

Zoology 300/301: Invertebrate Biology and Evolution

Location: Noland Hall 168 (lecture)
Noland Hall 559 (lab)

Instructor: **Prashant Sharma**
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Office hours: Wednesday, 10:30 AM to 11:30 AM

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Office hours:

3 credits (lecture) + 2 credits (lab)

Lectures: Tuesdays and Thursdays 11 AM-12:15 PM

Labs: Wednesdays: 1 PM to 5 PM

Grading (lecture)

10 pts	Participation
15 pts	Reading quizzes
25 pts	Midterm exam
50 pts	Final exam
<i>100 pts</i>	<i>Total</i>

Grading (lab)

10 pts	Participation
15 pts	Lab assignments
50 pts	Lab notebook (illustrations and identifications)
<i>75 pts</i>	<i>Total</i>

Grading scale: A (93-100%), AB (87-92%), B (83-86%), BC (77-82%), C (70-76%), D (60-70%), F (<60%).

Overview

This course provides an introduction to invertebrate diversity and biology, with emphasis on anatomy, development, and systematic relationships of the main animal phyla. Phyla are discussed in the context of major themes in animal evolution, such as the origin of tissue layers, the diversity of feeding mechanisms, the evolution of terrestrialization, patterns of diversification through time, and the conservation of transcriptional circuitry. The aim of this course is to understand animal diversity from a phylogenetic and developmental perspective, and to develop analytical ability to interpret organismal diversity.

Prerequisites

Zoology 101/101, 151/152 or Biocore 381

Learning outcomes (Zoology 300+301)

By the end of this course, you will be able to:

1. describe the major macroevolutionary trends spanning animal evolution through the Phanerozoic
2. recognize the differences between animal phyla
3. interpret and analyze phylogenetic trees
4. predict and interpret the function of a gene from a gene regulatory network
5. generate image data from biological samples

Readings

Mandatory textbooks: None.

Recommended textbooks: The following texts are strongly recommended as helpful resources and/or background reading.

- 1) Brusca, R. C., Moore, W., and S. M. Schuster. 2016. *Invertebrates*, 3rd edition. Sinauer Associates, Sunderland.
- 2) Gilbert, S. F. and A. M. Raunio. 1997. *Embryology: Constructing the Organism*. Sinauer Associates, Sunderland.
- 3) Minelli, A. 2009. *Perspectives in Animal Phylogeny & Evolution*. Oxford University Press, Oxford.

Reading room

Reserve copies of the Brusca et al. text are also kept in the lab space for Zoology 301 (559 Noland Hall). The door code for the key box is **4578** and the signup sheet for the text is posted outside the door. **The door key and the text copies should not be removed from this room under any circumstances.** Please do not make marks, highlights, or written notes in the textbook (if you would prefer to annotate while you read, please purchase your own copy or make scans from the class copy).

Reading room hours are any time of the week except for lab hours (Wednesdays, 1-5 PM). You are welcome to examine living and preserved specimens on display in this room during the week, but please do not disturb or change the lab setup—many of these specimens are rare, delicate, and/or painful to touch, and we have taken great pains to make them available to the class. **Please be respectful of these specimens and your fellow students' access to the reading room.**

If the door key, textbooks, living specimens, or preserved displays are at any point damaged, removed, altered, injured, and/or destroyed, the teaching staff reserves the right to recall access to the reading room for the whole class for the rest of the semester (at which time all students are welcome to enjoy the 0.7 mile walk to Steenbock Library mid-winter for the single copy we have on reserve there).

Office hours policy

The teaching staff is here to support your learning needs, including outside of class. If the available office hours do not fit your schedule, please schedule an appointment with us outside of those hours. I strongly recommend visiting office hours at least once during the semester to introduce yourself! If you find another student already in a meeting with me

during office hours, please make your presence known by knocking on the door, so I do not keep you waiting.

Lectures and sections

Attendance is mandatory in lectures and sections (Zoology 300 only) and in labs (Zoology 301). Absences are permitted only for cases of medical emergency or religious obligation.

