The history of Earth's biospheric productivity: a biogeochemical modeling perspective

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The modern Earth's biosphere is powered by the oxygenic photosynthesis, which can extract electrons from ubiquitous water molecules, maintaining a large net primary production (NPP) of ~100 Gt C every year. So productive are the effects of life itself on this planet that they bootstrap themselves into a highly productive state through recycling the materials, with the result that life plays a critical role in the chemical composition of the atmosphere. Perhaps even more remarkably, the interplay between life and the atmosphere has been occurring continuously for nearly 4 billion years and will continue to the future. However significant gaps remain in our mechanistic understanding of Earth's atmospheric evolution, and in particular the cause-and-effect relationships with evolving biosphere. Here, I use a suite of biogeochemical models to evaluate the history of the activity level of the biosphere. First, I employ the simple Earth system model of biogeochemistry (CANOPS) in order to constrain the oceanic biological productivity during the mid-Proterozoic. Using a stochastic approach (Monte Carlo simulation) with existing constraints on seawater SO_4^{2-} levels, NPP was estimated at 22^{+18}_{-10}% (1*sigma*) of the present value, providing a simple explanation for the protracted oxygenation of the Earth's atmosphere. Our model requires a scarcity of the primary nutrient (phosphorus) in the ocean interior (<~10% of the present value). While our results provide a comprehensive and statistically robust picture of the mid-Proterozoic Earth system that is consistent with available geologic records, further mechanistic understanding of the P cycle in the anoxic oceans is required to fully understand the stabilization mechanism of atmospheric O_2 during the Proterozoic. Next, a simplified photochemistry-ocean ecosystem model is employed to evaluate productivity on the early Earth before the advent of oxygenic photosynthesis. The results suggest that NPP was ~0.1% and 1% that of the modern Earth for non-photosynthetic (chemotrophic) biosphere and anoxygenic photosynthetic biosphere, respectively. The extremely low NPP fluxes produced by our model imply that the geological fluxes of reductants, rather than light or nutrients, would have been the limiting factor for biological productivity. Our biogeochemical models suggest that the Earth's biosphere overcame limitations for their activity through Earth history and have affected the chemical composition of the atmosphere.

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