

Heart and circulation
Brain
Sense organs

SHARK DISSECTION - PART 2

TASK: Dissect the heart and afferent branchial arteries.
Draw a diagram of the heart and the circulation to the gills.

DISSECTION

Approach from the VENTRAL surface. Remove the ventral skin between the lower jaw and the pectoral girdle. This will disclose a mass of muscle (what is its function?).

Pick away the muscle mass using sturdy forceps - pull the muscle towards you to avoid damaging the underlying heart and blood vessels. Watch for a shiny membrane enclosing the heart - the PERICARDIUM. It will appear just in front of the pectoral girdle. Carefully clear away the muscle from the pericardium and slit it open.

THE HEART

The shark heart has two main chambers (atrium and ventricle) with two accessory chambers (conus arteriosus and sinus venosus). Flow is one way.

- **ventricle** - this muscular chamber is immediately obvious when you open the pericardium
- **atrium** - larger than the ventricle but with much thinner walls. It is behind the ventricle and its sides protrude around the ventricle like two 'ears' (hence an old name for the atrium, 'auricle', which means ear). Satisfy yourself that it is indeed one chamber.
- **conus arteriosus** - a muscular extension of the ventricle, which looks like a big artery but is composed of cardiac muscle.
- **sinus venosus** - lift the heart by the tip of the ventricle. The sinus venosus is a triangular, thin-walled sac attached to the atrium. Slit the wall and use a blunt probe to find the venous connections. They are the:

  hepatic veins (from liver, very short)

  cardinal sinuses (in dorsal body wall)

THE AFFERENT BRANCHIAL ARTERIES

Afferent means 'towards' and branchial means 'gills', so these are the blood vessels carrying blood from the heart (hence they are arteries) to the gills. Following the **VENTRAL AORTA** forward from the conus arteriosus, work out and diagram the distribution to the gills (hint: there will ultimately be five afferent arteries on each side but they do not necessarily come off the ventral aorta independently).

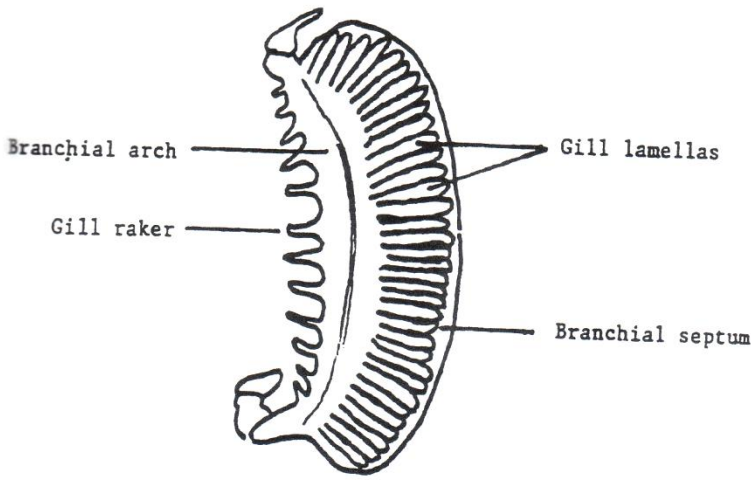
TASK: Examine a gill in situ.
Remove one complete gill and examine its structure.

Is there gill tissue on every wall of every gill slit? Is there gill tissue on the wall of the spiracle in your shark (there is in some species)?

What is the function of the spiracle?

What is the function of the GILL RAKERS?

The gill consists of an arched bar of cartilage (the branchial arch) which has rib-like projections supporting the BRANCHIAL SEPTUM. The soft tissue on both surfaces of the septum where gas exchange takes place is organized into a number of folds at right angles to the branchial cartilage - the GILL LAMELLAS.



TASK: Examine the demonstration latex-injected specimens to see the EFFERENT branchial arterial system

The EFFERENT BRANCHIAL ARTERIES carry blood from the gills. Their pattern is different to that of the afferents, because there are only four pairs. The four paired EFFERENTS join in the midline to form the DORSAL AORTA, which supplies oxygenated blood to all regions except the head.

The blood supply to the head region (including the brain, jaws and snout) comes off from the forward gill separately. The main supply is by the paired (left and right) HYOIDEAN ARTERIES. These arteries are reinforced by blood from the small PAIRED DORSAL AORTAS that branch off the FIRST EFFERENT BRANCHIAL ARTERY. The main branch off the hyoidean is the INTERNAL CAROTID to the brain.

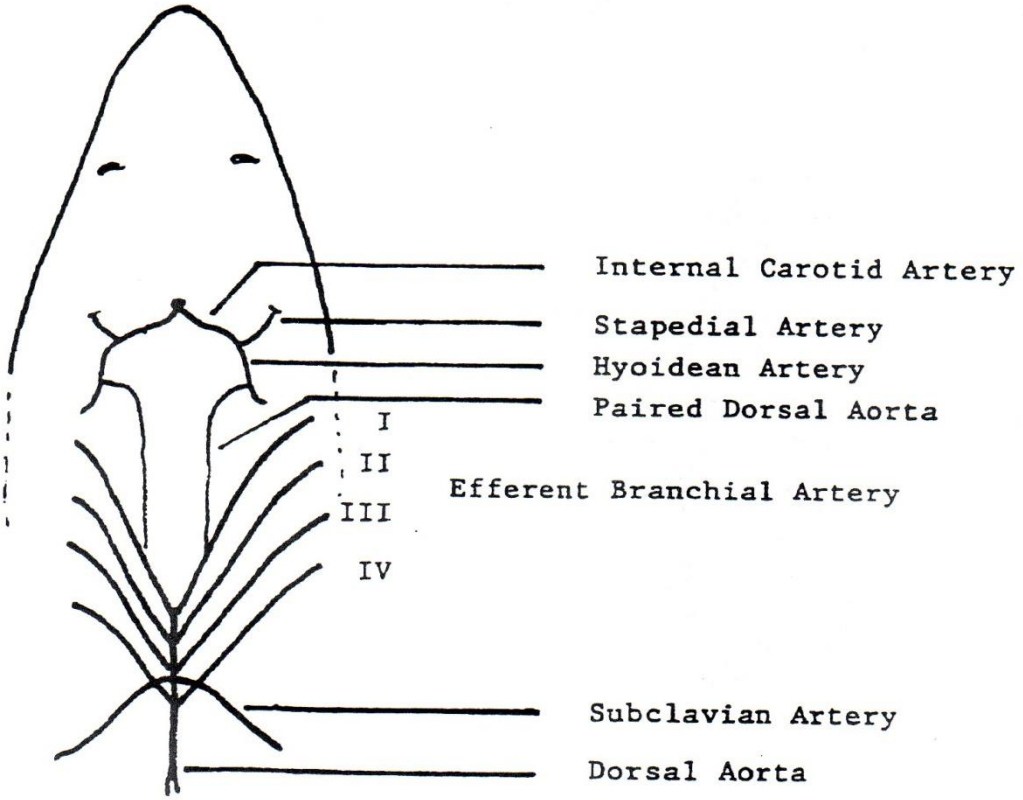


Fig. 1. Diagram of the EFFERENT branchial arteries
[Compare the above diagram with the demonstration (injected) shark.]

DORSAL AORTA - single, midline. Supplies the following:

Paired branches:

SUBCLAVIAN (or BRACHIAL) ARTERIES - to the pectoral fin

INTERSEGMENTAL ARTERIES - numerous branches to the muscles of the body wall. One pair between each vertebra.

GONADAL ARTERIES - to testes or ovaries

ILIAC ARTERIES - to pelvic fins

Unpaired branches

COELIAC - to liver, stomach and anterior intestine, branches to:
GASTROHEPATIC (to anterior stomach and liver) and ANTERIOR INTESTINAL

*POSTERIOR INTESTINAL - to posterior intestine

*GASTROSPLENIC - to posterior stomach and spleen
(*these two come off the dorsal aorta very close to each other)

POSTERIOR MESENTERIC to the rectal gland

CAUDAL - this is just the much reduced aorta supplying the tail

TASK: Examine the way in which venous blood returns to the heart

There are two major routes of venous return. One is for the blood from the stomach and intestine (which returns via the liver) and the other is from the rest of the body (which pools in large sinuses near the heart).

THE HEPATIC PORTAL SYSTEM

Blood from the gut drains via the HEPATIC PORTAL VEIN to the liver. Find this vein running alongside the bile duct. It disappears into the liver, wherein it breaks down into a capillary network. The liver is then drained by the short HEPATIC VEINS which empty into the sinus venosus. If you remove the liver, you may find two small holes in the anterior wall of the peritoneum where the hepatic veins pass to the sinus venosus.

VENOUS RETURN TO THE HEART

In some cases the veins run parallel to the arteries and have the same name (iliac, subclavian and segmental veins). However in the shark most of the venous system is quite different from the arterial, due mainly to the presence of large thin-walled sinuses where the blood pools near the heart. This is because the blood pressure is zero at this end of the circulation and the blood must be moved into the heart by the 'squeezing' action of skeletal muscle activity.

The ANTERIOR CARDINAL SINUSES (*cardinal* simply meaning *important* and implying large size) pool blood coming from the head region. The larger POSTERIOR CARDINAL SINUSES pool blood from the back of the body. The sinuses join with the ABDOMINAL, SUBCLAVIAN and JUGULAR veins at the point of entry into the sinus venosus as shown.

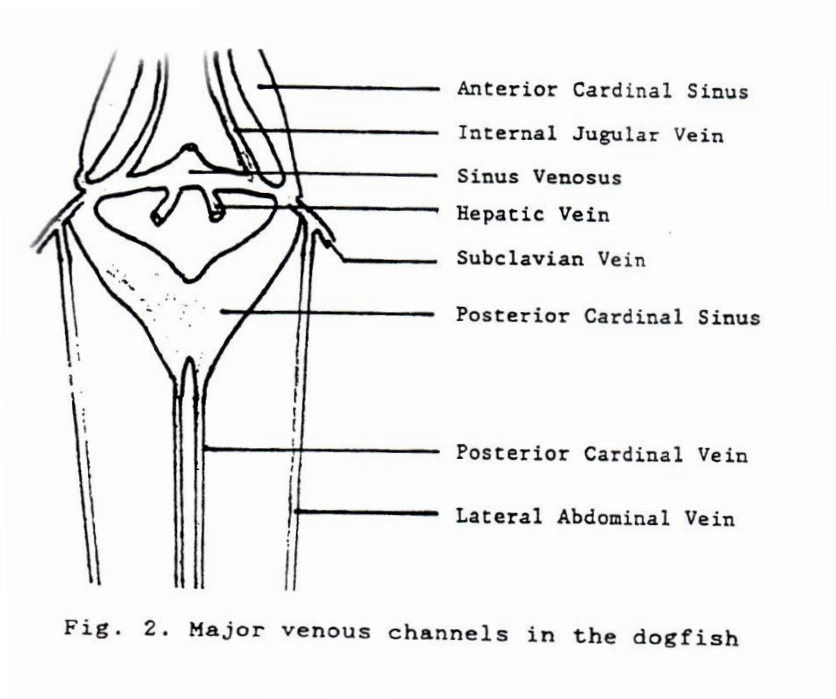


Fig. 2. Major venous channels in the dogfish

TASK: Chip away the chondrocranium on one side to expose the semi-circular canals and other parts of the inner ear

1. Your (mammalian) 'ear' serves two separate sense modalities - hearing and balance. The shark uses the LATERAL LINE SYSTEM for the fishy equivalent of hearing. However the shark organ for balance and perception of changes in angular momentum is exactly the same as the mammalian 'inner ear'. Since the shark cranium is cartilage, you have a chance to dissect and study this organ which is impossible to see in bony vertebrates.

2. The 'inner ear' is totally embedded in the OTIC CAPSULE of the chondrocranium. It consists of a triangular membranous sac, the SACCULUS, to which are attached both ends of three SEMI-CIRCULAR CANALS. Because all of these are embedded in channels in the cranium, the whole system is known as the 'labyrinth' (a labyrinth is a maze of tunnels). The labyrinth, including the semi-circular canals and the sacculus, is filled with a fluid called ENDOLYMPH which is an ultrafiltrate of plasma. Turning movements of the body in the three planes of space cause displacement of the endolymph with resulting differential stimulation of sensory cells in the AMPULLAS (bulbs at the ends of each semi-circular canal) and the sacculus. Thus information is provided for the brain in respect of changing body position. NOTICE that this system can only provide information about changing conditions which cause displacement of their endolymph.

   Information about the position of the body in relation to gravity is provided by another component of the inner ear. In the sacculus are fine grains (actual sand in some sharks; secreted crystals in most vertebrates) called OTOLITHS. You should be able to see these when you cut into the sacculus. The otoliths stimulate receptor cells (STATOCYSTS) when they shift, and their position depends on gravity due to their mass.

4. Find the ENDOLYMPHATIC PORES on the top of the head. They are the tiny openings of the endolymphatic ducts which connect directly to the sacculus of each inner ear (and provide an explanation how sand grains can come to serve as otoliths in this species). They are in a slight depression in the middle of the top of the head roughly between the spiracles.

5. *DISSECTION PROCEDURE*. Do this dissection slowly and carefully. Avoid damage to the brain. We will provide scalpels to allow you to slowly chip away at the chondrocranium. . . Remove the skin and underlying muscle on one side in the region of the endolymphatic duct. (If you are uncertain as to which part of the cranium you should be dissecting, examine one of the dried shark skulls on the side bench). . . Shave away the cartilage, beginning on the dorsal surface and working laterally. The canals of the labyrinth that house the semi-circular canals will be seen just before the actual ducts themselves.

6. Determine the plane in which each semi-circular canal lies.

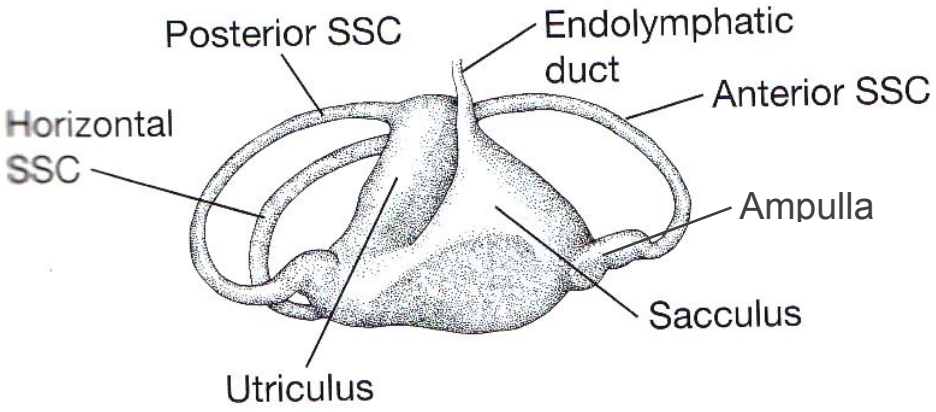


Fig. 3 Inner ear of a shark.
From Pough, F. H., Janis, C. M., and Heiser, J. B. 2002. Vertebrate Life. Prentice Hall. Fig 2.18, p. 45

TASK: Remove the brain INTACT from the chondrocranium and draw a side view labeling the following structures.

***** Hand in before leaving the lab *****

The brain will probably be partly exposed by the opening made to allow the preservative to penetrate the cranial cavity and by your activities in dissecting out the inner ear. Complete the exposure of the brain by chipping away the rest of the surrounding cartilage and attempt to remove it INTACT. You should then be able to find:

- **OLFACTORY TRACTS** - part of the brain (not nerves) that protrude from the front of the brain to the olfactory sacs.
- **OLFACTORY BULBS** – the enlarged ends of the olfactory tracts from which the very short olfactory nerves run to the sensory cells of the olfactory sacs.
- **CEREBRAL HEMISPHERES** - the two forward lobes. Note that they are not the largest part of the brain in sharks as they are in mammals.
- **OPTIC LOBES** - these are situated behind the cerebral hemispheres, separated by a large gap; that gap contains the
- **ANTERIOR CHOROID PLEXUS** - if still in place, this will appear as a plexus (network) of fine blood vessels forming a thin roof over the third ventricle (a ventricle in the brain is a cavity - see below) in the midline of the brain just in front of the optic lobes. It is one site of transfer, by diffusion, of material (glucose, oxygen) from the blood stream to the cerebro-spinal fluid in the brain cavities.
- **EPIPHYSIS** - unlikely to still be intact*. A thin strand of tissue running upwards, from just in front of the optic lobes to the under surface of the cranium. Homologous to the 'third eye' of lizards and the pineal of mammals. (*Indicate position on drawing.)

♦ **CEREBELLUM** - an unpaired, midline lobe that overlaps the optic lobes in the shark. Center of balance and equilibrium control.

♦ **MEDULLA OBLONGATA** - the brain stem underlying the cerebellum and being the part of the brain connecting to the spinal cord. It contains the centers for basic life functions such as respiration, heart beat and blood pressure regulation.

♦ **POSTERIOR CHOROID PLEXUS** - a plexus (network) of blood vessels forming a thin roof over the 4th ventricle (cavity) of the brain. It is on the roof of the medulla oblongata just behind the cerebellum. It is larger than the anterior choroid plexus but has the same function. Underneath it you should find the fourth brain ventricle.

♦ **OPTIC NERVES –** one of the 10 pairs of cranial nerves that pass out directly from the brain in the shark (mammals have another 2 pairs).

♦ **OPTIC CHIASMA –** the place on the underside of the brain where the optic nerves meet and visibly cross.

♦ **VENTRICLES** - an unfortunate name applied to the cavities in the brain that are continuous with each other and with the canal in the spinal cord. Ventricles 1 and 2 are in the left and right cerebral hemispheres respectively; ventricle 3 is in the mid-brain and 4 is in the hind-brain.

TASK: Examine the remaining sense organs

OLFACTORY SACS

1. Open one of the sacs and observe its structure.
2. Why is the sensory epithelium set into a pit?

AMPULES OF LORENZINI (look up the function in the text book)

1. Dissect back a flap of skin on the snout.
2. Observe the many ‘tapioca-like’ ampules and the ducts connecting them to the surface.

LATERAL LINE (look up the function in the text book)

1. Cut a section through the lateral line and see if you can find the channel that runs just beneath the surface of the skin.
2. Notice how the anterior end of the lateral line blends into the field of pores of the ampules of Lorenzini.

PRACTICAL 4

Vertebrate Jaws and Lungs

"Jaws and lungs" in vertebrate evolution and ecology:

- *Jaws led to improved respiration, which subsequently enabled jaws for predation;*
- *Improved air respiration via swimbladder/lung subsequently enabled buoyancy;*
- *Predation led to dermal armour (e.g. the ostracoderm fishes), which led to the pectoral girdle and skull being composed of dermal bone, eventually leading to endogenous bone (a skeleton);*
- *Tiktaalik had a wrist and a tilting (nodding) head to push-up, then breath or feed in a predator-free pond. It was almost a true hand, but no digits, only a fin ray.*

1) Clade Agnatha (Jawless fish)
    a. Ostracoderms†
    b. ammocoetes (larval lamprey),
    c. adult lampreys and hagfish.
2) Clade Chondrichthyes
    a. Chimaeras,
    b. 3 major groups of sharks (Galeo-, Squalo-, 7 gill) and
    c. Batoids (skates and rays)
3) Clade Sarcopterygii
    a. lungfishes (6 spp),
    b. coelacanths (2 spp),
    c. Tiktaalik and others.
4) Clade Osteichthyes (bony fish); Actinopterygii – ray-finned fish
    a. Chondrostei: sturgeon & bichir,
    b. Neopterygii: garpike & bowfin,
    c. Neopterygii: teleosts,
        i. Osteoglossids (our Saratoga)
        ii. eels and tarpons
        iii. herrings and anchovies
        iv. euteleosts, from catfish to flounder
5) Teleost dissection – to be handed in at end of lab, with lab completion sheet.
    a. External morphology,
    b. Internal.

LAMPREY and HAGFISH

VERTEBRATA

The oldest chordate fossils, the ostracoderms, were fish-like but lacked jaws, true appendages and vertebrae (Q1). The internal skeletal element was a notochord. Bone was present, but only in external plates in the earliest forms. During the mid-Paleozoic there were many clades with this general body plan.

Today only hagfish and lampreys remain, and they are very specialized animals whose relationship to each other is most uncertain. Traditionally hagfish and lampreys, as well as the Ostracoderms, have been classified as agnathan vertebrates (a = without, gnatha = jaws) regardless of the fact that none of these actually have a vertebral column! Therefore the taxon that includes the 'Agnathans' with the true vertebrates is better called Craniata. Craniata is a reasonable name, because the brain of 'Agnathans' does sit in a cranium (as opposed to tunicates and cephalochordates). This is a cartilage structure in lampreys and hagfishes, which completely lack bone. Since the fossil agnathans are characterized by bony plates, the lack of bone is probably a reflection of the specialized life styles of the living types. Agnathans have the three basic chordate structures (notochord, dorsal hollow nerve cord and gill slits).

Lampreys and hagfish are very different animals and probably have separate ancestors. 'Cyclostome', refers to the round-shaped mouth of the animals since they lack jaws, is best used as a nickname for living hagfish and lampreys.

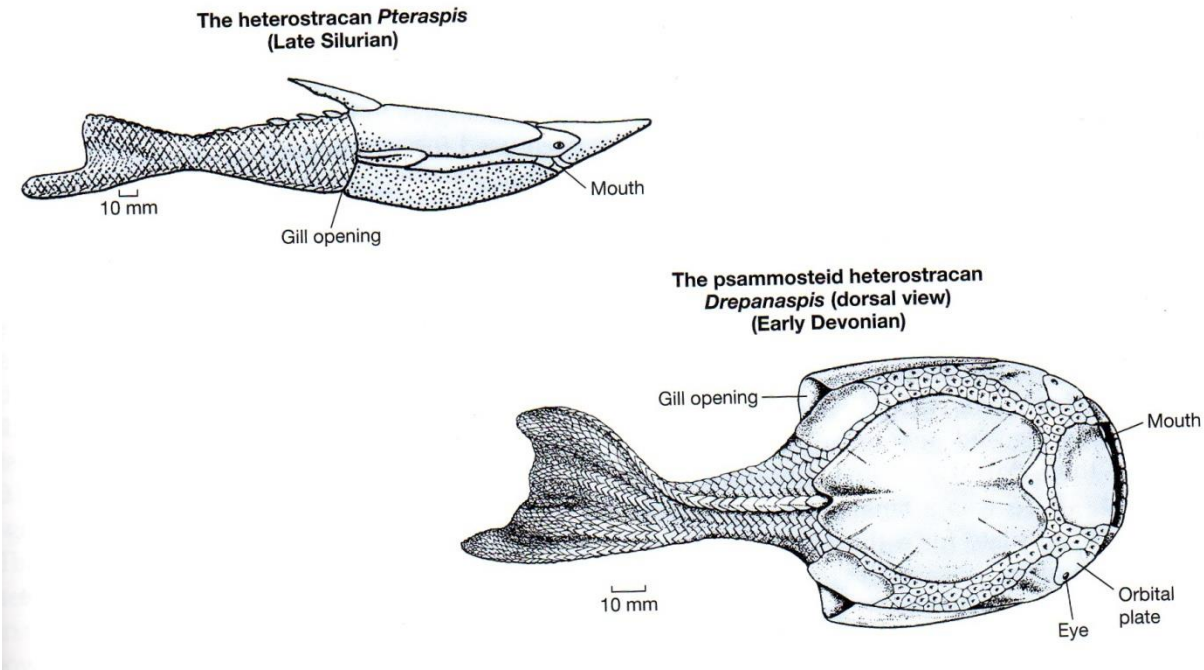


Fig. 1. Reconstructions of ostracoderm fossils

From Pough, F. H., Janis, C. M. and Heiser, J. B. 2002. Vertebrate Life. Prentice Hall. Fig 3.7, p. 61.

1) AMMOCOETE LARVA, or LARVAL LAMPREY

The ammocoete larva is the developmental stage of the lamprey. Most adult lampreys are parasites on marine and freshwater fish. The ammocoete larva is found in freshwater only. The blind and toothless larva is a filter feeder and has a long life, from 3 to 7 years. Superficial similarities to the amphioxus or lancelet (e.g. *Branchiostoma*, Lab 1, a cephalochordate you may recall) are remarkable but this larval stage shows many advances.

15 minutes
Bench 1 and Side Bench under window.

a) Ostracoderms†;
b) Examine a preserved ammocoete; and
c) compare the adult lampreys and hagfish in the collection.

1a) Note the dermal plates (armour) which form many of the bones in modern fish (and a few of our own – e.g. cranial bones and clavicle). See pictures

1b) Using a Petri dish, take a preserved ammocoete from the bottle on the side bench. Examine it with a hand lens or a binocular microscope. Note the nature of the mouth and the position of the gill openings.

The relations between the pharyngeal lumen, "gill pouches" and the gills themselves are not easy to determine from a cross section. The gill pouches are not the distinct structures they become in the adult. In most cases they are simply expanded areas of the wall of the pharynx. Each pouch opens separately to the outside. **There is no atrium, although at first glance it may exist in sections where there is no pharyngeal wall. Note this major difference between craniates and other chordates. Also notice that the pharynx is a sturdy structure, equipped with muscles and skeletal support. Q2, Q3. This represents a major advance in the evolution of the vertebrates.**

Amphioxus or lancelet (Lab. #1)	**Ammocoete larva (a larval lamprey)**
Branchiostoma	
Chordata; sub-phylum Cephalochordata	Chordata; sub-phylum Vertebrata
Filter feeder, living in burrows along coast	Filter feeder, living buried in mud of cool streams
No vertebrae, no scales, no paired fins	No vertebrae (! but the genes), no scales, no paired fins
*** Gills are used only for filter feeding**	Gills are used for respiration + gill pouches
Branchial basket, endostyle (food groove) and atrium	*** Branchial basket leading to the gill pouches, no atrium, endostyle**
Dorsal fin, and fin folds (e.g. the ventral "metaplural folds")	Dorsal fin (not in hagfish)
Myomeres (i.e. paired muscle blocks)	Myomeres, now sturdier
Notochord, & dorsal hollow nerve cord	Notochord & dorsal hollow nerve cord
Segmented primitive kidney, segmented gonads	Organs not segmented (?)

Barely a brain, only just a craniate, no eyes (but eye-spots)	More cephalisation, with primitive eye

A similar table could include larval tunicate (similar, but less derived than *Amphioxus*) and a larval fish (similar but more derived than an ammocoete).

THE ADULT LAMPREY

Mordacia mordax is a relatively small lamprey of eastern Australian waters. It has a 'sister' species on the western coast of South America. The ammocoete larva of *M. mordax* is found in freshwater streams of the eastern coast to southern Victoria. After metamorphosing in freshwater, the adults migrate to the sea but remain near the coast. The adult is parasitic on fish, reaching a maximum length of 12 cm (only half the ~30 lampreys are parasitic).

Examine the preserved specimens of adult lampreys and compare them with the specimens of hagfish (a list of contrasting characters is given below). There are a couple of demonstration dissections of the anterior region of lampreys that show the arrangement of the gill pouches. Take some notes so that you could recognize one if it sprung up in the lab quiz or lab exam.

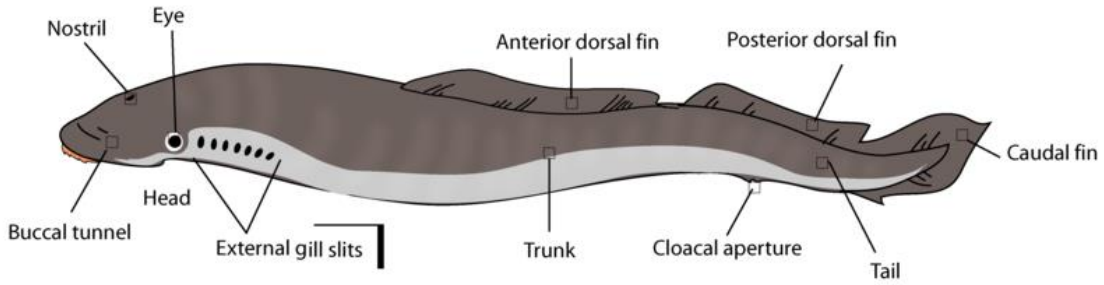


Fig. 2. External sketch of a lamprey (from Wikipedia)

LAMPREY and HAGFISH

Lampreys have no jaw and a well-developed **suctorial mouth** with large numbers of horny 'teeth' and a strong, muscular tongue which also bears horny 'teeth' (lampreys attach themselves to live fish and use the 'teeth' and rasping tongue to feed on blood and tissues). They have well developed **dorsal fins,** moderately **developed eyes and a** nasohypophyseal opening (nostril) on top of head. They have **7 gill pouches** which open to exterior by separate openings, close to the head; internally they open into the gill tube which lies below the esophagus. The larval form (ammocoete) lives in freshwater, which metamorphoses to an adult form; most adults are marine but some remain in freshwater throughout their life; the marine forms must return to freshwater to breed. *Mordacia* and *Geotria* are southern hemisphere lampreys, occurring off Australia, Tasmania, New Zealand and South America; *Lampetra* is one of the northern hemisphere lampreys

Hagfish also have no jaw, but no suctorial mouth; 'teeth' only on the tongue; sensitive tentacles around the mouth region (hagfish rarely attack free-swimming fish; they feed on dead or dying fish by boring into the carcass; mostly they feed on annelids, molluscs and other invertebrates occurring in the bottom mud). They have no dorsal fins, degenerate eyes and nasohypophyseal opening (nostril) at extreme anterior end. The **number of gill**

pouches variable (according to species); internally the pouches open directly into the pharynx; laterally they may open into a common duct that opens to the exterior far from the head OR 5-15 gill pouches may open separately to the exterior. The cartilage branchial skeleton rudimentary. There is no larval stage, and are entirely marine. They have **mucous glands** in a row on each side of the body are capable of producing large quantities of mucus (hence common European name 'slime eels') A world-wide distribution, especially the genus *Myxine.*

The visceral skeleton

The axial skeleton is composed of the skull and vertebral column; the appendicular skeleton is composed of the pectoral and pelvic girdles and the limbs. The VISCERAL SKELETON is comprised of very minor elements in mammals such as ourselves but is much more important in animals with gills. The visceral skeleton serves primarily to support the gill apparatus. Elements of the visceral skeleton are incorporated into the axial skeleton, into the jaws in particular, of terrestrial craniates. The visceral skeleton of early craniates LACKING jaws consists of a series of gill arches as shown in Fig. 4a. In jawed craniates (Gnathostomata) at least the first two arches are lost in development and a posterior gill arch gives rise to the jaws (Fig. 4b). The upper part of the next posterior arch (known as the HYOID arch) braces the jaw hinge against the skull and is known as the HYOMANDIBULAR (forms the stapes of the inner ear in terrestrial vertebrates; the other two bones of the inner ear of mammals is derived from the reptilian jaw!). The gill slit between the jaws and the hyomandibular may remain as the spiracle as seen in modern sharks and the Eustachian tube in terrestrial vertebrates.

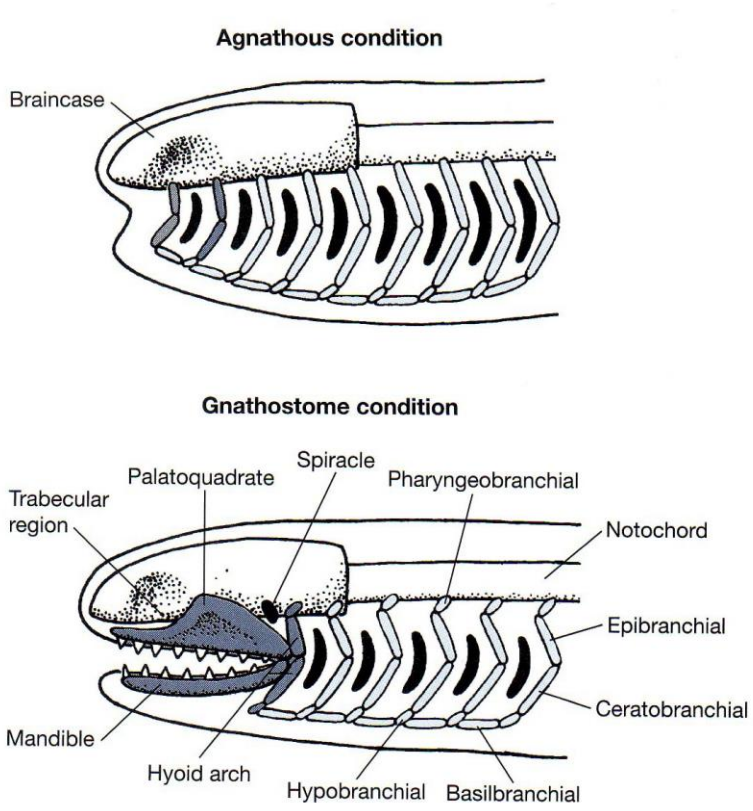
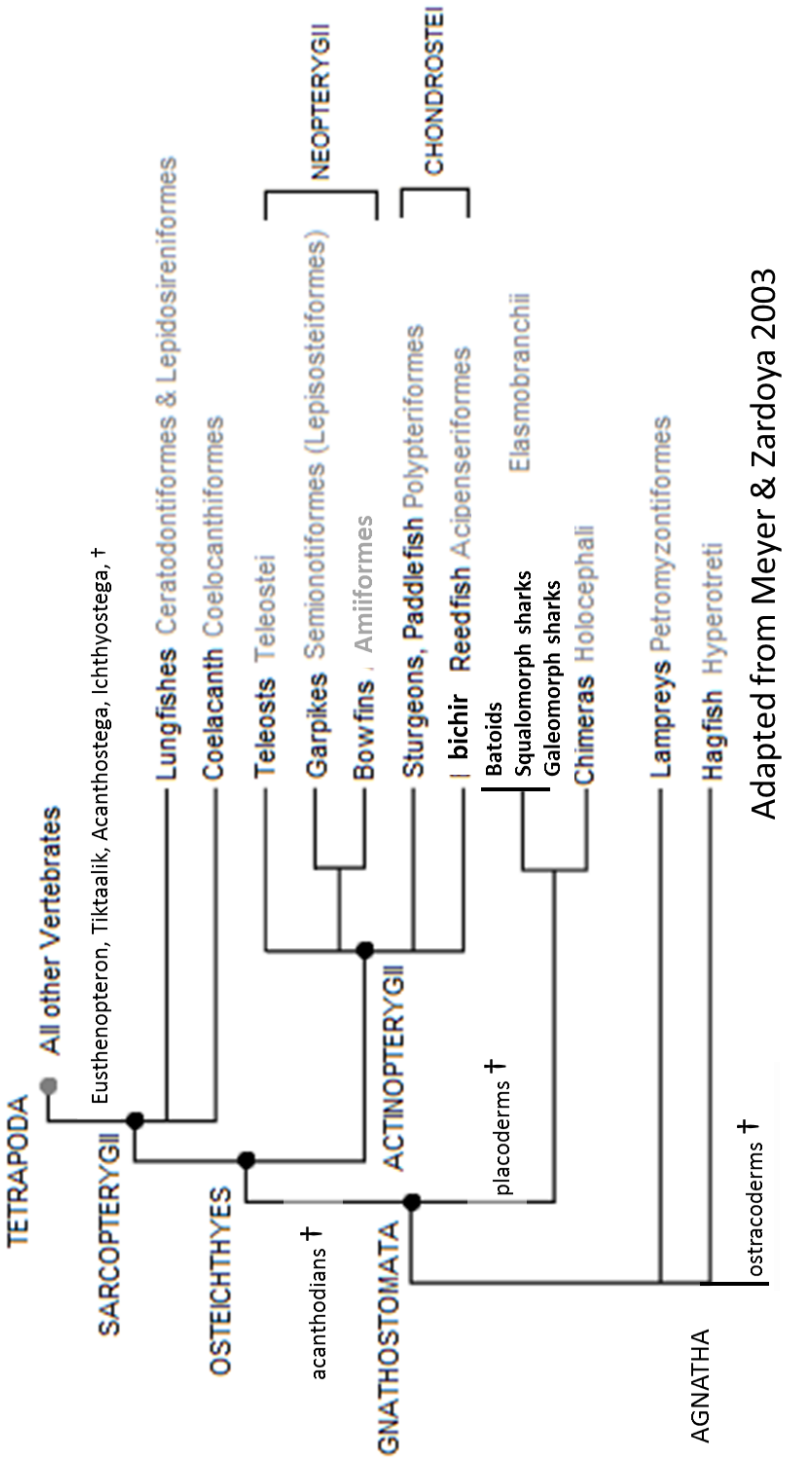


Fig. 3. The derivation of jaws from gill (branchial) arches.

From Pough, F. H., Janis, C. M. and Heiser, J. B. 2002. Vertebrate Life. Prentice Hall. Fig 3.9, p. 66.

