Organismic and Evolutionary Biology

OEB 213 - Evolutionary convergence, mass extinctions and the shape of Life

Javier Ortega-Hernández

Contact: jortegahernandez@fas.harvard.edu

Rationale: Understanding the processes responsible for the origin of major animal groups and the composition of the biosphere represent some of the core objectives of evolutionary biology. Despite monumental advances made possible by the onset of molecular techniques that allow to reconstruct phylogenetic relationships between phyla, as well as tracking the intrinsic developmental mechanisms behind their morphology, extant diversity inevitably offers an incomplete view of the evolutionary history of these organisms. This course examines how processes acting through deep time affect fundamental patterns of animal biodiversity, including topics such as the origin of animals, rapid diversification of major clades, and the impact of extinction in shaping extant biodiversity. The aim is to convey a sense of how evolutionary thinking has changed over the past few decades thanks to a combination of conceptual and technical advances, as well as to instill a sense of the importance of the animal fossil record as a valuable source of data with a uniquely historical component among the biological sciences.

Assessment: Final grades will be calculated from student presentations and participation in class (33%), and two graded essays (33% each, totaling 66%). Regular attendance and engagement during class and one-to-one discussions are essential for preparing presentations and essays.

Requirements: No prior courses required, but a basic understanding of evolution is essential.

Required reading: It is expected that students will thoroughly read the material provided in advance of each session (up to two scientific publications) to fully benefit from the discussions and practical activities. The full reading list is available at the course Canvas website.

Class activities: Most sessions will involve a practical component aimed at complementing the required reading and topical discussion. Instructions and materials will be provided in advance.

Course weekly format: All students will attend a live group discussion/practical session chaired by the course instructor focused on the assigned reading material and relevant activities. During selected classes, the discussion will be led by one or more **presenting students (§)** who will have an additional 1-2 hour preparation meeting with the course instructor ahead of their respective class presentation arranged at a flexible schedule. A typical class will start with a **15-20 minute introduction** by the course instructor, followed by a **30-45 minute student presentation and Q&A**, next a dedicated **practical activity** (e.g. probability games, online resources), and finally a **whole class discussion** addressing the topic.

September 3, 2020

Session 0: Welcome to OEB 213 – Introductory session, course overview, and Q&A.

September 10, 2020

Session 1: The shape of modern animal life – Brief introduction to major animal phyla, their phylogenetic relationships, and body plan disparity based on extant biodiversity.

Required reading:

Laumer et al. 2019. Revisiting metazoan phylogeny with genomic sampling of all phyla. *Proceedings of the Royal Society B 286*: 20190831.

Deline et al. 2018. Evolution of metazoan morphological disparity. *Proceedings of the National Academy of Sciences 115*: E8909-E8918.

Class activity: Understanding the diversity and disparity of modern animals.

September 17, 2020

Session 2: Life through deep time – Introduction to the animal fossil record, including studies that address geologic-scale patterns of marine invertebrate biodiversity.

Required reading:

Sepkoski 1993. Ten years in the library: new data confirm paleontological patterns. *Paleobiology 19*: 43-51.

§ Alroy et al. 2008. Phanerozoic trends in the global diversity of marine invertebrates. *Science 321*: 97-100. **Student presentation(s)**

Class activity: Diversity and disparity through time I – traditional view from shelly fossil record.

September 24, 2020

Session 3: Cambrian weird wonders and contingency – Discussion about the effect of contingency on evolution developed by Stephen J. Gould based on his interpretation of the Burgess Shale and the Cambrian Explosion.

Required reading:

§ Gould 1989. *Wonderful life: the Burgess Shale and the nature of history*. WW Norton & Company. **Student presentation(s)**

Class activity: Diversity and disparity through time II – Gould's view of the Burgess Shale and evolutionary implications of "failed evolutionary experiments" during the Cambrian.

October 1, 2020

Session 4: On the origins of Life and animals – Discussion on the precise timing for the origin of life on Earth, and the emergence of complex animals.