A 45-minute section will be scheduled for Zoology 300. This section will be led by one of the TAs and will cover the weekly mandatory readings, which will consist of one to two papers from the literature. You are expected to have read the paper(s), understood the content, and bring questions about unclear points. The goals of the section are to (1) help you understand the lecture content and the weekly readings; (2) help us assess topics that are unclear or otherwise in need of more explanation; and (3) help you prepare for reading quizzes and the two exams.

Readings and lab materials

Course materials will be made available online on the course website. We strongly **recommend** completing each weekly reading by the Tuesday of each week and we **require** completing each weekly reading before the start of your section.

Zoology 301 only: Lab worksheets are due by 5 pm on Friday of each week. Late assignments are docked a full grade for every 24-hour period.

Reading quizzes and exams

Reading quizzes are given at the start of every Thursday's lecture. They will consist of 2-4 questions about main ideas or takeaways from each week's reading(s). Your readings will be discussed in your weekly sections, so **attendance in section will improve your quiz scores**. There are no makeup quizzes except in the case of medical emergency or religious obligation.

There is one midterm exam and one final exam given in class, as indicated below in the lecture schedule. Practice exam questions will be posted online one week before each of these. There are no makeup exams except in the case of medical emergency or religious obligation.

Cell phone policy

In keeping with time-honored Department of Zoology tradition, if your cell phone rings or is used during class, I will stop the lecture and make you sing for your classmates. The teaching staff reserves the right to record your performance and post it to YouTube.

A note about participation

Participation in Zoology 300 and 301 is about more than showing up to class and section. This class is kept intentionally small (maximum of 15 students in lab, and 25 in lecture) to facilitate a high level of engagement and participation.

At various points in lecture, I may ask you to discuss a question or problem with your neighbors, and then ask you to share your thoughts or solutions with the class. For those of you taking the lab, we will periodically ask you to conduct a 3-minute show-and-tell about an interesting animal, problem, or question that you explored that day.

I do not care if you don't come up with the right answer right away. Invertebrate biology has changed radically over the last 40 years precisely through the interactions of different scientists with different, often contradicting, ideas (and major controversies remain unresolved to this very day). **Getting a wrong answer is often a necessary part of**

the scientific process. More important than being “right” is to exercise your ability to apply logic and reason, in a scientific context.

So be bold. Be respectful of your peers. Trust your instincts.
Have fun.

Lectures

Tuesday, 17 January

Introduction and general concepts in invertebrate biology

- Course overview
- What are animals?
- Themes in metazoan diversity

Thursday, 19 January

Introduction to systematics and tree thinking

- What does a phylogenetic tree tell you?
- Constructing phylogenies
- Characters, states, and costs

Tuesday, 24 January

The Cambrian Explosion

- Animal architecture and body plans
- The end of the Ediacaran biota
- Oxygen and complexity

Readings (mandatory): Invertebrates, Chapter 2

Readings (recommended): Invertebrates, Chapter 4

Thursday, 26 January

Multicellularity, complexity, and deep relationships

- Porifera: organization without nervous systems
- Cnidaria: complex life cycles, free-swimming stages, and nervous systems
- The problematic phylogenetic placement of Ctenophora

Readings (mandatory):

Jekely, G., Paps, J., Nielsen, C. (2015). The phylogenetic position of ctenophores and the origin(s) of nervous systems. *EvoDevo* 6:1.

Readings (recommended): Invertebrates, Chapters 6-8

Tuesday, 31 January

Deep relationships and the root of Metazoa

- Biology and genome of Ctenophora
- Further problematica: Placozoa and *Xenoturbella*
- Nemertodermatida

Readings (mandatory):

Rouse, G.W., Wilson, N.G., Carvajal, J.I., Vrijenhoek, R.C. (2016). New deep-sea species of *Xenoturbella* and the position of Xenacoelomorpha. *Nature* 530, 94-97.

Readings (recommended): Invertebrates, Chapter 9

Thursday, 2 February

Bilateral symmetry, blastopores, and nephridia

Readings (mandatory):

Seaver, E.C. (2003). Segmentation: mono- or polyphyletic? *Int. J. Dev. Biol.* 47, 583-595.

Balavoine, G., Adoutte, A. (2003). The segmented Urbilateria: A testable scenario. *Integr. Comp. Biol.* 43, 137-147.