Fig. 4. Fish taxonomy that you need to know:



Adapted from Meyer & Zardoya 2003
Clade-names (in grey) of Actinopterygii and Sarcopterygii are not examinable
Taxonomy that you need to know for this course

Fig. 5a. Chondrichthyes

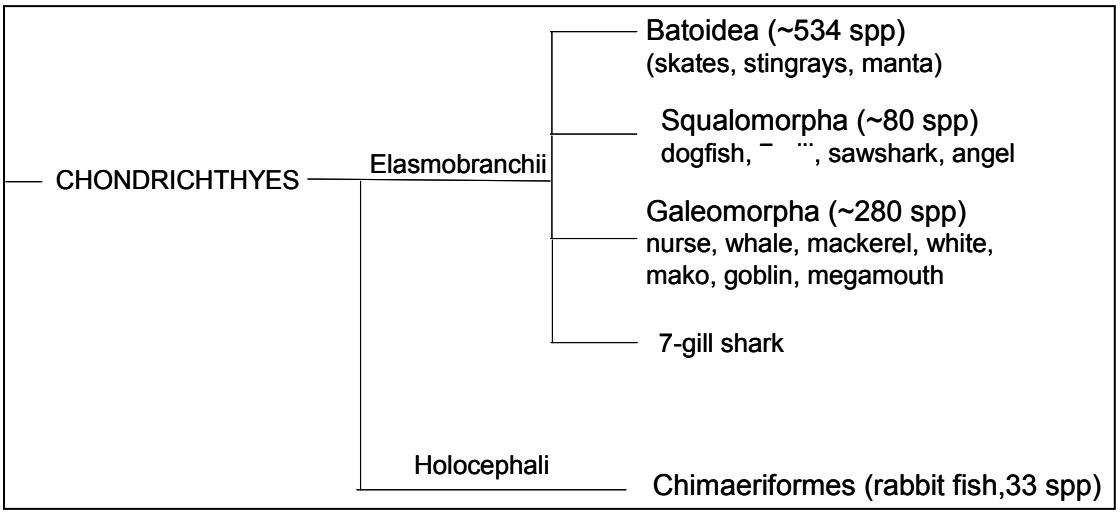
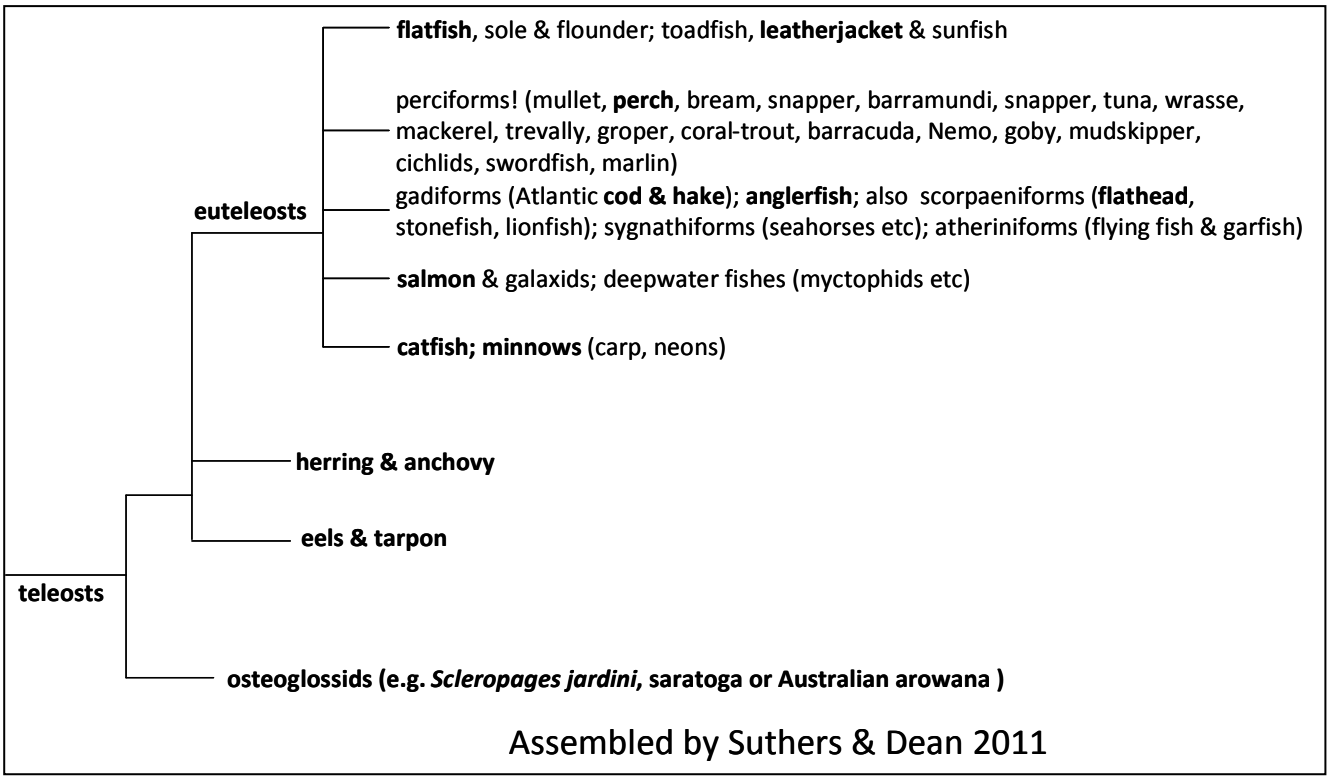


Fig. 5b. Major teleost clades, from least derived (Saratoga) to most derived (flatfish and leatherjackets). Note that the clades for euteleosts are not well resolved (e.g. catfish/minnows and salmon), but there is an accepted gradation of increasing diversity or specialization from hake and flatheads, to perciforms and flatfish.



2) Class CHONDRICHTHYES

There are two very different clades of living chondrichthyan fishes, probably sister groups:

- Holocephalians (Rabbit-fish or chimaeras)
- Elasmobranchs (sharks, dogfish, skates and rays)

THE **HOLOCEPHALIANS** are the older type in the fossil record, and the group contains several extinct clades. The living holocephalians are usually called chimaeras, ratfish or rabbit-fish (the latter is an Australian common name) and are worldwide in distribution but poorly known, probably due to the fact that most forms are benthic. Characters that distinguish holocephalians from elasmobranchs include (Q4):

- gills covered by operculum
- scales lacking
- tooth plates (for crushing invertebrate prey) present
- no spiracles
- mace-like cephalic clasper on males

THE **ELASMOBRANCHS** may be divided into 4 groups:

Hexanchiformes, **or 7 gill sharks** (4 species in 3 genera)- presence of a 6th and in two genera, a 7th gill slit, in addition to the five found in all other sharks. Considered the most primitive of all living sharks, because their skeletons resemble those of ancient extinct forms, with few modern adaptations. Their excretory and digestive systems are also unspecialised, suggesting that they may resemble those of primitive shark ancestors. 1 anal fin, 1 dorsal fin.

Galeomorphs (about 250 spp.) – Presence of an anal fin; two (2) dorsal fins often without spines. Includes 4 major orders (order names for your interest only): Heterodontiformes (e.g. PJ), Orectolobiformes (wobbegon, whale shark), Lamniformes (great white, mako, thresher, gray nurse but also basking and megamouth), and Carcharhiniformes (bull, thresher, hammerhead, cat). The oldest type is the Port Jackson (PJ) shark (examine the specimen in the collection); also includes hammerheads (look at the specimens in the collection - can you see any advantage to the 'hammer' head?). 1 anal fin and 2 dorsals. Q6

Squalomorphs (about 80 spp)- No anal fin (but don't be misled by the ventral fin of course), two (2) dorsal fins often with spine in front of each, often deep water., this group includes 3 major orders (order names for your interest only): Squaliformes (dogfish, Sleeper sharks, cookie cuttershark); Squatiniformes (angel sharks); And Pristiophoriformes saw shark (with weakly embedded teeth of unequal size). No anal fin, 2 dorsals. Q5

Batoids (about 530 spp) - flattened dorso-ventrally, gill slits ventral. Includes rays, stingray, manta, torpedo, guitarfish, sawfish (saw in the collection, with strongly embedded teeth and equal in size) and skates. Q7) Why did this body form and lifestyle have so many more species? Expanded pectorals, 2 dorsals, no anal fin and ventral gills.

REPRODUCTION IN ELASMOBRANCHS

Some species lay eggs (oviparous) while others give birth to live young. In sharks that give birth to live young, such as the spiny dogfish, the nourishment of the developing young comes from the mass of yolk material retained in the oviduct, so it really is a case of retention of the egg inside the mother rather than releasing it to the outside - this is OVOVIVIPARITY (or these days "aplacental viviparity"). A few species have carried this process a step further and, as well as receiving nourishment from the yolk, also receive it direct from the mother by way of a YOLK SAC PLACENTA. This is approaching true VIVIPARITY.

2) Class CHONDRICHTHYES
45 minutes, Benches 2-4

Compare and make notes or sketches of the following, noting the number of dorsal and anal fins, the shape of fins and the presence or absence of a spiracle (and whether the shark is male or female)

a) Bench 2. The chimaera shark. Where do you find them? What do they eat? How can you tell this specimen is a male? Consider the remarkable separate evolution of the holocephalans and elasmobranchs;

b) Bench 2. The sharpnose seven-gill shark, *Heptranchias perlo*; (one dorsal, one anal fin)

c) Bench 3. The galeomorph sharks including the Port Jackson shark pup, the hammerhead (regularly and uselessly culled by beach meshing), the wobbegong, white shark, bull shark, grey nurse (2 dorsals, 1 anal fin); (Q8, Q9)

d) Bench 3. The squalomorph sharks including the dogfish (male and female), the sawshark, and the angel sharks (2 dorsals, no anal fin); and

e) Bench 4. The batoids, noting various rays with the large pectoral fins characteristic of this order, 2 dorsals, no anal fin). Note which are males and females, and the saw from a sawfish; (Q10)

f) Bench 4. Reproduction in sharks and rays – see the various eggs and pups.

g) Bench 4. Jaws in sharks and rays – see the various jaws and infer the diets (it is not difficult).

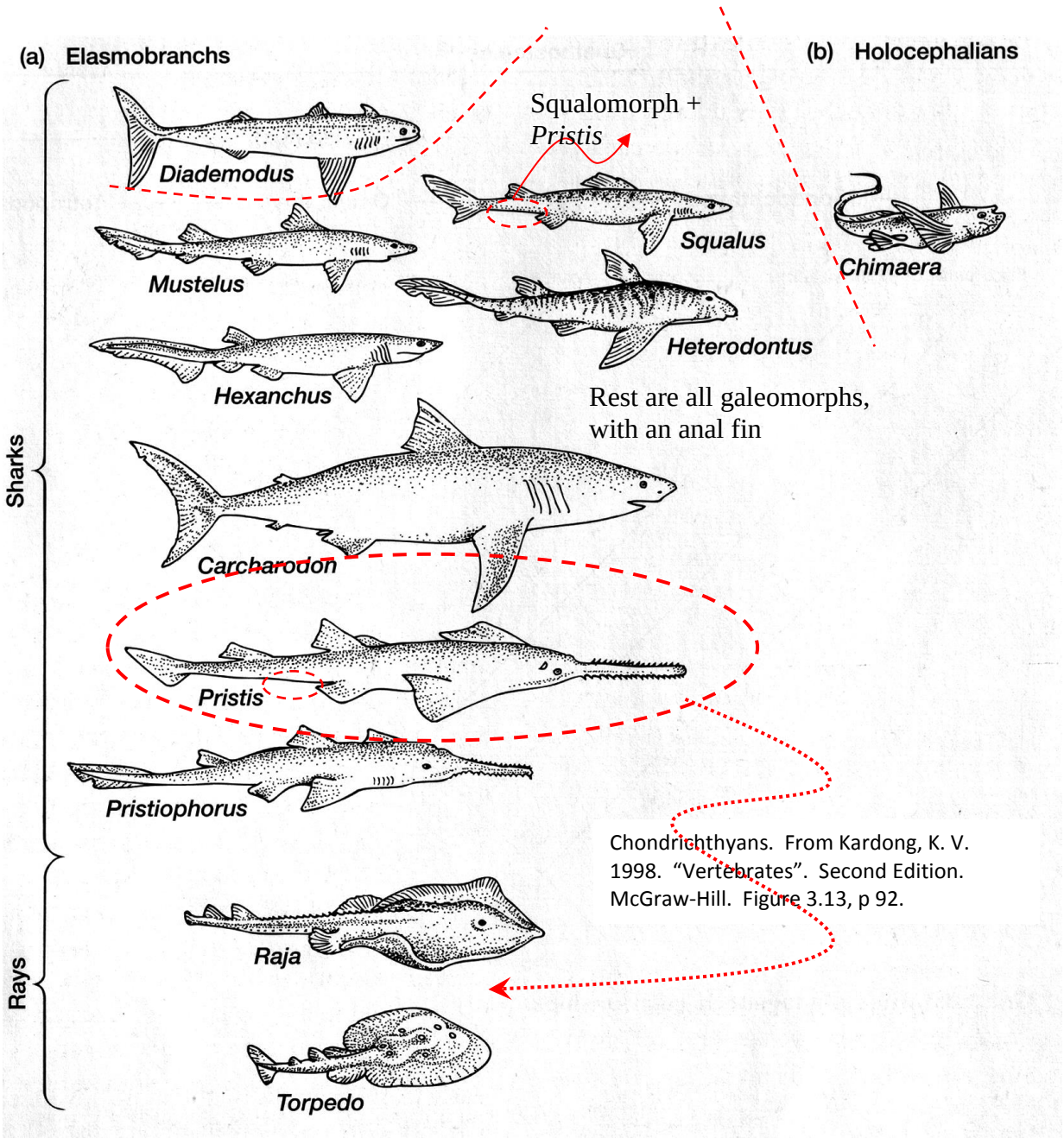


Fig. 7. Overview of the elasmobranchs.
NB – there is an interesting mistake here! *Pristis* is a sawfish (really a "saw-ray"), and should be grouped with the Batoidea; *Pristiophorus* is the sawshark and is indeed a squalomorph shark. Note (at least) the location of the gill slits.

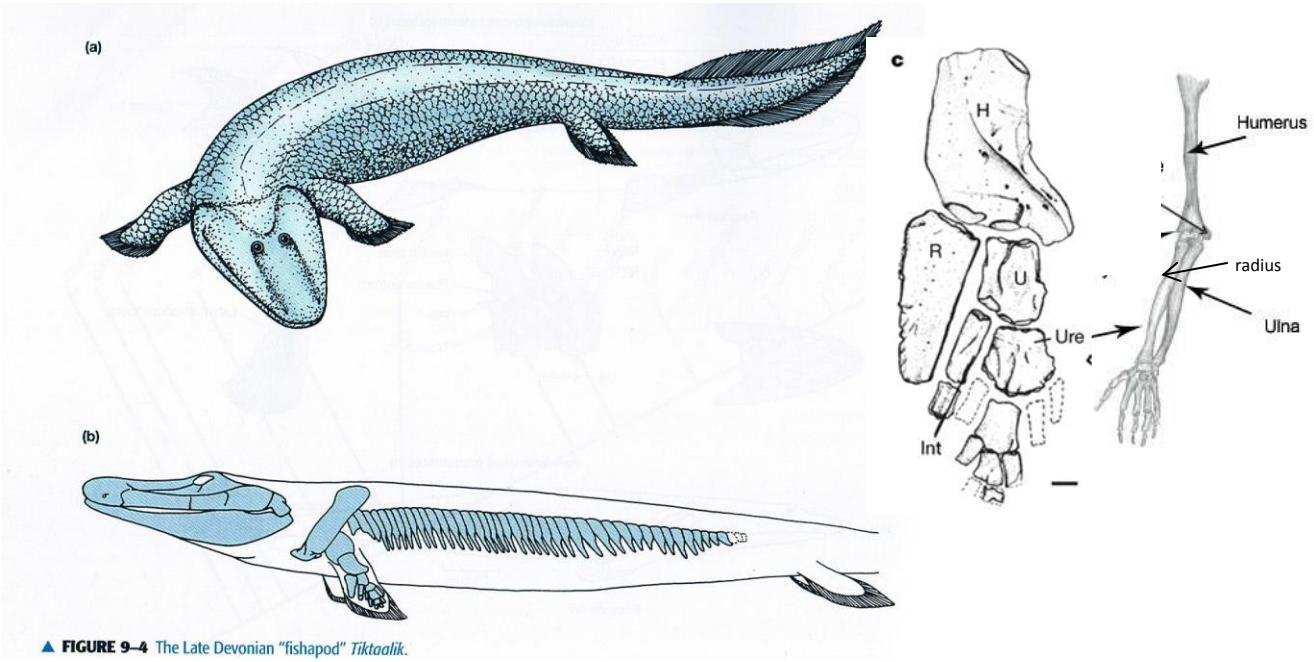
3) Clade SARCOPTERYGII

(Bench 5), 15 minutes

a) Sketch and examine the drawing of a coelacanth (note esp the two dorsal fins (one ray-fined, the other lobe-based) and note the distinctive tail unchanged from the fossil record, spiracle.

b) Sketch and examine the drawing of the Australian lungfish (*Neoceratodus*). Note the tail, the stout base to the fins, and the heavy scales;

c) Make brief note the pictures on Tiktaalik and other ancient "fishapods". Where are the major findings being made? What was their likely habitat? Notice how Tiktaalik's fins rays skidded on the mud as she pushed up to breath.

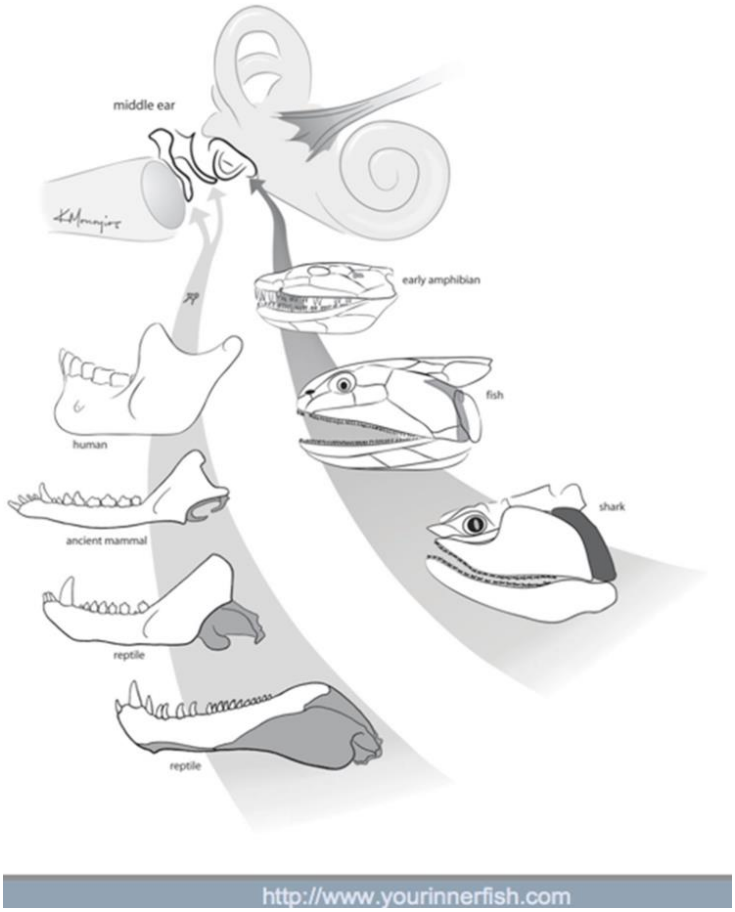


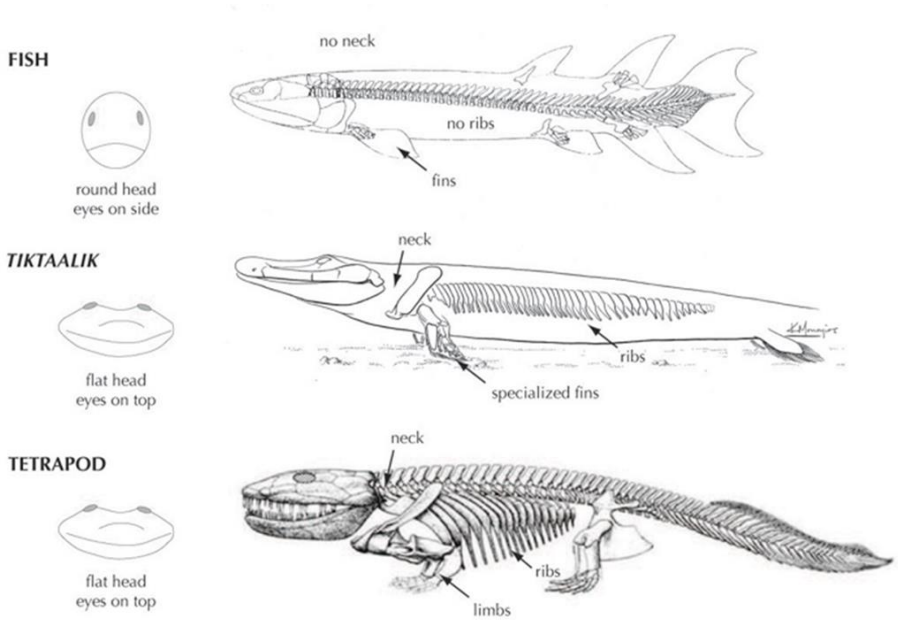
▲ FIGURE 9–4 The Late Devonian "fishapod" *Tiktaalik*.

Fig. 8. Note:
Gills, scales and fins living in water (like a fish);
At the time very large predatory fish were in the lakes and rivers. Shallow ponds were its only refuge.

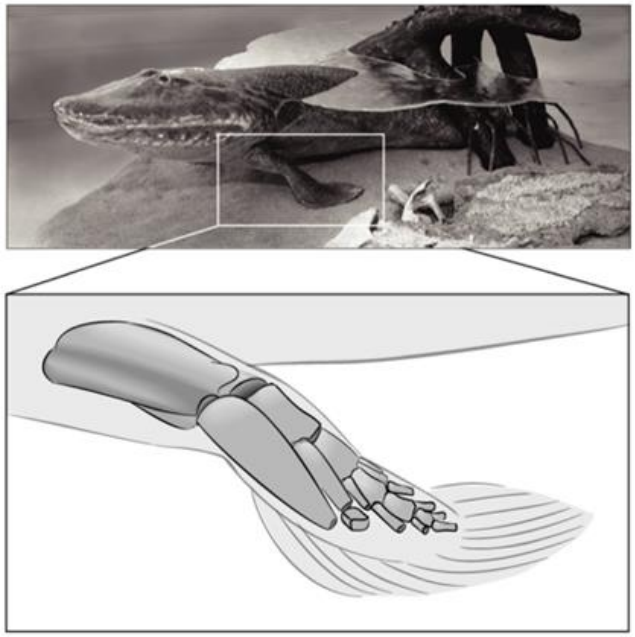
But also,
i) eyes on the top of its head, in the middle;
ii) Loss of bony gill cover (operculum), but still gills, maybe for the gill rakers to lacerate food but not for respiration;
iii) tilt its head up to breath oxygen-rich air (i.e. a neck) + swimbladder/lungs of some sort!
iv) Ribs large, overlapping, for body support in air;
v) Pectoral fin can bend – note all the major limb bones are present for the first time!! It can twist its wrist with the radius/ulna and do lots of push-ups to breath, nod and possibly feed.

The following figures are from Neil Shubin's website, where there are more lecture-note style figures, www.yourinnerfish.com

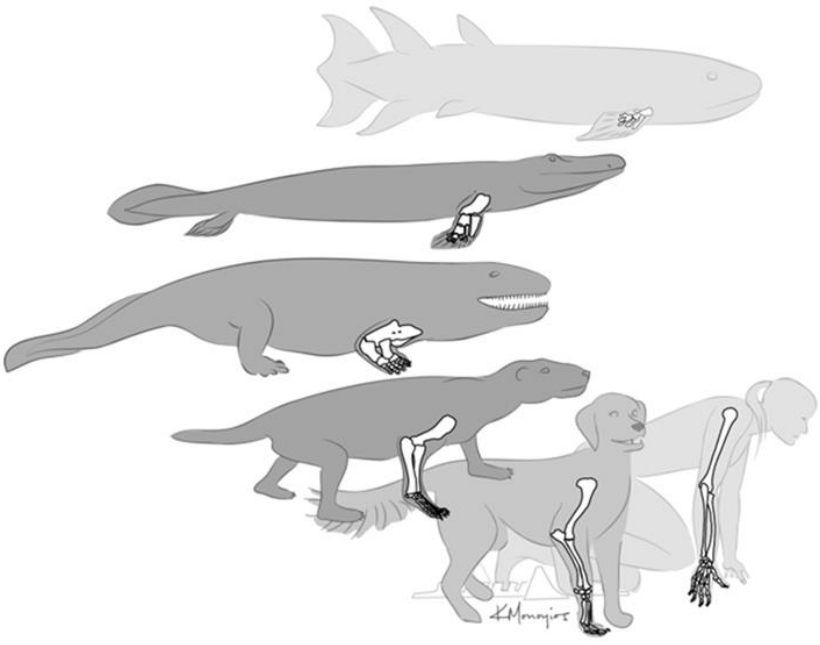




This figure says it all. *Tiktaalik* is intermediate between fish and primitive land-living animal.



A full-scale model of *Tiktaalik*'s body (top) and a drawing of its fin (bottom). This is a fin in which the shoulder, elbow, and proto-wrist were capable of performing a type of push-up.



Tracing arm bones from fish to humans.

Shubin et al.
www.yourinnerfish.com

4) Clade ACTINOPTERYGII (ray-finned fish)

See the cladogram of this group (Fig. 5, and/or Fig. 3.14 of text)

Examine the specimens available in the lab. Remember that in many cases it is not possible to see the diagnostic characters in whole specimens - many of the apomorphic characters on which fish clades are established are conditions of internal structure. Fish phylogeny and taxonomy is a very specialized and often controversial field. There are many fish whose diet and habitat you should be able to deduce from their structure.

Bench 6-8
(30 min) – Sketch or photograph the above fish to remember for lab exam.
Examine the display of fresh (and possibly preserved) fish provided and relate them to the 6 major groups noted in lectures:

a) Bench 6. Sturgeon & bichir
   - Picture, noting the heterocercal tail, spiracles and the scales (Q 11).

b) Bench 6. Garpike & bowfin – 2 beautiful specimens
   - One preserved garpike (nb the relative fin location and ganoid scales), noting in particular the asymmetrical (heterocercal) tail.
   - Q. 12 Where are they both found; what is their shared habitat?

c) Bench 6. Teleost - bony tongues
   - gulf saratoga (nb the scales, fin location, mouth and fin shape)
   - See the live one in Rob Brook's office, or Iain Suthers' office

d) Bench 7. Teleost - eels and tarpons
   - Fresh or preserved eel (note which fins are absent, and scales?). Note in particular how the tail ends in a notochord with dorsal and ventral rays (i.e no dorsal flexion like the herterocercal shark tail, and how larval fish tails develop)

e) Bench 7. Teleost - herrings and anchovies
   - Fresh or preserved herring (nb the soft rayed dorsal, fin location, mouth and maxilla)

f) Bench 7 . Teleost - euteleosts including:
   - catfish & minnows/carp (Ostariophysi)
   - salmon (Protacanthopterygii)
   - small deepwater fish (Stenopterygii and Scopelomorpha et al.)
   - cod, hake, anglerfish (Paracanthopterygii)

   Bench 8 – all the highly derived fishes.
   - the many perch-like fish in the order Perciformes (Acanthopterygii), and
   - flatfish and leatherjackets – the most derived acanthopterygians!

g) Tuna Skull preparation on the side bench
   In bony fish the skull has enormous variation in shape. Be sure to examine the peculiar skull of the tuna or snapper. You are not expected to know the names of any of the bones of the skull - they are difficult to identify. You should however be able to identify the elements of the visceral skeleton mentioned above that are associated with the skull

Notes on the above clades:

Esocids - Northern hemisphere freshwater forms, known as 'pikes' but not to be confused with 'gar pikes'. Esocids and Salmoniformes are often incorporated into the same Superorder viz, Protacanthopterygii.

Ostariophysi - the predominant fishes of most freshwater systems except Australia. There are a few native to Australia (e.g. the catfish), but major groups such as carp and minnows are absent from South America and Australia

Salmoniformes - these are plesiomorphic forms, including salmon and trout. Many Australian freshwater fish are **galaxiids**, which are found only in the Southern hemisphere

Myctophiformes (=Scopelomorpha) - worldwide marine fish in the mesopelagic zone. Lantern fish are typical

Paracanthopterygii - includes cod and anglerfish

Acanthopterygii - often referred to as the 'true' spiny-rayed fishes, this clade contains about 10,000 species, and all the fish we know and love from the coast: flathead, bream, tuna, mullet flatfish and toadfish. Mostly Order Perciformes.

THE FISH SKELETON

In bony fish, dermal bones extending backwards from the head armor become applied to the girdle. The largest of these is usually the cleithrum which bears, in primitive fish, the clavicle at its ventral end beneath the fins. Other dermal bones connect the cleithrum to the back of the skull (fish have little mobility of the head and are unable to 'look over their shoulder'). The small ossified scapula and coracoid are on the inner surface of the cleithrum and bear the fin (FIG. 9, below).

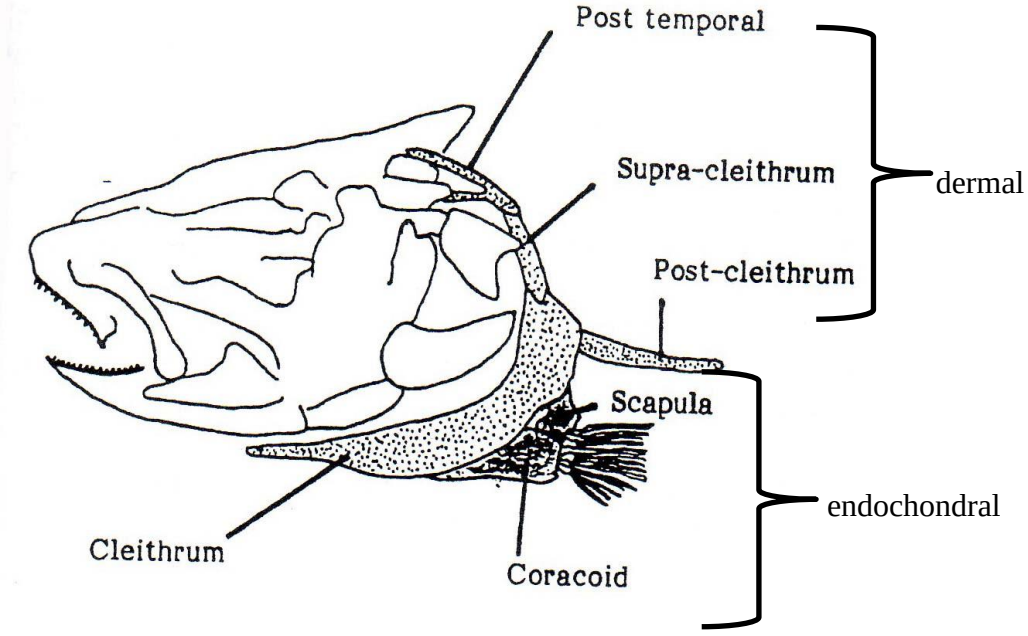


FIG. 9. Left side of cod, showing how endochondral elements (shaded, scapula and coracoid) of the pectoral girdle are braced against the skull by dermal bone elements (dotted, cleithrum etc) of the girdle. This condition is typical of teleost fish.

The PELVIC girdle differs from the pectoral girdle in that it is never reinforced by dermal bones in any living bony fish - in fact the pelvic girdle is often much reduced. It is usually represented by two ventral plates (i.e. the left and right halves of the girdle) in the muscles

just anterior to the cloaca. The two halves may meet ventrally or even fuse. The girdle supports the pelvic fin but is never attached to the vertebral column. In terrestrial craniates the pelvic girdle is usually larger and more sturdy than the pectoral girdle because it bears the weight of the posterior body at least.

5) Fish Dissection

Bench 1, 2 and Bench 5, 8, plus side bench.

Note down the name, the Genus and species.

A (40 MIN): Complete a fish dissection (one fish per pair of students) with particular attention to the external features noting:

a) the fin formulae for dorsal fin and anal fin (e.g. DXII,12 AIII,12 wrt spines and rays)
5b) mouth, gill arches, gills, gill rakers,
5c) scales, lateral line, pectoral fins, pelvic (or ventral fins), caudal fin (or tail)

AND

B) Dissect the fish to reveal the internal organs. Using your scissors, cut carefully from the cloaca anteriorly, through the pectoral girdle and right up into the gular region ("throat") between the gills to reveal the heart. Then cut away the muscle and ribs. Note the location of:
a) liver,
b) stomach and gut,
c) gonad, (girl or boy?)
d) swimbladder, (Q18)
e) kidney,
f) heart.
A dissection of the otoliths may be made for you.
Q19 How many gill arches are there?
<u>Make a single, large sketch of the external features (A) and showing internal organs (B), and attach to your completion sheet.</u>

C: Consider transverse Sections (TS) of your fish across the gills and across the dorsal fin. Compare this sketch with Fig. 2 and 3 of the lamprey.
Q. 20.

SOFT ORGANS (the viscera)

The following features will be evident in your dissection.

A. DIGESTIVE TRACT. The gut and other contents of the peritoneal cavity are much the same as in the shark. Compared to mammals, the digestive tract is short and simple. However,

bony fish do have PYLORIC CAECA, a ring of long pouches in the region of the pyloric sphincter.

B. SWIM BLADDER - in bony fish the ancestral gas bladder is modified to an organ of buoyancy known as the swim bladder. In its simplest form the swim bladder was probably inflated by gulping air through the mouth and forcing it into the bladder by constriction of pharyngeal muscles. In its most elegant form, the swim bladder is completely disconnected from the pharynx and buoyancy is controlled by release of gas from and resorption of gas into the blood stream.

The herring (Fig. 10a) represents an in between state, with a duct still connecting the pharynx and swim bladder. Note that the swim bladder must be above the center of gravity! It is usually above the digestive tract and just under the vertebral column and a bit anterior as in (a). However in the embryo it arises as a ventral pocketing of the pharynx and migrates to the dorsal position.

In those bony fish in which the duct connecting to the pharynx is lost in development (Fig. 10b), the vascular connections represent the only avenue for filling and draining the gas in the bladder. This is accomplished by a combination of a **rete mirabile** countercurrent exchanger for gases (primarily oxygen) and a **gas gland** on the surface of the swim bladder that produces lactic acid, forcing oxygen out of solution. No elaborate mechanisms are necessary to remove gas from the bladder, since gas at high partial pressure will diffuse into the blood readily from the **ovale gland**. Control of the ovale gland is by simple vasomotor action, shutting off or increasing blood flow into the wall of the swim bladder.

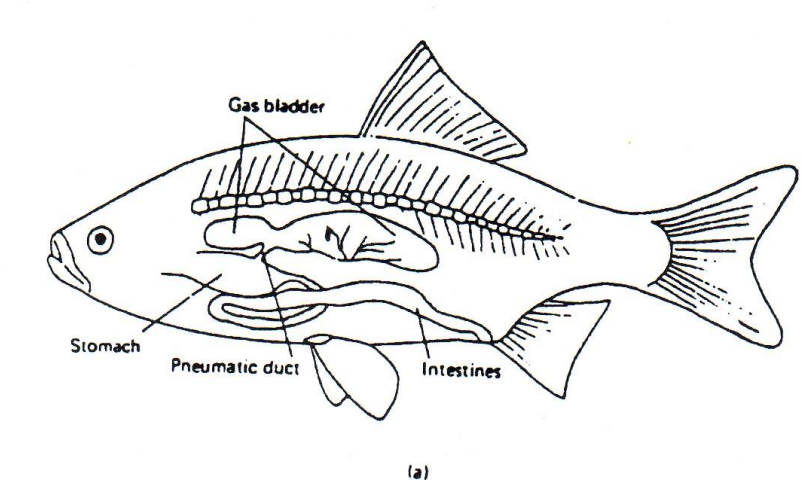
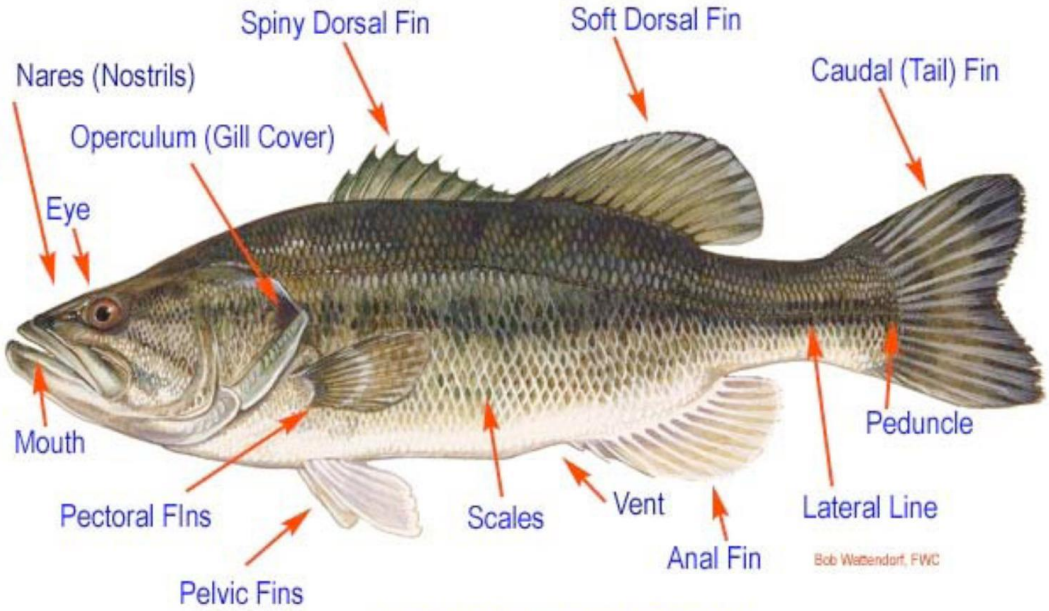
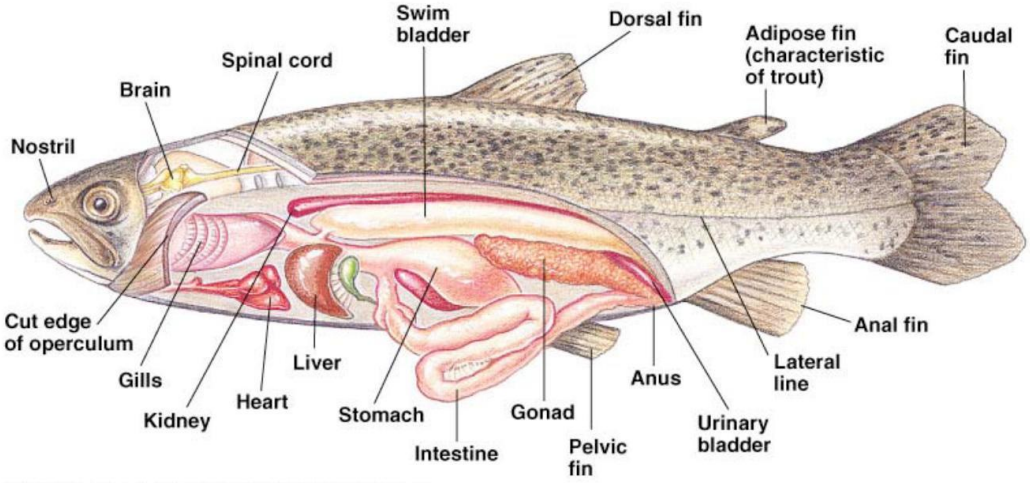


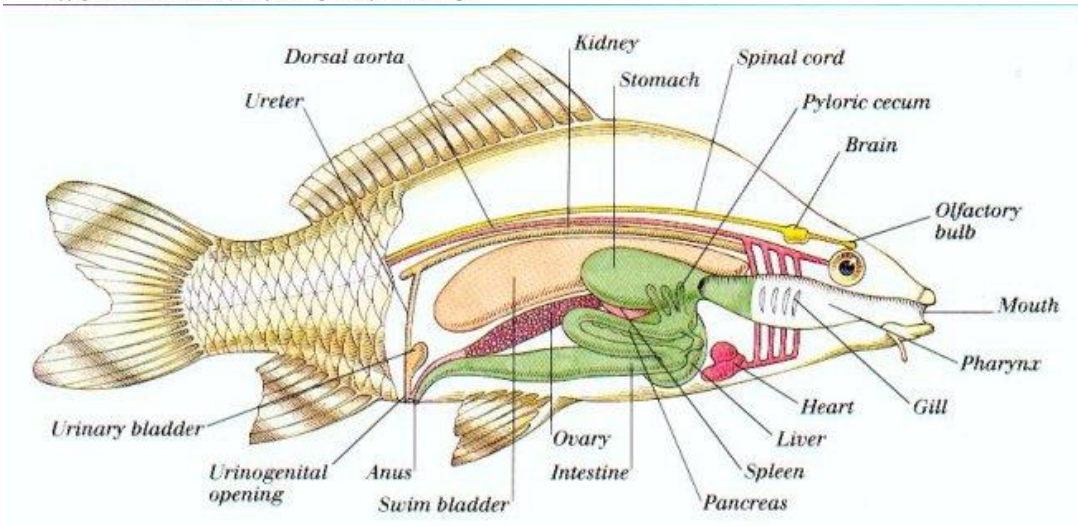
Fig. 10. The swim (gas) bladder (after Pough et al. 2002)



http://myfwc.com/fishing/freshwater/fishing-tips/anatomy/

**** Fin formula is DIX, 13; A III, 10 – can you see why/how?**





http://www.aquamania.co.uk/fish-info-anatomy.asp

THE END

NOTES

PRACTICAL 5

The Tetrapod Skull and Skeleton

THE TETRAPOD SKELETON

There are a number of mounted skeletons available for you to use in learning the names and functions of the major bones of terrestrial vertebrates (tetrapods). Most of these are mammals; therefore the following notes refer to mammals. You should know all of the terms and bones underlined in the following text. Fig. 1 is a labelled cat skeleton to use as a guide.

