Syllabus GEOG 244: Complex Environmental Systems

McCone Hall, Room 575, Tu 9-12 Course website: http://www.esdlberkeley.com/teaching/complex-environmental-systems/

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The environment is a classic complex system, composed of multiple interacting "agents," or variables, that cause emergent behavior. Applying a complex-systems approach to environmental problems such as climate change, landscape evolution, or societal-ecological sustainability can yield valuable insight into risk, potential drivers of change, likely outcomes of perturbation, and whether it is even possible to forecast or manage the system. This is a graduate-level seminar course that will expose you to classical complex systems analysis, along with frontiers in applying a complex-systems approach to environmental problems. You will read about and participate in some of the most lively debates in the field and become acquainted with tools and approaches for applying complex-systems theory in your own research.

The format of this class is primarily reading and discussion. What you get out of this class will be proportional (nonlinearly?) to your participation. On some days we will debate controversial issues, and you will be divided into groups in advance and have an opportunity to specialize and lead discussion in certain arguments. The course is designed by be highly interdisciplinary, and the hope is that new ideas will be seeded by readings in physics, ecology, earth science, and social science, followed by discussion with your peers from various fields. To document these insights and assemble a resource center for your own endeavors, we will be building and maintaining a course website with a blog to which everyone will contribute.

You'll begin the semester by learning the rich language of complex-systems analysis and immersing yourself in and debating theory. In the second part of the semester you will examine the modeling and analysis tools that are used to apply that theory to real-world problems and data. The semester will conclude with a special-topics focus to examine further how complex-systems theory is applied in the study of climate change, coupled human-environmental systems, and even in your own research area. Other special topics that will be integrated throughout the semester include river networks, desertification and desert vegetation shifts, forest fires, earthquakes, and peatlands.

Text:

Most of the reading will come from the primary literature, but the text by Solé and Bascompte (<u>Self-organization in complex ecosystems</u>, Princeton University Press, 2006) provides excellent, readable theoretical background that will form a foundation for the rest of the class. Although written for ecologists, the book does a better job of explaining complex-systems concepts for the lay reader than any other text I have examined and is an excellent general reference. You have several options to acquire the reading from this book:

- 1. Go online and purchase the book (~\$62.95, <u>www.press.princeton.edu/titles/8224.html</u>).
- 2. Check out the book from the Earth Sciences library, where a copy is on reserve.
- 3. Download the required reading (pp. 1-84 only) from the course website.

Links to the primary texts have been placed on the syllabus below and are live on the course website.

Expectations:

It is my intent that this class will stimulate new thinking for your research and aid in your comprehension of the literature. The benefits you will reap from this class increase in proportion to your investment in reading and discussion. I hope that you will be sufficiently motivated to engage in both pursuits with enthusiasm and drive. To facilitate the process and also to increase your experience in professional, cross-disciplinary communication, there were also be several assignments:

- 1. Weekly: Submit discussion questions related to the reading to the course website. (See accompanying instructions.) Due weekly by end of day on Friday preceding class, starting with readings for week 3. (25% of grade)
- 2. Once per course: Read an extra "case-study" paper and prepare a 10-15 minute presentation (up to 20 minutes including questions and discussion) to brief your classmates. Also prepare a blog entry (1-3 paragraphs) summarizing the study. (10% of grade)
- 3. Final project: Prepare an NSF-style grant proposal to apply the concepts of this course to an area of interest to you. In the final class meeting period, you will provide the class with a brief summary of your proposal. Proposals will be distributed to groups of peers, who will read them and provide brief critiques. The final class meeting (during reading and recitation week) will take the form of a faux NSF panel. The intent here is to familiarize you with grant proposal writing and provide you with an opportunity to jump-start your research. More detailed instructions to follow (35% of grade).
- 4. ~Twice per course, post a class discussion summary online. (5% of grade)

The remaining 25% of your final grade will be based on your attendance and active participation in class. Contact me if you need to miss more than one class.

