Review of: Self-organization in Complex Ecosystems

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These days, it needs little explanation that the complexity of the natural world makes prediction of future development difficult for many types of dynamical systems. For example, it is clear that the climate is changing due to elevated atmospheric CO₂ levels, but there is little understanding what, in the end, the effects on our local climate will be. Effects will vary in space, and direct effects of elevated CO₂ can be reversed by complex changes in weather systems or in ocean currents. A similar degree of complexity makes it very difficult to understand how ecosystems will respond to change. The book by Ricard Solé and Jordi Bascompte gives a thorough overview of the causes and implication of ecological complexity for our understanding of ecological systems, and provides us with a wide range of mathematical tools to address the complexity of ecosystems.

Complexity theory has its origins in physics and mathematics, and it built strongly on a small number of paradigm models that show how interactions between the components of a system can generate patterns at a larger scale. Examples of such paradigm models are the contact process modeled in cellular automata, or reaction-diffusion processes modeled using partial differential equations. These models are used in various contexts, including physical and chemical systems. Ecologists have adopted techniques from fields like statistical physics, and adapted them as tools to understand complexity in ecosystems. The book of Solé and Bascompte provides a nice and comprehensive overview of these techniques, and how they have led to insights in the causes and implications of complexity in ecological systems.

The book starts with a general introduction and overview, and introduces a number of key concepts within complexity theory, such as localized interactions and emergence. I will not describe the introduction in more detail, because the reader can read Chapter 1 at the publisher’s website (http://press.princeton.edu/chapters/s8224.pdf).

Chapter 2 uses classical ecological models to show that simple ecological dynamics can induce complex dynamics in ecological systems. Key ideas are introduced with regard to the dynamics of an ecological system, such as local stability and the emergence of population cycles, the causes of catastrophic shifts, and the possibility of chaotic, unpredictable dynamics in ecological models.

Chapter 3 discusses how ecological interactions can cause complex spatial patterns. One of the first examples is how the interaction between local positive feedback (an activator) and negative feedback at a larger spatial scale (an inhibitor) can cause regular spatial patterning in ecosystems. Examples of this are found for instance in arid ecosystems, where grass-dominated vegetation or bushland can exhibit regular spatial vegetation patterns. This approach is then generalized using coupled map lattice models that allow for introduction of space in models of predator–prey, host–parasite, competition, and dispersal dynamics. The chapter ends with a discussion of the importance of space in evolutionary dynamics.

The fourth chapter deals with scale invariance: ecological properties can be independent of scale. This phenomenon is best known in fractal patterns. Many features of ecological systems have also been found to be scale invariant: the distribution of vegetation patches, biomass of organisms, and population change were independent of spatio-temporal scale. The authors discuss a number of models that have been proposed to explain scale dependence. These models are based on strongly simplified descriptions of an ecological process; one can think of the “branching process”, “percolation process”, or “contact process”, names that originate from physics or mathematics. When these processes are modeled for ecological settings, interesting properties emerge: ecological or evolutionary processes seem to drive ecosystems towards a critical state, characterized by scale-invariant properties. This phenomenon, called “self-organized criticality”, may hence explain the widespread occurrence of scale-invariance in ecological systems.

Chapter 5 deals with a more down-to-earth topic: the implication of spatial complexity generated by habitat loss and fragmentation for population persistence, and in particular implications for extinction thresholds. The authors start with some very simple models that show how habitat loss affects population dynamics, but then increase the complexity by explicitly dealing with spatial complexity and food-web structure. Here a nice application is given of percolation models to show how the relation between fragmentation and species persistence can be highly nonlinear, where persistence collapses to near zero when a critical proportion of the habitat has been destroyed.
The sixth chapter deals with the most iconic form of complexity in ecosystems: food-web complexity. By consuming others, species form complex networks of feeding relations. Theory of food webs has centered on the question how complexity relates to the fragility of food webs; while our intuition suggests that more complex food webs are more stable, food-web models point out that complexity in food webs makes them more fragile. The authors discuss how topological and dynamical constraints can shape food webs, emphasizing that food webs are more than just random collections of species: they contain structure. Moreover, some species, so-called keystone species, have a more profound role in the stability and functioning of food webs than others, and their removal can have a large influence on the entire community. A good overview is given of the mechanisms that (may) structure food webs and allow complex systems to persist, despite of their complexity.

The final chapter deals with a topic that is clearly close to the hearts of the authors: how complexity affects evolutionary processes. Many evolutionary studies emphasize that evolution allows species to adapt to changing conditions, typically referring to environmental conditions. The authors argue that in complex ecosystems, species also adapt to other species. A well-known example of this is of course co-evolution, in which two species are locked in an arms-race race of adaptation to each other. Most species, however, do not have a single food source, predator, or parasite, but have to deal with a continuum of change within a community of potential predators and prey. The authors discuss a number of models that reveal that in such complex ecosystems, disturbances can induce evolutionary cascades that can lead to the collapse of natural communities (in an evolutionary sense). Using the models to develop scaling relations that are compared with the fossil record, the authors develop a story that centers around the question whether the dramatic changes in biodiversity that have been observed in the fossil record are, at least in part, due to complex evolutionary dynamics, rather than due to large-scale disturbances such as meteor strikes.

After reading the book, I was impressed by the thorough job that the authors have done in reviewing the use of complexity principles and models in ecology. Even in my own field (spatial self-organization), they introduced me to a number of studies that I hadn’t seen before. The other chapters give a thorough introduction into the other ecological and evolutionary fields where complexity principles are used. The book has a number of weak points, nevertheless. When explaining models of complexity, the authors adhere to formal mathematical notation, using mathematical equations rather than words to explain assumptions. As I do not have a mathematical background, I often find myself rereading the formulations a couple of times in order to grasp what they mean, which is followed by “Oh, that’s all” feeling when I see the logic. Another thing that struck me as a weak point of the book is the surprisingly low coverage of empirical studies on ecological complexity. The book mostly deals with mathematic and numerical models. In most chapters, the authors list a small number of empirical studies to provide examples of the models that were explained. These examples are not discussed in detail, and this often leaves me with the question: does the described study system really agree with the model? I am not sure, however, whether the authors are really to blame for this. In my opinion, the topic of complexity in ecology is in its current state mostly about the complexity of models rather than of the natural world. The number of good example systems in which percolating disturbances generate complex spatial patterning (see Chapter 4) is limited to forest fire and mussel beds on rocky shores. Turing-type patterning (Chapter 3) has so far only convincingly been found in arid grass and bush lands (the so-called tiger and leopard bushes), although new examples are quickly emerging. Despite of these weaker points, the book gives a great and thorough overview of complexity theory and how its principles have invaded ecology and evolution.

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