OVERALL

In the normal posture of a tetrapod such as a cat the head end is the anterior end, the tail end is the posterior end, and the sides are lateral. The back is dorsal and the belly is ventral. These terms are also used for upright animals such as kangaroos and humans. Therefore what is in common language your 'top' is anterior and your 'bottom' is posterior. The 'front' of your body is likewise ventral and the 'back' dorsal.

Using positional terms for your own body if put in the posture of the cat skeleton, the most anterior part of body is _____ (choose: top of head; nose; chin)

The skull and vertebral column (with the ribs and sternum) are known as the axial skeleton. The two girdles (pectoral and pelvic) with their limbs are the appendicular skeleton. The branchial (visceral) skeleton is much reduced in tetrapods (only the jaws and a few cartilages in the throat region remain in mammals) but is important in fish.

What does your eustachian canal represent in terms of 'your inner fish' anatomy?

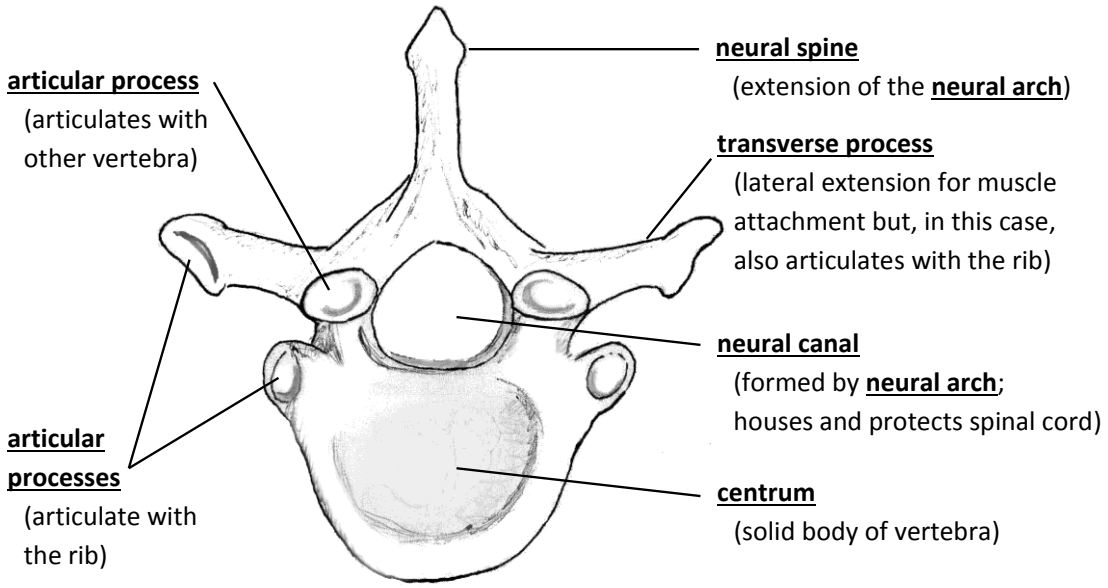
_____

VERTEBRAL COLUMN

Individual vertebrae

Each vertebra consists of a solid body or centrum (the ends of which are usually flat in mammals) which lies ventral to the neural canal. The spinal cord passes through the neural canal which is in the neural arch of the vertebra. The neural arch may be extended dorsally to form the neural spine. The neural spine varies in size along the vertebral column - why? . . . . The lateral extensions of the vertebra are the transverse processes. They are also variable in size and shape along the vertebral column.

THORACIC VERTEBRA



Look at a reptile skeleton if one is available. Look at the junction between the vertebrae. Describe the shape of the ends of the centra at the front and back of each vertebra _____
_____

Regions of the vertebral column

CERVICAL - There are 7 cervical vertebrae in most mammals (including the giraffe). The first is the atlas which is specially adapted to articulate with the occipital condyles of the skull. It has no solid centrum. The second is the axis, with the anterior face of its centrum drawn out into the odontoid process. The atlas and axis form a unit which allows the wide range of movement of the tetrapod head. The remaining cervical vertebrae have neural spines that increase in size towards the thorax. Their transverse processes may be divided into two branches.

When someone is hanged until they are dead, it commonly involves fracturing of the odontoid peg. How would you think this would result in death?

_____

_____

Does having a neck in terrestrial animals increase the risks they face in spinal column fractures? _____.

If so, why do we have necks?

_____

_____

THORACIC - The thoracic vertebrae always bear ribs and the facets for rib articulation can be seen on the centrum. The size of the neural spines decreases posteriorly.

LUMBAR - These vertebrae do not bear ribs but have long, conspicuous transverse processes in mammals.

What would the muscles do that attach to the tops of the neural arches of the vertebrae? _____
_____.

What human-built structures resemble this natural system? _____
_____.

Getting ideas from the natural world about useful things that humans could design is called biomimetics—mimicking the biological world.

SACRAL - There are 2 or 3 of these and they are fused together to form the sacrum which has a firm articulation with the pelvis.

Why do you suppose the sacral vertebrae in mammals are fused into a single unit? What possible advantage over the condition in reptiles related to locomotion might this provide? _____

CAUDAL - These are the tail vertebrae. They vary greatly in number. Some of the anterior ones may be fused to the sacrum. The anterior caudals have a short centrum with well developed transverse processes. Further down the tail the neural arch and all processes diminish, while the centrum becomes elongated and rod-like. V-shaped chevron bones are found on the ventral surface of the centrum in well-developed tails (see the dolphin suspended from the ceiling, and a kangaroo). These bones give extra surface for muscle attachment and protect the caudal blood vessels.

Vertebral formula

The number of vertebrae characteristic of a species or other taxon can be indicated by a formula.
For example:

Human = C7 T12 L5 S5 C4
Red Kangaroo = C7 T13 L6 S2 C21

Ribs and sternum

Most ribs articulate at their ventral ends with costal cartilages (also known as sternal ribs). The costal cartilages may be calcified in some species. They articulate with the sternum. Floating ribs do not reach the sternum.

The sternum is made up of segments. The anterior segment is the manubrium and the posterior segment is the xiphisternum, to which an expanded xiphoid cartilage is attached (however the xiphoid cartilage is often not present in prepared skeletons).

Is there a difference between the number of ribs in a human male and female? (On the cardboard diagrams of the human skeletons, the individual facing you is male; the individual facing away is female) _____.

How many heads (points of attachment/articulation to the vertebrae) are there on each mammalian rib? _____ Does this differ from the number for reptilian ribs? _____.

What major difference would you expect to find in the soft anatomy of a mammal versus a reptile at the base of the rib cage_____ _____ that relates to the way each group breathes?

PECTORAL GIRDLE

A scapula is always present. It has a ridge, or spine, which is continued at the ventral end as the acromion process to articulate with the clavicle. The clavicle is a slightly curved rod of bone which runs between the acromion process and the manubrium. It varies in size, being stout in diggers and reduced or absent in fast-running mammals where mobility and freedom of the forelimb is important.

What striking difference do you note in the construction of most mammal pectoral girdles and those of reptiles—focusing in particular on the mobility of the scapular portion of the girdle? _____

_____

What possible advantages and disadvantages could this provide for mammals?

_____

_____

FORELIMB

The humerus is the stout bone of the 'upper arm'. It articulates with the glenoid cavity of the scapula by a rounded head. The radius and ulna lie parallel in the 'forearm'. The radius is usually the stouter bone. The ulna has an enlarged upper end - the olecranon process or 'funny bone'.

The manus ('hand' in human) is composed of a group of small carpal or 'wrist' bones and five digits. The first digit is on the radial (or inner) side of the manus - in humans this is the thumb (sometimes called the pollex). Each digit is composed of a metacarpal bone and smaller phalanges. The number of phalanges varies with species and in some the terminal phalanx may bear a hoof, claw or nail. There are of course many modifications of the manus, such as for wings.

What mechanical advantage or system does the olecranon process of the ulna provide for tetrapods in which this is enlarged? _____
_____.

Does the size or orientation of this process differ in mammals from reptiles and if so, why might this be so in relation to body posture and locomotion? _____

_____

_____.

On which side of the forelimb is the thumb (that is, on the ulnar or radial side of the forelimb)? _____

If you had a diagram of muscles, you would be able to answer the following question! Which muscle adducts the forelimb? (hint: biceps). Which muscle extends the forelimb (hint: triceps). Feel these muscles operate in your own arm when you flex and then extend your arm.

PELVIC GIRDLE

The pelvic girdle, or pelvis, is formed of two fused halves, each of which is itself formed of three fused bones. The ilium articulates with the sacrum; the ischium is posterior to the ilium and usually dorsal although you sit on yours; and the pubis is ventral. The left and right pubic bones are joined by the pubic symphysis, which is cartilage and can be relaxed in female mammals prior to birth. All three bones of each side of the pelvis meet in the acetabulum, the cup-shaped socket for articulation of the femur.

Note: epipubic bones stretch anteriorly from the pelvis in marsupials and monotremes. However these are sesamoid bones and not strictly part of the pelvis.

Why is the pelvic girdle of tetrapods fused into a solid unit when it is actually composed of individual, separate bones? _____
_____.

What striking difference do you see in the shape of the ilium of a human versus that of a horse? _____
_____.
Why would there be this difference? _____
_____. Comparing other mammalian skeletons, which mammal is the most similar to humans in this respect?
_____

Only one of the mammal skeletons has a baculum indicated. What is it?
_____. Which of the groups shown has this bone?
_____.
What does the mnemonic PRICCCS stand for in this regard?
_____ (Hint: Primates, Rodents, Insectivores, Carnivores, Chiropterans, Cetaceans, Sirenians… members of each of these orders have a baculum—members of the other orders don't).

HIND LIMB

The femur is usually a smooth straight bone with a globular head at the proximal end and a pulley-shaped articulation at the distal end. The patella or kneecap lies over this pulley (the patella is the largest sesamoid bone). In the lower leg the tibia and fibula lie parallel to each other. The tibia is the larger bone and is usually triangular in cross section, with a pronounced crest on its anterior surface. The fibula is slender and lies 'outside' of or lateral to the tibia.

The pes (foot in humans) has the general structure of the manus. The bones of the ankle region are the tarsal bones, including the 'heel bone' (calcaneum) and the 'ankle bone' (astragalus). In the unmodified pes there are five digits, each composed of a metatarsal bone and phalanges. Digit 1 is on the tibial (or inner) side of the pes and is the big toe (sometimes called the hallux) in humans. There are many modifications of the pes, and the terminal phalanges may bear hooves, claws or nails.

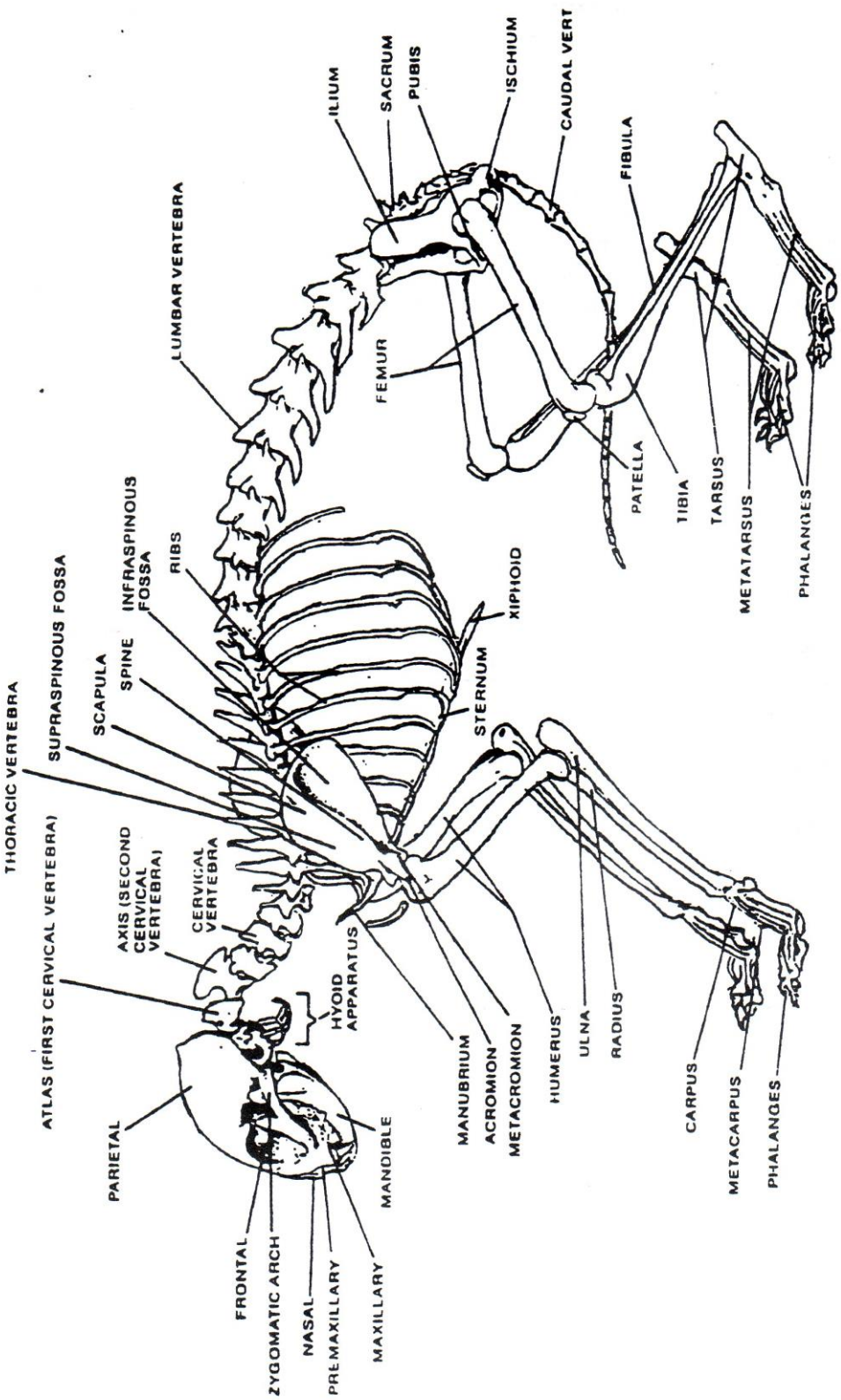
NOTE: the terms podial and metapodial may be used when it is not necessary to distinguish between carpal and tarsal or metatarsal and metacarpal.

In what way is the posterior process of the calcaneum like the olecranon process of the ulna? _____. How do you suppose it is involved in movement of the hind leg? _____.

Do you know what tendon connects this process to the powerful gastrocnemius extensor muscle at the bag of the lower leg? _____ (Hint: Brad Pitt played him in 'Troy' and died because of his mother's failure to get this part of his leg wet in the immortality soup on Mount Olympus…yeah, well…). Feel your own Brad Pitt sound-alike structure and while doing this contract your gastrocnemius to see what happens to the calcaneum.

Why do you suppose there are two bones with rotary ability in both the fore and hind limbs of most tetrapods? Why wouldn't one bone in each limb be better or sufficient? _____

_____



THE TETRAPOD SKULL

The object of this practical exercise is to make you familiar with the basic ground plan of the tetrapod skull, using a generalized mammal skull such as a dog or kangaroo. When using the kangaroo skull, be aware of the ways in which marsupial skulls differ from placental skulls as listed at the end of these notes. In older individuals the sutures between bones may be fused obscuring the shape of individual bones. To help show individual bones, some bones on some skulls in the anatomical series have been painted with random colors to set them out. There are also a few skulls painted in KEY COLORS which conform to bones as listed on the color chart provided. Use these skulls to check your knowledge. You are expected to know all underlined bones and structures.

What are two of the primary advantages of having a skull in the first place?
_____ and _____.

Why do you think are there so many bones in the skull? Why isn't there just one bone? _____

If you were to start evolution all over again with a skull in mind, would you construct it out of more than one bone? If not, why not?
_____.

STRUCTURES OF THE MAMMAL SKULL

In this usage, 'structures' are not individual named bones, but are anatomical features (including holes and spaces), comprising only part of a named bone (such as condyles, which are 'knobs' on the exoccipital) or being comprised of several bones (such as the cranium).

At the posterior end of the skull is a large hole, the foramen magnum, through which the spinal cord emerges. On either side of the foramen magnum are the smooth, rounded and elongated occipital condyles- by which the skull articulates with the first vertebra (known as the atlas).

Coming forward from the condyles, the rounded vault of the skull, the cranium, houses the brain. A midline, longitudinal crest known as the sagittal crest may be developed on the dorsal surface of the cranium in many adults (see the opossum for a good example). This gives additional surface for muscle attachment.

On either side of the skull are the slender zygomatic arches. The space between the zygomatic arch and the main part of the skull houses the eye anteriorly (in the orbit) and muscles from the lower jaw posteriorly in the temporal fossa.

On the ventral surface of the skull, forming the roof of the mouth, is the hard palate (or secondary palate) which separates the air passage from the food passage. At

the posterior end of the palate are the internal nares by which the air passage enters the pharynx.

At the posterior end of each zygomatic arch is the flat or curved glenoid fossa with which the lower jaw articulates. The lower jaw is the dentary (mandible if the two dentaries are fused), and the glenoid fossa is sometimes called the mandibular fossa.

Posterior to the glenoid fossa there is often a bulla (the Latin plural is bullae). A bulla is a bubble-like inflation in a bone. If a bulla is present in a placental mammal, it is usually composed of the endotympanic bone and forms a bony protection for the middle ear. In marsupials, if a bulla is present it is formed from the alisphenoid or squamosal, never the endotympanic.

The middle ear cavity is closed laterally by the ear drum or tympanic membrane. Between the tympanic membrane and the surface of the head is, in life, a cartilaginous tube - the external auditory meatus. Sometimes a tubular extension of the tympanic bone supports the inner part of the meatus.

NOW IDENTIFY THE INDIVIDUAL BONES THAT MAKE UP THE SKULL

POSTERIOR VIEW

Exoccipital - forms the occipital condyle on either side of the foramen magnum
Supraoccipital - above the exoccipital and usually bearing scars from the attachment thereon of strong muscles coming from the neck.

note: in most skulls it is difficult to see the sutures between the various occipital bones. Because of the importance of the articulation between the skull and the neck and because of the forces exerted by the muscles that move the head, the occipital bones surrounding the foramen magnum fuse early.

DORSAL VIEW

Parietal - forms the dorsal and lateral wall of the cranium.
Interparietal - a small bone dorsal to the supraoccipital and sometimes extending between the parietals. Not present in all mammals.
Frontal - forms the anterior dorsal part of the cranium, extending on to the face and into the orbit. Part of this bone forms the core of horns (e.g. cow) and forms the entire antler (e.g. deer).
Nasal - forms a roof over the nasal cavity.

VENTRAL VIEW

Basioccipital - lies between the tympanic bones and helps form the rim of the foramen magnum.
Basisphenoid - median bone anterior to the basioccipital, to which it fuses early in development.
Presphenoid - median bone anterior to the basisphenoid. Like a hawk with its wings raised, the presphenoid has two lateral projections into the orbits - the orbitosphenoid wings. These bear the optic foramens.
Vomer- a trough-like bone anterior to the presphenoid. To see it you need to look into the nasal cavity through the external nares. There are some broken and

bisected skulls in the collection which show this bone well. It is particularly clear in the larger skulls such as cows. The trough supports a bony septum that divides the two nasal passages.

Premaxilla - bears the incisors (when present) and forms the anterior lateral wall of the nasal cavity. In an animal with a snout it forms the anterior tip of it.

Maxilla - bears the canine, premolar and molar teeth. It forms the side of the face, the lateral wall of the nasal cavity and the anterior part of the palate. In some mammals it forms the anterior end of the zygomatic arch.

Palatine - forms the posterior part of the palate and the side of the posterior region of the nasal cavity.

Pterygoid - usually triangular bone forming the side of the posterior nares behind the palatine. Its dorsal surface lies on the presphenoid and/or basisphenoid.

Endotympanic - forms the bulla in placentals but not marsupials.

Ectotympanic - holds the ear drum in marsupials and placentals.

Periotic - is on the internal wall of the cranium (observe using a bisected skull). It is composed of very hard bone and encloses the semicircular canals and the cochlea (an elaboration of the sacculus as seen in the shark).

LATERAL VIEW

Squamosal - forms the ventral lateral wall of the braincase below the parietal, the articulation of the lower jaw (the glenoid fossa) and the posterior part of the zygomatic arch.

Jugal - forms the lower rim of the orbit and part of the zygomatic arch; may extend onto the face.

Lacrimal - on the anterior wall of the orbit or may extend onto the face (depending on whether the skull is elongated into a snout or flattened like a human). The main character is the presence of a foramen for the lacrimal (tear) duct.

*Orbital wing of the presphenoid - on the inner wall of the orbit; bears the optic foramen.

*Alisphenoid - forms part of the anterior wall of the braincase and is usually just anterior to the squamosal.

***note** - these bones are difficult to find in many adult skulls. You may need to find a juvenile skull or use one of the painted specimens.

ANTERIOR VIEW

Turbinals - delicate rolled bones inside the nasal cavity. They are frequently damaged and/or missing - look for them in some of the larger skulls such as a cow.

Internasal septum - a vertical partition separating the two nasal passages with its bottom lying in the trough of the vomer. Ossification of this structure is variable, although in most mammals it is completely bone in adults. Therefore it is sometimes called the internasal bone. In some mammals it also contributes to the complex folding of the nasal mucosa created by the turbinals. It is best seen in a bisected skull.

The posterior end of the internasal bone forms the cribriform plate , a perforated area at the anterior end of the brain case. This can again best be seen in the bisected skull, although sometimes you can see it by looking through the foramen magnum. Fibers of the olfactory nerve pass through the cribriform plate to the nasal mucosa.

MISCELLANEOUS

Lower jaw (or mandible) - is formed of only one bone (the dentary) in mammals. In other tetrapods it is composed of at least three (dentary, angular, articular). Each dentary (or side of the jaw) joins anteriorly as the symphysis.

Hyoid - a chain of bones stretching from the tympanic membrane to the larynx giving support to tongue muscles and the larynx ('voice box'). They are almost never saved with a skull but there is one specimen on display which has part of the hyoid apparatus intact.

Mammals belong to the group of tetrapods known as synapsids. Among other ways in which they differ from diapsids reptiles is they have only one opening in the outer braincase rather than two. Where is that single opening in the mammal skulls in front of you? _____

The hard palate of the mammalian skull is not present in most reptiles. What does it do in mammals in terms of its position that facilitates simultaneous breathing and eating? _____.

Why might this be more important in mammals than reptiles?
_____.

The whole of the lower jaw may correctly be called the mandible, but it is made up of two bones, a left and a right _____.

What massive chewing muscle do you suppose inserts into the masseteric fossa of the dentary? _____.

In mammals the dentary articulates with which bone in the skull ?
_____. In reptiles, do the dentary and this bone articulate? _____ (the answer is 'No'!). If not, which bones are involved in the articulation of the lower jaw in reptiles?
_____(Hint: the articular bone of the lower jaw in reptiles and the quadrate bone in the skull of reptiles).

The auditory bulla of the major groups of mammals is commonly formed from bones in a pattern unique to that group. In placental mammals it is a bone unique to that group: the entotympanic (sometimes inappropriately called simply the 'tympanic'). Which bone(s) is it formed from in the marsupial skull available to you ?
_____ (you will probably need help to work this out—but see if it's an extension of the alisphenoid bone)

What do you suppose is the function of the auditory bulla?
_____

What difference do you see in the size of the pterygoid processes in the dog versus the kangaroo? _____

The muscle that attaches to the pterygoid process is (surprise, surprise) the external pterygoid muscle which attaches to the inside (medial face) of the dentary. When it contracts, what motion would this confer to the dentary ?
_____.

How would this explain the difference between the dog and the kangaroo?
_____.

What tiny often stirrup-shaped bone involved in hearing would you expect to find making contact with the periotic bone? _____.

MARSUPIAL SKULL

SKULLS OF MARSUPIALS SHOW THE FOLLOWING DIFFERENCES FROM PLACENTALS AS DESCRIBED ABOVE:

1. The ectotympanic bone may be small and even loose. It does not form a bulla. If there is a bulla in a marsupial species, it is formed by the alisphenoid and/or squamosal and/or petrosal

2. There are no orbitosphenoid wings of the presphenoid in marsupial skulls.

EIGHT CHARACTERISTICS BY WHICH YOU CAN NORMALLY DETERMINE IF A SKULL IS MARSUPIAL (THERE ARE EXCEPTIONS):

1. The inflected (turned-in) angle of the mandible.

2. The palatine and maxillary bones are commonly (but not always) perforated with holes of various sizes and the palate commonly has a thickened posterior edge.

3. Nasals widen posteriorly

4. Alisphenoid tympanic wing large

5. Lacrymal commonly extends out onto the facial part of skull

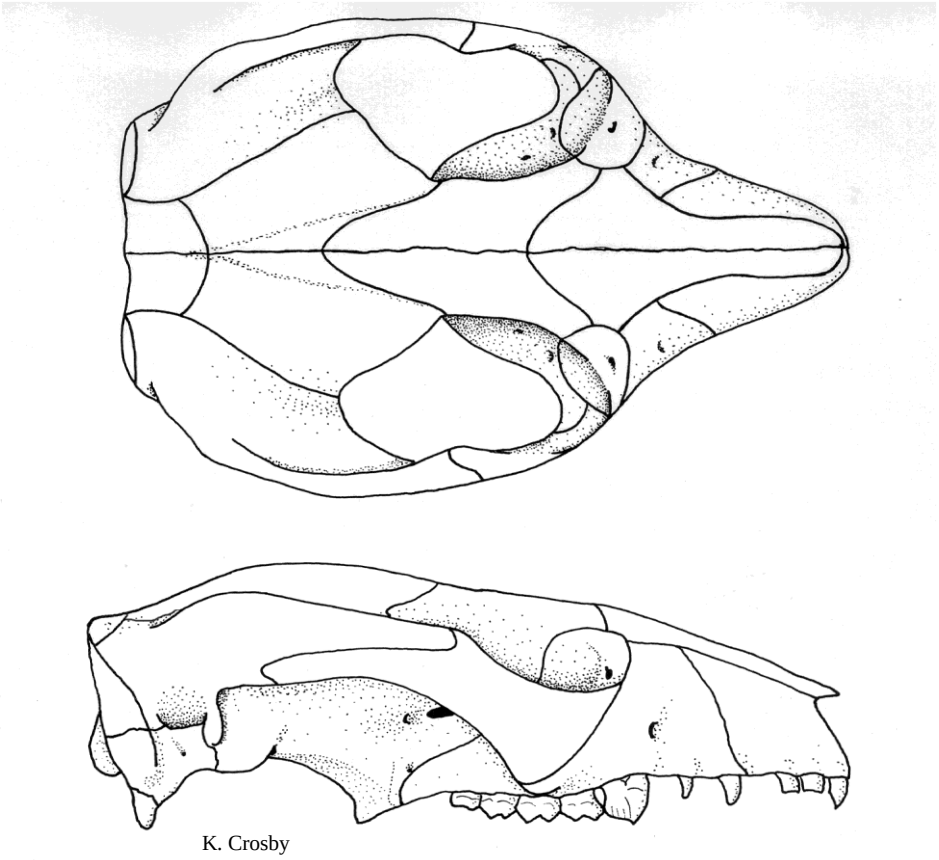
6. Jugal commonly reaches glenoid fossa

7. Four molars in adults

8. P3 is the only postcanine tooth that has a milk-tooth predecessor

These characters are comparative and you will need to look at a marsupial skull and a placental skull side by side to make the comparison.

Practice your new knowledge of osteology by labelling the various bones visible in this diagrammatic marsupial skull.



Dorsal and lateral views of the brushtail possum skull.

YOU'VE FINISHED and YOU'RE FREE but OH SO MUCH WISER !

GLOSSARY

Antlers - bony outgrowths of the frontal bones. May be shed periodically, and in some species are larger in males. Found in the Cervidae (deer) family of the clade Artiodactyla.

Condyle - a rounded protrusion from the surface of a bone which functions in articulation with another bone.

Ethmoid bone - a synonym for mesethmoid.

Foramen (Latin plural is foramina, English plural is foramens) - a hole in a bone or a hole formed by several bones through which nerves and/or blood vessels pass.

Fossa (Latin plural is fossae, English plural is fossas) - a depression in a bone in which some structure (usually a muscle mass) is situated.

Horns - hardened (keratinized) epidermal structures overlying a bony core formed by the frontal bone. They are never shed. True horns are found in the Bovidae family (cattle, sheep, antelopes) of the Artiodactyla. The horn of the rhino (Perissodactyla) is an exception, being a massive structure of keratinized epithelium on the snout.

Malar - a term used (rarely) for the jugal.

Mesethmoid bone - a name used in some books for the internasal septum if it is completely ossified. Sometimes this bone is called the ‘ethmoid’

Nares - external nares are synonymous with nostrils. The internal nares are the openings at the back of the nasal passages to the pharynx. The correct Latin singular is naris. Nostril is better useage.

Sagittal - that plane which would exactly bisect a skull or complete animal.

Sphenoid bone - a name used in human anatomy for the fused basisphenoid, alisphenoids, presphenoids and orbitosphenoid wings.

Suture - the line where bones, formed as separate centers of ossification in the embryo, join in formation of the skull. May be difficult or impossible to see in adults.

Temporal bone - a name used in human anatomy for the fused periotic, squamosal and tympanic bones.

NOTES

PRACTICAL 6

AMPHIBIANS AND AMNIOTES

Lissamphibia and Lepidosauria

Lab Quiz

At the beginning of this Practical there will be a Lab Quiz. You will be notified in which room this test will be held.

The Lab Quiz is approximately 40 minutes long and consists of 25 questions about material encountered in Practicals of Weeks 2 to 6.

You may only take writing materials into the quiz.

‘AMPHIBIA’ and AMNIOTA

In older zoological classifications, tetrapods (four-footed animals) were grouped into four equally distinct classes: Amphibia, Reptilia, Aves, Mammalia. In more modern classifications, based on understanding of the evolutionary relationships of these groups (their **phylogeny**), the latter three are regarded to be members of the clade Amniota (all of which share the obvious synapomorphy of amniote eggs, as well as other synapomorphies).

Amniotes evolved from earlier and more plesiomorphic tetrapods that in the older classifications were called ‘amphibians’. Hence Amphibia used in this ‘traditional’ sense is a paraphyletic taxon, because it does not contain all the descendants of its last common ancestor – amniotes are left out.

‘AMPHIBIA’

LABYRINTHODONTIA

The earliest amphibians belonged to the now extinct taxon, Labyrinthodontia.

Labyrinthodonts, named for the labyrinth-like infolding of the enamel layer on their teeth, were abundant during the Carboniferous and Permian but became extinct by the end of the Triassic. They typically resembled heavy-bodied salamanders with solid flattened skulls and conical teeth. EXAMINE the life size ‘body map’ of the temnospondyl, *Siderops kehli,* from an Early Jurassic deposit in Queensland.

LISSAMPHIBIA

Modern amphibians fall within a true clade outside that of all amniotes, called **Lissamphibia**. Although Lissamphibia is the correct cladistic terminology, lissamphibians are often referred to simply as ‘amphibians’.

The clade Lissamphibia contains three extant clades that are probably derived from either temnospondyls or lepospondyls:

Gymnophiona (caecilians)
Urodela (salamanders and newts)
Anura (frogs and toads)

The relationship between the three clades remains uncertain, but the majority view is that Gymnophiona is a sister clade to Urodela and Anura. Urodeles have the most plesiomorphic body form, whereas the Gymnophiona and Anura have highly modified body forms.

The clade Lissamphibia is characterised by the following apomorphic (i.e. derived) characteristics:

- operculum-plectrum complex - bones in the inner ear that transmit sound.
- pedicellate teeth (small, stalk-like)
- structure of the epidermis which serves an important role in gas exchange and contains numerous glands (including granular glands, also known as poison glands)
- papilla amphibiorum - a structure in the inner ear sensitive to low frequency sound waves
- green rods in the retina
- structure of the levator bulbi muscle on the floor of the orbit

Note: the last four characters are all composed of soft tissue and thus not preserved in fossils; therefore, it remains possible that they are plesiomorphic (i.e. ancestral) relative to the amniote condition.

Other characteristics of extant amphibians:

- clawless pentadactyl manus and pes (if limbs are present)
- ectothermic
- lungs usually present (absent in derived forms)
- tympanum present (in anurans only)
- unshelled eggs laid in water or a moist site
- metamorphosis in most species

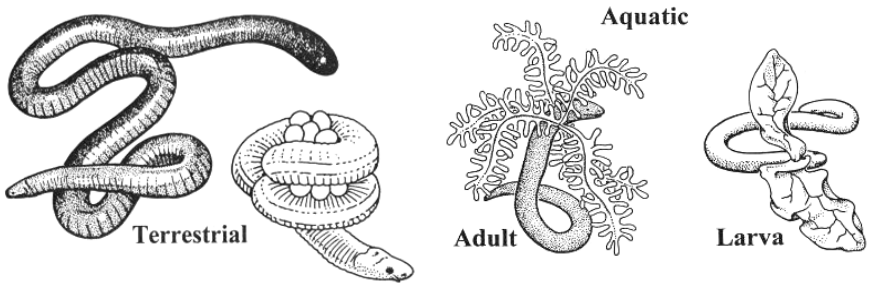
The structure of the amphibian heart (see diagram) provides a more efficient circulatory system than that of the shark and fish you looked at in previous practicals, but not as efficient as it is to become in birds and mammals.

How does the circulation of blood through the amphibian heart differ from your own heart?

_____
_____
_____
_____
_____

GYMNOPHIONA

The common name for this clade of amphibians is **caecilians**. These amphibians have a highly specialised body form adapted to a fossorial existence, though some species are aquatic or semi-aquatic. They possess some plesiomorphic traits such as the presence of embedded dermal scales.



Caecilians are distributed primarily in tropical South and Central America, SE Asia and in parts of Africa and India. There are currently 188 species in 6 families.

At first glance, caecilians are quite worm-like with an elongated, segmented body. The largest caecilians can be 1.5m long. The limbs are completely absent in almost all species and the tail is very short with the cloaca being almost terminal. The eyes are reduced or absent and they have a protrusible chemosensory tentacle on the snout.

Caecilians have internal fertilisation and viviparity is widespread (~75% of species). In at least some viviparous species the young are nourished through scraping the oviduct lining with embryonic teeth which stimulates the production of ‘uterine milk’.

There is only a single specimen of unknown genus and origin in the collection.

Living caecilians exhibit an interesting mixture of plesiomorphic (primitive) and apomorphic (derived) features compared with other amphibians.

Name at least ONE derived and ONE primitive feature characterizing this group?

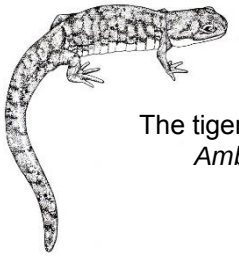
derived _____

primitive _____

URODELA

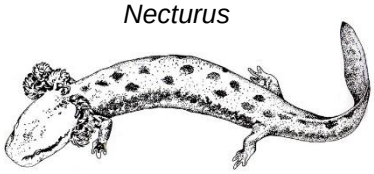
Like caecilians, salamanders and newts are not native to Australia. The clade is distributed predominantly in the northern hemisphere and tropical South and Central America.

Urodeles are the most similar of the living amphibians to the ancestral form, at least superficially. They have an elongated body with a tail that is retained throughout life. The limbs are weak and the gait sprawling.

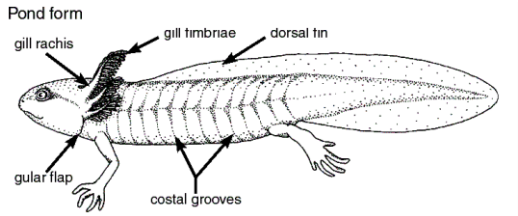


The tiger salamander
Ambystoma

The mud puppy
Necturus



A notable difference between the larva of the Urodela and Anura is that the former has stalked gills which are external whereas in anurans they become internal early in development.