Tentative Schedule:

WEEK 1 (1/21/13): Introduction to course, complex systems, and Gaia theory

Optional reading:

Levin, S. A. 1998. Ecosystems and the biosphere as complex adaptive systems. Ecosystems 1:431-436. Link

Lenton, T. M. and M. van Oijen. 2002. Gaia as a complex adaptive system. Phil. Trans. R. Soc. Lond. B. **357**:683-395. Link

Resources:

NSF web page on Complex Environmental Systems: Synthesis for Earth, Life, and Society in the 21st Century: Link

StarLogo simulation software: Link

WEEK 2 (1/28/13): Nonlinear dynamics and chaos

Required reading: Sole and Bascompte, pp. 1-64

Optional reading:

Glass, L. (2009), Introduction to Controversial Topics in Nonlinear Science: Is the Normal Heart Rate Chaotic?, *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 19(2), 028501-028504. Link

WEEK 3 (2/4/13): Spatial complexity: role of dispersal and diffusion

Required reading:

Sole and Bascompte, pp. 65-84

- Allesina, S., and J. M. Levine (2011), A competitive network theory of species diversity, *Proceedings of the National Academy of Sciences*, 108(14), 5638-5642. Link
- Kerr, B., M. A. Riley, M. W. Feldman, and B. J. M. Bohannan (2002), Local dispersal promotes biodiversity in a real-life game of rock-paper-scissors, *Nature*, *418*(6894), 171-174. Link

WEEK 4 (2/10/13): Spatial pattern formation

Required reading:

- Rietkerk, M. and J. van de Koppel. 2008. Regular pattern formation in real ecosystems. Trends in Ecology & Evolution 23:169-175. Link
- DeAngelis, D. L. 2012. Self-organizing processes in landscape pattern and resilience: a review. ISRN Ecology, doi:10.5402/2012/274510. Link
- Weerman, E. J., J. van de Koppel, M.B. Eppinga, F. Montserrat, Q. X. Liu, and P. M. J. Herman. 2010. Spatial self-organization on intertidal mudflats through biophysical stress divergence. The American Naturalist 176:doi:10.1086/652991. Link

Optional:

Bascompte, J. and R. V. Sole. 1998. Spatiotemporal patterns in nature. Trends in Ecology and Evolution

13:173-174. Link

WEEK 5 (2/17/13): Alternate stable states

Required reading:

- Suding, K. N., K. L. Gross, and G. R. Houseman. 2004. Alternative states and positive feedbacks in restoration ecology. Trends in Ecology & Evolution 19:46-53. Link
- Didham, R. K. and C. H. Watts. 2005. Are systems with strong underlying abiotic regimes more likely to exhibit alternative stable states? Oikos **110**:409-416. Link
- Didham, R. K. and D. A. Norton. 2007. Alternative logical states. A reply to N. W. H. Mason, J. B. Wilson and J. B. Steel. Oikos **116**:358-360. Link
- Mason, N. W. H., J. B. Wilson, and J. B. Steel. 2007. Are alternative stable states more likely in high stress environments? Logic and available evidence do not support Didham et al. 2005. Oikos 116:353-357. Link
- Fukami, T., and W. G. Lee (2006), Alternative stable states, trait dispersion and ecological restoration, *Oikos*, 113(2), 353-356. Link
- Didham, R. K., and D. A. Norton (2006), When are alternative stable states more likely to occur?, *Oikos*, *113*(2), 357-362. Link

Case-study:

- Heffernan, J. B. 2008. Wetlands as an Alternative Stable State in Desert Streams. Ecology 89:1261-1271. Link
- Lansing, J. S. 2012. Alternate stable states in a social-ecological system. Working Papers of the Santa Fe Institute. Link

WEEK 6 (2/25/13): Self-organized criticality and power laws

Required reading:

- Bak, P., and K. Chen (1991), Self-organized criticality, Scientific American, 264(1), 46-53. Link
- Brown, J. H., V. K. Gupta, B.-L. Li, B. T. Milne, C. Restrepo, and G. B. West. 2002. The fractal nature of nature: power laws, ecological complexity and biodiversity. Phil. Trans. R. Soc. Lond. B. 357:619-626. Link
- Sapozhnikov, V.B. and Foufoula-Georgiou, E. 1996. Do the current landscape evolution models show self-organized criticality? Water Resources Research **32**:1109-1112. Link
- Sapozhnikov, V.B. and Foufoula-Georgiou, E. 1999. Horizontal and vertical self-organization of braided rivers toward a critical state. Link

Case-studies:

- Zinck, R. D. and V. Grimm. 2009. Unifying wildfire models from ecology and statistical physics. The American Naturalist **174**:E170-E185. Link
- Jameson, A. R. and A. B. Kotinski. 2002. Spurious power-law relations among rainfall and radar parameters. Q. J. R. Meteorol. Soc. **128**:2045-2058. Link
- Touboul, J., and A. Destexhe (2010), Can Power-Law Scaling and Neuronal Avalanches Arise from Stochastic Dynamics?, *PLoS ONE*, *5*(2), e8982. Link
- Farber, D. A. (2003), Probabilities behaving badly: Complexity theory and environmental uncertainty, *Environs: Environmental Law and Policy Journal*, *37*, 145-174. Link

WEEK 7 (3/4/13): Predicting catastrophic shifts

Required reading:

- Batt, R. D., S. R. Carpenter, J. J. Cole, M. L. Pace, and R. A. Johnson. 2013. Changes in ecosystem resilience detected in automated measures of ecosystem metabolism during a whole-lake manipulation. Proc. Nat. Acad. Sci. 110: 17398-17403. Link
- Peters, D. P. C., R. A. Pielke, B. T. Bestelmeyer, C. D. Allen, S. Munson-McGee, and K. M. Havstad (2004), Cross-scale interactions, nonlinearities, and forecasting catastrophic events, *Proceedings of the National Academy of Sciences of the United States of America*, 101(42), 15130-15135. Link

Scheffer, M., et al. (2012), Anticipating Critical Transitions, Science, 338(6105), 344-348. Link

Optional reading:

- Rietkerk, M., S. C. Dekker, P. C. de Ruiter, and J. van de Koppel. 2004. Self-organized patchiness and catastrophic shifts in ecosystems. Science **305**:1926-1929. Link
- Scheffer, M., J. Bascompte, W. A. Brock, V. Brovkin, S. R. Carpenter, V. Dakos, H. Held, E. H. van Nes, M. Rietkerk, and G. Sugihara. 2009. Early-warning signals for critical transitions. Nature 461:53-59. Link

Case-studies:

- Kefi, S., M. Rietkerk, C. L. Alados, Y. Pueyo, V. P. Papanastasis, A. ElAich, and P. C. de Ruiter. 2007. Spatial vegetation patterns and imminent desertification in Meditteranean arid ecosystems. Nature 449:213-218. Link
- Dai, L., D. Vorselen, K. S. Korolev, and J. Gore. 2012. Generic indicators for loss of resilience before a tipping point leading to population collapse. Link

WEEK 8 (3/11/13): Resilience

Required reading:

- Allen, C., L. Gunderson, and A. R. Johnson (2005), The Use of Discontinuities and Functional Groups to Assess Relative Resilience in Complex Systems, *Ecosystems*, 8(8), 958-966. Link
- Hirota, M., M. Holmgren, E. H. Van Nes, and M. Scheffer (2011), Global Resilience of Tropical Forest and Savanna to Critical Transitions, *Science*, *334*(6053), 232-235. Link
- Holling, C. S. (2001), Understanding the Complexity of Economic, Ecological, and Social Systems, *Ecosystems*, 4(5), 390-405. Link

Optional reading:

Folke, C. (2006), Resilience: The emergence of a perspective for social-ecological systems analyses, *Global Environmental Change*, 16(3), 253-267. Link

WEEK 9 (3/18/13): Signals and noise

Required reading:

Freitas, U. S., and C. Letellier (2009), Using a nonlinearity detection as a prior step for global modeling,

paper presented at ICCSA 2009. Link

Jerolmack, D. J. and C. Paola. 2010. Shredding of environmental signals by sediment transport. Geophysical Research Letters **37**:L19401, doi:19410.11029/12010GL044638. Link

D'Odorico, P., F. Laio, and L. Ridolfi. 2005. Noise-induced stability in dryland plant ecosystems. Proc. Nat. Acad. Sci. **102**: 10819-10822. Link

WEEK 10: Spring break!

