**Module Essay 1**

The microbiology community’s general consensus is that humans would not be able to live without microbes. Falkowski et al.(1) commented that “*Microbial life can easily live without us; we, however, cannot survive without the global catalysis and environmental transformations it provides.".* It may be bold to assume they are necessary for our survival, but their existence is essential to our current lifestyle. Microbial networks facilitate the biogeochemical processes that cycle our nutrients and maintain a livable atmosphere. They are difficult to replicate because of their complexity and scale, and efforts to emulate them have resulted in environmental damage. Furthermore, their resilience makes them valuable assets in our fight against climate change.

Microbes form metabolic networks that facilitate the biogeochemical processes which fix and cycle our nutrients. Carbon and nitrogen are necessary for the production of biological building blocks that make up our body (2), but they cannot be utilized as our nutrients unless they are either converted from its inorganic form or reduced. Nitrogen can only be incorporated into biological molecules through nitrogen fixation, where nitrogen gas (N2) is reduced to ammonium. Microbes are the only organisms that can accomplish this biotically, since their genes encode the enzyme nitrogenase—a heterodimeric complex that breaks apart the N≡N bond of N2 (1). Similarly, microbes are necessary for the movement of carbon between sinks. There are three times as many global organic carbon stocks stored in soil as the amount of inorganic carbon stored in the atmosphere as CO2 (3). If microbial respiration were to cease, current primary production would deplete atmospheric CO2 stocks in 12 years (4) and dramatically decrease the rate of photosynthesis in our crops.

We currently do not have the technological capacity to replace these metabolic networks due to their complexity and scale. Metabolic networks consist of individual redox reactions that are carried out by different macromolecular complexes that are encoded by many genes or housed in different microbial groups. In oxygenic photosynthesis, 100 genes alone are needed to encode the molecular complexes required for energy transduction (6). To further complicate matters, some pathways in biogeochemical cycles are catalyzed by diverse multispecies microbial interactions. In the nitrogen cycle, NH4+ is first oxidized to NO2- by a group of Bacteria or Archaea then a different group of nitrifying oxidizing bacteria oxidizes NO2- to NO3- (7). The scale of these reactions is another challenging aspect we would need to overcome. There are approximately prokaryotes on earth in total (8) and these numbers do not include eukaryotic microorganisms. The sheer abundance of these microorganisms demonstrates that these microbial metabolic networks exist at a large scale that we may never be able to reconstruct entirely.

Our attempts to emulate some of these metabolic networks have been damaging for the environment and further highlights our limitations. Humans have acquired the ability to fix nitrogen inorganically through fossil fuel combustion, almost doubling the rate of terrestrial nitrogen fixation. The excess NH4+ produced industriallyis converted to NO3- , which leaches into water reserves and creates anoxic zones. This lead to a rise in atmospheric N2O—a greenhouse gas that has 300 times global warming potential of CO2. These environmental damages are a testament of our inability to construct an elegant biochemical network like microbes. Until we can balance the inputs of our activities with an output that does not alter the climate, we will need to rely on the adaptive capabilities of microbes to produce a new steady state for the biosphere.

Microbes are invaluable allies in our efforts to combat climate change and our foray into the Anthropocene Era because of their resilience to environmental changes. We have disturbed major Earth-system processes through our interference with the nitrogen cycle and climate change, disturbing the very environmental conditions that enabled our development. To salvage the damage, we would require the help of microbes. They can adapt to environmental changes quickly because their large numbers and rapid growth gives them the capacity create genetically diverse groups—granting them the ability to form new metabolic networks. The formation of these new networks can create a new steady state where excess nitrogen or carbon dioxide is removed from the system at the same rate it is added (8). Indeed, up until the Industrial Revolution, the evolution and basic composition of Earth’s atmosphere was tightly linked to the evolution of their metabolic networks (5). Cyanobacteria, which are oxygen producers as well as major nitrogen fixers, have had to evolve complex mechanisms to protect their oxygen sensitive nitrogenase. Taken together, microbes’ ability to resist environmental changes through evolutionary processes makes them indispensable allies in the fight against human-driven climate change.

In conclusion, microbes are necessary because of the metabolic networks they form. These networks facilitate biogeochemical process that are critical to our current lifestyle. Moreover, our attempts to mimic these processes have significantly damaged the environment and spurred climate change. The resilience of these metabolic networks to our activities will be instrumental as we enter the Anthropocene Era, but our perturbation of microbial-driven biogeochemical processes could lead to irreversible changes unless we practice restraint.

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