Salamander larva: (Modified from JBGrant ©2001)

Represented in the collection by the following specimens:

Smooth Newt *Triturus vulgaris* – Europe
Spotted Salamander *Ambystoma maculatum* – North America
California Giant Salamander *Dicamptodon ensatus* – North America
Chinese Giant Salamander *Andrias davidanus* – China
Japanese Giant Salamander *Andrias japonicus* – Japan
Northern Slimy *Plethodon glutinosus* and Dunn's *P. dunni* salamanders – North America

Note: members of the family Plethodontidae are called 'lungless salamanders', gas exchange is solely through valerian respiration

Greater Siren or Mud Puppy *Siren lacertina* – paedomorphic, North America
Congo Eel *Amphiuma* sp. – a very poorly chosen common name! North America

In their larval stage, how do salamanders differ from frogs?

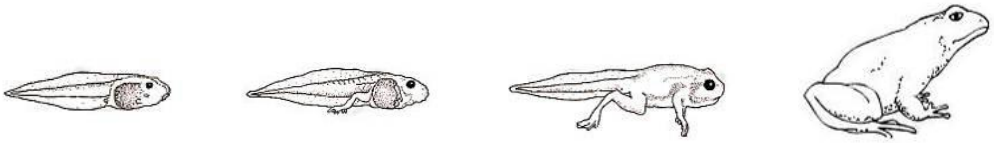
_____

_____

ANURA

The clade Anura includes the frogs and toads. 'True toads' are members of the family Bufonidae. The common names 'toad' and 'frog' are used interchangeably for some species, and members of the same genus can be either referred to as toads or frogs. Therefore, these names have no taxonomic significance.

Most anurans (except those with direct development) have a marked metamorphosis from the larva (tadpole) to the adult form:



Metamorphosis in anurans
Source: Sacramento Zoo website www.saczoo.org accessed April 2011. Image modified.

The following apomorphic characters of the anuran skeleton are observed in the adult form.

- no tail, caudal vertebrae fused to form urostyle
- hind limb modified for jumping
  - tibia and fibia fused (termed tibiofibula)
  - tarsals (calcaneum and astragalus) elongated
- radius and ulna fused (termed radioulna)
- shortened vertebral column with well-developed zygapophyses
  - 5 to 9 presacral vertebrae
  - 1 sacral vertebra
- lack thoracic ribs
- pelvic girdle highly modified
- skull thin with flattened roof
- numerous bones in skull much reduced

Examine all these features in the disarticulated and mounted cane toad skeletal material in the collection, and compare with the skeleton of a salamander (alizarin preparation).

Other features (not apomorphic for Anura) that you should examine are:

- dentition much reduced or absent (look at the skull of the Cane Toad, *Rhinella marina,* formerly known as *Bufo marinus*)
- jaw articulation is quadrate/articular
- columella conducts vibrations from tympanum to inner ear (this small bone is lost in most preparations)
- occipital condyles articulate with the atlas
- webbing between fingers and toes (variable among species)
- lack thoracic ribs

On the diagram of the frog skeleton below, label the following bones:

in AXIAL SKELETON: presacral vertebrae / sacral vertebra / urostyle

in APPENDICULAR SKELETON: suprascapula / radioulna / humerus / ilium
ischium / tibiofibula / femur /
tarsals (calcaneum and astragalus)

(Note the clavicle, scapula, sternum and pubis are not visible in these diagrams; examine a mounted toad skeleton to locate these bones)



Frog skeleton

Source: Modified from Pough, Heiser and McFarland (1989). Vertebrate Life. New York: MacMillan.

What are some of the modifications to the anuran skeleton associated with locomotion?

_____

_____

_____

_____

AUSTRALIAN ANURANS

- Ranidae
- Hylidae
- Myobatrachidae
- Microhylidae
- Bufonidae
- Leiopelmatidae (NZ)

Because the anuran skeleton is so highly specialised, morphological convergences are numerous, and the fossil record is poorly known. It is not surprising, then, that there is much confusion about frog taxonomy. However, the classification of the families of Australian and New Zealand anurans and the genera within them are generally accepted. The characteristics used to define the different families are based on muscular anatomy and osteology; consequently, it is difficult to identify the family to which a frog belongs using external features.

Ranidae

Typical frogs – all continents (except Antarctica)

1 species in Australia



Australian Woodfrog
Rana daemeli

Defining characteristics (you are not expected to know these, may only apply to Australian species)

- firmisternal pectoral girdle with sternum fused to the pectoral arch and epicoracoidal cartilages fused
- phalanges lack intercalary cartilages
- toes and fingers have grooved, dilated tips and toes are webbed
- dorso-lateral skin fold from behind eye to hindlimb
- maxillae dentate
- sacral diapophyses cylindrical
- sacrococcygeal articulation is bicondylar
- ilial shaft bears large, tapering, fin-like, dorsal crest

Other characteristics

- toes fully webbed
- male has twin vocal sac

Represented in the collection by Edible Frog (*Pelophylax esculentus*) metamorphosis display and replica skull of the Goliath Frog (*Conraua goliath*), the largest living anuran.

Hylidae

Tree frogs – all continents (except Antarctica)

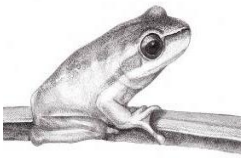
79 species in 3 genera found in Australia



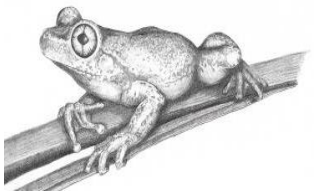
Water-holding Frog
Cyclorana platycephala



Green and Golden Bell Frog
Litoria aurea



Eastern Dwarf Tree Frog
Litoria fallax



Peron's Tree Frog
Litoria peronii

Sources: Tyler *et al*. (2009) and O'Brien (2009)

Nyctimystes dayi and most species of *Litoria* have expanded discs on the ends of the fingers and toes used for climbing. Similar structures have evolved independently in several families of anurans. In Hylidae these discs have a circum-marginal groove, though this is absent in terrestrial species. *Cyclorana* spp. burrow to aestivate and have an unpigmented metatarsal tubercle to aid burrowing.

Defining characteristics (you are not expected to know these)

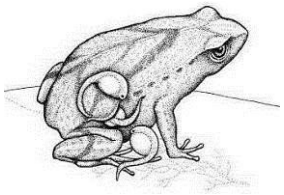
- 8 procoelus, non-imbricate, presacral vertebrae (anterior two unfused)
- lack ribs
- sacrum has dilated diapophyses
- arciferal pectoral girdle with cartilaginous omosternum and sternum
- palatines present
- parahyoid absent
- maxillae and premaxillae are dentate
- astragalus and calcaneum fused distally and proximally
- two tarsalia

Represented in the collection by Green Tree Frog *Litoria caerulea* and Verraux's Tree Frog *L. verrauxii.*

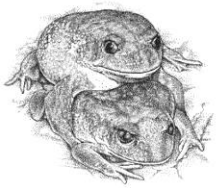
Myobatrachidae

Southern frogs – endemic to Australia and New Guinea

116 species in 21 genera found in Australia (one genus presumed extinct!).



Hip-pocket Frog
Assa darlington



Giant Burrowing Frog
Heleioporus australiacus



Southern Gastric-brooding Frog
Rheobatrachus silus (extinct)



Eastern Froglet
Crinia signifera

Source: Glasby et al. (1993)

Almost all species lack toe and finger discs (they are present in *Assa* and *Taudactylus*) but these lack a circum-marginal groove (*cf* Hylidae)
Burrowing species have an enlarged metatarsal tubercle (pigmented, edged black or entirely black).

<u>Defining characteristics</u> (you are not expected to know these)

- 8 (or functionally 7) presacral vertebrae with persistent notochord
- lack ribs
- sacrum has dilated diapophyses
- arciferal or modified arciferal pectoral girdle
- anterior part of scapula not overlain by clavicle
- palatines present
- parahyoid absent
- maxillae and premaxillae are dentate in some genera/species
- astragalus and calcaneum fused distally and proximally
- two tarsalia

Note: Difficulty in defining synapomorphic characters for this group has been the basis for arguments that these frogs be included within the family Leptodactylidae.

Represented in the collection by Eastern Banjo Frog *Limnodynastes dumerilii*, Tusked Frog *Adelotus brevis* and Giant Barred Frog *Mixophyes iterates*.

Microhylidae

Narrow-mouthed frogs – all continents (except Antarctica)

18 species in 2 genera in Australia (all found in tropical northern Australia).

Defining characteristics (you are not expected to know these)

- firmisternal pectoral girdle
- broad sacral diapophyses
- one or more transverse folds on the roof of the mouth
- procoelus vertebrae

Australian species

- edentate
- transverse grooves on the tips of their variously expanded digits
- terminal phalanges of fingers and toes are T-shaped or Y-shaped with transverse grooves
- toe and finger discs may be present, if so they are truncated and non-circular.

We do not have any specimens from this family in the collection.

Bufonidae

True toads – native to all continents, except Australia and Antarctica

1 species in Australia: Cane Toad *Rhinella marina* (formerly *Bufo marinus*) (introduced to Australia in 1935)

Defining characteristics (you are not expected to know these)

- skin is thick and contains pustular warts in many species
- large parotoid glands are present in *Rhinella* and some other genera
- toes lack discs
- maxillae and premaxillae edentate
- Bidder's organ present in males (absent in mature individuals of some species)
- ventral parts of pectoral girdle overlap

Represented in the collection by numerous specimens of the Cane Toad, *Rhinella marina*, (possibly still labelled *Bufo marinus*) including skeletal material and mounted skeleton, specimens preserved in spirit and alizarin preparations.

Examine the spirit specimen of the Cane Toad.

What types of granular glands are visible? What is their function?

_____

What is the most speciose family of Australian anurans?

_____

NEW ZEALAND ANURANS

Leiopelmatidae

Bell frogs – endemic to New Zealand

4 species in one genus are the only frogs found in New Zealand



Maud Island Frog
Leiopelma pakeka

Source: Almost extinct website www.almostextinct.co.uk

This family is sister to all other within anurans. These frogs exhibit many plesiomorphic characters such as vestigial tail muscles, 9 presacral vertebrae and a tail-like copulatory organ.

Characteristics

- ventral inscriptional ribs
- absence of horny beaks in larva
- lack a closed branchial chamber and spiracle

Represented in the collection by Hochstetter's Frog *Leiopelma hochstetteri*

Compare the worldwide distributions for the three main groups of amphibians.

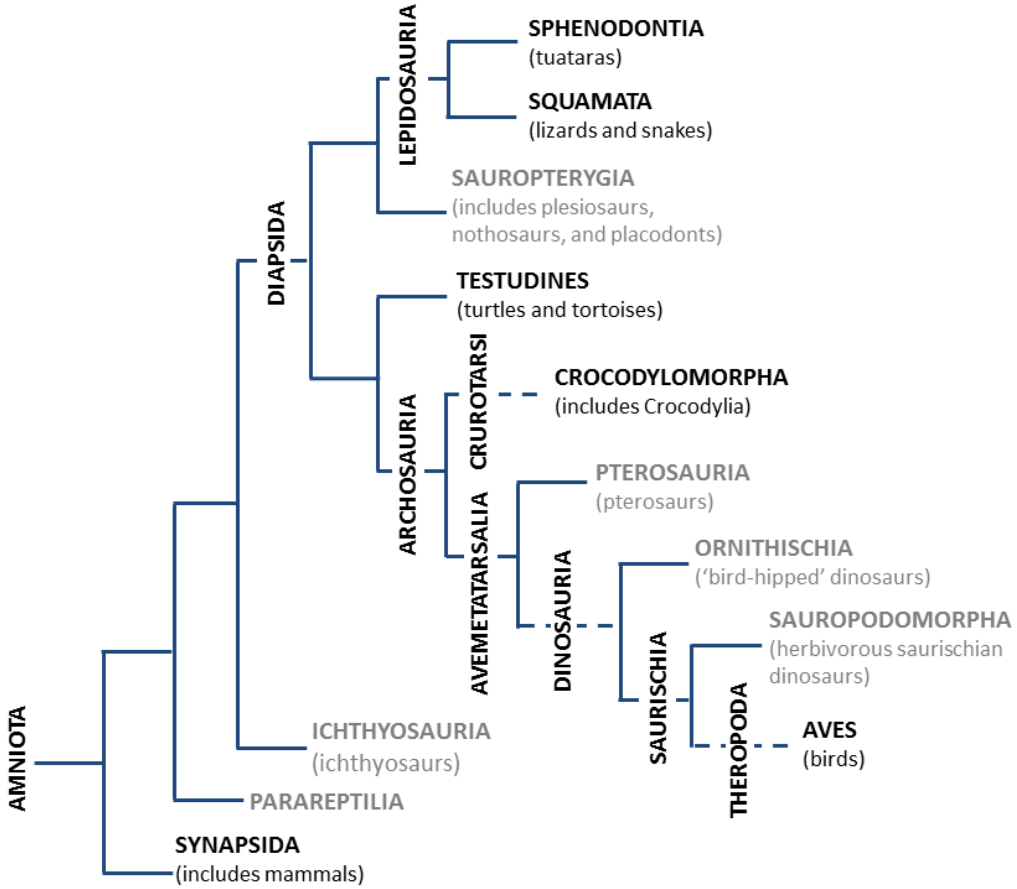
How do the frogs (anurans) stack up? What do you think has contributed to that pattern?

_____

_____

_____

AMNIOTA



Phylogeny of the Amniota showing all extant clades (black font) and major extinct clades (grey font). Dashed lines indicate other extinct lineages within the clade are not shown.

AMNIOTA

- no larval stage
- cleidoic (enclosed) egg
- extra-embryonic membranes (amnion, chorion and allantois)
- skin dry with outgrowths (such as scales, feathers and hair)
- pterygoid flange

ANAPSIDA

- skull lacks temporal fenestra

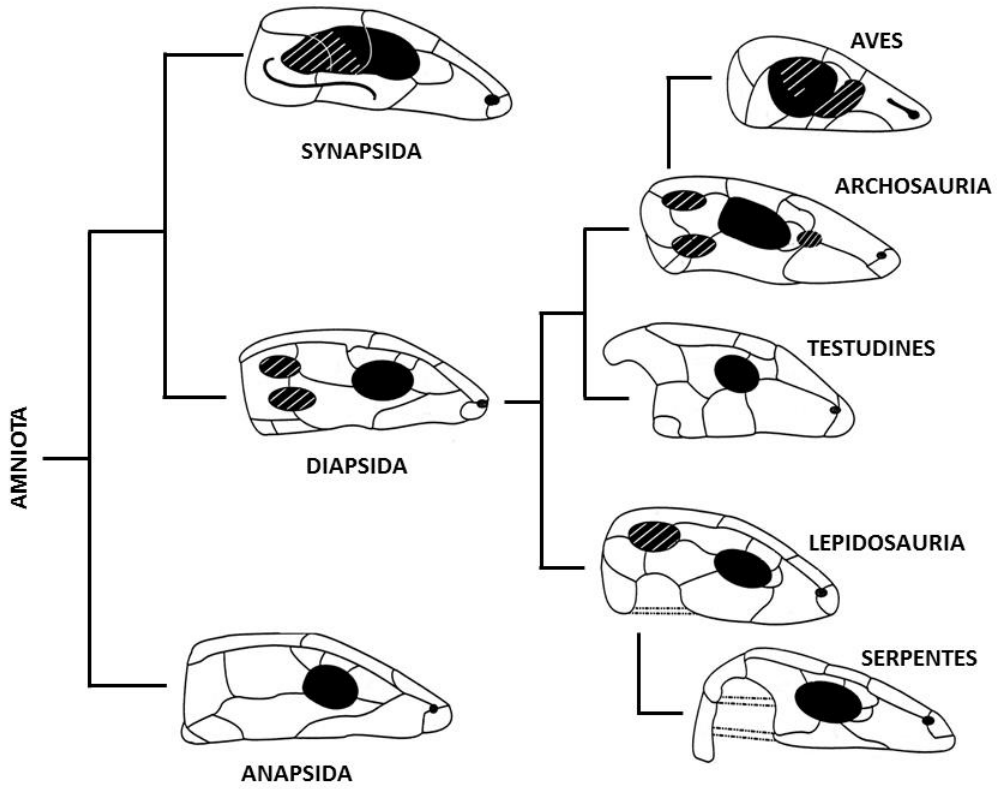
SYNAPSIDA

- skull with one lateral temporal fenestra

DIAPSIDA

- skull with two temporal fenestrae. However, the skulls of some modern diapsids have become so modified that this character is no longer evident
- upper temporal arch formed by triradiate postorbital and triradiate squamosal
- olfactory bulbs anterior to eyes
- vomeronasal (Jacobson's) organ present at least in embryos

Temporal fenestration in Amniotes



Modifications of the primitive diapsid condition are shown for some of the extant clades of diapsids

Amniota includes the extant groups commonly known as reptiles, birds and mammals. Why might we use inverted commas around the formal name ‘Reptilia’ but not Aves or Mammalia?

_____

_____

What are the three patterns of skull fenestration found in extant (living) amniotes?

_____

What pattern of skull fenestration do the following groups display?

mammal _____ bird _____

snake _____ lizard _____

crocodile _____ frog _____

LEPIDOSAURIA

LEPIDOSAURIA

- determinant growth with epiphyses on articulating surfaces of the long bones
- postfrontal bone enters into the dorsal border of the upper temporal fenestra
- additional articulating surface in midline of neural arch
- ribs with a single point of articulation with vertebra
- pelvis fused in adults
- pleurodonty (teeth attached to lingual side of jaw and not surrounded by extensive attachment bone; lost in some groups)

SPHENODONTIA (tuataras)

- premaxillary teeth replaced by elongation of premaxillae
- 4-5 enlarged teeth at anterior end of palatine tooth row
- narrow quadrate with lateral conch
- scales granular
- mid-dorsal row of low spines
- mandibles joined by ligament
- no male copulatory organ

(*note: the last 6 traits could be plesiomorphic*)

SQUAMATA (lizards and snakes)

- fusion of bones in snout region
- loss of lower temporal bar and quadratojugal
- eight cervical vertebrae
- pterygoid separated medially by palatines and usually in contact with quadrate

SPHENODONTIA

The clade Sphenodontia comprises two families, the Sphenodontidae (~29 genera) and Pleurosauridae (extinct; 2 genera), and two basal genera, *Planocephalosaurus* and *Diphydontosaurus*. The clade originated in the Mesozoic Era, but since this time the diversity of sphenodontians has been considerably reduced to a single extant genus comprising two species: Northern Tuatara *Sphenodon punctatus* and Brother's Island Tuatara *S. guntheri*. Both are restricted to New Zealand.

Examine the Northern Tuatara skull (replica or alizarin preparation) to clearly see what is meant by a diapsid skull. The two fenestrae are easily seen, while in all living lizards the skull is so modified that this primitive condition is typically obscured.

Unlike squamates, the tuatara has two rows of teeth in the upper jaw. Tooth attachment is acrodont (fused to the jaw), so teeth are not replaced; the serrated edge gradually wears over time. The upper jaw is rigidly attached to the cranium so there is little cranial kinesis (*cf* many modern lepidosaurians).

Sphenodontia forms a larger clade with the genus *Gephyosaurus*, called the Rhyncocephalia, which is sister to the Squamata.

SQUAMATA

The skulls of squamates are believed to be derived from the basic diapsid pattern exhibited by the tuatara, but have been lightened considerably through loss of some bones and fusion of others. In all squamates, the lower temporal arch is incomplete and the quadratojugal bone is missing. Some lizards, and all snakes, have also lost the upper arch.

The skull appears fragile and scaffold-like, and it is difficult to identify individual bones. The result is considerable cranial kinesis: the facial part of the skull is able to move in relation to the cranial part. Movement can occur between the basisphenoid and the pterygoids ventrally, increasing the gape.

Upper teeth are present on the premaxilla and the maxilla, and in some snakes also the palatine and pterygoid. Dentition is usually pleurodont (teeth attached on inner side of jaw) but some families have acrodont dentition.

Features of the lizard postcranial skeleton include:

- 4th digit usually longest
- pectoral girdle poorly ossified
- sternum cartilaginous
- centra of vertebrae usually have ball-and-socket articulation; the socket is on the anterior face of the centrum

When present, lizard limbs are not specialized and reflect the basic ground plan of terrestrial vertebrate appendages. However there are many lizards with reduced or absent limbs. This is particularly common in some families, such as the Scincidae. There are approximately 50 families within the Squamata (the number varies depending upon reconstructed phylogenies). The phylogenetic relationships among these families have yet to be fully resolved.

Parthenogenesis (a type of asexual reproduction in which new individuals develop from unfertilized eggs) is increasingly being discovered in species from many families, including Gekkonidae, Leptodactylidae, Lacertidae, Teiidae, Typhlopidae, Boidae and Varanidae. Some species are obligatory parthenogenic and may arise from hybridisation of sexually reproducing congeners.

All families occurring in Australia are described on the following pages, grouped within the major clades (capitalised). Synapomorphies (shared derived traits) are listed for some clades, but note many clades are difficult to diagnose, especially considering extensive revisions to the hypothesised phylogeny of Squamata.

How to tell a salamander from a lizard

Salamanders are amphibians and are very different from lizards 'beneath the skin'. Of course we do not have salamanders in Australia, but here are some superficial characters that differentiate them from lizards that will be useful when examining specimens in the practical:

SALAMANDER	LIZARD
wide, flat head	higher, pointed head
no tympanum	tympanum present
no scales	scales present
soft, moist skin	skin smooth and dry
no claws	claws present
never more than 4 digits on fore foot	usually 5 digits on fore feet
cloaca a longitudinal slit	cloaca a transverse slit

GEKKOTA

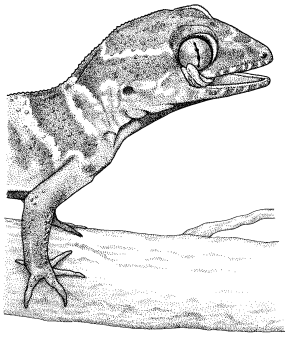
Geckos and flap-footed lizards – ~1500 species, all continents (except Antarctica) particularly tropical and subtropical regions

This clade comprises seven families, four of which occur in Australia: Carphodactylidae, Diplodactylidae, Gekkonidae, and Pygopodidae.

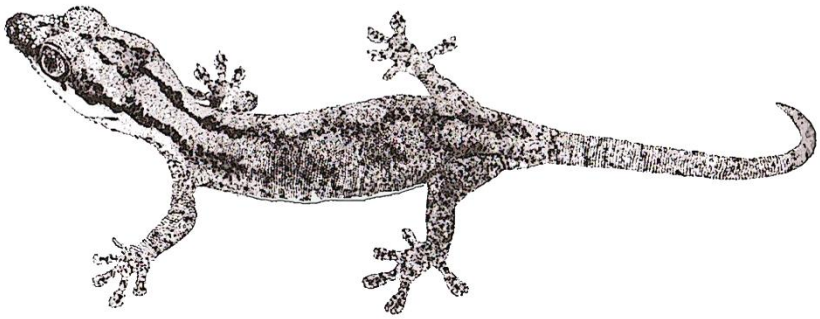
- postorbital, supratemporal arch, squamosal and lacrimal lost
- paired dentinal egg-teeth
- persistent notochord canal in adults
- caudal autotomy septa posterior to a single pair of transverse processes of caudal vertebrae (widespread)
- thin, flat foretongue, with broad and untapered tip (possibly related to facial tongue-wiping)
- vertically elliptical pupils
- eyelids fused and transparent (brille)
- oviparous (all Australian species) or viviparous (some geckos)

Carphodactylidae, Diplodactylidae, Gekkonidae (geckos)

143 species in 24 genera occur in Australia



Coastal Ring-tailed Gecko
Cryptodactylus tuberculatus
Source: Glasby et al. (1993)



Pseudothecadactylus australis
Source: Cogger (1986)

- terrestrial or arboreal
- usually nocturnal
- usually feed on small arthropods
- paired sac-like pouches in post-anal region of males
- large, glossy scales on rostrum, chin and along mandibles
- digits with laterally expanded pads and subdigital lamellae (some families); though considerable variation in morphology, including simple digits.
- loose-fitting skin covered by small, granular, juxtaposed scales on dorsum; some species with clusters of pronounced tubercles
- some parthenogenic species (e.g. Bynoe's Gecko *Heteronotia binoei*)

How do the toes of the marbled velvet gecko (largely arboreal) differ from the terrestrial thick-tailed gecko?

_____

What is the functional significance of this morphology?

_____

Pygopodidae

Flap-footed lizards – 42 species (8 genera), endemic to Australia and PNG



Common scaly-foot *Pygopus lepidopodus* with close-up of vestigial hind foot ('flap')
Source: Glasby et al. (1993)

- forelimbs absent
- hindlimbs vestigial - reduced to 'flaps'
- fossorial or terrestrial
- smooth or keeled, overlapping body scales; well-developed head scales
- insectivorous/carnivorous
- left lung much shorter than right lung
- right gonad lies more anteriorly than left gonad
- superficially resemble snakes but: tail long and fragile
  external ear opening
  flat, unforked tongue

What position do the geckos and legless lizards (Pygopodidae) occupy in the current hypothesis of the phylogeny of the Squamata?

_____

What morphological features distinguish the pygopodids from Serpentes?

_____

_____

What are some of the differences between pygopodids and their closest relatives?

_____

Scincidae

Skinks – 1500+ species, all continents (except Antarctica)

The Scincidae were previously grouped in a large clade, the Scincomorpha, which has since been shown to be paraphyletic.

- 435 species in 47 genera occur in Australia
- species richness especially high in Australasian region
- most species are diurnal
- insectivorous or omnivorous (larger species)
- oviparous, ovoviviparous or viviparous
- most species have slightly to markedly elongate bodies
- moderate to short limbs; though often reduced and sometimes absent (evolved independently >20 times)
- caudal autotomy almost universal
- variation in lower eyelid: moveable with or without transparent disc (window, spectacle), transparent and immoveable either distinct from or fused to upper eyelid

Synapomorphies

- typically smooth and glossy cycloid scales (round margins) reinforced by compound osteoderms dorsally and ventrally
- enlarged shield-like scales on top of head, regular and usually symmetrical
- tongue with scale-like papillae; tip feebly indented

What bones have been modified in the skulls of lizards?

_____

What advantage might that provide?

_____

What is caudal (tail) autotomy and in which groups of squamates is this behaviour well known?

_____

_____

ANGUIMORPHA

Dragons, monitors, iguanas, chameleons, anoles and allies

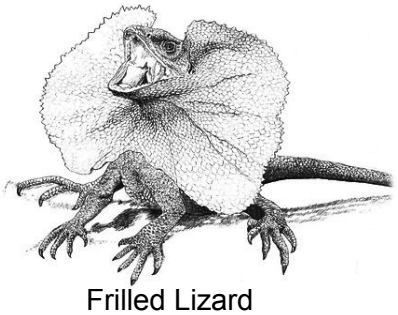
Agamidae

Dragons – ~430 species, Western Pacific, Australia, Indo-Malaysia, Asia to Africa

The Agamidae is within the large clade Iguania (which is within the Anguimorpha).



Thorny Devil
Moloch horridus



Frilled Lizard
Chlamydosaurus kingii

Sources: http://museumvictoria.com.au and Laura Grogan www.redbubble.com

- 77 species in Australia, many in arid zone
- most species are diurnal
- typically oviparous (one genus, *Phrynocephalus*, viviparous)
- venomous (simple glands in upper and lower jaw; some species)
- generally insectivorous; some larger species also feed on small vertebrates; largely ambush predators
- scales typically ridged or keeled (granular or tubercular in primitive genera)
- melanophores in scales of some species (allows darkening of skin; under hormonal control)
- modified hyoid apparatus supports an erectile beard/frill in some species (e.g. *Pogona* spp.; *Chlamydosaurus kingii*)
- skull typical of primitive squamates
- some species use bipedal gait when running

Synapomorphies

- some body scales with greatly enlarged tubercles and spines (not all species)
- tongue short and thick
- throat sacs in many species
- caniniform teeth at anterior ends of maxillae and dentaries (heterodonty; not all species) - note posterior teeth acrodont and anterior teeth pleurodont

The Agamidae includes the 'flying dragons' or 'gliding lizards', of the genus *Draco*. These dragons glide by extending a flap of skin, attached to their ribs, laterally.

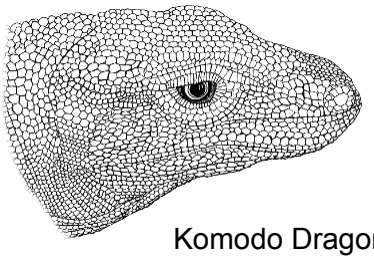
Examine the spirit specimens of various agamids. How does the morphology of the scales differ among different regions of the body?

_____

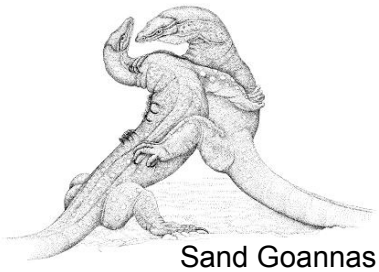
_____

Varanidae

Goannas or monitors– ~70 species, Africa and Asia to Australia



Komodo Dragon
Varanus komodoensis



Sand Goannas
Varanus gouldii fighting

Source: Kerstin Klein www.flickr.com and Glasby et al. (1993)

- single genus: *Varanus*
- 28 species in Australia
- includes world's largest lizard: Komodo Dragon *V. komodoensis*
- terrestrial or arboreal (some species have prehensile tail); though several species amphibious
- well-developed vomeronasal (Jacobson's) organ
- limbs well developed and powerful
- venomous (gland in lower jaw; teeth not grooved in extant species)
- loose-fitting skin with small, juxtaposed scales
- hemipenes contain ossified hemibacula
- well-developed cranial kinesis
- pleurodont dentition
- food swallowed whole; hyoid apparatus moves food into esophagus

Synapomorphies

- scales on top of head small and fragmented
- teeth large, laterally compressed, pointed and recurved (serrated edges in some species)
- long, protrusible (fits into sheath on floor of mouth), deeply forked (>50% of length) tongue, which lacks papillae (smooth)
- osteoderms not fused to skull

How does the dentition of the Komodo Dragon (the largest varanid) and the Green Iguana (a large iguanid) differ? What does this indicate about their diets?

_____

_____

How does the modified diapsid skull of varanids assist with feeding?

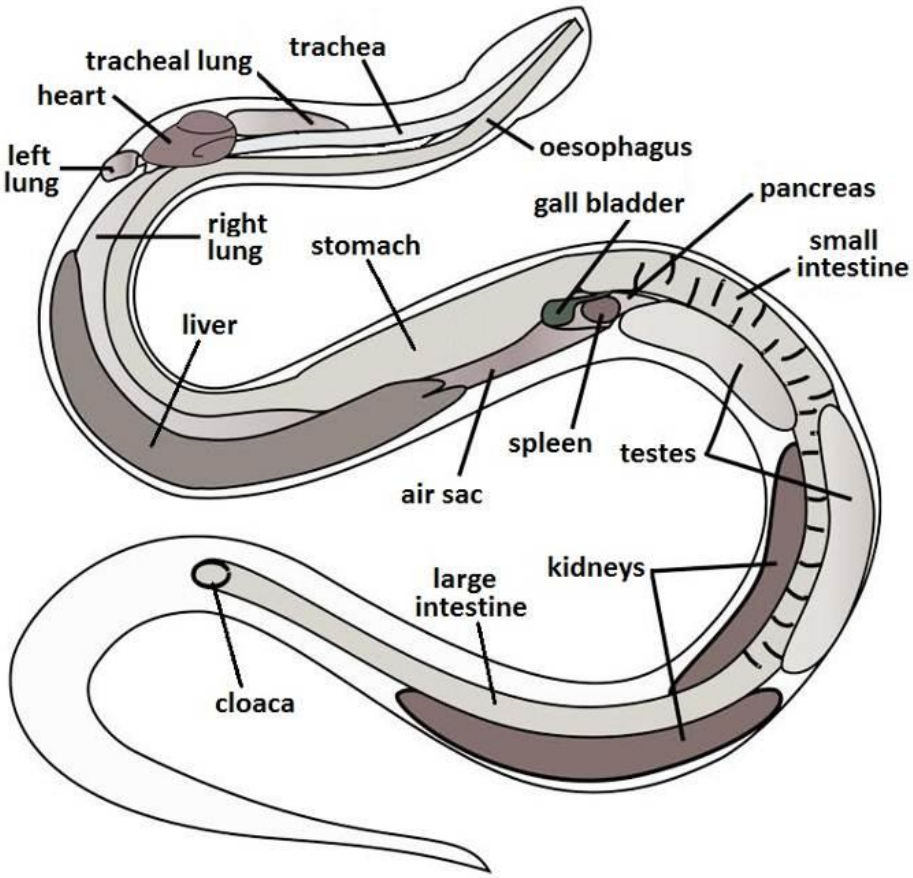
_____

SERPENTES

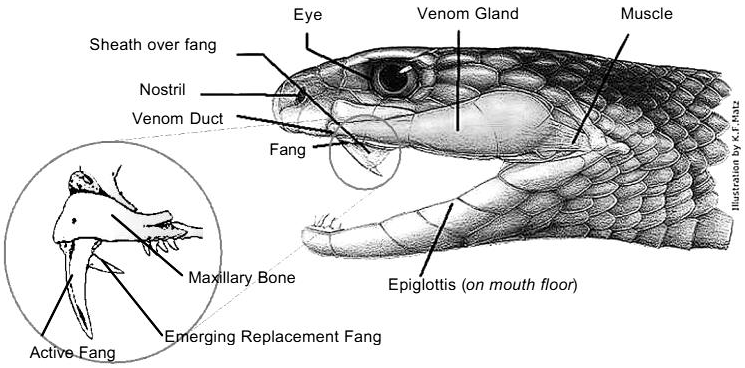
Snakes (Serpentes) evolved within the 'lizard' lineage, and are most closely related to the Anguimorpha, which includes the Iguania. Hence the name 'lizard' refers to a paraphyletic grouping of clades.

The elongated body is achieved through addition of thoracic vertebrae. There are few cervical, lumbar and sacral vertebrae.

Paired organs (kidneys, reproductive organs) are positioned one ahead of the other, and the left lung is reduced (up to 85% length of right lung) or absent. The posterior portion of the right lung in most snakes is non-respiratory and serves as an air sac; it is particularly well-developed in aquatic species, where it may extend posteriorly to near the cloaca. Some species have an additional 'lung', the tracheal lung, which allows gas exchange when the bronchial lung is compressed by ingested prey.



Venom glands – found only in families Atractaspididae, Colubridae, Homalopsidae, Elapidae and Viperidae – are located in the upper jaw on the maxillae. Fangs are produced from a separate tissue than other teeth and originate developmentally in the rear of the maxilla. Snakes with fangs at the front of the mouth (solenoglyphous and proteroglyphous fangs) result from loss of the anterior portion of the maxillae and their accompanying teeth.



Fang and venom gland of typical elapid snake
Source: Williams (2004)

Differences in the snake skull from most other squamates include:

- much stronger, more rigid braincase (protecting brain from injury by prey being swallowed)
- no epipterygoid bones
- upper jaw only loosely attached to rest of skull
- upper jaw reduced to a tooth-bearing rod
- greater cranial kinesis
- dentary bones connected by highly elastic ligament
- additional teeth on palatine and pterygoid bones (some snakes only)

<u>How to tell a snake from a legless lizard</u>

Snakes (excl. blind snakes) can be differentiated from legless lizards by a combination of the following features:

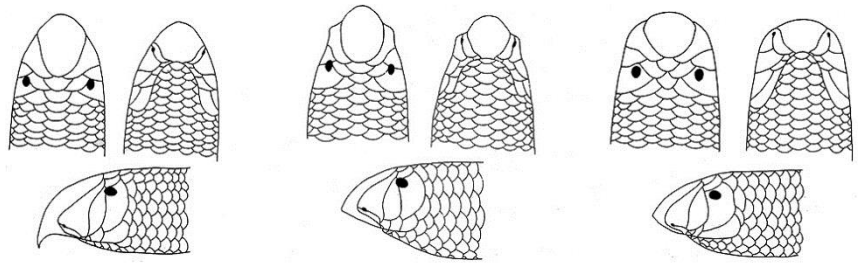
<u>snakes</u>	<u>legless lizards</u>
eyelids replaced by transparent scales	eyelids
no tympanum or ear hole	visible tympanum or ear hole
tail considerably shorter than body	tail as least as long as body
single row of belly scales	several rows of scales across belly
forked tongue	tongue not forked

There are approximately 20 families, eight of which occur in Australia. Systematics within Serpentes continues to be debated (see www.reptile-database.org/db-info/snakes.html).

Typhlopidae

Blind snakes – ~250 species, mostly tropical regions of Africa, Asia, and the Americas and across Australia.

- 43 species in 2 genera occur in Australia: *Ramphotyphlops (42 spp.)* and *Typhlops* (1 spp.)
- aglyphous (no fangs: non-venomous, feed on ants and termites)
- oviparous
- fossorial
- remnants of pelvic girdle and hindlimb present
- robust skull
- marked variation in head morphology: rounded and blunt, wedged and slightly blunt, wedged with distinct edge, hooked



Ramphotyphlops grypus Ramphotyphlops bituberculatus Ramphotyphlops endoterus

Source: Cogger 1986

Synapomorphies

- nearly cylindrical, rigid body
- eye vestigial and covered by scales (and dermis)
- all body scales similar in size (no belly 'shields') and overlap extensively
- small, curved mouth is well behind and below tip of snout
- very short tail; usually ends in short, conical spine
- teeth restricted to maxilla
- well-developed anal glands, which emit strong odour
- external nares lie within nasal cleft, and are directed postero-ventrally

What are some of the adaptations of blind snakes for burrowing?