Required reading:

§ Marshall 2006. Explaining the Cambrian "explosion" of animals. *Annual Review of Earth and Planetary Sciences 34*: 355-384. **Student presentation(s)**

Smith and Harper 2013. Causes of the Cambrian explosion. *Science 341*: 1355-1356.

Class activity: Breakout rooms discussion followed by student presentations (~15 minutes) exploring proposed causes for the Cambrian Explosion, followed by whole class discussion.

October 6, 2020

Session 5: Precambrian ghost lineages and molecular clocks – Addresses the fossil evidence for a Precambrian origin of animals and the use of molecular clocks to estimate clade diversification in the presence of an incomplete fossil record.

Required reading:

§ Erwin et al. 2011. The Cambrian conundrum: early divergence and later ecological success in the early history of animals. *Science 334,* 1091-1097. **Student presentation(s)**

Warnock 2015. Molecular clock calibration. *Encyclopedia of scientific dating methods* 576-583.

§ Cunningham, Liu, Bengtson, and Donoghue. 2017. The origin of animals: can molecular clocks and the fossil record be reconciled? *BioEssays 39*: 1-12. **Student presentation(s)**

Class activity: Fossil calibrations and molecular clock estimates for the origin of metazoans.

October 15, 2020

Session 6: The Five Laws of Paleobiology – Discusses the main processes that affect biodiversity through time, as well as the influence of extinction.

Required reading:

Marshall 2017. Five palaeobiological laws needed to understand the evolution of the living biota. *Nature Ecology & Evolution 1*: 0165.

Friedman and Sallan 2012. Five hundred million years of extinction and recovery: a Phanerozoic survey of large-scale diversity patterns in fishes. *Palaeontology 55*: 707-742.

Class activity: Diversity and disparity through time III – the modern view and the impact of background extinction in shaping the composition of the biosphere.

October 22, 2020

Session 7: Stem and crown groups – Introduces the modern approach to the study of problematic fossil taxa as extinct representatives of living phyla.

Required reading:

Budd and Jensen 2000. A critical reappraisal of the fossil record of the bilaterian phyla. *Biological Reviews* 253-295.

Ortega-Hernández 2019. Exceptionally Preserved Cambrian Fossils in the Genomic Era. In *Old Questions and Young Approaches to Animal Evolution* Springer, Cham. pp. 39-54.

Class activity: Student presentations (~15 minutes) on selected studies that explore evolutionary links between problematic Cambrian organisms to extant biodiversity.

October 29, 2020

Session 8: The speed of evolution – Challenges the classical Darwinian notion of evolution as an agonizingly slow process, and discusses evidence for accelerated rates of evolution at critical points in the history of life from the perspective of the fossil record.

Required reading:

§ Lee et al. 2013. Rates of phenotypic and genomic evolution during the Cambrian explosion. *Current Biology 23*: 1889-1895. **Student presentation(s)**

§ Paterson et al. 2019. Trilobite evolutionary rates constrain the duration of the Cambrian explosion. *Proceedings of the National Academy of Sciences 116*: 4394-4399. **Student presentation(s)**

November 5, 2020

Session 9: History is written by the victors – Introduces the idea of the Push of the Past, which posits that lineage longevity is largely reliant on early high rates of evolutionary change, and that extinction fundamentally models our understanding of extant biodiversity.

Required reading:

Budd and Mann 2018. History is written by the victors: the effect of the push of the past on the fossil record. *Evolution 72*: 2276-2291.

§ Budd and Mann 2020. Survival and selection biases in early animal evolution and a scource of systematic overestimation in molecular clocks. *Interface Focus 10*: 20190110. **Student presentation(s)**

Hughes et al. 2013. Clades reach highest morphological disparity early in their evolution. *Proceedings of the National Academy of Sciences 110*: 13875-13879.

Class activity: Modeling the modern effects of the Push of the Past with online Blackjack.

November 12, 2020

Session 10: Convergence and the inevitability of complexity – Discusses the ideas of Simon Conway-Morris of convergence as a fundamental constrain that may even allow to predict evolutionary change.

