Towards a theoretical ecology for global biogeochemical cycles

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Abstract

Biogeochemistry is the science of elemental flows across the Earth as mediated by living organisms. The most important ones are carbon, water (oxygen), nitrogen, and phosphorous, all of which have been included into Earth system models. However, only very few of the multiple flows and their interactions with climate can be described based on sound theoretical concepts: notably the trade-off between carbon and water uptake during photosynthesis of higher plants, and the low-temperature limits to the spread of certain woody species.

Life on Earth evolved as a system of interacting micro-organisms exploiting various forms of free energy with the help of complex biomolecules. Selection among micro-organisms is rapid and it can be assumed that microbial ecosystems are optimally adapted to their environement. This situation opens the way for a theoretical foundation of biogeochemistry that allows quantitative prediction based on physical biochemistry and the principle of Darwinian selection at the individual, species and ecosystem level. Some progress has been made in this direction, notably for marine ecosystems (Follows et al., 2007; Follows and Dutkiewicz, 2011). Models of metabolic flows have been used as a basis for ecological models (Brown et al., 2004), and it has become possible to use genetic information to predict complex metabolic flows of some well-studied micro-organism (Edwards et al., 2001). Another useful concept is the use of scaling laws for organism size during growth, where organism size becomes a guiding variable of the predictive model (Kooijman 2001). However, the main challenge of these models is the accurate assignmenty of material and energetic trade-offs between different adaptation strategies. A good example is the energetics of nitrogen fixation (Geider & La Roche, 2001).

I believe that the time has come to adapt some of these concepts to the soil biogeochemistry of terrestrial ecosystems in general. Compared to the large structural species that have been the mainstay of terrestrial bioechemical models, microbial ecystems have the advantage of being smaller and thus more amenable to experimentation. Darwinian selection should also be more complete and closer to optimal because of rapid exchange of genetic material and large numbers of individuals. In this talk, I will therefore sketch some ideas for a modelling framework that would describe the adaptation of microbial decomposers of soil organic carbon to micro-climate and substrate. The ideas should be testable by expriment, and therefore the number of parameters has to be kept small. The principle of optimality and Darwinian adaptation underpins the framework, in which functional groups should be allowed to emerge from first principles combined with physically based limits and functional trade-offs. The goal is to start a discussion that will lead to a first set of questions that could be addressed during a short start-up project, but with a perspective of developing this into a long-term theoretical-experimental collaboration.

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