_____

_____

Pythonidae

Pythons – ~40 species, Africa, and Asia to Australia

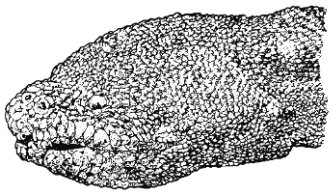
- 13 species in 4 genera occur in Australia: *Antaresia, Aspidites, Liasis, Morethia*
- oviparous
- aglyphous (no fangs: non-venomous)
- relatively narrow belly scales
- feed largely on birds and mammals, killing by constriction
- previously included within the family **Boidae**
- infra-red sense organ (labial pits within the labial scales; except *Aspidites*)
- paired cloacal spurs (vestiges of hind limbs and pelvis)
- elongated supratemporal and quadrate bones

Synapomorphies

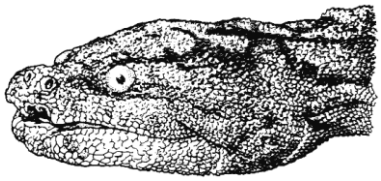
- well-developed body wall musculature
- prehensile tail

Acrochordidae

File snakes – 3 species, south-east Asia and Australia



Arafura File Snake
Acrochordus arafurae



Marine File Snake
Acrochordus granulatus

Sources: Glasby et al. (1993) and http://animaldiversity.ummz.umich.edu

- two species occur in Australia: *Acrochordus arafurae, A. granulatus*
- aglyphous (no fangs: non-venomous)
- viviparous
- mainly piscivorous

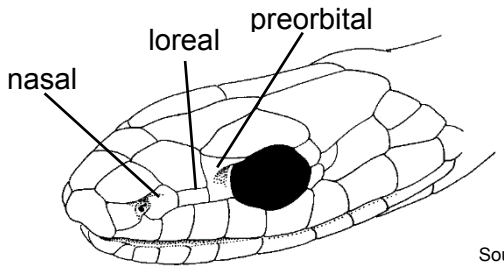
Synapomorphies

- small, finely keeled and pointed scales
- series of loreal scales
- sublingual salt gland

Colubridae

Colubrids – 1700+ species, all continents (except Antarctica)

Distinguished from the Elapidae by the presence of a loreal scale between the preorbital and nasal scales (most species, including all but one Australian species), as shown in this Green Tree Snake *Dendralephis punctulatus*



Source: Glasby et al. (1993)

- 12 species in 5 genera (*Boiga, Dendrelaphis, Lycodon, Stegonotus, Tropidonophus*) occur in Australia.
- opisthoglyphous fangs (posterior portion of the maxilla: 'rear-fanged') or aglyphous (no fangs)
- mostly oviparous
- terrestrial and arboreal
- includes venomous (mostly weak venom) and non-venomous species

Synapomorphies

- facial bones moveable
- squamosal loosely attached to skull
- maxillaries horizontal, forming most of upper jaw
- fewer than 30 mid-body scale rows
- loreal shield usually present

Elapidae

Elapids – ~350 species, Asia, Australia, Africa, Americas

Distinguished from most colubrids by the absence of a loreal scale.

- 99 species in 26 genera occur in Australia
- oviparous, ovoviviparous or viviparous
- mostly terrestrial

Synapomorphies

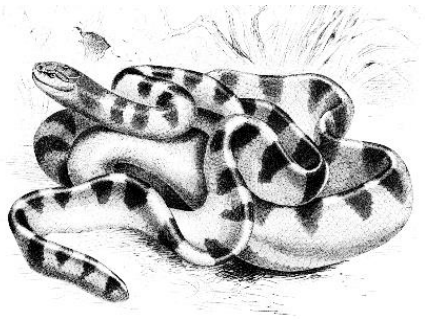
- short, hollow fangs at the front of the maxillary bones ('front-fanged'); formed by infolding over an anterior groove (proteroglyphous)
- venom mainly neurotoxic (acts on nervous system); death of prey usually results from asphyxiation because contraction of the diaphragm is inhibited

Three subfamilies within the Elapidae have been erected – Elapinae, Hydrophiinae and Laticaudinae – but the phylogenetic relationships within the family are poorly resolved and the groupings are probably paraphyletic. Nonetheless, the Hydrophiinae and Laticaudinae are discussed below because of their unique adaptations for living in a marine environment.

Hydrophiinae

True sea snakes – 62 species, marine: south-east Asia, Japan, India, Australia, eastern Africa, central Pacific, western Mexico (two species are restricted to land locked lakes, either brackish or freshwater)

33 species in 12 genera occur in Australian waters.



Blue-banded Sea Snake
Aipsyurus. laevis
Source: www.commons.wikimedia.org

Adaptations to living in a marine environment include:

- viviparous
- valvular nostrils
- nostrils dorsally positioned
- compressed, paddle-like tail
- laterally compressed body (with narrower belly scales)
- sublingual salt gland
- rear portion of lung ('saccular' lung) used in buoyancy

Laticaudinae

Sea kraits – 6 species in a single genus: *Laticauda.* Marine: south-east Asia, Melanesia and northern Australia.

Laticauda is sometimes classified within the subfamily Hydrophiinae

2 species occur in Australia: *Laticuada colubrina, L. laticaudata*

Sea kraits can be differentiated from true sea snakes by the following:

- oviparous
- nasal scales separated by 1-2 internasal scales
- nostrils laterally positioned
- cylindrical body
- wide belly scales (allows movement on land)
- less well-developed caudal fins

What are the differences among the types of snake fangs?

_____

_____

What modifications of the skull allow snakes to swallow prey larger than the width of their mouth?

_____

Examine the articulated trunk region of the vertebral column of the reticulated python. What do you notice about how the vertebrae articulate with one another and why is this important for locomotion in snakes?

_____

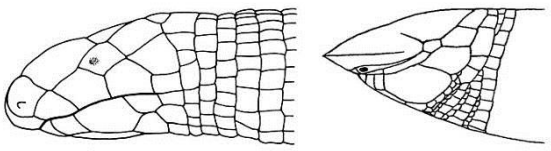
_____

Notable squamate groups that do not occur in Australia

AMPHISBAENIA

Amphisbaenians or worm lizards – ~170 species, mainly in S. America and Africa

Comprises at least three families: **Amphisbaenidae**, **Bipedidae**, **Trogonophidae**



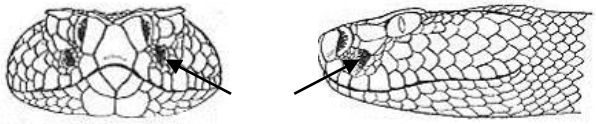
Amphisbaena medemi (left) and Blunt-tailed Worm Lizard *Dalophia pistillum* (right)
Sources: Gans and Mathers (1977) (and www.commons.wikimedia.org)

- fossorial
- scales go all the way around the body like a ring
- right lung reduced (*cf* snakes)
- limbless (Amphisbaenidae, Trogonophidae)
- hindlimbs absent (Bipedidae – 4 species in a single genus)
- robust heads
- a single median tooth in upper jaw

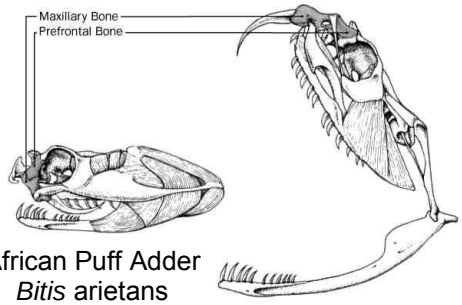
SERPENTES

Viperidae

Vipers, pit vipers, rattlesnakes, adders – ~310 species, Eurasia, Africa, Americas



Head of Timber Rattlesnake *Crotalus horridus* showing heat sensing loreal pits
Source: www.flmnh.ufl.edu/herpetology



African Puff Adder *Bitis* arietans
Source: www.flmnh.ufl.edu/herpetology

Most species within the subfamily Crotalinae (220 species)

- ovoviviparous, some species oviparous
- typically nocturnal ambush predators
- keeled scales
- elliptical pupils

Synapomorphies

- solenoglyphous fangs–needle-like fangs, folded backwards when not in use; erected via rotation of the maxilla
- infra-red sense organ (loreal pit; subfamily Crotalinae)
- venom mainly hemotoxic (acts on cardiovascular system), but digestive function also important

ANGUIMORPHA

Helodermatidae

Two species: Gila Monster *Heloderma suspectum* and Bearded Lizard *H. horridum*. Southwestern United States and Mexico

- oviparous
- low metabolic rate
- carnivorous (mostly immobile or slow-moving prey, especially eggs)
- venomous (venom from modified salivary glands in lower jaw; neurotoxic)
- pleurodont dentition
- grooved lower teeth to aid venom delivery
- large osteoderms (gives 'beaded' look to non-overlapping, dorsal scales)

Chamaeleonidae

Chameleons – 197 species, mainly Madagascar and Africa, but also southern Europe and south Asia

- oviparous, some species ovoviviparous
- mostly arboreal, some species terrestrial
- insectivorous or carnivorous (plant material supplemental)
- some species have horns or shields on head
- swaying gait with limbs oriented below body
- many species sexually dimorphic
- males typically more colourful
- acrodont dentition (synplesiomorphic with Agamidae)
- chromatophores in skin which allow colour change (some species)

Synapomorphies

- zygodactylous feet (toes fused in paired flattened fascicles)
- stereoscopic, independently moving eyes, covered by granular lid with small opening for pupil
- highly modified, elongated, projectile tongue (up to twice body length)
- no external ear opening or tympanic membrane
- premaxillary teeth greatly reduced in size and number
- scapula extremely tall and narrow, suprascapula cartilage relatively small
- laterally compressed body (including girdles)
- prehensile tail (many species)

Iguanidae

The Iguanidae is a very large and highly diverse clade allied to the Agamidae and Chamaelionidae, which together form the clade Iguania.

- oviparous
- most species insectivorous or omnivorous; largest species herbivorous
- terrestrial and arboreal species; one marine species
- typically diurnal
- some species communicate visually: bright colours, body adornments (e.g. dewlaps, crests)
- Anoles have expanded toe pads with microscopic setae

REFERENCES

Barker, J., Grigg, G.C. and Tyler, M.J. (1995). 'A field guide to Australian frogs'. (Surrey Beatty and Sons: Chipping Norton.)

Cogger, H.G. (1979). 'Reptiles and Amphibians of Australia'. (Reed: Sydney.)

Gans,C. & Mathers,S. (1977). Amphisbaena medemi, an interesting new species from Colombia (Amphisbaenia, Reptilia) with a key to the Amphisbaenians of the Americas. *Fieldiana Zoology* **72**, 21-46.

Glasby, C.G. et al. (1993). 'Fauna of Australia. Volume 2A amphibian and reptilia'. (AGPS: Canberra.)
(Available at www.environment.gov.au/biodiversity/abrs/publications/fauna-of-australia/fauna-2a.html)

Kardong, K.V. (1998). 'Vertebrates: Comparative Anatomy, Function, Evolution' (second edition). (McGraw-Hill: New York.)

Kley, N.J. (2001). Prey transport mechanisms in blindsnakes and the evolution of unilateral feeding systems in snakes. *American Zoologist* **41**, 1321-1337.

O'Brien, D. (2009). 'Frogs of Kooragang Island'. Available at www.flickr.com/photos/ pokerchampdaniel/ [accessed 10 February 2013].

Pough, F.H., McFarland, W.N., and Heiser, J.B. (1989). 'Vertebrate Life'. (MacMillan: New York.)

Schulte, J.A., Valladares, J.P., and Larson, A. (2003). Phylogenetic relationships within Iguanidae inferred using molecular and morphological data and a phylogenetic taxonomy of iguanian lizards. *Herpetologica* **59**, 399-419.

Tyler, M.J. and Knight, F. (2009). 'Field guide to the frogs of Australia'. (CSIRO Publishing: Collingwood.)

Wiens, J.J., Hutter, C.R., Mulcahy, D.G., Noonan, B.P., Townsend, T.M., Sites, J.W., and Reeder, T.W. (2012). Resolving the phylogeny of lizards and snakes (Squamata) with extensive sampling of genes and species. *Biology Letters* **8,** 1043-1046.

Williams, D. (2004). Snakes of Papua New Guinea. In '*Clinical management of snakebite in Papua New Guinea*' (Eds D. Williams, S. Jensen, and K. Winkel.) Pp. 2.1-2.23. (Port Moresby: Independent Publishing.)

PRACTICAL 7

Turtles, Crocodiles and Birds

TESTUDINES

The first amniotes in the fossil record have a heavy outer vault to the skull lacking fenestrae. This is the anapsid skull condition, which is also seen in modern Testudines (turtles and tortoises). For this reason, it was long-held that the Testudines were part of the clade Anapsida, and that this clade was the first to diverge within Amniota, with Diapsida and Synapsida more closely related. However, molecular and some morphological phylogenetic studies place the Testudines within the Diapsida, suggesting that the two temporal fenestrae characteristic of diapsids have been lost secondarily.

The position of the Testudines within the Diapsida has been controversial, but most recent studies place the Testudines as a sister clade to the Archosauria (crocodiles, dinosaurs, birds), rather than the Lepidosauria (tuatara, lizards, snakes). The earliest known fossil Testudines date back to 220 million years

Examine some turtle/tortoise skulls closely and be sure you understand the anapsid condition and the position of the braincase. Some species (especially the North American Snapping Turtle) show the anapsid condition more clearly than others.

Examine any turtle skulls and note the following apomorphic (derived) characters:

- Emargination from posterior edge of outer skull vault (in some)
- Position of the tympanic membrane on the quadrate
- Lack of teeth
- 'Horny' (keratinized protein) plates which function as teeth
- Small brain case
- Position of the jaw muscles
- Fusion of the two halves of the mandible

How does the number of bones in a turtle skull compare with those in a mammal skull?_____

In turtles which bones form the jaw articulation?_____
_____

What bone conveys vibrations to the inner ear?_____

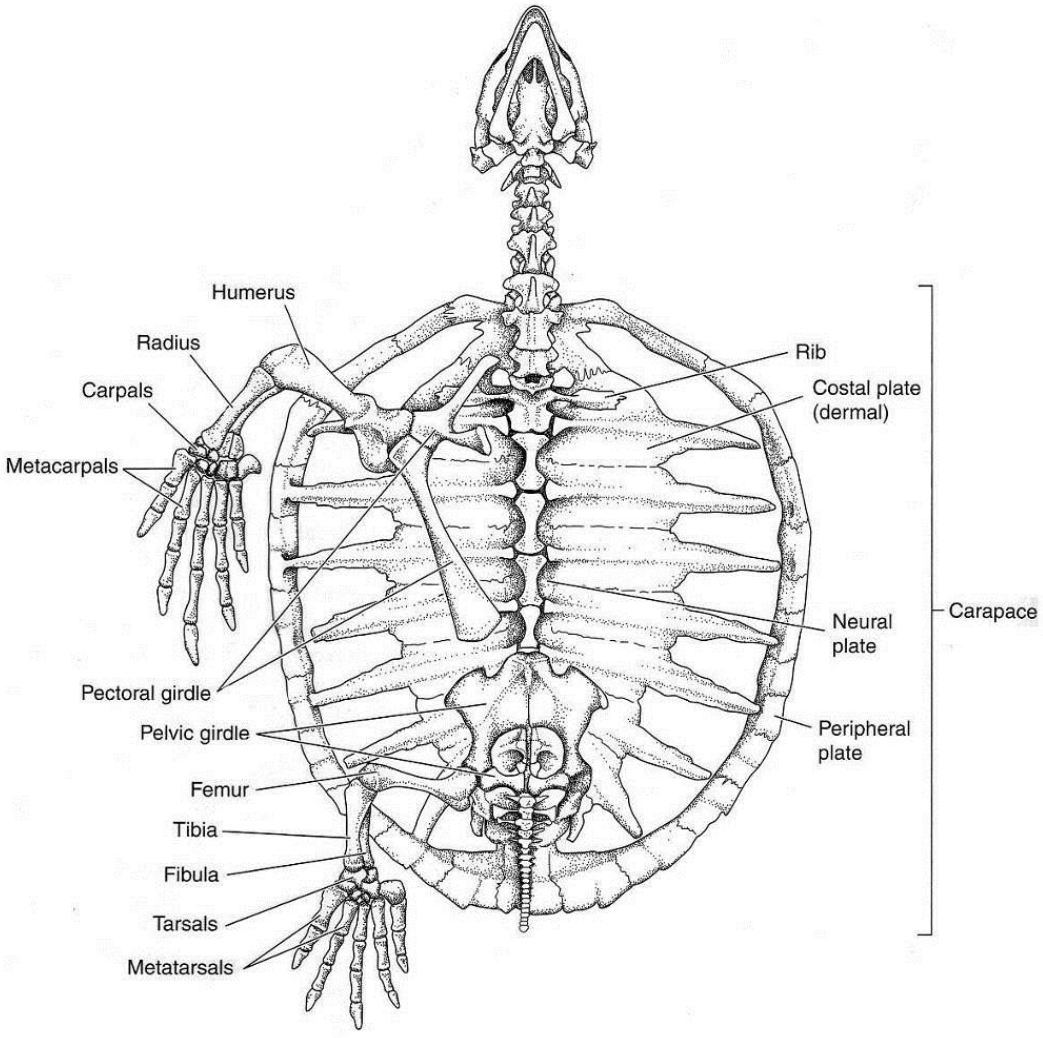
The 'shell' is composed of a dorsal curved part (carapace) and a ventral flatter part (plastron). In most species, both are covered by an epidermal layer of large keratinous scales, usually referred to as scutes (therefore turtles don't really have a shell; the carapace and plastron are part of an *endo*skeleton). In other species, including the Leatherback Turtle (*Dermochelys coriacea*), soft-shelled turtles (Trionychidae) and Pig-nosed Turtle (*Carettochelys insculpta*), the shell is covered by a layer of leathery skin.

The bony **carapace** is formed from bony plates developed in the dermis which are fused to the ribs and to the neural arches of all 10 thoracic, 2 sacral and the first caudal vertebrae.

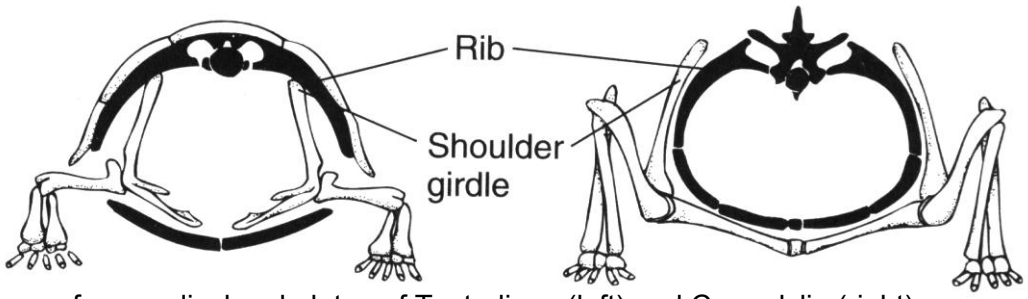
The bony **plastron** is a dermal structure and is partly derived from the abdominal ribs (gastralia) that were present in ancient amniotes. Parts of the pectoral girdle are also incorporated into the plastron; the clavicles form the epiplastrons and the interclavicle is the entoplastron.

The **pectoral girdle** is unique among tetrapods in being ventral to the ribs. It has a characteristic tri-radiate form; an elongated scapula with a long acromion process, and a long ventral coracoid.

The **pelvic girdle** may or may not be fused to the shell (a character which separates the two extant clades of Testudines now living).



Skeleton of marine turtle (Cryptodira) with plastron removed



Comparison of appendicular skeleton of Testudines (left) and Crocodylia (right)
Source: Kardong (1998)

What is peculiar about the arrangement of the pectoral girdle in turtles compared to other tetrapods? _____

_____

_____

What bones of an ancestral amniote have been incorporated into the carapace? _____

_____

What about the plastron? _____

_____

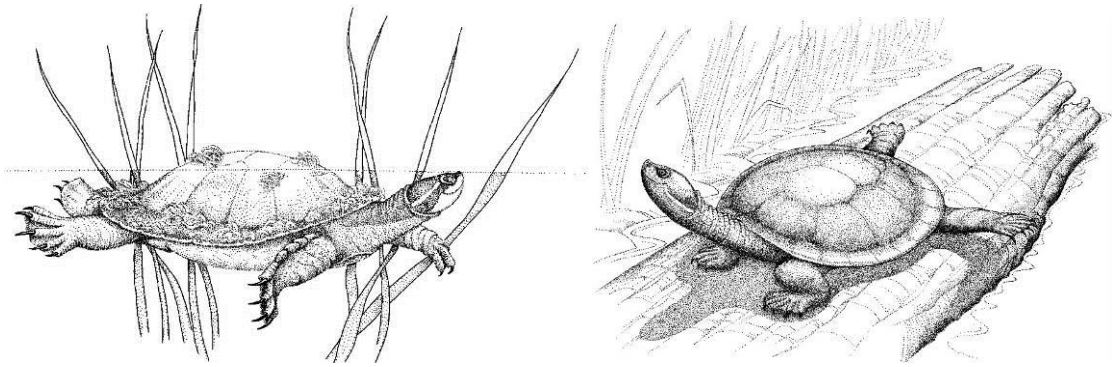
MODERN TESTUDINES

Modern Testudines form two clades. In traditional, phenetic taxonomy they usually appear as suborders (a third suborder, the Proganochelydia, is extinct). They are probably sister groups whose origins lie in the early Mesozoic. The two clades are most readily distinguished by the method the neck and head are withdrawn into the shell, and fusion of the pelvis to the plastron or lack thereof (examine the mounted skeletons of Green Turtle (*Chelonia mydas*) and eastern Long-necked Turtle (*Chelonia longicollis*)).

PLEURODIRA (side-necked tortoises). Can bend their necks laterally to withdraw them into the shell. Pelvic girdle is fused to both the carapace and the plastron.

There are only three extant families within the clade: Chelidae, Podocnemididae, and Pelomedusidae. Only the Chelidae is represented in

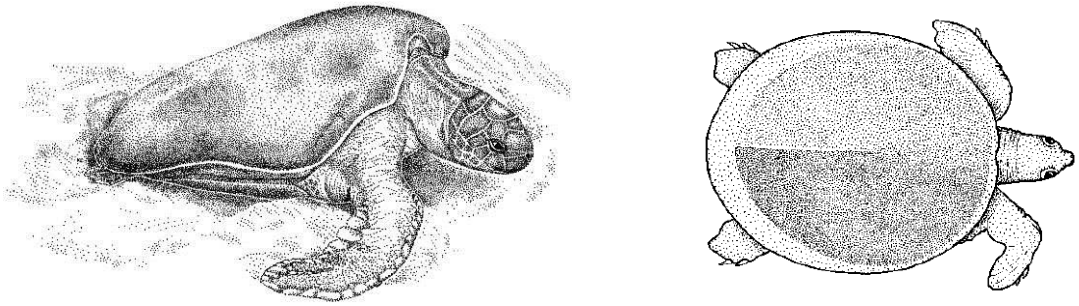
Australia with 27 species in 7 genera. Examples include the Broad-shelled Turtle (*Chelodina* expansa) and Murray River Turtle (*Emydura macquarii*).



Murray River Turtle *Emydura macquarii*
Source: Glasby et al. (1993)

CRYPTODIRA. Can retract their heads straight back into the shell by a ventral S-bend of the neck. Pelvis is not fused to the shell.

The Cryptodira includes the majority of extant Testudines (12 extant families). Families represented in Australia include the Cheloniidae (marine turtles; 5 of the 6 extant species), the Dermochelyidae (1 extant species: Leatherback Turtle, *Dermochelys coriacea*), and the Carettochelyidae (1 extant species: Pig-nosed Turtle, *Carerttochelys insculpta*). Other cryptodirans found elsewhere in the world include tortoises, snapping turtles, mud turtles, and soft-shelled turtles.



Flatback Turtle *Natator depressus*, a marine species from the family Cheloniidae (left), and Pig-nosed Turtle *Carettochelys insculpta*, a freshwater species (right)
Source: Glasby et al. (1993)

What is the most prominent difference between the skulls of the Green Turtle and Alligator Snapping Turtle? Why is this functionally important for Alligator Snapping Turtles?_____

_____

_____

Compare the mounted skeleton and loose carapace of the eastern long-necked turtle. Do the keratinous scales (scutes) correspond to the neural, costal and peripheral plates? _____

_____

How does the shell of the pig-nosed turtle differ from most other cryptodirans?

_____

CROCODILES

Vertebrata
Gnathostomata
Diapsida
Archosauria
Crocodilia

Apomorphic characters of crocodilians observable in living specimens:

- crescentic nostrils in small eminence at tip of snout
- ear openings hidden by flaps of tissue (which can be opened by muscles)
- heavy, scaly skin on the back is strengthened by underlying dermal bony plates (osteoderms)

Observe the following on the skulls & skeletons in the lab:

- diapsid with both temporal fenestra complete
- teeth conical (also replaceable up to 45 times)
- secondary bony palate involves the maxilla, palatine and pterygoid.
- only 2 sacral vertebrae
- chevron bones well developed
- abdominal ribs (gastralia) present (these are ossifications in the abdominal body wall not true ribs)
- scapula and coracoid elongate
- pubis excluded from acetabulum

Types of crocodilians (treated as families in a traditional, phenetic taxonomy):

TRUE CROCODILES

- Family Crocodylidae, 13 spp. including 2 Australian
- Narrower snouts than alligators and the large teeth of the lower jaw are visible when the jaws are closed.
- Equatorial, worldwide.

ALLIGATORS AND CAIMANS

- Family Alligatoridae, 7 spp.
- Broad ‘shovel’ shaped snouts and when the jaws are closed the teeth of the lower jaw fit into sockets within the upper jaw.
- Caimans are South American.

GHARIALS

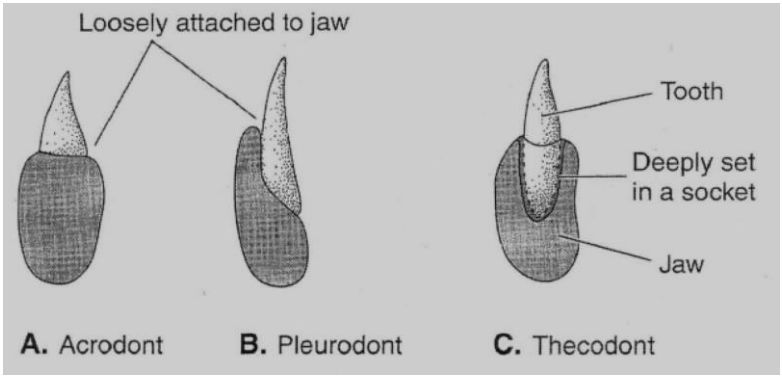
- Family Gavialidae
- Very rare, there being only 2 species and they are basically limited to India and Malaysia.
- Elongated snout.
- Males have a bulb-like structure at the tip of the snout used for behavioral displays and modulating sounds.

What are the two species of crocodile extant in Australia?_____

_____

What kind of teeth do crocodilians have?

_____



What is the function of the hard (false) palate in crocodilians?

_____

_____

How do diapsid skulls differ from anapsid and synapsid ones? Name 1-2 taxa characterised by each condition.

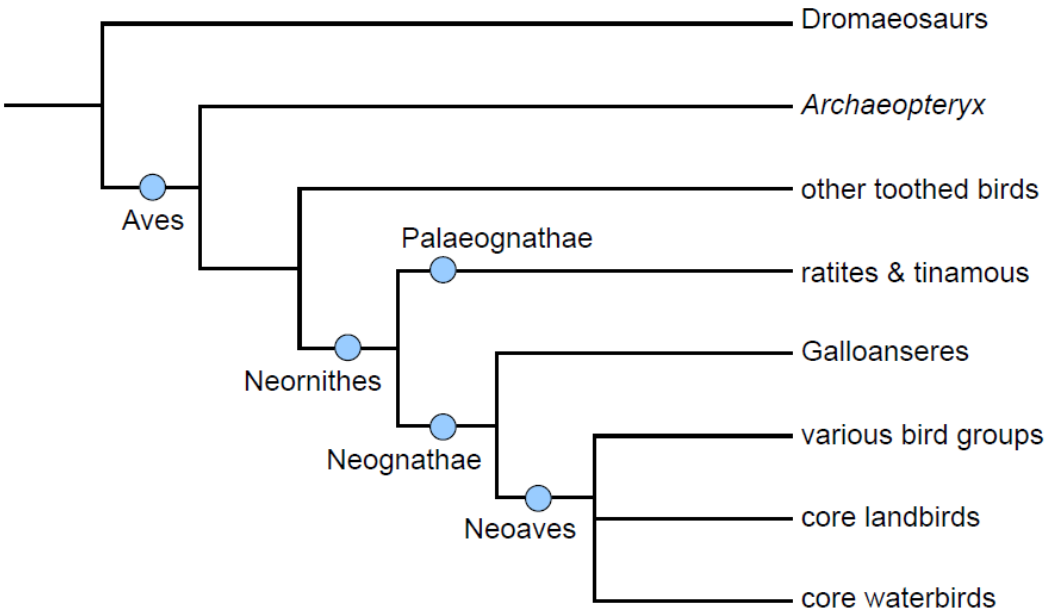
Anapsid_____

Diapsid_____

Synapsid_____

BIRDS

A SUMMARY **CLADOGRAM** OF BIRDS
(with saurischian dinosaurs as a sister group)



AVES

Powered flight
Well-developed bill
Fused wrist bones (carpometacarpus)
Fused foot bones (tarsometatarsus)
Synsacrum
Pygostyle (fused tail bones)

Toothed Birds – various species that had teeth. These birds disappeared by the start of the Cenozoic era.

NEORNITHES

Characterised by lack of teeth

PALAEOGNATHAE & NEOGNATHAE

This is the first major division within extant birds. The two clades were originally separated based on characteristics of the bony palate.

GALLOANSERES

The second major division in modern birds separates the Galloanseres (waterfowl and landfowl) from the Neoaves.

NEOAVES

This clade contains the majority of the world's extant birds. Early in the evolution of this clade there was an explosive radiation of birds. This rapid evolution has made it difficult to resolve the inter-relationships between the different groups within Neoaves.

However, there does appear to be two distinct groups within the clade:

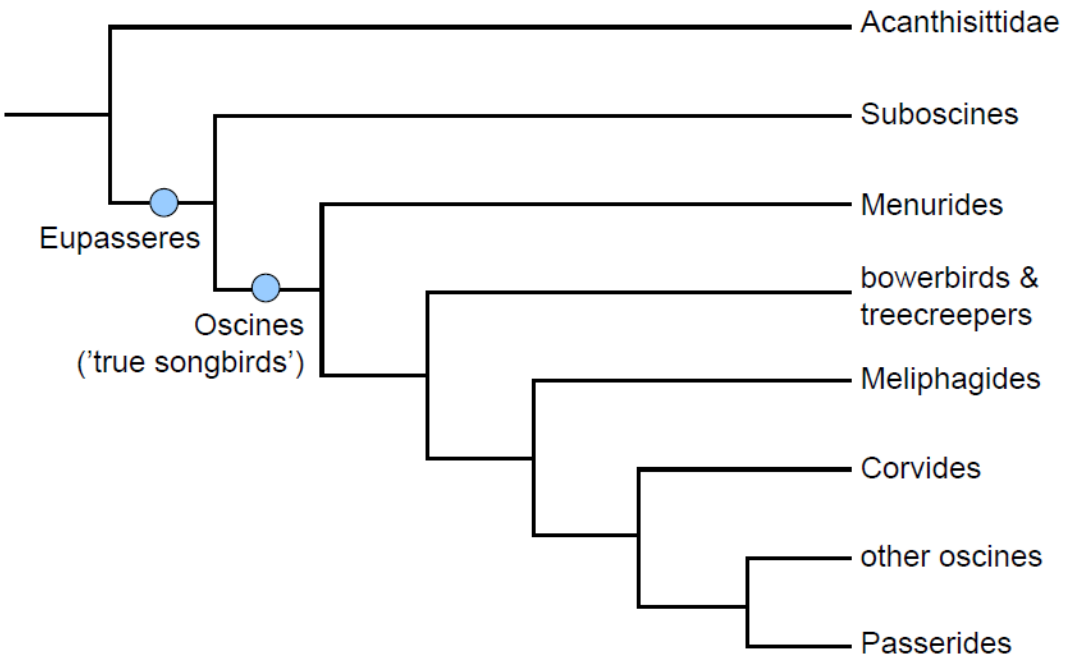
1) core waterbirds (including penguins, pelicans, and loons)
2) core landbirds (including birds of prey, parrots, and songbirds)

The remaining birds within Neoaves belong to numerous clades of uncertain relationship to one another and to other clades within Neoaves.

The order PASSERIFORMES, which is within the core landbirds clade of Neoaves contains more than half of all extant bird species. This order is characterized by:

- specialized syrinx for voice production
- anisodactyl foot (three forward toes, one rear toe – neither reversible or united)
- locking device on tendon of hallux

Because of these characteristics, this group of birds is often referred to as 'perching birds' or 'songbirds'. Below is a cladogram of this group.



Chordata
Vertebrata
Gnathostomata
Amniota
Diapsida
Archosauria
Aves

CHARACTERISTICS OF BIRDS

- Feathers
- Jaws form a beak with horny covering
- No teeth (living forms)
- Hollow bones
- Furcula (wish bone)
- Keeled sternum (no keel in flightless birds)
- “Semilunate” carpal
- Forelimbs modified for flight (wings)
- Heterocoelous (having saddle-shaped facets) cervical vertebrae
- Large egg with mineralized shell

What are some of the differences and similarities between the skeletons of *Archaeopteryx* and modern birds?

_____

_____

_____

What apomorphic features define the clade Neornithes?

_____

How do birds compensate for the lack of teeth?

_____

_____

Are feathers unique to the clade Aves? If not, what other groups possess them?

_____

_____

BIRD TAXONOMY

In traditional taxonomy there are about 40 orders of living birds, which contain about 247 families. The classification of these orders within the phylogeny presented above is given below. Many of the relationships at the deep ordinal level within the Neoaves are still unresolved, and several traditional orders may not represent true monophyletic clades (these are denoted by an asterisk below).

What is presented here is a hypothesis of the phylogeny for Aves, based largely on recent research using DNA. Considerable research into the phylogeny of Aves continues.

Palaeognathae
- Order Struthioniformes – Ostrich
- Order Rheiformes – Rheas
- Order Tinamiformes – Tinamous
- Order Casuariiformes – Cassowaries and Emu
- Order Apterygiformes – Kiwis

Neognathae
- Galloanseres
  - Order Anseriformes – Ducks, Geese, Screamers and other waterfowl
  - Order Galliformes – Pheasants, Quails, Curassows, Guans, Megapodes other landfowl
- Neoaves
  - core waterbirds
    - Order Gaviiformes – Loons
    - Order Ciconiiformes* - Storks
    - Order Suliformes – Frigatebirds, Gannets, Cormorants & Anhingas
    - Order Pelecaniformes* - Ibises, Herons, Egrets, Hamerkop, Shoebill & Pelicans
    - Order Sphenisciformes – Penguins
    - Order Procellariiformes – Albatrosses, Shearwaters & Petrels
  - core landbirds
    - Order Coliiformes – Mousebirds
    - Order Accipitriformes – Hawks, Eagles & New World Vultures
    - Order Strigiformes – Owls
    - Order Leptosomiformes- Cuckoo-roller
    - Order Trogoniformes – Trogons
    - Order Bucerotiformes – Hornbills, hoopoes & woodhoopoes
    - Order Coraciiformes* - Kingfishers, Rollers, Bee-eaters, Motmots, Todies, Cuckoo-roller & allies
    - Order Piciformes – Barbets, Honeyguides, Woodpeckers & allies
    - Order Cariamiformes - Seriemas
    - Order Falconiformes – Falcons
    - Order Psittaciformes – Parrots
    - Order Passeriformes – Passerines
  - various groups
    - Order Charadriiformes – Sandpipers, Plovers, Gulls, Oystercatchers, Jacanas, Snipes, Button-quail & allies.
    - Order Caprimulgiformes* - Nightjars & Frogmouths
    - Order Apodiformes – Owlet-nightjars, Swifts & Hummingbirds
    - Order Columbiformes - Pigeons & Doves

Order Pterocliformes – Sandgrouse
Order Mesitornithiformes - Mesites
Order Podicepediformes – Grebes
Order Phoenicopteriformes - Flamingoes
Order Cuculiformes – Cuckoos
Order Musophagiformes – Turacos
Order Otidiformes - Bustards
Order Opisthocomiformes – Hoatzin
Order Gruiformes – Rails, Finfoots, Cranes, Limpkin & Trumpeters
Order Eurypygiformes – Sunbittern & Kagu
Order Phaethontiformes – Tropicbirds

For the following species, what is the largest clade to which they belong, but none of the other species belong?

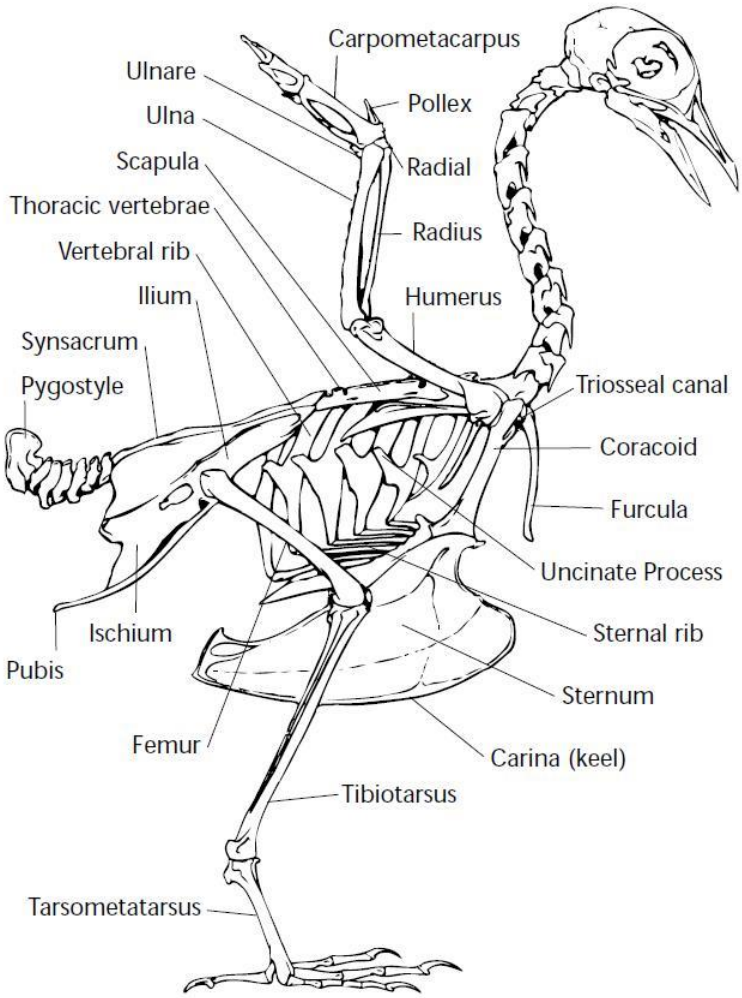
1. Emu (skeleton)
   _____
2. Great Cormorant (skeleton)
   _____
3. Little Penguin
   (skeleton)_____
4. Musk Duck
   (skeleton)_____
5. Forest Kingfisher (mounted specimen) _____
6. Parrot
   (skeleton)_____

THE BIRD SKELETON

Birds have developed two methods of locomotion - flying and walking. Forelimbs and hindlimbs are therefore adapted for different purposes, but both of the girdles are strong and well developed. The trunk is short, and the skull is small with a long and flexible neck. The bones are usually hollow, and the design provides maximum strength for minimum bulk. For unknown reasons, some large bones are connected to the air sac system (pneumatization).