Readings (recommended):

Invertebrates, Chapters 14-15

Tuesday, 7 February

Annelids, segmentation, and spiral cleavage

Readings (mandatory):

Grande, C., Patel, N.H. (2009). *Nodal* signaling is involved in left-right asymmetry in snails. *Nature* 457, 1007-1011.

Readings (recommended): Invertebrates, Chapter 13

Thursday, 9 February

Developmental data and body plan disparity

Readings (mandatory):

Pratt, M.C. (2008). Living where the flow is right: How flow affects feeding in bryozoans. *Integr. Comp. Biol.* 48, 808-822.

Readings (recommended): Invertebrates, Chapters 13, 17

Tuesday, 14 February

Mollusks

Readings (mandatory):

Sigwart, J.D., Lindberg, D.R. 2015. Consensus and Confusion in Molluscan Trees: Evaluating Morphological and Molecular Phylogenies. *Syst. Biol.* 384-395.

Readings (recommended): Invertebrates, Chapter 13

Thursday, 16 February

The lophophorate phyla

- Phoronida
- Brachiopoda
- Bryozoa (Ectoprocta)
- Entoprocta (Kamptozoa)

Readings (mandatory):

Funch, P., Kristensen, R.M. (1995) Cycliophora is a new phylum with affinities to Entoprocta and Ectoprocta. *Nature* 378, 711-714.

Readings (recommended): Invertebrates, Chapters 15, 17

Tuesday, 21 February

Platyhelminthes, Orthonectida, Dicyemida, and Gastrotricha

Readings (mandatory):

Sikes, J.M., Newmark, P.A. (2013) Restoration of regeneration in a planarian with limited regenerative ability. *Nature* 500: 77-80.

Readings (recommended): Invertebrates, Chapters 10, 11

Thursday, 23 February

Gnathifera

- Gnathostomulida
- Rotifera/Syndermata
- Micrognathozoa

Readings (mandatory):

Pouchkina-Stantcheva, N.N., McGee, B.M., Boschetti, C., Tolleter, D., Chakrabortee, S., Popova, A.V., Meersman, F., Macherel, D., Hinch, D.K., Tunnacliffe, A. (2007) Functional divergence of former alleles in an ancient asexual invertebrate. *Science* 318: 268-271.

Readings (recommended): Invertebrates, Chapter 16

Tuesday, 28 February

Introduction to Ecdysozoa

- What are ecdysozoans?
- Ecdysone and molting

Readings (mandatory):

Borner, J., Rehm, P., Schill, R.O., Ebersberger, I., Burmester, T. (2014) A transcriptome approach to ecdysozoan phylogeny. *Molecular Phylogenetics and Evolution* 80, 79-87.

Readings (recommended): Invertebrates, Chapters 18

Thursday, 2 March

Scalidophora

- Kinorhyncha
- Priapula
- Loricifera

Readings (mandatory):

Martín-Durán, J.M., Janssen, R., Wennberg, S., Budd, G.E., Hejnol, A. (2012) Deuterostomic development in the protostome *Priapulus caudatus*. *Current Biology* 22: 2161-2166

Readings (recommended): Invertebrates, Chapter 19

Tuesday, 7 March

Panarthropoda

- Tardigrada
- Onychophora

Readings (mandatory):

Smith, F.W., Boothby, T.C., Giovannini, I., Rebecchi, L., Jockusch, E.L., Goldstein, B. (2016). The Compact Body Plan of Tardigrades Evolved by the Loss of a Large Body Region. *Current Biology* 26, 224-229.

Readings (recommended): Invertebrates, Chapter 20

Thursday, 9 March

Midterm exam

Tuesday, 14 March

Arthropoda

- The arachnid book lung
- The insect tracheal tubules
- The Malpighian tubule system

Readings (mandatory):

Damen, W.G.M., Saridaki, T., Averof, M. (2002). Diverse adaptations of an ancestral gill: a common evolutionary origin for wings, breathing organs, and spinnerets. *Current Biology* 12, 1711-1716.

