Environmental regulation by higher level selection in a simulated network of microbial ecosystems

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The Earth possesses a number of regulatory feedback mechanisms involving life. In the absence of a population of competing biospheres it has proved hard to find a robust evolutionary mechanism that would generate environmental regulation. It has been suggested that regulation must require altruistic environmental alterations by organisms and would therefore be evolutionarily unstable. This need not be the case if organisms alter the environment as a selectively neutral by-product of their metabolism, as in the majority of biogeochemical reactions, but the question then arises: why should the combined by-product effects of the biota have a stabilising, rather than destabilising, influence on the environment? In certain conditions selection acting above the level of the individual can be an effective adaptive force. Here we present an evolutionary simulation model in which environmental regulation involving higher level selection robustly emerges in a network of interconnected microbial ecosystems. The Flask model simulates an evolving microbial community suspended in flasks of liquid with prescribed inputs of nutrients. The system is seeded with a clonal population of 'microbes' that are subject to mutation on genetic loci that determine their nutrient uptake patterns, release patterns, and their effects on, and response to, other environmental variables. Nutrient recycling loops robustly emerge from local adaptation, but populations are vulnerable to crashes caused by 'rebel' mutants which push abiotic conditions away from habitability. In previous work we have demonstrated a community-level response to artificial selection at the level of a single flask. Here we show that spatial structure in a network of interconnected flasks creates conditions for a limited form of higher level natural selection to act on the collective environment-altering properties of local communities. Local communities that improve their environmental conditions achieve larger populations and are better colonisers of available space, while local communities that degrade their environment shrink and become susceptible to invasion. The spread of environment-improving communities alters the global environment towards the optimal conditions for growth and tends to regulate against external perturbations. This work suggests a new mechanism for environmental regulation that is consistent with evolutionary theory. Interestingly, the system appears to be ultrastable — a term originally introduced in cybernetics by W. Ross Ashby — in that its stability requires the maintenance of key variables within bounds. We speculate that the biosphere may also be ultrastable.