VERTEBRAL COLUMN

The neck is the most flexible part of the skeleton. The number of cervical vertebrae varies among taxa, depending on the length of the neck of the species. Part of the flexibility of the neck is due to the saddle-shaped facets at the articulation of the centra of the cervical vertebrae.



The rest of the skeleton is fairly rigid, to provide a sturdy frame against which the flight muscles exert considerable force. In some taxa (e.g. some galliforms, pigeons and grebes), the anterior thoracic vertebrae are fused into a single mass to stabilise the anterior end of the body. One or two of the posterior thoracic vertebrae may be fused into the synsacrum, which is composed of the fused lumbar, sacral and anterior caudal vertebrae. Together with the pelvis this forms a rigid structure which carries the weight of the hind end. Posterior to the synsacrum there are usually only a few free caudal vertebrae. The rest of the caudal vertebrae are fused into a solid, upturned bone, the pygostyle. The tail feathers are attached to the tissue covering the pygostyle. Some ratites such as the emu have only a small pygostyle and freer caudal vertebrae.

RIBS

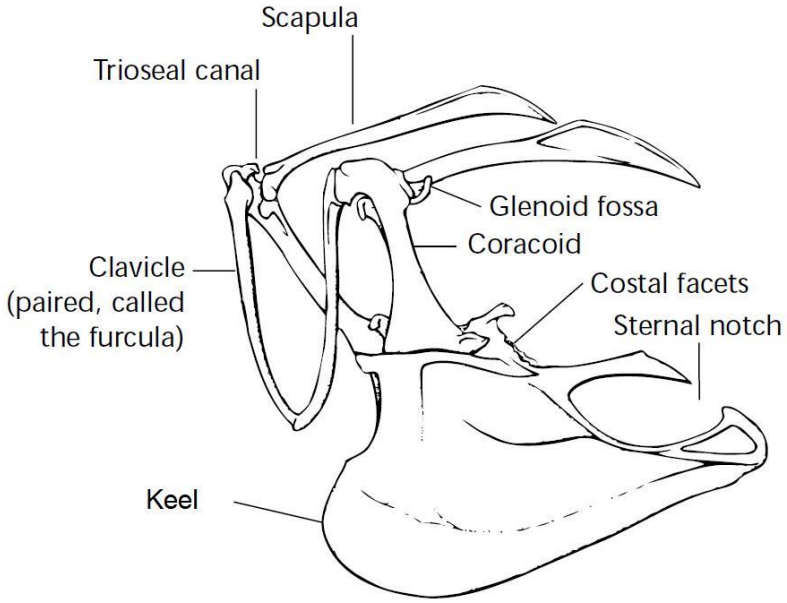
The most caudal cervical vertebrae bear small visible cervical ribs, although all the more anterior ones have a rib fused early in ontogeny forming a laterally-placed lamina on the vertebra. The thoracic ribs are formed of two bony parts - the rib proper with 2 articulations to the vertebra and the ossified costal cartilage that links to the sternum (which is not usually ossified in mammals), with a moveable joint between the two parts. The rib cage, as a whole, is made more rigid by the uncinate processes which overlap the ribs.

STERNUM

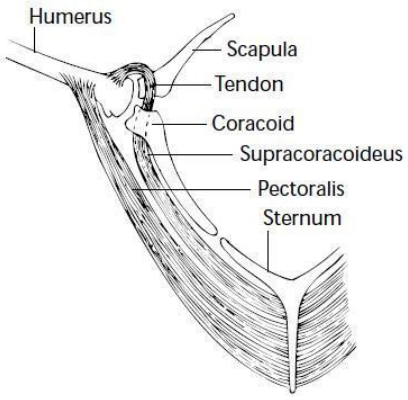
The sternum is variable in structure. In flying birds it has a keel, the size of which gives an index of wing power. In flightless birds, the keel is reduced, but present in all neognaths: only in ratites (palaeognaths) is it lacking.

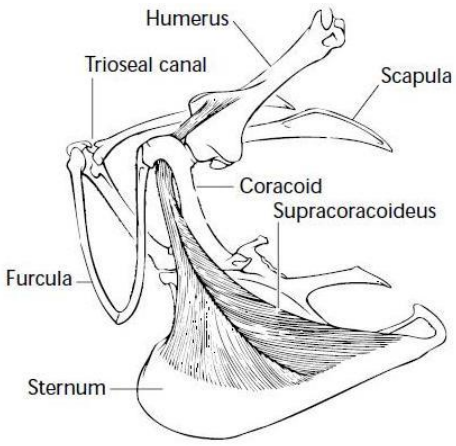
PECTORAL GIRDLE

The scapulae are long and narrow and are connected to the sternum by the coracoids. The coracoids are, compared to mammals, strong and massive, and with the clavicles they act as struts, taking the force of the wing beats and holding the wings away from the sternum. Clavicles usually fuse ventrally to form the furcula (wishbone). Clavicles are reduced or missing in ratites and some parrots. In flightless birds the pectoral girdle is relatively small.



The meeting of the scapula, coracoid and clavicle surround the foramen triosseum. Through this passage goes the tendon of the supracoracoideus muscle. In this way the muscle (which has its origin on the sternum) passes dorsally to the dorsal surface of the humerus to ELEVATE the wing. The larger pectoralis major muscle which gives the powerful down beat, has its origin on the keel of the sternum and on the clavicle, and is inserted on the greater tuberosity of the humerus.



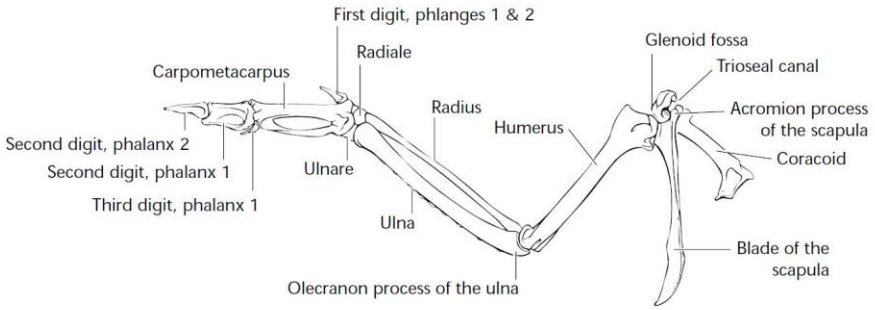


WINGS

The humerus is strong. You may be able to see large pneumatic foramina on the inner surface of the head where the connection to the air sac system is made. The radius is more slender than the ulna. The ulna is stout and may have nobs on its surface where the quills of the secondary flight feathers attach.

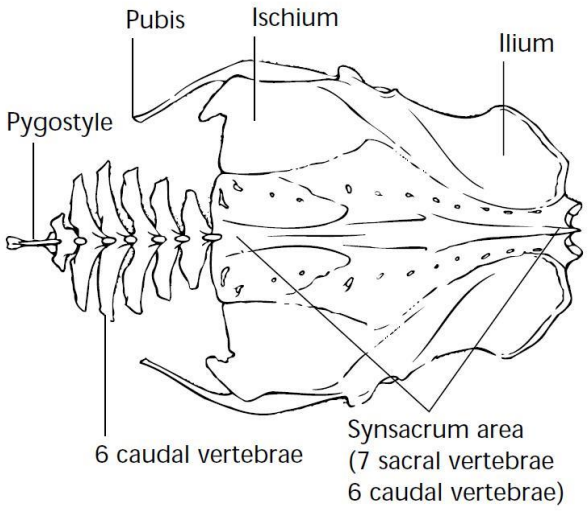
There are two free CARPALS at the end of the radius and ulna. However, some of the distal carpals fuse with the three metacarpals of digits 2, 3 and 4 to form the carpometacarpus.

Digits 2 and 4 consist of one phalanx each. Digit 3 may have two or three phalanges. Digits 1 and 5 have disappeared. Digit 2 may have some power of independent movement, forming (with its feathers) the alula (also called bastard wing).



PELVIC GIRDLE

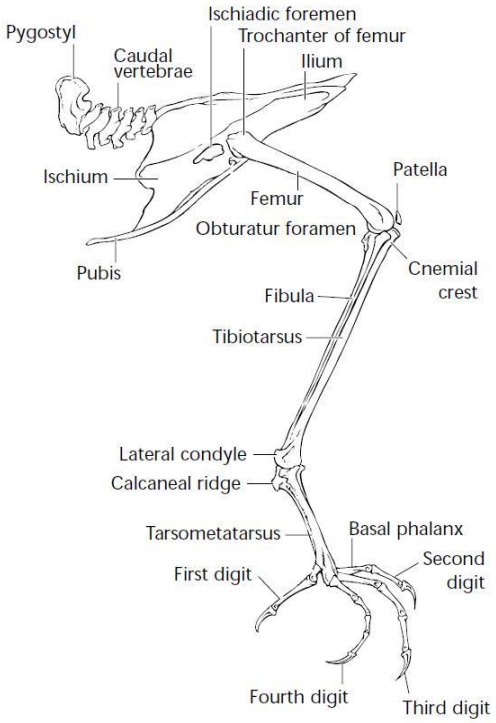
The ilium extends a considerable distance anteriorly and posteriorly of the acetabulum, and fuses with the synsacrum. The ischium lies ventral to the posterior part of the ilium. The pubis has rotated backwards during development and lies ventral to the ischium. There is usually no pubic symphysis between left and right sides (allowing the passage of the relatively large egg characteristic of birds).



LEG

The femur is usually short. The distal end of the tibia fuses with the proximal tarsal bones to form a tibiotarsus. The fibula is usually reduced to a splint.

While the proximal row of tarsals fuses with the tibia as stated above, the distal row fuses with the metatarsals to form the tarsometatarsus. However only the metatarsals of digits 2, 3 and 4 are involved. Those of digit 5 are lost and only one remains of digit 1 (it is small and points backwards in most birds). Note that the tarsometatarsus has three characteristic pulley-shaped processes which articulate with the phalanges of digits 2, 3 and 4.



FEET

There is much adaptive modification of bird feet (eg. ducks vs. perching birds). Most birds have four toes (digits 1,2,3 and 4), although digit 1 may be short and point backwards in perching birds. Digit 1 is much reduced in non-perching birds. Parrots and woodpeckers have digits 1 and 4 pointing backwards (with 2 and 3 pointing forwards), which is thought to help in climbing. In pelicans all four toes point forward. Emus have three toes and ostriches have two.

Flight is a conspicuous characteristic of birds. How do birds flap their wings? What unique feature of the pectoral girdle is associated with this?

_____

_____

_____

Examine the different skeletons of volant (flying) birds. What is the most robust bone in the skeleton? Why is this bone so strong?

_____

_____

List three features of the bird skeleton that are adaptations to flight.

1. _____
2. _____
3. _____

What is the name of the process on the thoracic ribs of birds? What is its function?

_____

_____

_____

Compare the pelvic girdle of a bird to that of other tetrapods. How does it differ? Why? _____

_____

_____

What bones form the tibiotarsus and tarsometatarsus? (hint: examine the juvenile emu skeleton).

Tibiotarsus: _____

Tarsometatarsus: _____

Which digit on the foot (i.e. 1, 2, 3, 4 or 5) is the hind toe? How many phalanges does it have?

_____

Do all birds possess a hind toe? If not, why not?

_____

FEATHERS

Feathers have long been considered the ultimate avian apomorphic character. But we now know they help define a more inclusive group of 'reptiles' including the theropod dinosaurs dromaeosaurs and troodontids. They are modified reptilian scales, and are epidermal structures formed of keratin. They develop from follicles in the skin and are usually distributed in discrete tracts known as pterylae, separated by non-feathered tracts known as apteria.

Examine the structure of a large feather under the microscope? How do the vanes of the feather form an unbroken surface? Do all feathers have this structure?

_____

_____

_____

List four functions of feathers

1. _____
2. _____
3. _____
4. _____

How does a bird's wing generate lift and propulsion?

_____

_____

_____

LUNGS AND AIR SACS

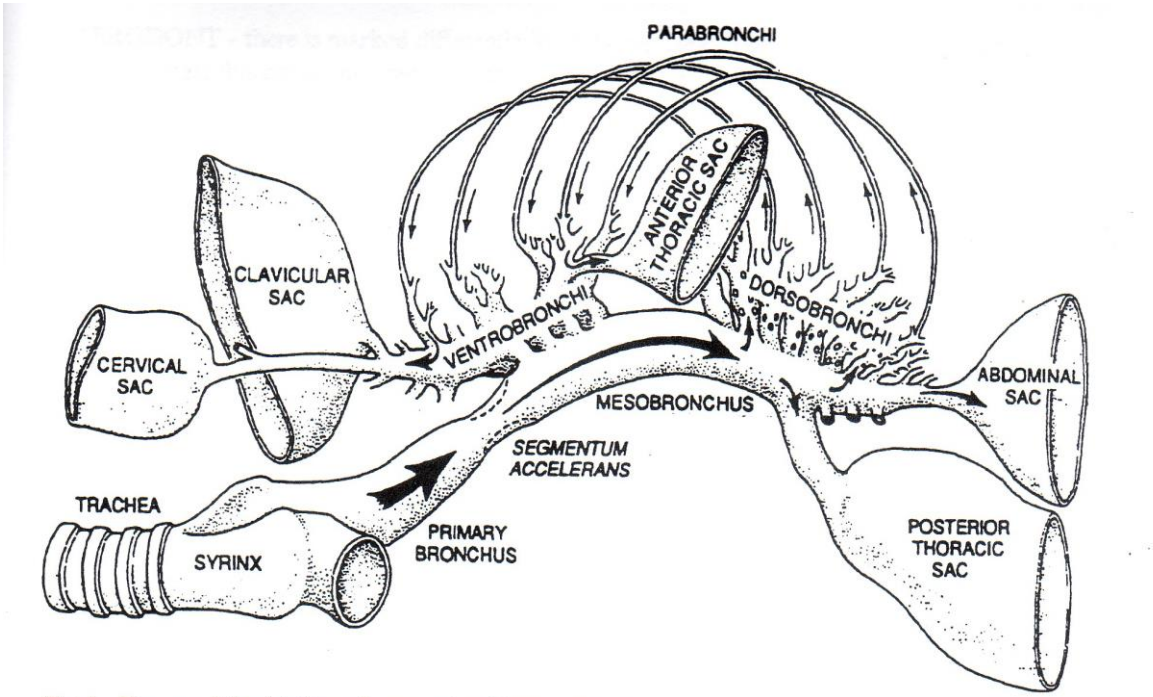


Fig. 1. Diagram of the right lung of a goose viewed from medial aspect. During inspiration, air is accelerated into the mesobronchus by a constriction (the segmentum accelerans) at the caudal end of the primary bronchus, thus bypassing the ventrobronchial openings. Air is thus brought into the respiratory part of the lung (parabronchi) via the dorsobronchi, as well as into the posterior thoracic and abdominal sacs (arrows). Air displaced from the parabronchi during inspiration passes into the cervical, clavicular and anterior thoracic sacs. During expiration, air passes from the posterior thoracic and abdominal sacs into the parabronchi via the dorsobronchi. The anterior air sacs empty via the ventrobronchi, which also receive air displaced from the parabronchi. For illustrative purposes, only part of the extensive air sacs is shown; a minor portion of the lung (neopulmo) is omitted.

BEAKS AND LEGS

Examine the different bird skeletons and mounted specimens in the collection, and answer the following questions.

Identify the likely diet of the following birds:

1. Eagle (skull) _____
2. Cormorant (skull & skeleton) _____
3. White-browed Scrubwren (study skin) _____
4. New-Holland Honeyeater (study skin) _____
5. Java Sparrow (preserved specimen) _____

What is the adaptive significance of the hind limb of the following birds?

1. Banded Stilt (mounted specimen)
   _____
2. Cormorant (skeleton)
   _____
3. Emu (skeleton, leg)
   _____
4. Eagle (foot)
   _____
5. Penguin (skeleton)
   _____

REPRODUCTION

Examine the displays on reproduction in birds and answer the following questions.

What shape are the eggs of the Ostrich, Cassowary and King Penguin?

Ostrich: _____ Cassowary: _____ King Penguin:_____

What is the advantage of a pyriform shaped egg?
_____
_____

How do the nests of megapodes, such as the malleefowl, differ from all other birds? How do they function?
_____
_____
_____

Why is the egg of the Kiwi so large relative to its size compared to most other birds?
_____
_____

Some birds incorporate moss, lichen or bark on the outside of their nests. Why do they do this? _____

What is the main advantage of a suspended nest? _____

_____

Nests that are on the ground are vulnerable to predators. How do ground-nesting birds reduce the risk of predation? _____

_____

_____

Have a look at the table of the altricial-precocial continuum. How would you classify the passerine and pigeon nestlings?

Passerine: _____ Pigeon: _____

Emu: _____ Penguin: _____

NOTES

PRACTICAL 8

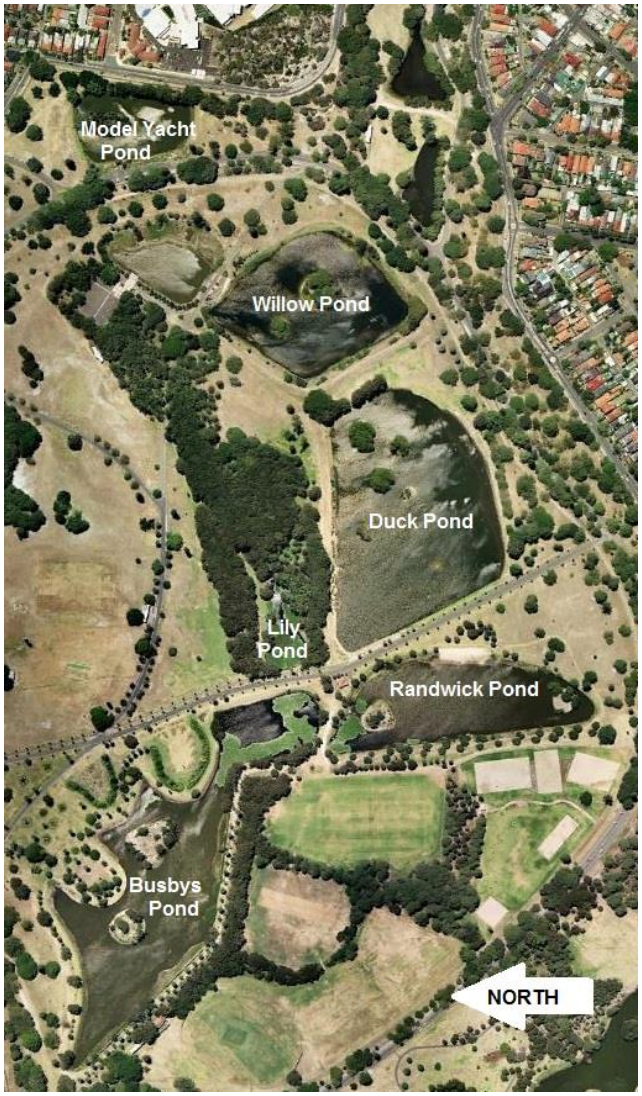
Birds in their Habitat

Birds at Centennial Park Wetlands

Aims:

- observe resource use of free-living waterbirds and relate this to their ecology, behaviour, and morphology
- identification of free-living birds using field guides

You will need to form groups of 3-5 students to complete the two exercises



IMPORTANT: Before you commence each exercise make sure you read through all the notes.

Exercise 1. Comparison of the ecology of three gallinules (Order Gruiformes; Family Rallidae): Dusky Moorhen (*Gallinula tenebrosa*), Purple Swamphen (*Porphyrio porphyrio*), and Eurasian Coot (*Fulica atra*)

This exercise aims to demonstrate the different use of resources available within the same habitat (freshwater wetland) by three related species, and how this is reflected in their morphology and foraging behaviour. This exercise should take about one hour.

Each group of students will visit three ponds near Parkes Drive in Centennial Park: Duck, Lily, and Willow (see map on previous page) and observe the microhabitat use, morphology and foraging behaviour of each of the three gallinules.

Instructions:

1. Before you begin collecting your data, make sure you can confidently identify the three different species of gallinule. *Use your binoculars* to look closely at the features of each species and *consult the bird field guide* provided.

   The diagnostic features that will help you distinguish the three gallinules are:

   Purple Swamphen: Largest species. Large red bill and frontal shield. Long red legs with long toes. Underside of the tail is completely white.

   Dusky Moorhen: Red frontal shield. Red bill with distinctive yellow tip. Underside of tail mostly dark with a thin white strip on both sides. (Juveniles lack the bill colouration.)

   Eurasian Coot: White frontal shield and white bill. Rest of body black. Indistinct tail. (Juveniles have a pale grey bill, small frontal shield, and paler underside.)

2. Select one of the three ponds (listed below) ‘randomly’ as your starting point (using ‘rock, paper, scissors’). Divide your group into a ‘scribe’ who will record the data, and ‘observers’ who will count the birds. You should rotate the role of scribe among members of your group so that you all get a chance to observe the birds.

   Duck Pond – this is a largest pond so, it is best to observe and count birds from the eastern and northern shorelines while you walk along them from the road. Be sure to look across the pond to the opposite shoreline to count all birds.
   Lily Pond – Treat the white footbridge as the end of the pond (i.e. ignore the creek flowing into Lily Pond).

Willow Pond – the large islands and vegetation around the pond make observing difficult, make sure you can see most of the pond while counting (walking will help! Also, if your group is large enough you can split in two).

3. If you divide the pond into sections among the observers in your group, clearly identify and agree upon the boundaries of the sections so you don't count any individual birds more than once.

4. Select one of the three gallinule species to count first at your pond. Do this randomly using the 'rock, paper, scissors' method.

5. Each observer should scan the entire area of their section of the pond and count the number of individuals of the focal gallinule species in each of the following five microhabitats:
   - open water - >3m from the edge of the pond or floating vegetation
   - water close to cover - <3m from the edge of the pond, wetland vegetation or floating vegetation
   - vegetation within or immediately adjacent to water – include e.g. lilies, floating debris, reeds, vegetation on islands
   - land close to water <3m from the edge of a pond or edge of island, include the edge where water meets land
   - land away from water >3m from the edge of a pond or island

   This scan should be completed in the shortest time possible to minimise the number of individuals switching between microhabitats during the period of data collection (i.e. be a representative 'snap shot' of the distribution of gallinules).

6. Record these data in the table on page 161 for the appropriate pond (i.e. either Table 1, 2 or 3)

7. Once you have completed the count, spend ~10 minutes observing the behaviour of multiple individuals of the focal gallinule species. Try to observe the behaviour of birds in each of the different microhabitats present at the pond. Pay particular attention to where individuals of each species forage and how they use the habitat. Where individuals are actively foraging, pay particular attention to how the birds use their bill and feet. Make notes about your observations in the sections provided on pages 162-163.

8. Repeat steps 5 to 7 for the second randomly chosen gallinule species (if present at the pond).

9. Repeat steps 5 to 7 for the third gallinule species (if present at the pond).

10. Move onto the second pond (chosen randomly) and repeat steps 3 to 9.

11. Move onto the third pond and repeat steps 3 to 7.

Once you have observed all gallinule species at each of the three ponds move to the Model Yacht pond to begin the second exercise (see page 167).

Microhabitat use of gallinules

For each gallinule species at each pond, record the number of individuals in each of the five microhabitats. If a gallinule species is absent at the pond record '0' for all microhabitats.

Table 1. Duck Pond

	Open Water	Water Near Cover	Vegetation in/near Water	Land Close to Water	Land Away from Water
Dusky Moorhen					
Purple Swamphen					
Eurasian Coot					

Table 2. Lily Pond

	Open Water	Water Near Cover	Vegetation in/near Water	Land Close to Water	Land Away from Water
Dusky Moorhen					
Purple Swamphen					
Eurasian Coot					

Table 3. Willow Pond

	Open Water	Water Near Cover	Vegetation in/near Water	Land Close to Water	Land Away from Water
Dusky Moorhen					
Purple Swamphen					
Eurasian Coot					

Observations of gallinule foraging behaviour

Spend several minutes observing the foraging behaviour of *multiple individuals* of each gallinule species at each pond (avoid the area where people feed the birds). Make notes about your observations below.
All species are primarily herbivorous, but supplement their diet with invertebrates. The Purple Swamphen may also include small vertebrates in its diet.

Duck Pond

Dusky Moorhen: _____

_____

_____

_____

Purple Swamphen: _____

_____

_____

_____

Eurasian Coot: _____

_____

_____

_____

Willow Pond

Dusky Moorhen: _____

_____

_____

_____

Purple Swamphen: _____

_____

_____

_____

Eurasian Coot: _____

_____

_____

_____

Lily Pond

Dusky Moorhen: _____

_____

_____

_____

Purple Swamphen: _____

_____

_____

_____

Eurasian Coot: _____

_____

_____

_____

Exercise 2. Resource use of a freshwater wetland bird assemblage

The aim of this exercise is to demonstrate: 1) how different species use different resources available within the same environment, and 2) how morphology is related to foraging ecology. This exercise should take about one hour.

In your group of 3-5 students visit each of the six ponds near Parkes Drive in Centennial Park (see map on first page of this practical). Complete the following tasks:

1) Record the resources available to birds provided at each pond in Table 4
2) Identify and count all the bird species present at the pond in the table on page 169 (this is part of your **Assessment Task**)

While you are identifying all the species at each pond observe their morphology and foraging behaviour. *Avoid the area where people feed the birds at Duck Pond*.

For each waterbird species you need to identify the broad foraging guild which best describes the species. *Use your knowledge of variation in bird bills and hindlimbs to help with classification.* A foraging guild comprises a group of species with similar diets and feeding behaviour, but can vary in their morphology. Guilds can be classified in many ways, but we will use the following categories:

Grazer (G) – consumes plants obtained by grazing on vegetation on land
Diver (DV) – consumes plants and/or animals obtained from deeper water by diving below the surface
Wader (W) –mainly consumes animals obtained in shallow water by wading
Dabbler (DB) – consumes plants and small animals obtained from the surface of the water by swimming or in shallow water by 'up-ending'
Prober (P) – consumes animals obtained by probing in mud or soil

Table 4. Resources available at Centennial Park ponds. Place a tick in the appropriate box if the resource is present at the particular pond

Resources	Lily	Duck	Willow	Busbys	Randwick	Model Yacht
Area (ha)	0.46	5.75	3.01	5.35	3.00	0.59
Floating vegetation						
Submerged Tree						
Island						
Open water*						
Shrubs at edge						

*large expanses of open water

Assessment Task

NAME:_____

STUDENT NUMBER:_____

This assessment task is worth **5%** of your final mark for BIOS2061 and should be completed during the practical. You will use the data you collected and the observations you made during this practical to answer the following questions for each of the two exercises. *Do not exceed the space provided and read all questions before you begin answering them.*

You will need to submit your answers to these questions at the end of this practical for examination. You may wish to print out these pages from the online copy prior to the practical.

EXERCISE 1

Question 1. Describe the *general pattern* of distribution of individuals across the five microhabitats for each gallinule species.

Dusky Moorhen: _____

_____

_____

_____

_____

Purple Swamphen: _____

_____

_____

_____

_____

Eurasian Coot: _____

_____

_____

_____

_____

Question 2. Describe the *morphology* and *foraging behaviour* of each gallinule species.

Purple Swamphen: _____

_____

_____

_____

_____

Eurasian Coot: _____

_____

_____

_____

_____

Dusky Moorhen: _____

_____

_____

_____

_____

Question 3. How do the differences in morphology and foraging behaviour of the three gallinule species relate to differences in their microhabitat use?

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

EXERCISE 2

Question 1. How does the waterbird assemblage differ among the ponds? In your answer, discuss differences in species richness and bird abundance. You may also wish to mention notable differences in species that are present or absent. *You should consult the completed table at the end of this practical.*

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Question 2. How do the differences you described above relate to differences in resource availability at the different ponds? *Consider other factors in addition to feeding by people.*

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Question 3. Choose four (4) species of waterbird that you observed at Centennial Park. For each species, identify the foraging guild that best describes the species, and briefly discuss the morphological adaptations related to its foraging behaviour. *Do not choose any of the gallinules*.

1) _____

_____

_____

_____

_____

2) _____

_____

_____

_____

_____

3) _____

_____

_____

_____

_____

4) _____

_____

_____

_____

_____

Waterbird species observed at Centennial Park ponds. For each waterbird species present, classify the species into one of the foraging guilds (FG) and record the number of individuals present. You can use abundance categories such as 1-10, 11-20, 21-50 etc.

Species	FG	Lily	Duck	Willow	Busbys	Randwick	Model Yacht
Silver Gull							
Musk Duck							
Black Swan							
Australian Wood Duck							
Domestic Duck*							
Domestic Goose*							
Pacific Black Duck							
Grey Teal							
Chestnut Teal							
Hardhead							
Australasian Grebe							
Australasian Darter							
Little Pied Cormorant							
Little Black Cormorant							
Pied Cormorant							
Great Cormorant							
Australian Pelican							
White-faced Heron							
Great Egret							
Intermediate Egret							
Australian White Ibis							
Straw-necked Ibis							
Royal Spoonbill							
Purple Swamphen							
Dusky Moorhen							
Eurasian Coot							
Black-winged Stilt							
Masked Lapwing							
Black-fronted Dotterel							

Species Richness						
Waterbird Abundance						

* Introduced species

NOTES

PRACTICAL 9

Mammal Skeletons 1

MAMMALIAN DENTITION

Teeth are the single most informative and diagnostic feature of mammals. Identification at least to family level and often to species can be made on teeth alone. In paleontology, a single tooth (especially a molar or premolar) or jaw in a fossil deposit is often sufficient to identify the presence of a particular genus or species. Teeth, being the hardest part of the skeleton, are the most commonly preserved tissue in fossil deposits. The tooth pattern (ridges, grooves, bumps, etc) and the dental formula are genetically determined, and these features have a functional basis (diet). Within a clade, tooth size responds to natural selection, but teeth of an individual do not grow after eruption. This important fact allows estimation and comparisons of body size (why is this not easily done for other bones such as limb bones?).

Mammalian dentition differs from that of other tetrapods in being:

DIPHYODONT - there are only two generations of teeth (other tetrapods typically have many generations).

HETERODONT - there is marked differentiation (specialization) of teeth along the tooth row (other tetrapods show much less, if any, specialization). In most mammals this occurs in a regular pattern - incisors (i), canines (c), premolars (p) and molars (m).

Mammalian tooth types

Mammalian teeth can be differentiated on the basis of their position in the jaw. Most anteriorly are the **incisors**, nipping teeth with a simple conical or chisel-like shape. Next in each series is a single **canine**, often a long, stout, deep-rooted tooth with a conical shape and a sharp point. Following the canine is a series of **premolars** (called 'bicuspids' by dentists) which frequently show a degree of grinding surface on the crown. Finally there are the **molars** which generally have a chewing function and a complex crown pattern. These general descriptions may be highly modified in some mammals with specialized diets, and in particular the premolars may be difficult to differentiate from the molars (in which case the premolars are known as 'molariform').

This regional differentiation is also related to skull anatomy in that the upper incisors are situated within the **premaxilla**, the canines are usually on the boundary between the premaxilla and the maxilla (although actually produced by the maxilla) and the upper premolars and molars are in the **maxilla**. Of course all of the teeth of the lower jaw are in the same bone - the **dentary**.

Since mammals are **diphyodont**, teeth can also be differentiated on the basis of being deciduous teeth and adult teeth. Deciduous teeth fall out to be replaced by the permanent teeth and are also known as 'milk' or 'juvenile'

teeth. Of course not all teeth have a juvenile precursor, but herein lies an important difference between marsupials and placentals. In placentals such as ourselves, only the last three teeth (the molars) are not preceded by 'milk teeth'. They of course erupt much later than the front teeth (and the human '**wisdom'** teeth may not erupt at all). In living marsupials only the third premolar (P3) has a "milk tooth" precursor (dP3).

WHY have mammals stopped replacing their molars when most sauropsids continuously replace ALL of their teeth?

Heterodonty refers to the fact that there are many different KINDS of teeth in the mammalian dentition—not just sharp pointy ones as in crocs, snakes or most lizards.

WHY would mammals have evolved heterodonty in the first place?

Mammalian tooth formulae

The tooth formula is a standardized way of writing the normal dentition pattern for a given taxon. THE FORMULA ALWAYS REFERS TO HALF OF THE JAW ONLY AS MAMMALS ARE BILATERALLY SYMMETRICAL. Unless otherwise indicated, such a formula refers to the adult dentition. Both upper and lower dentitions are given *as these are not necessarily the same in any given species*. Here is the basic formula for **placental** mammals given in two forms:

$$i\ \frac{3}{3}\ c\ \frac{1}{1}\ p\ \frac{4}{4}\ m\ \frac{3}{3} \qquad \text{OR} \qquad \frac{3\ 1\ 4\ 3}{3\ 1\ 4\ 3}$$

In this case both upper and lower dentitions are the same.

In **marsupials** the basic formula shows that the upper incisors can outnumber the lower incisors. Look at a bandicoot skull to see the basic, unmodified, marsupial dentition.

$$i\ \frac{5}{4}\ c\ \frac{1}{1}\ p\ \frac{3}{3}\ m\ \frac{4}{4} \qquad \text{OR} \qquad \frac{5\ 1\ 3\ 4}{4\ 1\ 3\ 4}$$

It is important to remember that the dental formula for a taxon (except at the species level) is for the *maximum* number of teeth in any species therein. The formula is the ancestral (plesiomorphic) dentition for the taxon. In fact in large

taxa such as Marsupialia and Placentalia very few groups retain the plesiomorphic dentition. Various reductions (only extremely rarely are there apomorphic increases in number) and changes in tooth morphology occur according to the diet of the animals concerned.

If you were to imagine the tooth formula for the common ancestor of both marsupials and placentals, what would it most likely be? In answering this, consider that *in mammals in general, teeth are LOST rather than gained from ancestral patterns*.

I __/__ C __/__ P __/__ M__/__

Some specialized dental conditions

DIASTEMA - a gap formed in the tooth row between the incisors and cheek teeth. This is a characteristic of herbivores. It allows the tongue to manipulate food between the cropping incisors and the posterior grinding teeth. Usually the canines and anterior premolars are lost. Premolars present are usually molariform. Cows, horses, and kangaroos are good examples.

The diastema in the tooth row of herbivores may serve another purpose, in relation to predation. Imagine you are a kangaroo having to eat all the time, but at the same time worrying about whether a Thylacine is somewhere in the grass creeping up on you. How might a diastema save your life?

CARNASSIALS - cheek teeth modified to form a shearing edge for cutting meat. A blade-like structure is formed by the sharp outer (cheek side) crests of the upper teeth concerned. This blade shears along the outside of the opposing lower teeth. Carnassials have arisen separately in several different clades: Carnivora, Creodonta, Dasyuroidea, Thylacoleonidae and Borhyaenoidea. This list includes good examples of CONVERGENT evolution. For example, in creodonts the back molars are involved; in carnivorans the last upper premolar forms most of the 'blade' (and works against the first lower molar). Compare the Tasmanian Devil and the Dog.

In contrasting the carnassial teeth of the Dog and the Devil, what is the main difference in the distribution of the carnassial teeth throughout the dentition of each?

Looking at the Dog and remembering that the lower teeth tend to bite (occlude) at least half way in front of the corresponding upper tooth, which upper and lower teeth are the carnassials in this species? Is the same situation occurring in the Devil?

HOMODONT - dentition in which all teeth are much the same. Since the basic mammalian dentition is HETERODONT, in homodont mammals such as dolphins this is a derived (apomorphic) state.

