Mitigation of global climate change – control of greenhouse gas flux by microbes

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The role of microbes in ecosystems is generally under-appreciated. In any ecosystem microbial biomass represents a large fraction of the macronutrients (C, N, P and S), microbial biochemical activity often dominates transformations of key compounds, and microbial behaviour and physiological activity influence translocation of chemical species. However, perhaps most importantly of all, their rapid growth rates give them a fast feedback response time. Microbes have a greater capacity to participate in ecological feedback mechanisms that contribute to homeostasis than other biological groups. All this means that microbes will be at the forefront of the global response to climate change [1, 2]. They will respond faster and at a larger scale than us. Our generation has the option of managing this global microbial response, either via strategies to adapt to climate change or via introduction of strategies to mitigate climate change.

In order of relative contribution, the most important greenhouse gases are presently water, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Water is not usually considered in the global context because its residence time is so short that it does not get globally mixed. The other three gases are globally mixed, continuing to increase and require internationally coordinated strategies to mitigate their atmospheric levels. In all cases, microbes and their interaction with anthropogenic activities form a significant part of the equation; however, not all microbes exert equivalent impact on gas flux. Atmospheric levels of gases are not only a function of production and consumption processes, but also distribution processes.

The influence of microbes on atmospheric composition is therefore a product of both their biochemistry (rate of production or consumption of the gas) and their location (how easily the physical exchange with the atmosphere occurs) [2]. A very simple illustration of the impact of location comes from comparing photoautotrophs and chemoautotrophs. Both autotrophic types consume CO_2 but only photoautotrophs, by virtue of their requirement for light, are restricted to locations where atmospheric CO_2 is their main source of carbon. We can also readily appreciate the importance of biochemistry from the example of methane removal. Methanotrophs are bacteria that can use methane as sole source of carbon and energy, but not all methanotrophs growing in surface environments contribute significantly to atmospheric methane removal. Methane levels are at concentrations that are orders of magnitude below the K_M for most methanotrophs and consequently only specialised, high affinity methanotrophs make an appreciable contribution to removal of methane from the atmosphere [3].

The above two simple illustrations show that some microbial communities will be far more important in the response to climate change than others [2]. In a global context, the key environments for microbially mediated greenhouse gas flux are those that have high rates of microbial activity, significant atmospheric gas exchange, include populations of organisms producing or consuming major gases and are big enough to be globally significant. These include the gastrointestinal tract of animals, wetlands (including rice paddies), surface upland soils (including most farmland) and the photic zone of marine environments.

The key processes and key organisms in each environment differ and so, consequently, do the options for mitigation strategies. From the perspective of carbon sequestration, greatest attention has been given to the oceans and arable soils. In each case, the potential for carbon trading via (micro)biological sequestration has been explored but considerable uncertainty remains regarding the efficiency, sustainability and capacity to verify long-term storage of carbon. Microbiologists have a significant role to play in ongoing research and also in public education around these issues [1, 2].

The ocean surface is not well mixed with the depths. Long-term carbon sequestration in the deep ocean results from physical transport of carbon from the photic zone below the ocean mixing barrier at around 200 metres [4]. The process is governed by the rate of formation of particulate organic matter (POM), which in essence means primary productivity. POM sinks, translocating carbon to deeper water and the slow rate of mixing of the oceans means that conversion of POM back to CO_2 in deep water does not result in return to the atmosphere. There is no obvious limit to the mass of carbon that could be stored in ocean sediments, therefore, in principle, oceanic carbon sequestration offers vast capacity as a greenhouse gas mitigation strategy.

Managing the process to increase the rate is essentially a microbiological question. Primary productivity in the open ocean is constrained by inorganic nutrients. The limiting nutrients vary in different regions of the ocean, but the majority of the oceans fall into one of two categories, nitrogen-limited or iron-limited. Proposals for both urea-based fertilisation and iron-based fertilisation have been put forward, although most attention has gone to iron. Fertilisation with appropriate nutrients has the advantage that it can be done with existing technology and the costs of supplying fertiliser are easily modelled and therefore readily incorporated into carbon trading schemes. The emerging consensus is that ocean fertilisation, by either route, is not a viable strategy for carbon mitigation.

In addition to uncertainties about the impact of interfering with the ocean ecosystem on such a large scale (especially for urea-based fertilisation), it is now evident that we do not understand enough to predict the efficiency of carbon sequestration. The most recent studies showed that carbon transport after iron fertilisation varied by approximately 80-fold between two relatively close regions of the Southern ocean [5]. Even if rates of carbon sequestration were sufficient to make a cost-effective difference to global atmospheric levels (they haven't been in most studies), verification would remain a major barrier to funding the process through any carbon trading scheme [4].

Soils operate differently to aquatic environments since processes that physically move the carbon to a location where it no longer exchanges with the atmosphere are very much slower [1, 2]. Soil carbon sequestration results when the carbon is transformed to a biochemically recalcitrant form. This presents two key differences with the oceanic carbon pool. The soil pool has a maximum capacity and it is in an environment that will directly experience climate change. A major proportion of the Earth's arable soils are already managed and there are essentially both adaptive and mitigative questions. How will climate change impact existing soil carbon pools? For example, do we need to adapt our existing practises simply to keep the soil carbon pool at current levels? The second aspect is what is the carbon carrying capacity of soils? Can we mitigate the effects of climate change by adopting practices that actually sequester additional carbon? In general terms, increasing soil carbon is seen as a good thing, so the potential for ecological damage is small (at least relative to ocean fertilisation). The major barriers here are our relatively poor understanding of the more complex system.

References

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