Seminar on *The Persistence of Earth's Biosphere*

12.091/12.S597 Spring 2021 G (2-0-4)
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Overview

Earth has undergone many dramatic perturbations throughout its history, yet life on Earth has continuously persisted for nearly 4 billion years. Why is that? The Gaia hypothesis—the idea that life acts to stabilize its own environment—is one potential explanation, but it suffers from a lack of clarity and an apparent conflict with standard ideas of evolutionary biology. This seminar examines how Earth's biosphere may have contributed to its own billion-year persistence, focusing on how stabilizing behavior could arise through Darwinian selection operating at smaller scales. The emerging story encompasses questions regarding the existence and dynamical evolution of biogeochemical cycles, planetary habitability more broadly, and the apparent absence of life elsewhere in the universe. We close by considering the implications for the resilience and future of Earth's biosphere in the Anthropocene epoch.

Organization

We will meet on Fridays from 2:30–4:00 in Rm 56-169. The initial meeting on Friday September 10 will be organizational. Interested students with scheduling conflicts should send their schedule to the instructor at dhr@mit.edu; we'll make accommodations if we can.

Participation, format, and expectations

Each week we will discuss the assigned readings. Rather than designating discussion leaders, we will each participate in discussions on an equal basis. No one is expected to have any special expertise in any of the subjects; instead, we will all come prepared to learn from each other. Participation is open to all, including undergraduates. Interested students should register (in advance, if possible) for 12.S597 (graduate students) or 12.091 (undergraduates). Grading is P/D/F; continual attendance and active participation is required for P. Postdocs, faculty, and research staff are also welcome. All participants will contribute to discussions.

Syllabus

The list of each week's topic and readings begins on the following page. All material will be available on Canvas or obtainable electronically from the MIT Library. The syllabus is tentative; any updates will be posted on Canvas.

Introduction

1. Life, Earth, and Gaia

   Lovelock, J. E. and L. Margulis (1974). "Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis". *Tellus* 26, pp. 2–10.

   Tyrrell, T. (2013). *On Gaia: a critical investigation of the relationship between life and Earth*. Chap. 1. Princeton University Press.

Is Earth's biosphere responsible for its own persistence?

2. Evolutionary deficiencies of Gaia theory

   Doolittle, W. F. (1981). "Is nature really motherly?" *The CoEvolution Quarterly* Spring, pp. 58–63.

   Tyrrell, T. (2013). *On Gaia: a critical investigation of the relationship between life and Earth*. Chap. 2. Princeton University Press.

3. Reconciling Gaia with natural selection

   Lenton, T. M. (1998). "Gaia and natural selection". *Nature* 394, pp. 439–447.

   Doolittle, W. F. (2014). "Natural selection through survival alone, and the possibility of Gaia". *Biology & Philosophy* 29, pp. 415–423.

4. Biogeochemical cycles as units of selection: "It's the song, not the singers"

   Morowitz, H. J. (1968). *Energy Flow in Biology: Biological Organization as a Problem in Thermal Physics*. pp. 22-33. Academic Press.

   Doolittle, W. F. (2017). "Darwinizing Gaia". *Journal of Theoretical Biology* 434, pp. 11–19.

5. It's the song, not the singers (2)

   Doolittle, W. F. and S. A. Inkpen (2018). "Processes and patterns of interaction as units of selection: An introduction to ITSNTS thinking". *Proceedings of the National Academy of Sciences* 115, pp. 4006–4014.

   Doolittle, W. F. (2019). "Making evolutionary sense of Gaia". *Trends in Ecology & Evolution* 34, pp. 889–894.

6. Models and views of emergent system-level behavior

   Levin, S. A. (1998). "Ecosystems and the biosphere as complex adaptive systems". *Ecosystems* 1, pp. 431–436.

   Williams, H. T. and T. M. Lenton (2007). "Artificial selection of simulated microbial ecosystems". *Proceedings of the National Academy of Sciences* 104, pp. 8918–8923.

Habitability: the cosmic perspective

7. Observer selection, the weak anthropic principle, and silicate weathering

Tyrrell, T. (2013). *On Gaia: a critical investigation of the relationship between life and Earth*. Chap. 9. Princeton University Press.

8. Gaian bottlenecks, Fermi's paradox, and separating habitability from inhabitance

Goldblatt, C. (2016). "The inhabitance paradox: How habitability and inhabitancy are inseparable". *arXiv:1603.00950*.

Chopra, A. and C. H. Lineweaver (2016). "The case for a Gaian bottleneck: the biology of habitability". *Astrobiology* 16, pp. 7–22.

9. The roles of chance and inhabitance in habitability models

Tyrrell, T. (2020). "Chance played a role in determining whether Earth stayed habitable". *Nature Communications Earth & Environment* 1, pp. 1–10.

Nicholson, A. E., D. M. Wilkinson, H. T. Williams, and T. M. Lenton (2018). "Gaian bottlenecks and planetary habitability maintained by evolving model biospheres: The ExoGaia model". *Monthly Notices of the Royal Astronomical Society* 477, pp. 727–740.

From persistence to resilience, and the lessons for Earth's future

10. Survival of ecological and social systems

Lenton, T. M., T. A. Kohler, P. A. Marquet, R. A. Boyle, M. Crucifix, D. M. Wilkinson, and M. Scheffer (2021). "Survival of the Systems". *Trends in Ecology & Evolution* 36, pp. 333–334.

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. De Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Maler, S. Polasky, M. Troell, J. Vincent, and B. Walker (2013). "Social-ecological systems as complex adaptive systems: modeling and policy implications". *Environment and Development Economics* 18, pp. 111–132.

11. Future of the Anthropocene biosphere

Williams, M., J. Zalasiewicz, P. Haff, C. Schwägerl, A. D. Barnosky, and E. C. Ellis (2015). "The Anthropocene biosphere". *The Anthropocene Review* 2, pp. 196–219.