Why would a homodont dentition in mammals be useful for piscivory (fish-eating)? Consider any time you have tried to catch a live fish with your hands…

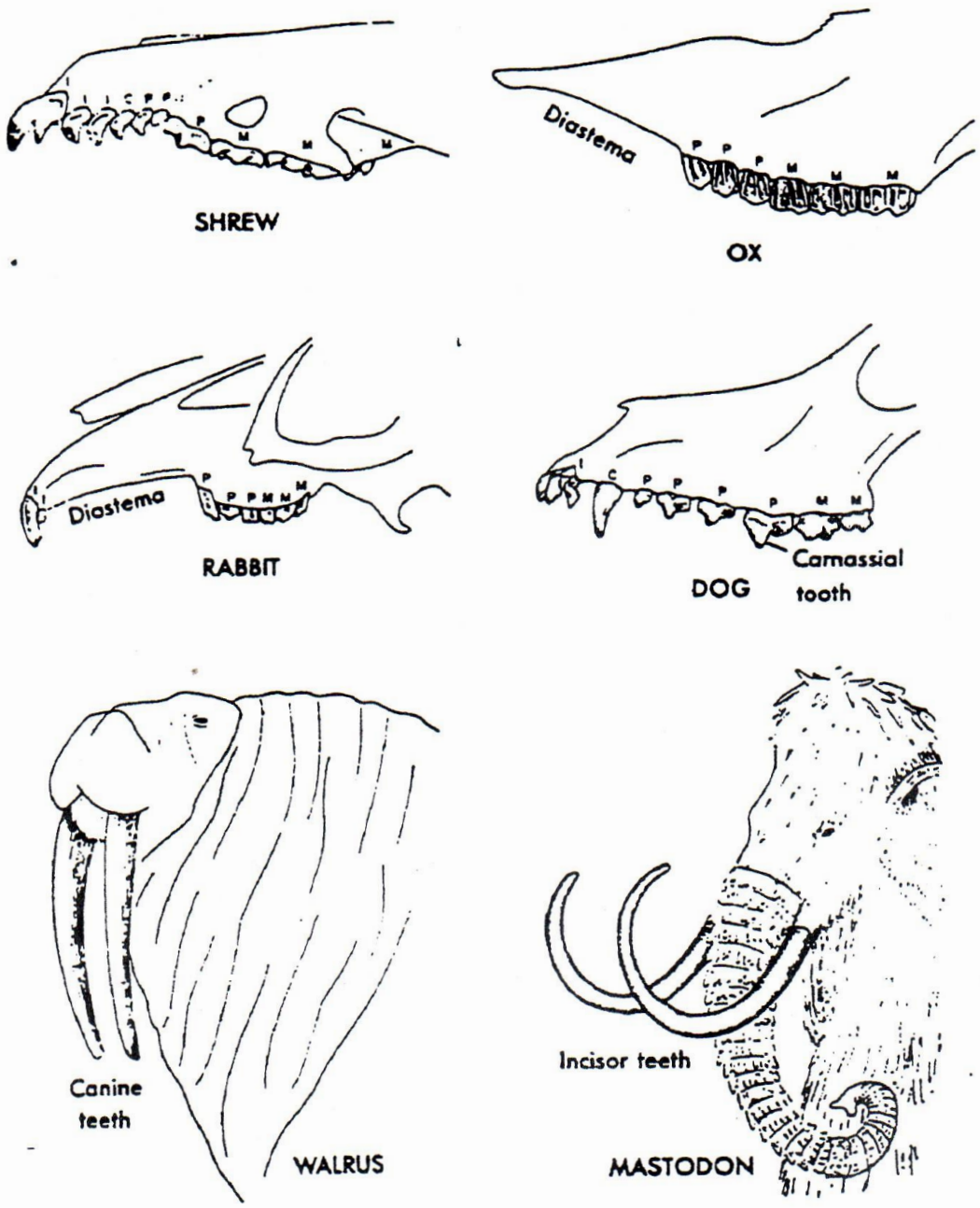
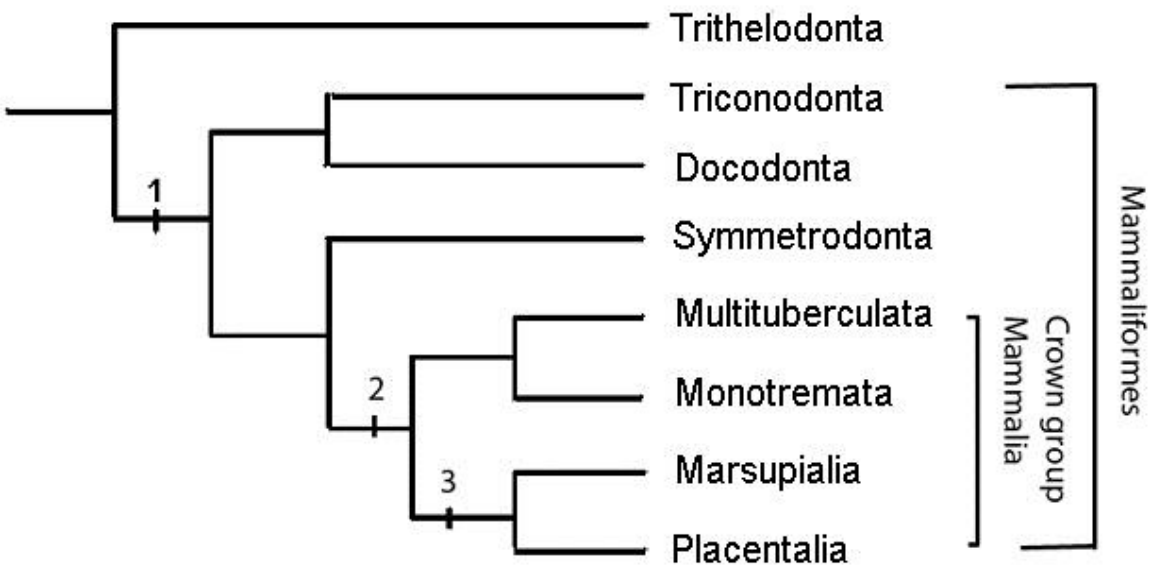


Figure 1. Mammalian upper teeth, showing generalized pattern (shrew), and specializations in a herbivore (ox), in a gnawing mammal (rabbit) and in a carnivore (dog). Extreme specialization of canines is seen in the walrus and of incisors in the mastodon. I = incisor; C = canine; P = premolar; M = molar.

E A R L Y M A M M A L S

A SUMMARY **CLADOGRAM** OF MAMMALIA



1. MAMMALIFORMES
   dentary-squamosal jaw joint larger than quadrate-articular jaw joint

2. MAMMALIA
   dentary and squamosal are involved in jaw articulation
   malleus / incus / stapes in middle ear
   mammary glands
   fur

3. THERIA
   tribosphenic molars
   expanded neopallium

NB: the details of the relationships between the various groups of fossil and living mammals have still not been fully worked out, so the above cladogram should not be viewed as the definitive answer. The relationships of multituberculates (superficially rodent-like omnivorous-herbivorous forms) have proved particularly problematic. However, all recent studies agree that marsupials and placentals (=Theria) are more closely related to each other than to monotremes.

MONOTREMES

Chordata
Vertebrata
Gnathostomata
Amniota
Synapsida
Monotremata

The living monotremes are the platypus (*Ornithorhynchus anatinus*) and the echidnas. The short-beaked or common echidna (*Tachyglossus aculeatus*) is found in Australia and PNG. The long-beaked echidna (*Zaglossus bruijni*) is now found only in PNG although long-beaked echidnas occurred in Australia from at least 18 million years ago until at least the late Pleistocene.

Monotremes have been referred to over the years as '**primitive mammals'**, '**living fossils'** and even '**missing links**'. This is because they contain some plesiomorphic synapsid characters. On balance, they possess far more synapomorphic mammalian characters. And of course both platypuses and echidnas are **specialists** with autapomorphic characters.

A couple of articulated skeletons of echidnas and platypuses are available in the lab. There are skulls and other bits in the 'Monotreme' cabinet under the side bench by the windows.

Plesiomorphic characters of monotremes

1. Oviparity. The egg of the platypus and echidna is similar to that of lizards.

2. Pectoral girdle with **precoracoid**. This is anterior to the **coracoid** bone of the shoulder. The coracoid itself is much larger in monotremes than in therians and is distinct even in adults.

3. **Interclavicle** present. In therians the only dermal bone present in the pectoral girdle is the clavicle. In monotremes a second dermal bone, the T-shaped interclavicle, is present and much larger than the clavicle. The clavicle is applied to the anterior edge of the interclavicle.

4. Pelvic girdle with **epipubic** (marsupial) bones. This character is shared with marsupials and with a few therapsids, and is therefore symplesiomorphic for marsupials and monotremes.

Characters synapomorphic with other mammals

1. **Hair**. The fur of the platypus is very insulating and water resistant. The spines of the echidna are individual hairs. A similar character is found in hedgehogs and porcupines, but in all three cases the character is convergent.

2. **Mammary glands**. Although monotremes lack teats, the mammary glands are well developed and produce milk which nourishes the young for months.

3. **Endothermy** (?). Although long considered a mammalian apomorphy, it cannot be certain whether at least some degree of endothermy was present in therapsids. The capability for heat production is clearly present in other amniotes (e.g. birds and pythons) and even some fish. Monotremes are clearly endothermic, maintaining body temperatures well above ambient, except during hibernation in echidnas.

4. Lower jaw one bone (dentary) only.

5. Three bones in middle ear - malleus, incus, stapes.

6. Two occipital condyles.

7. And many other features of anatomy and physiology.

Monotreme characters

1. **Spurs** on the ankles of males. In the platypus these are functional, being connected by a duct to a poison gland behind the knee. In the echidna the spurs are present in the male but the gland and duct are vestigial.

2. Mandible and snout elongated, forming the ‘beak’ or ‘bill’. The tips of the premaxillae appear hooked. In the platypus the snout is much wider than in the echidna. There are large foramina for the nerves to the sensitive covering of the bill.

3. Loss of teeth. In the echidna teeth never appear and the food (ants and termites) is crushed between horny plates at the back of the palate and on the back of the tongue. In the platypus a couple of teeth actually break through but regress in juveniles to be replaced by horny plates on the jaw in adults. Fossil platypuses and platypus-like monotremes, however, have well-formed teeth. Convergent loss in echidnas and platypus.

4. The limbs are short and powerful. The humerus has wide processes for muscle attachment. This is a common arrangement for animals that are strong diggers or swimmers.

5. **Electroreceptors** on the snout.

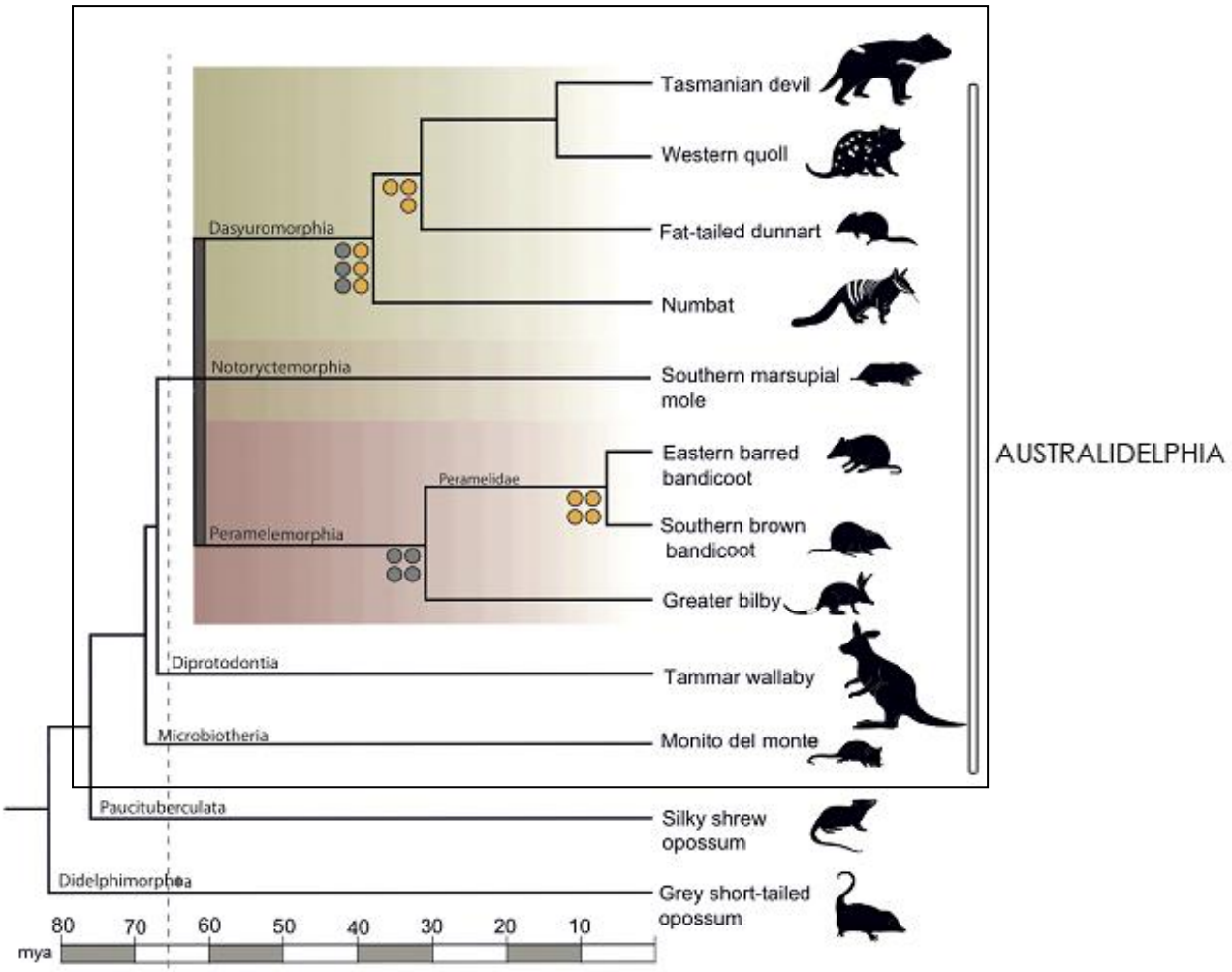
What are the bones in the pectoral girdle of monotremes that are missing from the pectoral girdles of marsupials and placentals, and what purpose might they be serving in monotremes in terms of life style?

Check out the spurs on the monotreme skeletons. It is now evident that some other groups of mammals had similar spurs. What is the purpose of these structures in at least the Platypus? If they were widespread within Mammaliformes, would their presence in monotremes be plesiomorphic or apomorphic?

From study of a middle Miocene Platypus skull from the World Heritage fossil deposits in Riversleigh, Queensland, it is clear that the distal end of the skull (the circular part of the 'bill') is made up of *two* bones: the premaxilla below (as everyone thought) but also a septomaxilla above. In the living Platypus, these bones are fused together and appear misleadingly to be one bone—which they were commonly perceived to be. The septomaxilla is known in older synapsids but no placentals or marsupials. This bone in monotremes would then be an apomorphic or plesiomorphic feature in monotremes?

M A R S U P I A L S

EVOLUTIONARY RELATIONSHIP OF MARSUPIALS



Phylogeny of extant marsupial orders from Gallus, S. et al. 2015. *Genome Biology and Evolution*

Defining traits of the Marsupial Clades

1. MARSUPIALIA
    - *__Stylar cusp C is present and large__
    - __*dP3 is the only postcanine milk tooth__
    - Alisphenoid forms the middle ear floor
    - Pseudovaginal canal occurs at the time of parturition
    - Sperm paired in epididymides

2. DIDELPHIMORPHIA
    - *__V-shaped centrocrista__
    - __*Upper ankle joint broad and curved__
    - __'Peg-like' calcaneocuboid joint in the ankle__

3. AUSTRALIDELPHIA
    - *__Continuous lower ankle joint pattern__
    - Non-pairing spermatozoa
    - Serological characters

4. PERAMELEMORPHIA
    - __*Metatarsal IV enlarged relative to other metatarsals (why?)__
    - Ectocuniform supports metatarsal IV
    - Rectus femoris scar on posterior face of femur
    - __* dP3 reduced__
    - __*Incisors laterally compressed__
    - __*Patella ossified__

5. DASYUROMORPHIA
    - __*Incisor number reduced to 4/3__
    - Large neocortex
    - Loss of calcaneal vibrissae
    - __*Unique tarsal morphology...what is it? Compare to bandicoots__
    - Serological characters

6. NOTORYCTEMORPHIA
    - __*Limbs highly specialized for digging__
    - __*Reduced eyes and external pinnae__
    - __*Zalambdodont (or proto-zalambdodont) teeth...what is it?__

7. DIPROTODONTIA
    - __*I/1 procumbent, I/2 vestigial (why is it like this?)__
    - __*Upper incisors reduced to 3__
    - Manus is forcipate
    - Superficial cervical thymus gland present
    - Brain has a fasciculus aberrans
    - Serological characters

9. VOMBATIMORPHIA (e.g. wombats and koala)
    Head of sperm with prominent hook
    Cardiogastric gland in stomach
    Brain ovoid and gyrencephalic
    Serological characters

10. PHALANGERIDA
    Kangaroos + possums

11. PHALANGREROIDEA + PETAUROIDEA (possums)
    ***Fusion of ectotympanic with surrounding bones**
    *Mastoid expanded anteriorly and laterally
    *Squamosal and mastoid bones pneumatized
    ***M/2 metaconid markedly reduced**
    Serological characters

12. MACROPODOIDEA (kangaroos)
    Masseteric canal developed
    ***P1 lost, P3 increased in size (what value is there is a large P3?)**
    Embryonic diapause occurs
    ***Hypertrophy of digit IV of pes**

Items in **BOLD** you should be able to find. The other characters can't be seen in the lab material, but are used to define the groups.

(NOTE. There has been a great deal of work on the components of DNA and blood serum in marsupials, which has shed much light on cladistic relationships. The details are too involved to list above, but where such characters are decisive we have simply noted 'serological characters').

Looking at the specimens of marsupials available, give the dental formula for the following families represented (we've filled out the dasyurid dental formula to remind you of what we expect you to do here.

1. Dasyuridae: I 4/3 C 1/1 P 3/ 3 M 4/ 4
2. Macropodidae: I _/_ C _/_ P _/ _ M _/ _
3. Phalangeridae: I _/_ C _/_ P _/ _ M _/ _
4. Peramelidae: I _/_ C _/_ P _/ _ M _/ _

If you found skulls with the following dental formulae, would each be more likely to represent a marsupial or a placental? Remember, placentals never have more than 3 molars or 3 incisors and marsupials never have more than 3 premolars.

1. I 1/1 C1/1 P4/4 M3/3 Marsupial? ___ Placental? ___
2. I 4/3 C0/0 P1/1 M1/1 Marsupial? ___ Placental? ___

3. I 3/1 C0/0 P1/1 M4/4 Marsupial? ___ Placental? ___
4. I 3/3 C1/1 P4/3 M2/3 Marsupial? ___ Placental? ___

What feature do bandicoots (peramelimorphians) and diprotodontians (kangaroos, possums, wombats, koalas) have in common in terms of hindfoot structure? What do they do with this structure? In German it's called a 'putzorgan'. If *Putz deine Zähne* means 'Clean your teeth' in German, how do you think 'putzorgan' might be translated?

_____

_____

What feature do dasyures and bandicoots have in common in terms of lower incisor number and posture which differs from diprotodontians? What term is given to this condition vs the condition in diprotodontian marsupials?

_____

_____

CHARACTERS OF MARSUPIALS AS OPPOSED TO PLACENTALS

SKELETAL

1. If a BULLA is present it is formed by the alisphenoid and/or squamosal and/or petrosal. In placentals the bulla is normally formed by a bone unique to this group (hence a synapomorphic character state for Placentalia), the endotympanic.
2. The palatine bones are **usually** perforated by holes of various sizes, and the posterior edges of the palatines are usually thickened.
3. The angular process of the lower jaw is usually inflected (turned inwards). Exceptions include koalas and honey possums. A very few placentals (such as *Tupaia*, the tree shrew) have an inflected lower jaw, but none occur in Australia. In most placentals the angular process extends ventrad.
4. Epipubic bones are typically present in both sexes. The thylacine and some borhyaenids, however, lacked epipubic bones.
   Q. How does this differ from the baculum which marsupials lack? Could there be an evolutionary relationship between the two structures?

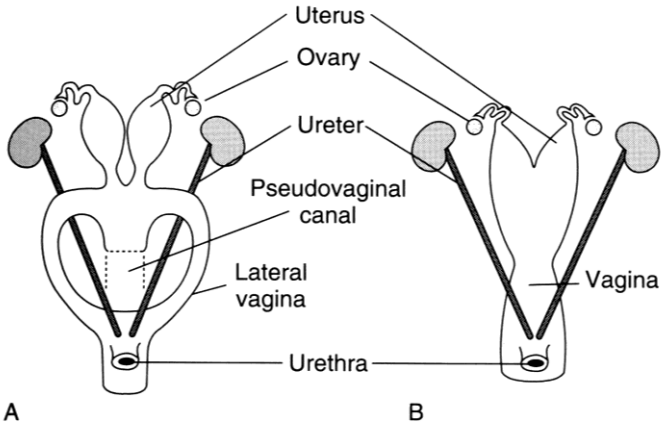
DENTAL

1. Postcanine milk (deciduous) teeth (dP3) precede only the third premolar (P3). Milk teeth precede the incisors and canines, but these are tiny.

2. Marsupials *may* have more than three incisors on upper jaw (placentals *never* have more than three).
3. Lower jaws typically do not have the same number of incisors as the upper jaw (there are fewer in the lower jaw). Wombats (and some fossil groups such as diprotodontoids and yalkiparidontids) are the exception (note: wombats are also an exception in lacking roots on their teeth – which hence grow throughout life).
4. The basic number of cheek teeth (premolars plus molars) in each half jaw for marsupials is 7, with 3 premolars and 4 molars. However a number of marsupial species have a reduced number due to teeth having been lost. Primitively, placentals also have 7 cheek teeth but these consist of 4 premolars and 3 molars.

OTHER

1. Presence of a pouch. Like the epipubic bones, this is plesiomorphic. And in some species the pouch is rudimentary to poorly developed or even absent.
2. Short period of life in the uterus as opposed to that attached to the teat and nourished by milk. This is of course in comparison to placentals.
3. Pseudovaginal canal present in females. (A).
4. Bifid penis
5. No baculum (though only some placental groups have them (PRICCCS).



From Vaughan, T. A., Ryan, J. M. and Czaplewski, N. J. 2000. Mammalogy. 4th Edition. Harcourt College Publishers. Figure 6.4, p. 77.

Check out the life history of *Antechinus*, one of the small dasyurids, and explain what feature is the most striking in terms of reproduction and male lifespans.

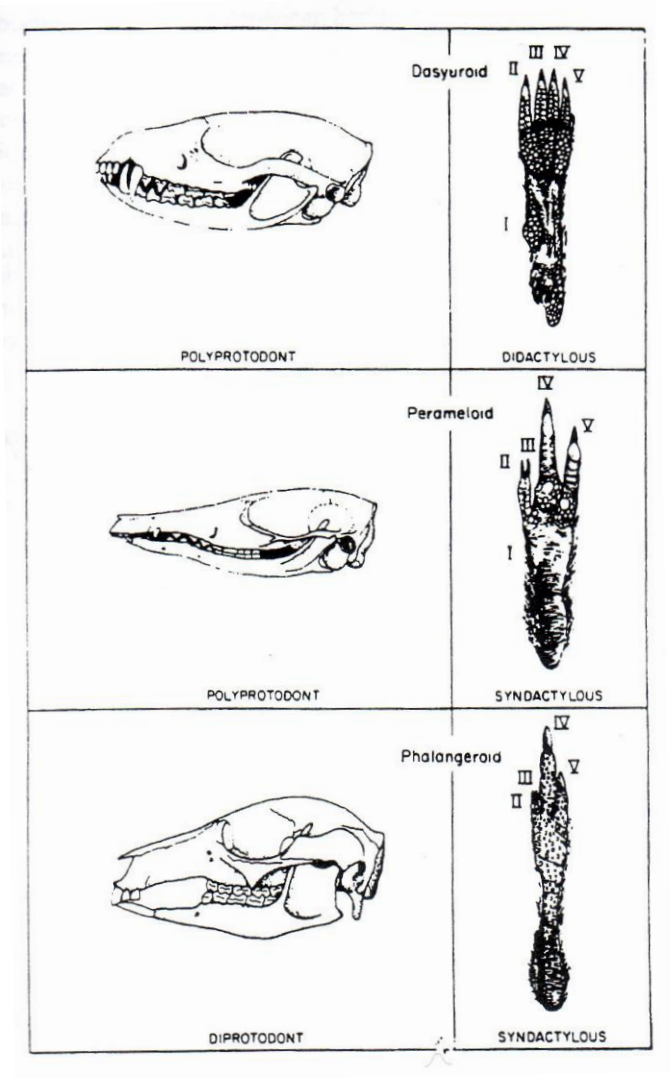
CHARACTERS USEFUL IN DEFINING MARSUPIAL TAXA

Syndactylous - 2nd and 3rd metatarsals and digits very slender and enclosed in a common sheath. 1st digit may be small or lost. 4th and 5th digits stout, with claws.

Didactylous - 2nd and 3rd digits not bound together.

Diprotodont - technically the term refers only to the two procumbent (forward pointing) central incisors in the lower jaw. However the following dental character states are linked with this condition:

- Diastema
- Other lower incisors small or absent
- Lower canines small or absent
- Central upper incisors tend to be larger
- Upper canines small or absent



Dental and hind foot character states in marsupials

Polyprotodont - this refers to a normal number of incisors in the lower jaw. This condition is not linked with any of the character states listed above.

NOTE: Diprotodont and syndactylous are the derived (apomorphic) character states from the ancestoral (plesiomorphic) states polyprotodont and didactylous. They also have functional significance.

LOOK FOR THESE CHARACTER STATES WHEN EXAMINING THE MARSUPIAL SPECIMENS.

In which marsupial groups here do you find a distinct diastema between the lower incisors and premolars? What do these groups share in common in terms of diet?

Explain what's meant by the statement that kangaroos are 'pentapedal' in terms of movement ('penta' means 5). Which is the '5th foot'?

Given the fact that Australia's forests didn't 'open' until possibly only 10-8 million years ago, why do you suppose Australian marsupials, despite developing so many other kinds of body forms and lifestyles, do not appear to evolved 'marsupial bats'?

What structures do possums such as brushtail and ringtail possums have that appear to be adaptations for living and moving in trees?

Wombats and koalas both have pouches that open in a direction that differs from the pouches of possums and kangaroos. What direction does it open in wombats and koalas?

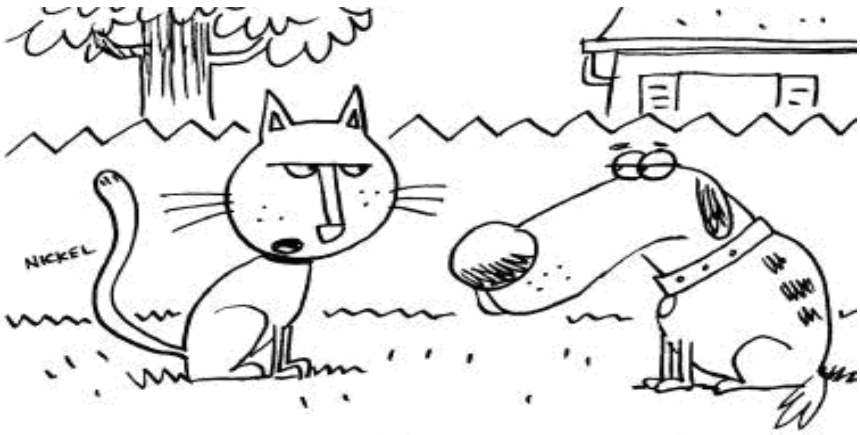


Look at the posterior, external (lateral) side of the dentary in kangaroos and compare this with the same area in the Koala or one of the possums. What striking difference do you note? This is a unique (among marsupials) feature in kangaroos and relates to the insertion of the masseter muscle, the most powerful adductor of the lower jaw.

Which metatarsal of the kangaroo hindfoot is the largest in terms of diameter? What are the five bones that directly link it back to the pelvis? Hint: one of them is the cuboid bone among the tarsal bones.

Looking at the auditory region of the dasyurid skull, which bone forms the 'bulla' (the dome-shaped bony wing behind the glenoid fossa for articulation of the dentary to the skull), and what three tiny bones are protected by this structure?

If it's true that upright stance, freed and grasping hands, and stereoscopic vision were major reasons for the rise of humans to dominance on the planet, if we pull our own plug, which group of living marsupials might then take over the world?



"You stick with learning new tricks…
I'm going for world domination."

PRACTICAL 10

Mammal Skeletons 2

PLACENTAL MAMMALS

Chordata
Vertebrata
Gnathostomata
Amniota
Synapsida
Mammalia
Placentalia

The cladogram for placental mammals in your textbook (and see diagram in this practical) gives 19 living clades within Placentalia (or Eutheria). These more-or-less correspond to the traditional, Linnean orders, with the exception of (for example) Scandentia, Afrosoricida (sometimes called Tenrecomorpha) and Macroscelidea which were previously included in the Linnean order Insectivora.

In the following list, clades which contain species native to Australia are indicated with an asterix (*) and the number of species worldwide in the clade.

THE MAJOR CLADES

Chiroptera*	1100	Volant	Bats
Rodentia*	2000+	Omnivores, granivores	Mice, squirrels, porcupine
Primates*	180	Mainly arboreal	Lemurs, monkeys, humans
Carnivora*	269	Predators	Cats, dogs, weasels, seals
Artiodactyla	185	Even-toed ungulates	Sheep, antelope[#]
Eulipotyphla	360	Insectivores	Shrews, moles, hedgehogs
Afrosoricida/Tenrecomorpha	51	Insectivores	Tenrecs and golden moles

THE SMALLER CLADES

Cetacea* [#]	78	Fully aquatic	Whales, dolphin
Xenarthra	29	Teeth reduced or absent	Sloths, armadillos, anteaters
Lagomorpha	65	Small browsers	Rabbits and hares

[#]Artiodactyla is now interpreted to include the Cetacea

THE RARE ONES

Dermoptera	2	Gliding Lemurs	Colugos
Hyracoidea	7	Small	Hyraxes
Proboscidea	2	Largest land mammals	Elephants, mammoths
Sirenia	4	Aquatic grazers	Dugongs, manatees
Tubulidentata	1		Aardvark
Pholidota	7	Scaly anteaters	Pangolins
Scandentia	16		Tree shrews
Macroscelidea	19		Elephant shrews
Perissodactyla	18	Odd-toed ungulates	Horses, zebra, rhinos, tapir

PLUS AT LEAST 13 EXTINCT CLADES (… AND PROBABLY MANY MORE!)

Creodonta	Eocene *	Early carnivores
Tillodontia	Eocene	Large, with rodent-like dentition
Taeniodontia	Eocene	Heavy herbivores with grinding teeth
Dinocerata	Eocene	Large North American herbivores
Xenungulata	Palaeocene	Large South American herbivores
Pyrotheria	Oligocene	South American trunked herbivores
Pantodontia	Oligocene	Large North American herbivores
Embrithopoda	Oligocene	Rhino-like African forms
Astrapotheria	Miocene	Large South American herbivores
Condylarthra	Miocene	Early omnivores/herbivores, including the ancestors of the various ‘ungulate’ groups
Desmostylia	Pliocene	Marine forms somewhat similar to Sirenia
Litopterna	Pleistocene	Horse-like, South American
Notoungulata	Pleistocene	Largest group of South American grazers and browsers, convergent on true ungulates

* era of extinction

The condylarth radiation – a stem group that includes the ancestors of ungulates

The extinct 'Condylarthra' include the ancestors of many herbivorous placental mammals (often referred to as 'ungulates' (from the Latin word for 'hoof) on all continents except Australia (although one early Eocene taxon from Queensland may represent this group). ‘Condylarthra’ is not a monophyletic group; it includes many different fossil species that show similar adaptations in the teeth and skeleton but that are not necessarily closely related. To indicate that ‘Condylarthra’ is not monophyletic, it is often, as here, written in quotes, i.e. 'Condylarthra'.

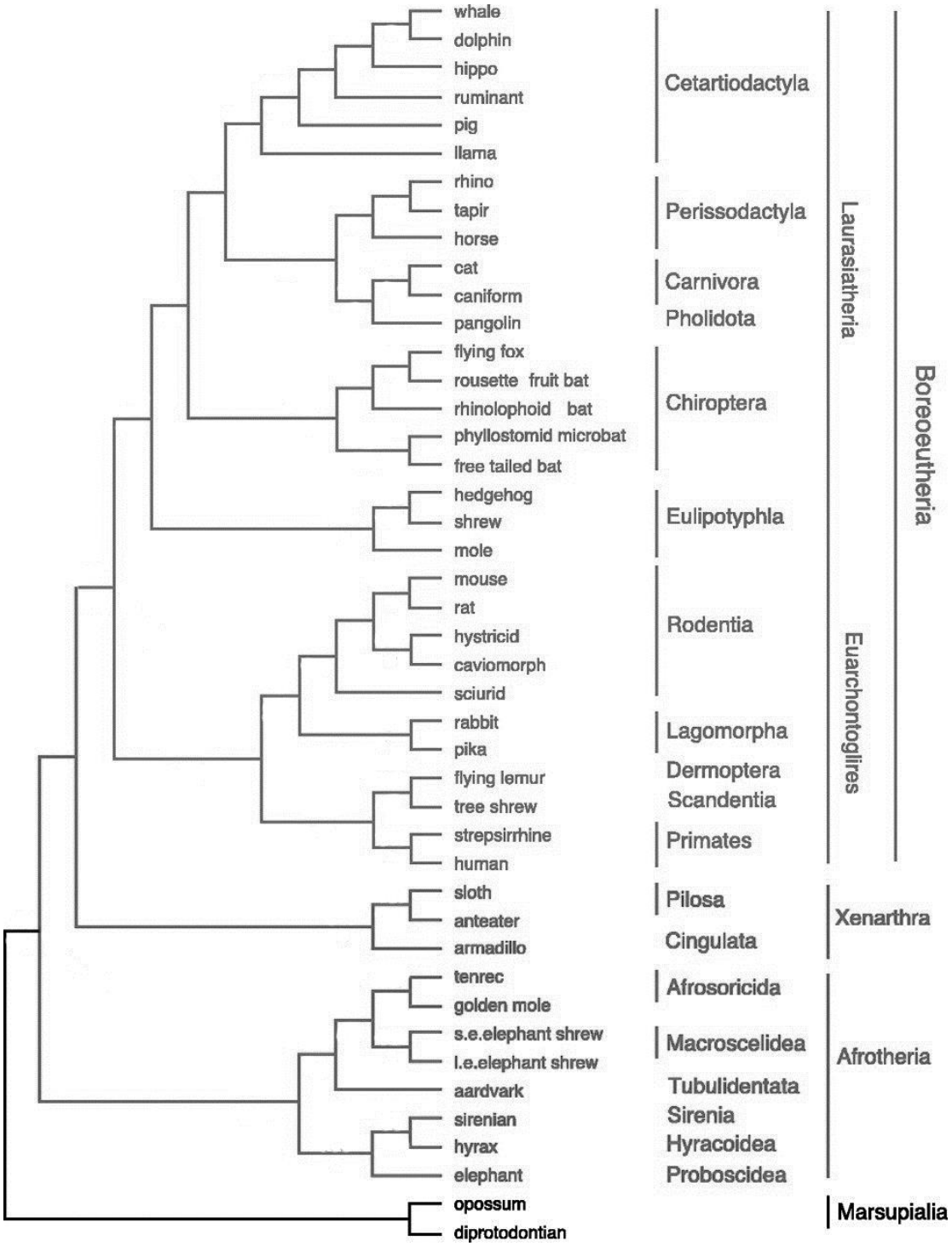
‘True’ ungulates (Artiodactyla and Perissodactyla) evolved from ‘condylarths’. The orders Hyracoidea (hyraxes), Proboscidea (elephants), Sirenia (seacows) and probably also Tubulidentata (aardvarks) and Macroscelidea (elephant shrews) also evolved from ‘condylarth’ ancestors in Africa.

‘True’ ungulates did manage to get an early toehold in South America although they didn’t last beyond the Pleistocene. Because fossil molecules have been found, we now know that South America’s extinct litopterns (giraffe-like herbivores) and notoungulates (cow to rhino-like herbivores) were perissodactyls, distantly related to horses and rhinos.

There were also a number of other extinct ‘condylarth’ groups known from South America whose relationships are far less clear. These were mostly browsers and grazers (the remains of which impressed Charles Darwin when he first saw fossil mammals from South America) and include xenungulata (very odd group; ‘xen’ in fact means ‘strange’), pyrotheres (trunked, elephant-like mammals) and astrapotheres (another very odd group).

It is not clear that any of these South American forms actually dispersed across Antarctica to reach Australia, although a ‘condylarth’-like 55-million-year-old fossil species (Tingamarra) has been found in southeastern Queensland. Of course, there were marsupials in South America at the time of most of the now-extinct ungulate-like placentals. There were some very strange kinds including shrew-opossums, rodent-like forms, hopping forms, parrot-like forms and the great group of didelphids which include the American Opossum. Most filled carnivorous niches. One extinct group, the sparassodontans, resembled Thylacines although some were huge, as big as bears. All of the sparassodontans became extinct at the end of the Pliocene (2 million years ago) for a range of complex reasons, possibly including competition with large, ferocious predatory ground birds.

A PHYLOGENY OF PLACENTAL MAMMALS



Amrine-Madsen *et al*. 2003. *Molecular Phylogenetics and Evolution* **28**, 186-196.

CHARACTERISTICS OF PLACENTAL CLADES

(corresponding to Linnean orders)

ORDER XENARTHRA (EDENTATA)

The name edentate means “without teeth”, but that is misleading since sloths and armadillos have cheek teeth (although they lack incisors and canines). The South American anteaters however are toothless and these were the first animals described for this clade (first genus named in a group tends to give it name to higher levels of classification).

Pangolins also lack teeth and are ant-eating, and they were often placed in ‘Edentata’ with the South American forms. However, it now appears that pangolins are not closely related to the South American ‘edentates’ (in fact, pangolins are more closely related to carnivorans, such as cats and dogs – check out the phylogeny on the previous page), and ‘Edentata’ is not used in modern mammal classifications. Instead, sloths, armadillos and anteaters are placed in the order Xenarthra (meaning ‘strange joint’ and referring to unusual extra articulations found between the vertebrae of all known xenarthrans, but not seen in pangolins).

Reduction or loss of teeth is usually associated with feeding on ants and/or other small invertebrates, which is the case with all xenarthrans, except tree sloths which are herbivorous. There is a rich fossil record of giant sloths in North America. Xenarthrans, living and fossil, are only known from the Americas. Check out the anteater skeleton and tongue in the collection.

Are all “edentates” toothless?

_____

_____

How and what do toothless mammals eat?

_____

_____

ORDER ‘LIPOTYPHLA’ (INSECTIVORA)

Examine the preserved mole (*Talpa*) and the hedgehog (*Erinaceus*). Note the sharply cusped teeth for cutting up worms and insects. Note also the relatively simple limbs of the hedgehog, in contrast to the digging specializations of the mole (a short, wide humerus and a wide, spade-like manus). Many of the traits used to define Lipotyphla are probably primitive for mammals.

In the last 10-15 years, new molecular data have suggested that 'Lipotyphla' is non-monophyletic (which is why we put it in quotes here) and actually comprises two distantly related clades: a predominantly African clade referred to as Afrosoricida or Tenrecomorphia, which includes golden moles and tenrecs, and a predominantly Northern Hemisphere (Laurasian) clade referred to as Eulipotyphla (the 'true' lipotyphlans), which includes true moles, shrews, hedgehogs and *Solenodon* from the West Indies. Surprisingly, these molecular data indicate that Afrosoricida is more closely related to the African 'ungulate' orders (Hyracoidea, Proboscidea and Sirenia), and Eulipotyphla is more closely related to the 'true' ungulate orders Artiodactyla and Perissodactyla than these two 'insectivore' groups are to each other – check out the phylogeny two pages earlier.