Required reading:

Conway-Morris 1999. *The crucible of creation: the Burgess Shale and the rise of animals*. Peterson's.

§ Orgogozo 2015. Replaying the tape of life in the twenty-first century. *Interface focus 5*: 20150057. **Student presentation(s)**

Class activity: Form, function and inescapable constraints; examples from Cambrian ecosystems.

November 19, 2020

Session 11: Experimental evolution and predictability – Will utilize a recent case study on the evolution of bacterial lineages in response to antibiotics as a demonstration of patterns of early diversification, extinction and convergence.

Required reading:

Conway-Morris 2009. The predictability of evolution: glimpses into a post-Darwinian world. *Naturwissenschaften 96*: 1313-1337.

§ Baym et al. 2016. Spatiotemporal microbial evolution on antibiotic landscapes. *Science 353*: 1147-1151. **Student presentation(s)**

Blount et al. 2018. Contingency and determinism in evolution. *Science 362*: eaam5979.

Class activity: What is the "true" nature of evolution?

Assessment – Student presentations

Instructions: Part of the final assessment will be based student presentations (30 to 45 minutes, depending on material) to take place throughout the course. The specifics regarding the number of speakers per topic will depend on the cohort size, and thus further details will be circulated once enrollment has finalized and prior to the corresponding sessions. **Student presenters (§)** will have an additional one to one hour-long meeting with the course instructor to help them prepare for leading the discussion during the main class session.

Pedagogical goal: The objective of the student presentations is to deepen into the diverse body of work on the topics covered throughout the course in greater detail than that possible within the conventional session format. Presentations should include relevant background information, explain the reasoning behind particular hypotheses discussed, and critically evaluate the body of supporting evidence. Please prepare your presentation in PowerPoint, or alternatively using the online whiteboard if you feel courageous (software details will be provided during the semester).

Assessment – Graded essays

Instructions: A significant component of the final assessment will be based on two graded essays designed around the first and second halves of the course respectively. The main text should comprise between 1,500 to 2,000 words (excluding reference list and/or figure captions). Feel free to include supporting material in the form of figures or schematic diagrams as you consider appropriate to complement the main text. The format should follow that of a manuscript for publication according to the submission guidelines for an "Insights and Perspectives" contribution to the journal *Bioessays* (see Parry et al 2018 in course reading materials as an example). Essays will be assessed based on the clarity, breadth, and depth of the content, as well as overall presentation, similarly to a work submitted for peer-review. The essays should broadly address each of the questions posited below, however, there is ample freedom to choose the best approach and/or specific subject matter for achieving this objective. The essays should be emailed to the course instructor by the due dates specified below. If you foresee any complications in fulfilling these requirements please get in touch as soon as possible.

Pedagogical goal: The objective of the essays is to give the students an opportunity to think critically and broadly about the course material, as well as develop their own informed perspective on the contributions of the animal fossil record for understanding evolution. Since there is no single correct answer to the questions posited below, the essay should demonstrate appropriate mastery over the main ideas and material discussed during the course, and evidence the ability to integrate a diverse body of work into a logical discussion.

Essay due dates:

October 22, 2020 – First essay, encompassing Sessions 1 to 6.

Q: How does the study of animal evolution in deep time inform our current understanding of the origin and composition the modern biosphere?

November 26, 2019 – Second essay, encompassing Sessions 7 to 11.

Q: Consider an idealized scale for the "predictability of evolution" ranging from 0 (evolution is purely the result of historical contingency) to 10 (evolution is completely deterministic, even predictable given enough information). What do you think is the current consensus among evolutionary biologists in its broadest sense? What is your own perspective on this topic?

Other formatting requirements:

- Adhere to either American or British spelling consistently
- Font Times New Roman, 12pt for main text, 14pt for headings/subheadings
- 1.5 or double spaced
- Numbered pages
- Include contact details (e.g. full name, email)
- Please limit the graphical content (if any) to a maximum of four accompanying figures.