Readings (recommended): Invertebrates, Chapters 23, 24

Thursday, 16 March

Pancrustacea

- Insects and mouthpart evolution
- The origin of insect wings
- Detecting co-diversification using dated phylogenies
- Hyperdiverse groups

Readings (mandatory):

Niwa, N., Akimoto-Kato, A., Nilmi, T., Tojo, K., Machida, R., Hayashi, S. (2010). Evolutionary origin of the insect wing via integration of two developmental modules. *Evolution and Development* 12, 168-176.

Readings (recommended): Invertebrates, Chapters 21, 22

Tuesday, 28 March

New axes of symmetry

- Chaetognatha
- Ambulacraria

Readings (mandatory):

Telford, M.J., Lowe, C.J., Cameron, C.B., Ortega-Martinez, O., Aronowicz, J., Oliveri, P., Copley, R.R. (2014). Phylogenomic analysis of echinoderm class relationships supports Asterozoa. *Proceedings of the Royal Society B: Biological Sciences* 281, 20140479.

Readings (recommended): Invertebrates, Chapters 11, 25

Thursday, 30 March

The journey of the notochord

- Chordata
- Neurogenesis and the road to Vertebrata

Readings (mandatory):

Stach, T. (2008). Chordate phylogeny and evolution: a not so simple three-taxon problem. *Journal of Zoology* 276, 117-141.

Satoh, N., Rokhsar, D., Nishikawa, T. (2014). Chordate evolution and the three-phylum system. *Proceedings of the Royal Society B: Biological Sciences* 281, 20141729.

Readings (recommended): Invertebrates, Chapters 26, 27

Tuesday, 4 April

Metazoan phylogeny and genome-scale datasets

Readings (mandatory):

Nosenko T., Schreiber, F., Adamska, M., et al. (2013). Deep metazoan phylogeny: When different genes tell different stories. *Mol. Phylogenet. Evol.* 67, 223-233.

Sharma, P.P., Kaluziak, S.T., Pérez-Porro, A.R., González, V.L., Hormiga, G., Wheeler, W.C., Giribet, G. (2014). Phylogenomic interrogation of Arachnida reveals systemic conflicts in phylogenetic signal. *Molecular Biology and Evolution* 31, 2963-2984.

Thursday, 6 April

Historical biogeography of invertebrates

Readings (mandatory):

Boyer, S.L., Clouse, R.M., Benavides, L.R., Sharma, P., Schwendinger, P.J., Karunarathna, I., Giribet, G. (2007). Biogeography of the world: a case study of globally distributed arachnids. *Journal of Biogeography* 34: 2070–2085.

Murienne, J., Daniels, S.R., Buckley, T.R., Mayer, G. Giribet, G. (2014). A living fossil tale of Pangean biogeography. *Proceedings of the Royal Society B: Biological Sciences* 281, 1471-2954.

Tuesday, 11 April

Population genetics and delimiting species

Readings (mandatory):

Etter, R.J. Boyle, E.E., Glazier, A., Jennings, R.M., Dutra, E., Chase, M.R. (2011) Phylogeography of a pan-Atlantic abyssal protobranch bivalve: implications for evolution in the Deep Atlantic. *Molecular Ecology* 20, 829-843.

Thursday, 13 April

Emerging non-model organisms in invertebrate evodevo

Readings (mandatory):

Sharma, P.P., Schwager, E.E., Extavour, C.G., Wheeler, W.C. (2014). Hox gene duplications correlate with posterior heteronomy in scorpions. *Proceedings of the Royal Society of London B: Biological Sciences* 281:20140661.

Tuesday, 18 April

Homology concepts and gene networks

Readings (mandatory):

Ben-David, J., Chipman, A.D. (2010) Mutual regulatory interactions of the trunk gap genes during blastoderm patterning in the hemipteran *Oncopeltus fasciatus*. *Developmental Biology* 346, 140-149.

Thursday, 20 April

Morphology in the genomic era

Readings (mandatory):

Giribet, G. (2015) Morphology should not be forgotten in the era of genomics—a phylogenetic perspective. *Zoologischer Anzeiger* 256, 96-103.

Tuesday, 25 April

Review I

Thursday, 27 April

Review II

Tuesday, 2 May

Final exam