The "Order Insectivora" traditionally included moles, shrews, hedgehogs, tenrecs and golden moles, while the "Order Edentata" traditionally included the pangolin, sloths, aardvark and anteater. Neither of these "orders" of mammals is now recognised because they represent polyphyletic groups. What is a polyphyletic group?

What marsupial groups also show similarly convergent traits with "insectivores"? Give two examples.

What adaptations do golden moles (Order Afrosoricida or Tenrecomorphia) show for a subterranean life?

ORDER CHIROPTERA

Bats are the only truly flying mammals. Note the modifications of the forelimbs for flying:

- Ulna reduced (proximal portion usually present, distal portion fused to radius)
- First digit short and bears a claw

- Remaining digits elongate and bear the PATAGIUM (wing membrane) which runs from manus (hand) to ankle and usually continues from the ankle to the tail
- Clavicle and scapula strong
- Sternum with keel
- A **baculum** is usually present (although often missing from skeletal preparations)

Until fairly recently (last 10 years) bats were split into two separate suborders: Megachiroptera (flying-foxes, fruit bats and blossom bats) and Microchiroptera (all other bats). However, most studies (molecular and morphological) now recognize that such a distinction is not warranted (since "megabats" as a group nest tightly within the radiation of "microbats"). Striking morphological differences between "megabats" and other bats appear to be related to their different diets.

FLYING-FOXES (Family Pteropodidae)
These tropical and subtropical bats include the flying-foxes common in the Sydney region. The second digit of the manus is relatively independent and bears a claw. These animals are herbivorous, usually feeding on blossoms and fruit. **Can you find evidence of this diet in their teeth?**

INSECTIVOROUS BATS (19 different families)
These are the smaller bats (although the Australian Ghost Bat is larger than the smaller mega-bats). They are mostly insect eaters and use sonar to navigate and hunt at night. The second digit of the manus is relatively incorporated into the wing (not independent) and lacks a claw.

What bones make up a bat's wing?

How does a bat wing differ from a bird wing or pterosaur wing?

What adaptations do bats show for flight apart from wings?

Examine the teeth of an insect-eating bat and a fruit-eating bat. Notice anything odd about the fruit bat's teeth? Why might this occur?

What is the dental formulae for the fruit bat and insect-eating bat on display?

I / C / P / M / (*Pteropus*)

I / C / P / M / (*Miniopterus*)

ORDER PRIMATES

While the basic adaptations of this group are towards arboreal living, some species are more terrestrial than others. The sturdy clavicles and the forward orientation of the orbits are related to their arboreal habit. There are never more than 2 incisors nor more than 3 premolars on one side of either jaw. The traditional, phenetic taxonomy given below is widely used but should be treated with scepticism.

Suborder Strepsirrhini

This group includes lemurs, bushbabies and lorises. The orbit is in open communication with the temporal fossa.

Suborder Haplorrhini

This group contains the tarsiers, monkeys and apes including humans. Orbits completely cut off from temporal fossae by flanges from frontals, jugals and alisphenoids.

Tarsii

Includes the tarsiers.

Platyrrhini

New World monkeys such as spider monkeys (*Ateles*), howler monkeys (*Alouatta*), squirrel monkeys (*Saimiri*) and marmosets.

Cebus paella (capuchin) skull

Catarrhini

Old World monkeys such as rhesus monkeys (*Macaca*), baboons (*Papio*), guenon (*Cercopithecus*) and proboscis monkeys (*Nasalis*).

- Dentition: I2/2 C1/1 P2/2 M3/3

- Last molar not reduced
- Bulla not inflated
- Ectotympanic extended into a long, ossified external auditory meatus
- Tail never prehensile
- Nostrils close together

Superfamily Hominoidea

Apes and humans

- Dentition I2/2 C1/1 P2/2 M3/3
- In humans, one or more of the rear molars (wisdom teeth) may fail to develop

Family Hylobatidae

Gibbon (*Hylobates*)

Family Hominidae

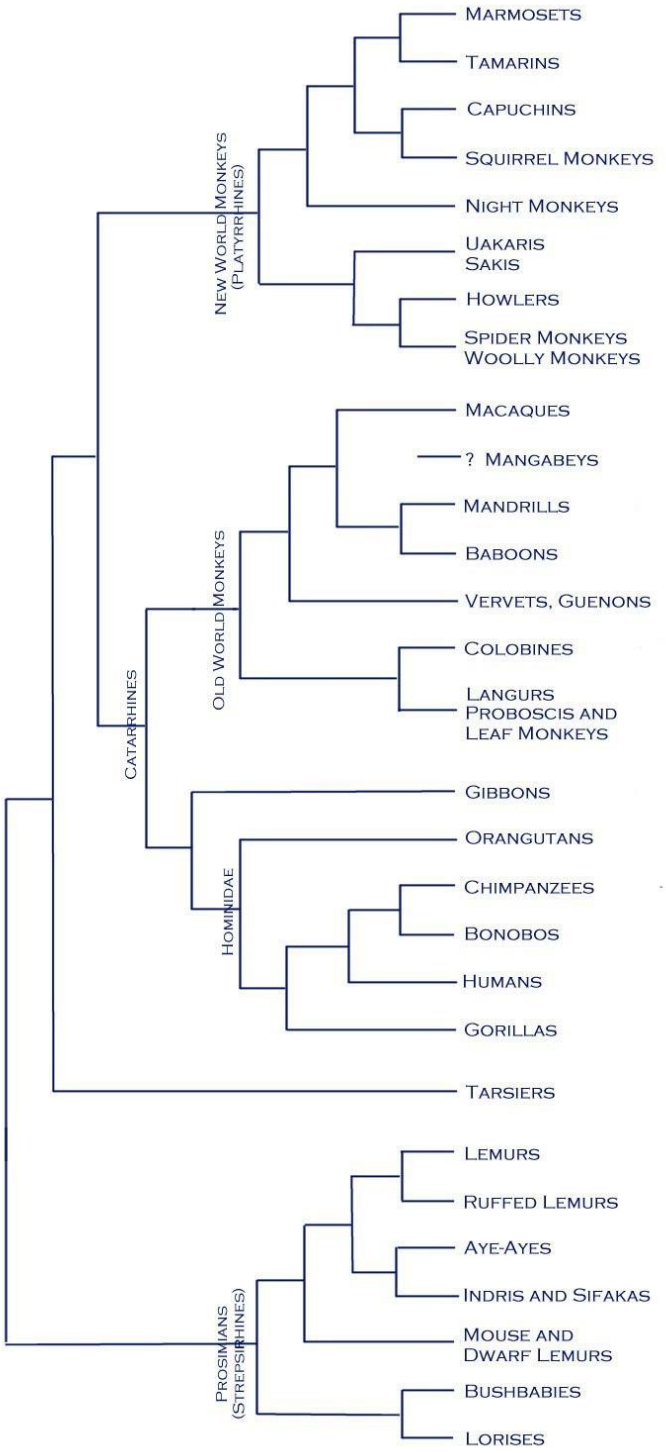
Chimp (*Pan*), gorilla (*Gorilla*), orangutan (*Pongo*) and humans (*Homo*)

Until recently, humans were placed in their own family (Hominidae), and all other apes (including the gibbon) were placed in Pongidae. This division conflicts with the cladistic/phylogenetic approach to systematics, in which only monophyletic groups/clades are recognised, and was a hang-over from Victorian sensibilities.

Apes	**Humans**
Canines large	Canines small
Forelimbs larger than hindlimbs	Forelimbs shorter than hindlimbs
Pollex (thumb) opposable	Pollex (thumb) opposable
Hallux (big toe) opposable	Hallux (big toe) not opposable
Body hairy	Body not hairy

A Phylogeny of Primates

(http://www.whozoo.org/mammals/Primates)



What are the two main groups of primates? Give examples of three species from each group

What do the various members from this group eat; how can you tell?

What adaptations do primates have for life in the trees? How do these compare with those seen in (marsupial) possums?

ORDER LAGOMORPHA

Rabbit (*Oryctolagus*), hare (*Lepus*) and pika (*Ochotona*)

Dentition: I2/1 C0/0, P3/2 M2-3/3

Dentition is of herbivorous type. First upper incisor has a longitudinal groove on the anterior face. Second upper incisor is small and directly behind the first (good characters to differentiate from rodents). Facial portion of maxilla **fenestrated** (lots of holes). Bony palate short. Closely related to the Order Rodentia (with which they form the superordinal group Glires).

What are the main differences between the skulls of rabbits and rodents?

ORDER RODENTIA

Rodents are the most diverse and arguably most successful of the placental mammals. More than 42% of mammals are rodents and they have exploited almost every environment on earth

Rodents are defined by their unique teeth and most importantly, a single pair of incisors in each jaw which are:

- persistently growing
- covered with enamel on anterior surface only
- great for gnawing

Dental formula: I1/1 C0/0 P2/1 M3/3

Australia has just one family of native rodent, the **Muridae**

Family Muridae

- Old world rats and mice, sometimes referred to as the "true" rats and mice
- Three waves of migration into Australia
- Old endemics
  - Arrived approximately 10 million years ago
  - Oldest fossils at 5mya
  - *Pseudomys* – including many desert mice
  - *Notomys* – Australian hopping mice
  - *Conilurus* – rabbit rats
  - *Leporillus* – stick-nest rats
  - Zyzomys – rock-rats
  - *Uromys* – giant naked-tailed rats
  - *Mastacomys* – broad-toothed rats
  - *Mesembriomys* – tree-rats
  - *Hydromys* – water-rats
  - *Melomys* – mosaic tailed rats
- New endemics
  - Arrived 1 mya
  - *Rattus* – three native species
- Modern invasion
  - Reached Australia with Europeans
  - Black rat (*Rattus rattus*), Norway rat (*Rattus norvegicus*), house mouse (*Mus musculus*)

All the rodent families were traditionally divided into two main groups based on the arrangement of their jaw muscles (hystricognathy and sciurognathy). It is now recognized that the condition found in 'scurognaths' is probably plesiomorphic (primitive) for rodents and that the group is now recognised to be non-monophyletic (hence we place the name in quotes).

HYSTRICOGNATHS

Porcupines, guinea pigs, agoutis, capybara, African mole rats, dassies.

'SCIUROGNATHS'

Squirrels, mice, rats, beavers, jerboas, voles, chipmunks, mountain beaver

What families of rodents occur in Australia today?

_____

How do rodent incisors stay sharp?

What use is a diastema in these species?

ORDER CARNIVORA

- 3RD incisors larger than others, especially in upper jaw
- 3 incisors on each side of lower jaw
- canines well developed
- carnassial teeth developed from the last upper premolar and lower M1 (especially in cats and dogs)
- turbinals complicated
- As many as 17 living families, many of which have only been recognised recently based on genetic evidence
- They can be divided into two major subgroups: Feliformia ('cat-like' forms) and Caniformia (dog-like' forms)

FELIFORMIA

FELIDAE

- lion (*Leo*) and pussycat (*Felis*)
  - digitigrade, reduction in tooth number, almost fully enclosed orbit
  -
- VIVERRIDAE
  - genets, civets, linsangs and others
  - Asia, southern Europe, Africa
  - Recent genetic work suggests that this family should actually be split into as many as four separate families: Nandiniidae (the African palm civet), Prionodontidae (the Asian linsangs), Eupleridae (endemic Magascar carnivorans, including the cat-like fossa) and Viverridae ('true' civets and genets)

- HERPESTIDAE
  - meerkats and mongooses

- HYAENIDAE
  - Hyenas – four species

Examine the carnassial teeth in the skull of the Lion; which tooth types are involved?

CANIFORMIA

CANIDAE
- fox (*Vulpes*) and dog (*Canis*)
  - plantigrade or digitigrade, open orbit
  - **can you tell dogs from foxes based on their skulls?**

URSIDAE
- bears – mostly omnivorous
- polar bear – almost exclusively carnivorous
- giant panda – almost exclusively herbivorous

PROCYONIDAE
- mostly medium sized carnivores and omnivores, e.g. raccoon, kinkajous, coatis
- at one time, the giant panda and red panda were thought to belong to this family, but the giant panda is actually a true bear (Ursidae) while the red panda belongs to its own family (Ailuridae)

MUSTELIDAE
- skunks, polecats, badgers, ferrets, weasels, otters
- these animals have well-developed scent glands
- Recent genetic work suggests that skunks and the attractively named ‘stink badgers’ should be placed in their own family (Mephitidae)

Examine the turbinate bones in the display: what function do these have?

NOTE: the following three semi-aquatic carnivoran families are often grouped as PINNIPEDIA (which means 'fin-footed').

In older classifications, this group was sometimes treated as a full order, distinct from Carnivora, and others suggested that members of this group evolved their aquatic specialisations independently from different carnivoran ancestors (i.e. their similarities are convergent).However, recent genetic evidence indicates that Pinnipedia is a monophyletic group within the dog-like carnivorans (Caniformia). Check out the two skeleton specimens, make sure you can tell them apart

OTARIIDAE

- sea lions and fur-seals
- **hind flippers can be brought forward under the body**
- **small external ear pinna**
- **some upper incisors with transverse groove**
- **post-orbital process present**
- Australian species
    - *Neophoca cinerea* – Australian Sea-lion
    - *Arctocephalus pusillus* – Australian fur-seal
    - *Arctocephalusforsteri* – New Zealand fur-seal

ODOBENIDAE

- Walrus
- Hind flippers can be brought forward
- No external ear pinna
- Upper canines form long tusks in both species

PHOCIDAE

- **Hind flippers cannot be brought forward**
- **No external ear pinna**
- **Incisors without transverse groove**
- **Post-orbital process lacking**

Which seal skeleton has the baculum intact?

Which seal skeleton has the hyoid arch intact? What is its function?

ORDER CETACEA

- Bones of skull strongly “telescoped”
- Fused neck vertebrae, WHY?
- Rostrum elongated
- Tympanic and periotic not fused to skull for sonar dampening
- Body streamlined
- Front limbs form flippers
- No hindlimbs
- Tail flukes horizontal - compare this to fish
- No external ear pinna
- Hair reduced to bristles on head
- Studies over the last 20 years or so strongly indicate that Cetacea is actually a subgroup within the order Artiodactyla
- Two major living clades: Odontoceti (toothed whales) and Mysticeti (baleen whales)

ODONTOCETI

- Homodont teeth present
- Maxilla has spread backwards over frontals, almost reaching the supraoccipital – check the colour-coded skull
- Nostrils dorsal on skull, asymmetrical (blowhole)
- Killer Whales, Dolphins, Sperm whale

MYSTICETI

- No teeth
- Food is gathered by filtering water through **baleen plates** (epidermal structures, not teeth, compare this to the sheaths of horns
- Blue Whales, Right Whales, Humpbacks

What is baleen? Where does it occur in the whale, and how does it function?

Examine the teeth of a dolphin. What is special about them and why?

The blowhole in cetaceans is surrounded by which bones?

What are the two major groups of cetaceans?

ORDER PROBOSCIDEA

- Elephants, Mammoths
- Nose extended into long trunk
- Third upper incisor forms tusk
- Cheek teeth very large (see specimen in lab) with transverse loops of enamel and dentine
- Usually one cheek tooth on each side is functional at any time
    - Molar irruption
- Graviportal limbs
- African elephant (*Loxodonta*)
- Indian elephant *(Elephas*)

Examine the elephant foot. It exhibits what is called a graviportal stance. What bones are involved and what adaptations are there to support an elephant's massive weight?

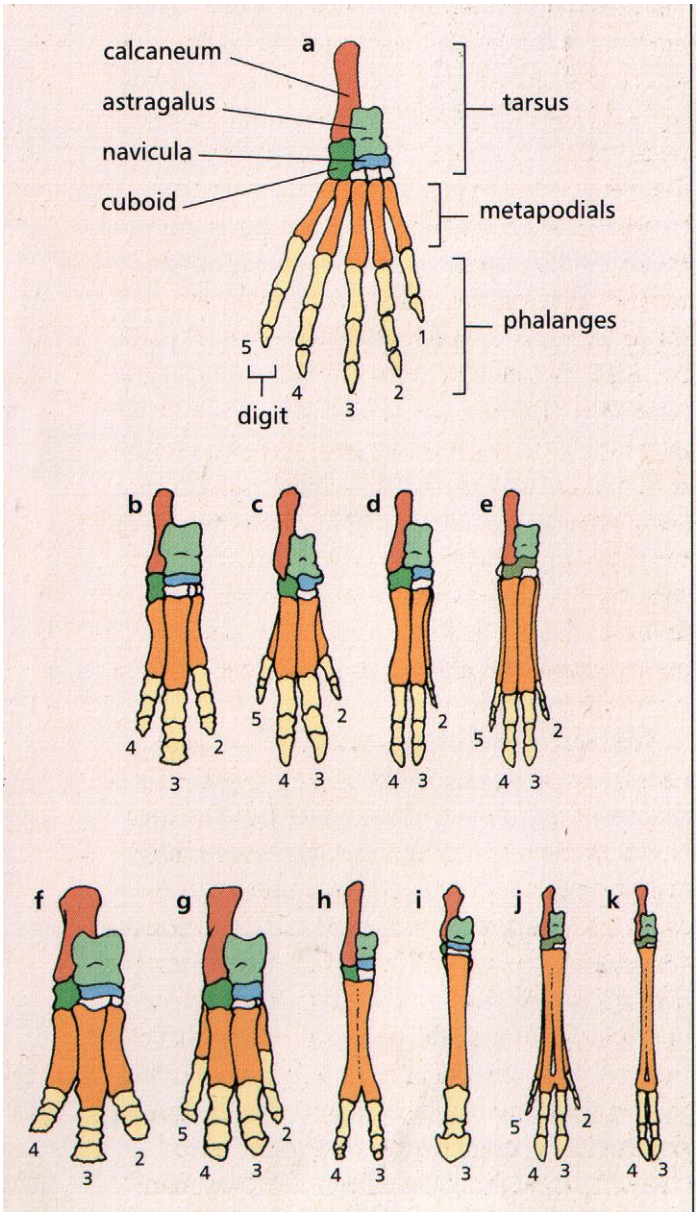
ORDER SIRENIA

- Dugong *(Dugong*) – bays of northern Australia and across to east Africa
- Manatee (*Trichechus*) – bays and sluggish rivers of the Americas and west Africa
- Recently extinct Steller's Sea Cow (*Hydromalis*) – up to 9 metres and long and 10 tonnes in weight; last seen in the 18th century
- Bones very heavy
- Skull modified and most unusual in appearance
- Cheek teeth are like flattened pegs
- Incisors form tusks in males; tusks do not usually erupt in females but can be seen in skull
- The anterior part of the palate and corresponding surfaces of the lower jaw are covered with horny plates
- Nasal bones are small and loose
- Tympanic is semicircular
- Body streamlined although bulky

What is odd about sirenian skulls?

UNGULATES

- Animals that walk on the tips of the digits and have elongated legs for running
- Artiodactyls and perissodactyls are the 'true' ungulates, but other groups, such as proboscideans (elephants) sirenians (sea cows) and hyracoids (hyraxes) are often also referred to as 'ungulates'
- Recent molecular studies indicate that the ungulate body type has evolved multiple times independently within placental mammals



Primitive mammalian foot **(a)** is modified in various ways in ungulates – the toes are reduced in number, the long bones (metapodials) extended, the foot is held lifted (tips only on ground), and the joints are restricted to reduce rotation. These changes facilitate fast running.

Generalized ungulates: **(b)** tapir, **(c)** pig, **(d)** peccary, **(e)** chevrotain. One or two digits are lost, metapodials somewhat elongated, tarsal bones more ordered.

Feet specialized for weight-bearing (graviportal): **(f)** rhino, **(g)** hippo. Short digits and a spreading foot in which side toes touch ground when standing.

Fast running (cursorial) existence: **(h)** camel, **(i)** horse, **(j)** deer, **(k)** pronghorn. In h, j, k the metapodials are long and fused into a single bone. In horses (i) there is only a single digit. Deer (j) retain side toed, which have been lost in camels (h) and pronghorn (k).

From McDonald, D. 2001. "The New Encyclopedia of Mammals". Oxford University Press. P 457.

ORDER PERISSODACTYLA

- Odd-toed ungulates
- Horses, tapirs, rhinos
- Middle digit (3) is larger than the others (in horses it is the entire hoof)
- Facial region elongated
- Herbivores – postgastric digesters
- Dentition I3/3 C1/1 P4/4 M3/3
    - Females have no canine, but why do males?

EQUIDAE

- Horses, zebra
- Only 3rd digit is functional
- 3rd metapodial is elongated and strong (cannon bone)
- 2nd and 4th metapodials reduced to splints

TAPIRIDAE

- tapirs
- 3 toes front, 4 toes back
- snout elongated into a small trunk
- 3 species from South America, 1 from SE Asia

RHINOCEROTIDAE

- horn on snout does not have a bony core
- African and Asian

ORDER ARTIODACTYLA

- Even-toed ungulates
- Pigs, hippos, camels, deer, giraffe, cattle, sheep, antelopes
- Main axis of the foot is between the 3rd and 4th digits (in most only these two digits are present)
- First digit always absent
- Herbivorous dentition (except pigs)
- No upper incisors in most
- Horns or antlers may be present on the frontal
- Evidence accumulated over the last 20 years indicates that Cetacea (whales) is a subgroup within Artiodactyla, most closely related to hippos

SUIDAE

- Pigs
- Omnivores
- Upper canines form curving tusks
- Molars are similar to humans (check this)

HIPPOPOTAMIDAE

- Hippos
- Amphibious
- Four toes on each foot
- Closest living relative of whales

CAMELIDAE

- Camels
- Only upper I\3 present in adults
- Lower incisors procumbent and patulate
- Canines present
- 3rd and 4th metapodials fused for most of their length but separate distally
- stance is digitigrade with toes spread widely
- feet well padded

CERVIDAE

- deer, elk, reindeer
- no upper incisors
- lower canine present but incisiform
- 3rd and 4th metapodials fused (cannon bone)
- antlers present
    - bony core is an outgrowth of the frontal
    - core is at first covered with a vascular haired skin (velvet)
    - males only (except reindeer)
    - shed annually

GIRAFFIDAE

- giraffe and okapi
- no upper canines or incisors
- bony prominences from the frontal form “horns” which are covered with normal skin and are not shed
- neck vertebrae extended (still 7)
- metapodials 3 and 4 form cannon bones, but there are no toes on 2 and 5 (cf. deer)

BOVIDAE

- cattle, sheep, antelope
- no upper canines or incisors
- lower canines incisiform
- metapodials 3 and 4 form cannon bones
- horns formed as outgrowths of frontals
    - always males, sometimes female
    - bony core is hollow, unbranched, not shed
    - keratinized sheath forms outer horn

What are the two major groups of ungulates, and where do cetaceans fit in?

Why are ungulate legs so long? What bones are involved, and how do they differ between the two groups?

How does an ungulate's dentition compare to a kangaroo's?

What is the difference between horns and antlers?

What is a cannon bone?

What bones make up a horse's hoof?

http://www.ultimateungulate.com/



PRACTICAL 11

Practical Exam

The Practical Exam is approximately 1.5 hours long and consists of 50 questions about material encountered in all BIOS2061 lab sessions but in particular that studied in the Practicals 6 to 11.

The exam is of the “musical chairs” type where you have 1.5 minutes at each question and then move on to the next.

You may only take writing materials into the exam.

The Practical Exam will be held in Teaching Lab 3 in your normal practical timeslot.

VERTEBRATE ZOOLOGY BIOS2061

GLOSSARY

Abbreviations used in this glossary
Gr. = Greek
L. = Latin
pl = plural

Common Prefixes
a- (indicates separation) from L. 'ab' meaning away from
ab- (indicates separation) from L. 'ab' meaning away from
ala- (wing) from L. 'ala' meaning wing
an- (without, lacking) from Gr. 'an' meaning not
ap- (separate) from Gr. 'apo' meaning away from
apo- (separate) from Gr. 'apo' meaning away from
arch- (primitive or first) from Gr. 'arch' meaning first in time
auto- (self) from Gr. 'autos' meaning self

basi- (lower or base) from Gr. 'basis' meaning foundation
bi- (two or double) from L. 'bi' meaning two

cardi- (relating to the heart) from Gr. 'kardia' meaning heart
chond- (cartilaginous) from Gr. 'chondros' meaning gristle
chord- (refers to spinal cord or indirectly the vertebral column) from Gr. 'chorde' meaning string
circ- (around in the sense of encircle) from Gr. 'kirkos' meaning circle or L. 'circa' meaning around

de- (down or away) from L. 'de' meaning down or away from
di- (two or double) from Gr. 'di' meaning two

e- (from, out of) from L. 'ex' meaning away from
en- (internal or inside) from Gr. 'en' meaning in, on or among
epi- (on, upon) from Gr. 'epi' meaning on, upon
ex- (from, out of) from L. 'ex' meaning away from

hemi- (half) from Gr. 'hemi' meaning half
hetero- (different) from Gr. 'heteros' meaning other, different
holo- (whole) from Gr. 'holos' meaning whole, entire
homo- (same) from Gr. 'homos' meaning common, equal, alike
hyper- (above) from Gr. 'hyper' meaning above, beyond
hypo- (below) from Gr. 'hypo' meaning under, less than
infra- (below) from L. 'infra' meaning below, lower than
inter- (between) from L. 'inter' meaning between, among
intra- (within) from L. 'intra' meaning inside
iso- (equal) from Gr. 'iso' meaning equal

macro- (long or large) from Gr. 'macros' meaning long or tall

mega- (big) from L. ′megas′ meaning great
mes- (between) from Gr. ′mesos′ meaning middle
meta- (after) from Gr. ′meta′ meaning after, next
micro- (small) from Gr. ′micros′ meaning small
my- (muscle) from Gr. ′mys′ meaning muscle

para- (alongside of) from Gr. ′para′ meaning alongside, near
peri- (around) from Gr. ′peri′ meaning around
post- (behind, after) from L. ′post′ meaning behind, after
pre- (before, in front) from L. ′pre′ meaning before, in front
pseudo- (false) from Gr. ′pseudes′ meaning false, fake
pter - (wing or wing-shaped) from Gr. ′pteryx′ meaning a wing or ′pteron′ meaning feather

sub- (below, under) from L. ′sub′ meaning below, almost
super- (above) from L. ′super′ meaning above, over, top
supra- (above) from L. ′supra′ meaning above, beyond, over
sym- (with) from Gr. ′syn′ meaning together
syn- (with) from Gr. ′syn′ meaning together

Common suffixes
-lith (stone) from Gr. ′lithos′ meaning stone

-mys (mouselike) from L. ′mus′ meaning mouse

ANATOMICAL TERMS

ACETABULUM (the depression into which the head of the femur fits) from L. ′acceptabulum′ meaning a little receptacle
AFFERENT (headed towards) from L. ′ad′ meaning towards and ′ferre′ meaning to bring
ALISPHENOID (a bone in the base of the skull) from L. ′ala′ meaning wing and Gr. ′sphenoeides′ meaning wedge-shaped
ALVEOLUS (a little hole or, in the case of the lung, a small pouch) from L. ′alveus′ which is the diminuitive form of belly
AORTA (the large systemic artery leaving the left ventricle of the heart) from Gr. 'aorte' meaning aorta
APOMORPHIC (derived) from Gr. ′apo′ meaning separate and ′morphe′ meaning form
APOMORPHY (a derived character state)
ARTERY (a vessel carrying blood away from the heart) from Gr. ′aer′ meaning air and ′terein′ meaning to keep (the early anatomists thought the arteries carried air to the tissues)
ARTICULATION (a moveable joint) from L. ′artus′ meaning a joint
ASTRAGALUS (the anklebone) from Gr. ′astragalos′ meaning a die (these bones in some ruminants have six faces and can be used for playing dice)
ATLAS (the first cervical vertebra) from the Greek god who held the world on his shoulders
ATRIUM (a heart chamber that receives blood from the body) from L. ′atrium′ meaning a small room

AUDITORY (related to hearing) from L. 'audire' meaning to hear
AXIS (the second cervical vertebra) from L. 'axis' meaning a pivot

BASISPHENOID (a bone in the base of the skull) from Gr. 'basis' meaning base and 'sphenoeides' meaning wedge-shaped
BRANCHIAL (refers to gills) from Gr. 'branchia' meaning gills
BULLA (a dome-like structure enclosing the inner ear) from L. 'bulla' meaning a bubble

CALCANEUM (heel bone) from L. 'calyx' meaning heel
CANNON BONE (the greatly developed metapodial of ungulates extending from the podials to the first joint of the digit) from 'cannon' as being tube-shaped
CAROTID (main artery to the head) from Gr. 'karos' meaning deep sleep (the Greeks believed compression of the carotid artery resulted in deep sleep)
CARPAL (one of a series of small bones between the forelimb and the manus) from Gr. 'karpos' meaning wrist
CAUDAL (at or towards the rear end) from L. 'cauda' meaning tail
CLOACA (the chamber into which the digestive tract, urinary tract and reproductive tracts empty in those animals in which they do not have separate openings to the outside of the body) from L. 'cloaca' meaning sewer or drain
CLOACAL APERTURE (the single opening to the outside from the cloaca)
COCCYX (the small bone comprised of fused caudal vertebras in humans) from Gr. 'kokkyx' meaning cuckoo (resemblance of the structure to a cuckoo's beak)
COCHLEA (the coiled inner ear) from L. 'cochlea' meaning snail
COLUMELLA (the single bone in vertebrates except mammals conducting sound from the outer to the inner ear, homologous to the mammalian stapes) from L. 'columna' meaning column
CONDYLE (a raised, smooth surface on a bone against which another bone articulates, especially where the occipital articulates with the atlas) from Gr. 'kondylos' meaning knuckle
CORACOID (ventral element of the pectoral girdle; reduced in mammals to a knob on the scapula shaped like a raven's beak) from Gr. 'korax' meaning raven and 'eoides' meaning form.
CRANIUM (that part of the skull enclosing the brain) from Gr. 'kranion' meaning skull
CRIBRIFORM (sieve-like, especially in reference to the perforated plate between the brain and the nasal region) from L. 'cribrum' meaning sieve and 'forma' meaning shape

DENTINE (the hard and brittle bone portion of teeth – commonly found beneath the harder layer of enamel – and some scales) from L. 'dens' meaning tooth
DERMAL (pertaining to skin) from Gr. 'derma' meaning skin
DIAPHRAGM (the muscular wall between the thorax and abdomen in mammals) from Gr. 'dia' meaning across and 'phragma' meaning wall
DIGITIGRADE (weight supported only on the phalanges)

DISTAL (away from the body center) from L. 'di' meaning aside and 'sta' meaning situated
DORSAL (top side, in vertebrates the side of the body with the notocord or vertebral column) from L. 'dorsum' meaning back
DUODENUM (the first part of the small intestine into which the pancreatic duct and bile duct open) from L. 'duodenarius' meaning to contain twelve (from the fact that in human anatomy this structure is in length equal to the width of twelve fingers - a ready reference for surgeons in the days before anesthetics)

EFFERENT (headed away from) from L. 'ex' meaning out and 'ferre' meaning to bear
EPIPHYSIS (accessory ossification center at the end of a long bone; last area to ossify in growth)

FEMUR (first bone in the hindlimb after the pelvic girdle) from L. 'femur' meaning thigh
FENESTRA (a large opening in a bone) from L. 'fenestra' meaning window
FIBULA (the smaller of the two bones distal to the femur) from L. 'fibula' meaning a pin or skewer
FORAMEN (a small opening in a bone through which a blood vessel, nerve or tendon passes) from L. 'foramen' meaning hole
FOSSA (a depression in a bone, usually the skull, which does not have an opening) from L. 'fossa' meaning ditch or grave
FURCULA (the fused clavicles, or wishbone, of birds) from L. 'furca' meaning a fork

GLENOID (a shallow articular cavity as in the glenoid fossa for the lower jaw articulation or the glenoid cavity for the humerus articulation with the scapula) from Gr. 'glenoeides' meaning a shallow joint socket.

HALLUX (big toe)
HEPATIC (referring to liver) from Gr. 'hepar' meaning liver
HETERODONT (having different types of teeth, e.g. incisors and molars) from Gr. 'heteros' meaning other and 'odous' meaning tooth
HETEROTOPIC BONE (bones that occur only in a few species and usually appear late in the development of the embryo. The baculum in the seal penis is an example, and there is a good display of these bones in the 5th Floor Museum)
HOMODONT (having all teeth of similar shape, e.g. lizard) from Gr. 'homos' meaning same and Gr. 'odous' meaning tooth
HOMOLOGOUS (similar structures in different organisms, inherited from a common ancestor) from Gr. 'homos' meaning sameness and 'lego' meaning to denote.
HUMERUS (the first bone in the forelimb) from L. 'humerus' meaning shoulder
HYOID (a cartilage in the neck region of terrestrial animals derived from the branchial skeleton) from Gr. 'hyoeides' meaning U-shaped

IMBRICATE (an arrangement of scales) to overlap like roof tiles
INSECTIVORE (an animal that eats insects) from L. 'vorare' to devour

LABYRINTH (a complex channel in bone such as the inner ear) from Gr. ′labyrinthos′ meaning a maze
LACRIMAL (the bone containing the opening of the tear duct or lacrimal duct) from L. ′lacrima′ meaning tear
LINGUAL (referring to the tongue) from L. ′lingua′ meaning tongue
LOREAL SCALES (scales that separate the top from the side of the snout; in snakes they lie on the side of the snout between the nasal and preocular sclaes; may be enlarged to form a LOREAL SHIELD).

MANDIBLE (the structure comprised of the left and right rami, or halves, of the lower jaw) from L. ′mando′ meaning to chew
MANUS (the structure at the end of the forelimb comprised of the carpals, metacarpals and phalanges) from L. ′manus′ meaning hand.
MASTOID (the portion of the periotic bone visible behind the ear on the outside surface of the skull
MEATUS (a passage, such as the external auditory meatus which allows passage of sound from outside to the eardrum) from L. ′meatus′ meaning way or passage

NOTOCHORD (the cartilaginous precursor of the vertebral column) from Gr. ′noton′ meaning back and ′chorde′ meaning string of a lyre

OLECRANON (the part of the ulna beyond the elbow joint, i.e. the 'funny bone') from Gr. 'olenokcanon' meaning the point of the elbow
ORBIT (the depression in the skull in which the eye and associated structures are located) from L. ′orbis′ meaning something circular
OSSIFICATION (the process of becoming bone) from L. ′os′ meaning bone and ′facere′ meaning to make

PALATE (the structure dividing the nasal cavity from the oral cavity; may consist of several bones and cartilage) from L. ′palatum′ meaning palate
PECTORAL GIRDLE (the structure articulating the forelimb to the vertebral column; including the scapula and clavicle) from L. ′pectus′ meaning breast
PELVIS (=PELVIC GIRDLE, the structure articulating the hindlimb with the vertebral column, usually composed of the ischium, ilium and pubis) from L. ′pelvis′ meaning a basin
PES (the structure at the end of the hindlimb comprised of the tarsals, metatarsals and phalanges) from L. ′pes′ meaning foot
PLANTIGRADE (a foot posture in which the entire sole rests flat on the ground and the entire foot skeleton supports the weight of the body)
PLESIOMORPHIC (ancestral) from Gr. ′plesios′ meaning close to and ′morphe′ meaning form; opposite of apomorphic
PLESIOMORPHY (an ancestral character state)
PODIAL (tarsal or carpal or both; this term does not differentiate between elements of the hind- and forelimbs) from Gr. ′podos′ meaning foot
POLLEX (thumb)

PORTAL (a capillary bed that occurs wholly within the venous system; that is, the capillaries are fed by one vein and drained by another. Systemic capillary beds are fed by an artery and drained by a vein)
PROCUMBENT (a condition of the lower incisors in which they protrude forward; in diprotodont marsupials there is only one pair of incisors in the lower jaw and they are procumbent to the extent that they are almost parallel with the dentary)
PROXIMAL (towards or near to the body center) from L. ′proximus′ meaning nearest

RENAL (pertaining to the kidney) from L. ′renes′ meaning kidney
ROSTRUM (nose, beak or snout) from L. ′rostrum′ meaning snout

SACRUM (bone formed by the fusion of the sacral vertebras) from L. ′sacrum′ meaning sacred; it is thought that this bone was used in sacrifices
SCAPULA (shoulder blade, a structure composed of several bone elements) possibly from Gr. ′skapto′ meaning to dig or ′skapte′ meaning a boat or skiff
SCIATIC (refers to the hip region) from Gr. ′ischion′ meaning hip joint
SESAMOID (a small bone or cartilage formed in connection with muscle tendons at points of potential friction
SPATULATE (shovel-shaped; usually in reference to the shape of the manus)
SPHENOID (a bone complex in the base of the skull) from Gr. ′sphen′ meaning wedge and ′oeides′ meaning shape, describing the shape of the bone
STAPES (the bone in the mammalian middle ear homologous to the columella and the hyomandibular) from L. ′stapes′ meaning stirrup
SYMPLESIOMORPHY (a shared, ancestral character state)
SYNAPOMORPHY (a shared, derived character state)

TARSAL (one of several small bones in the hindlimb between the tibia/fibula and the metatarsals) from Gr. ′tarsos′ which is a flat basket for drying cheeses on; originally the word tarsus seems to have been used for the flat part of the foot (sole)
TEMPORAL (in the region of the temple at the side of the head) from L. ′tempus′ meaning time; time in the sense of age being evident in a person by the grey hairs in this region
TRICUSPID (a tooth with three cusps or bumps) from L. ′tres′ meaning three and ′cuspis′ meaning point
TYMPANUM (or TYMPANIC MEMBRANE, the ear drum) from L. ′tympanum′ which was a musical instrument made from a wooden hoop covered on one side with hide

UNCINATE (vaguely hook-shaped processes which overlap the ribs in birds) from L. ′unca′ meaning hook
UNGULIGRADE (posture in which the weight of the body is supported entirely by hoof-clad terminal plananges)

VIBRISSA (one of the stiff,bristly hairs usually about the mouth of certain animals.Sometimes found in other areas especially the ankles. Serve as a tactile sensor)

ZYGOMATIC (the arch in mammals just below the orbit, often called the cheek-bone and composed of the jugal and the squamosal) from Gr. *'zygoma'* meaning yoke