WEEK 11 (4/1/13): Approaches to modeling complex systems

Required reading:

- Rounsevell, M. D. A., D. T. Robinson, and D. Murray-Rust. 2012. From actors to agents in socioecological systems models. Phil. Trans. R. Soc. Lond. B. **367**:259-269. Link
- Rozier, O. and C. Narteau. 2014. A real-space cellular automaton laboratory. Earth Surf.Process. Landforms **39**: 98-109. Link
- Grimm, V., E. Revilla, U. Berger, F. Jeltsch, W. F. Mooij, S. F. Railsback, H.-H. Thulke, J. Weiner, T. Wiegand, and D. L. DeAngelis. 2005. Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. Science 310:987-991. Link

Case studies:

- Epstein, J.M. 2002. Modeling civil violence: An agent-based computational approach. Proc. Nat. Acad. Sci. **99:**7243-7250. Link
- Axtell, R. L., J. M. Epstein, J. S. Dean, G. J. Gumerman, A. C. Swedlund, J. Harburger, S. Chakravarty, R. Hammond, J. Parker, and M. Parker (2002), Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley, *Proceedings of the National Academy of Sciences of the United States of America*, 99(Suppl 3), 7275-7279. Link
- Bonabeau, E. (2002), Agent-based modeling: Methods and techniques for simulating human systems, *Proceedings of the National Academy of Sciences of the United States of America*, 99(Suppl 3), 7280-7287. Link

WEEK 12 (4/8/13): Big-data (top-down) approaches to understanding complex systems

Required reading:

- Ruddell, B. L. and P. Kumar. 2009. Ecohydrologic process networks: 1. Identification. Water Resources Research **45**:W03419, doi:03410.01029/02008WR007279. Link
- Kirchner, J. and C. Neal. 2014. Universal fractal scaling in stream chemistry and its implications for solute transport and water quality trend detection. Proc. Nat. Acad. Sci. doi:10.1073/pnas130428110. Link
- Boers, N., B. Bookhagen, N. Marwan, J. Kurths, and J. Marengo. 2013. Complex networks identify spatial patterns of extreme rainfall events of the South American Monsoon System. Geophys. Res. Letters **40**:4386-6392. Link

Case-study:

Zanin, M., and S. Boccaletti (2011), Complex networks analysis of obstructive nephropathy data, *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 21(3), 033103-033105. Link Also read popular summary of Zanin and Boccaletti here: Link

Smirnov, D. A., and I. I. Mokhov (2009), From Granger causality to long-term causality: Application to climatic data, *Phys Rev E*, *80*(016208), doi: 10.1103/PhysRevE.1180.016208. Link

Moffatt, A. M., C. Beckstein, G. Churkina, M. Mund, and M. Heimann. 2010. Characterization of ecosystem responses to climatic controls using artificial neural networks. Global Change Biology 16:2737-2749. Link

WEEK 13 (4/15/13): Hierarchies and hierarchical modeling

Required reading:

Lane, D. (2006), Hierarchy, Complexity, Society, in *Hierarchy in Natural and Social Sciences*, edited by D. Pumain, pp. 81-119, Springer, Netherlands. Link

Guest lecture on hierarchical modeling in climate science. Associated reading TBD.

WEEK 14 (4/22/13): Sensitivity and uncertainty analyses

Required reading:

- Larsen, L. G. and J. W. Harvey. 2010. How vegetation and sediment transport feedbacks drive landscape change in the Everglades and wetlands worldwide. The American Naturalist **176**:E66-E79. Link
- Spear, R. C. 1997. Large simulation models: calibration, uniqueness, and goodness-of-fit. Environmental Modelling & Software **12**:219-229. Link
- Eppinga, M. B., P. C. de_Ruiter, M. J. Wassen, and M. Rietkerk (2009), Nutrients and Hydrology Indicate the Driving Mechanisms of Peatland Surface Patterning, *The American Naturalist*, 173(6), 803-818. Link
- Beven, K. (1996), Equifinality and uncertainty in geomorphological modelling, in *The Scientific Nature of Geomorphology: Proceedings of the 27th Binghampton Symposium in Geormophology held 27-29 September 1996*, edited by B. L. Rhoads and C. E. Thorn, pp. 289-313, John Wiley & Sons. Link

Optional:

Hornberger, G. M. and R. C. Spear. 1981. Approach to the preliminary analysis of environmental systems. Journal of Environmental Management **12**:7-18. Download from course website.

Case studies:

Eppinga, M.B., M. Rietkerk, W. Borren, E. D. Lapshina, W. Bleuten, and M. J. Wassen. 2010. Regular surface patterning of peatlands: Confronting theory with field data. Ecosystems **11**: 520-526. Link

WEEK 15 (4/29/13): Presentation of NSF proposals. Proposals due for peer review

READING AND RECITATION WEEK (5/6/13): Mock NSF panel meeting, synthesis, and wrap-up