Selection for Gaia at multiple scales

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Biological regulation of the environment is present at scales from individuals, to ecosystems, to the global biosphere. However, the emergence of regulation at scales which cannot have been units of natural selection is a very different problem from the Darwinian evolution of organism-level homeostasis. Nevertheless, at local ecosystem level, regulation is beginning to be understood as a consequence of “niche construction” [1]. Recent work [2] has also demonstrated the evolutionary emergence of global regulation from local selection in spatially structured environments that tend to distribute the benefits from regulation preferentially to regulators (and not free-riders or organisms with a destabilising effect). At global scales, biosphere regulation must in addition be reconciled with geochemical feedbacks, often involving well-mixed global reservoirs such as the atmosphere, or geological time delays. This temporal and/or spatial decoupling of effects from actors make evolutionary explanations problematic.

Here we investigate mechanisms by which global regulation might emerge by a non-evolutionary process of self-organisation. We argue that the global biota is assembled over time by a process analogous to ecological community assembly [3], but operating at global scale over geological and macroevolutionary timescales and perturbed by macroevolutionary innovations [4] and geological events. By a process of “sequential selection” [5], fragile systems, or those that destabilise their environment, are then short-lived, and result in extinctions and reorganisations until a relatively stable (but possibly lifeless) state is temporarily reached. We employ simple conceptual models for community assembly, evolutionary innovation, life-environment interaction, and anthropic bias to test three hypotheses for the implications of this mechanism for the stability and regulation of an observed biosphere. The limited information input and the “satisficing” (rather than optimising) nature of the sequential selection mechanism make it probable that: (i) regulation at the global level involves only simple configurations of multiple (individually local and Darwinian) physiologically limited “biotic plunder” mechanisms [7],[8] combined with abiotic feedbacks, and (ii) regulation of the environment is strongest at limits, rather than at optimal conditions for life. Anthropic bias [6] applies a further filter to the distribution of biosphere properties such that (iii) our observed biosphere need be only sufficiently stable for the evolution of complex life.

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A bottom-up perspective on N and P cycling in low oxygen environments: the Baltic Sea versus the Peruvian shelf

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This study presents a combination of field measurements and state-of-the-art modeling to investigate N and P cycling in sediments of two contrasting oxygen stressed systems. Boknis Eck is a 28 m deep channel in the southwest Baltic Sea which experiences severe hypoxia (< 2 μM O_2) in boreal summer lasting until October [1]. A time series analysis of benthic nutrient analyses based on monthly samplings from February to December 2010 revealed that N and P fluxes were elevated in winter due to porewater pumping by bioirrigating organisms which efficiently flushed the upper 10 cm of sediment. During hypoxia, no bioirrigation was measurable, macrofauna were absent and phosphate accumulated to concentrations exceeding 400 μM, resulting in a large diffusive flux to the water column. At the same time, denitrification rates were elevated yet dissimilatory nitrate reduction to ammonium (DNRA) by sulfide oxidizing bacteria (*Beggiatoa* spp) played a much larger role in recycling N between the water column and sediments, thus conserving reactive N in the system. By January 2011, typical winter conditions were once again established.

In the Peruvian OMZ, anoxia is more permanent and ventilation events are less predictable. Benthic N and P cycling investigated at six stations along 11 °S using landers revealed very high rates of ammonium and phosphate fluxes on the shelf and upper slope (80 – 250 m water depth) where extensive areas of mats of *Beggiatoa* were present [2]. DNRA dominated total N turnover (≤ 2.9 mmol N m^{-2} d^{-1}) and accounted for ≥ 65 % of nitrate uptake by the sediments from the bottom water. Only at greater water depths within the OMZ (300 – 1000 m) were the sediments a net sink for reactive N due to denitrification. Overall, our findings in Peru and the Baltic Sea show that high measured benthic uptake rates of oxidized N within OMZs do not necessarily indicate a loss of fixed N from the marine environment, but are instead recycling sites converting nitrate into ammonium. Phosphate release is elevated in both environments, which altogether indicate that similar processes occur in sediments underlying seasonal and more permanent OMZs. Due to the high rates of benthic N and P turnover in OMZs, pelagic models ought to incorporate benthic dynamics in their calculations.

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