MICB425 – Microbial Ecological Genomics
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"Microbial life can easily live without us; we, however, cannot survive without the global catalysis and environmental transformations it provides."

Microbial life can easily survive without humans thanks to their high diversity and adaptability to harsh environments with the help of lateral gene transfer and point mutations. Microbes also played a significant role in the creation of Earth's biosphere billions of years ago and they still play a major role in maintaining the nutrient cycles in present day Earth. However, given enough time and resources, the statement "[humans] cannot survive without the global catalysis and environmental transformations [that microbes provide]" will eventually become invalidated by human ingenuity. Humans are sentient beings that have the capacity to innovate and invent technologies to adapt to the changing environment. To expand on this point, this paper will cover the effects of human impacts on the nutrient cycles, humanity's ability to overcome thermodynamic barriers with the help from current available technologies, and the potential technologies that may simulate the global catalysis and environmental transformations provided by microbes.

The balances of the nutrient cycles – such as the carbon and nitrogen cycles – have been disturbed significantly due to human activities (Denman *et al*. 2007). For instance, in the carbon cycle the atmospheric CO_2 concentration has almost exceeded 100 ppm above pre-industrial level due to fossil fuel burning and cement production (Denman *et al*. 2007). The effects of these human activities in the carbon cycle alone have caused a shift in ecosystem structure in response to climate change, which can affect the environment of microbes in terms of temperature, nutrient supply availability, ocean pH, and other factors (Denman *et al*. 2007). Furthermore, the coupled climate-carbon cycle models proposed in Denman *et al.* have indicated an increase in CO_2 emissions and a decrease in efficiency of CO_2 uptake by land and ocean, which in turn produces a positive feedback to climate change (Denman *et al.* 2007). As for the nitrogen cycle, human activities have significantly increased the influx and efflux of reactive N to the global atmosphere by three to five-fold (Denman *et al.* 2007). The use of synthetic nitrogen fertilizers, intensification of agriculture, and fossil fuel combustion are most likely the link to "acceleration" of the nitrogen cycle (Denman *et al*. 2007). For instance, the nutrient supply to the ocean has been altered due to increased nitrate release from lands utilizing synthetic nitrogen fertilizers (Denman *et al.* 2007). In another paper, similar observations were made with the study mentioned above in regards to human contributions in the nitrogen cycle. The paper separated the sources of N_r into reduced nitrogen – which were produced from the Haber-Bosch process – and oxidized nitrogen – via combustion of fossil fuels (Fowler *et al.* 2013). For the reduced nitrogen, anthropogenic production of N_r were estimated to be 120 Tg N in the first decade of the twenty-first century and have steadily increased to 180 (±20) Tg N annually (Fowler *et al.* 2013). The inefficient use of synthetic nitrogen was also noted as only 17% of the nitrogen used were consumed by humans in crops, dairy, and meat products; the remainder of nitrogen were lost to soils, freshwaters, and the atmosphere (Fowler *et al.* 2013). In addition to this, oxidized nitrogen via combustion within internal combustion engines and industrial power plants also contributed to the nitrogen cycle via the creation of N_r (Fowler *et al.* 2013). The global NO_x production and emission estimates were approximately 40 Tg N yr^{-1}, which comprised of 30 Tg N from fossil fuel combustion (creation of new N_r), 5 Tg N from biomass combustion, and 5 Tg N from soil NO emissions (Folwer *et al.* 2013). These results demonstrated that human impacts can significantly influence the nutrient cycles as much as microbes and that the survival of microbial species also becomes increasingly dependent on humanity as time progresses.

Microbial communities are required to work together in order to overcome the thermodynamic barriers of their biogeochemical processes in a stepwise fashion (Ho *et al.* 2016). The loss of one community due to a slight variation in their environment may significantly hinder these biogeochemical processes (Ho *et al.* 2016). Humans are not dependent on these constraints due to the advancements of technologies such as the Haber-Bosch process – which enables artificial nitrogen fixation. Currently, the use of nitrogen fertilizers from the Haber-Bosch process contributes to approximately 45% of the world's population through agriculture (Smil 2011). Simply relying on microbes alone for nitrogen fixation will not be enough to satisfy the increasing demand for food. By increasing temperature, pressure, and using iron catalyst to overcome the thermodynamic barrier in producing ammonia, humans can mass produce inexpensive nitrogen fertilizers for agricultural use (Smil 2011, Chaban and Prezhdo 2016). There are even attempts of making the Haber-Bosch process more efficient in terms of reaction yield and reducing operation costs (Chaban and Prezhdo 2016). The Haber-Bosch process only requires a source of energy and resources to produce ammonia, whereas microbes that participate in nitrogen fixation depend on conditions such as the environment (anaerobic conditions, pH, temperature, etc.), the amount of resources available, and other (Hartmann and Burris 1987, Ferreira *et al* 2016). Since the remainder of nitrogen from synthetic fertilizers were lost to soils, freshwaters, and the atmosphere, humans have developed ways to salvage the remainder of these synthetic nitrogen fertilizers via physical, chemical, and biological processes for reuse (Fowler *et al.* 2013, Crab *et al.* 2007). Microbes alone cannot facilitate the reuse of these resources efficiently since they cannot control the flow of resources in and out of their surroundings. However, with human intervention this becomes possible since humans can easily maintain a mini-ecosystem with the help of available technologies such as earthen treatment ponds/reservoirs and a variety of filters such as trickling filters, bead filters, and fluidized sand biofilters (Crab *et al.* 2007). For humans, controlling the flow of resources becomes significantly easier with these existing technologies and microbes have a better chance of thriving in these artificially created mini-ecosystems (Crab *et al.* 2007).

Considering that humans have developed technologies that can drastically alter the nutrient cycles in just a few decades, developments of processes that can alter the nutrient cycles in the reverse direction should also be possible. Currently, there are various types of research that simulate processes performed by many microbes in addition to the removal of greenhouse gases, albeit on a smaller scale. Some of this research include the use of industrial enzymes – such as carbonic anhydrase – for CO_2 sequestration, the use of CH_4 decomposition on Raney-type catalysts for H_2 production, and artificial photosynthesis through solar thermochemical splitting of water to generate H_2 and potentially O_2 (Yadav *et al*. 2014, Rao and Dey 2017, and Figueiredo *et al*. 2010). The only conditions that these technologies need to operate are reliable energy sources and resources for these reactions to occur. These artificial processes do not need to satisfy additional conditions that biological organisms require to operate at their maximum capacity. These researches alone demonstrate that humans can potentially reverse the effects of their impacts on a global scale in a much smaller timescale than what the microbes need to achieve this. However, in order to overcome the high energy barriers, additional research is required for these potential technologies to become applicable on a global scale.

Humanity is not completely at the mercy of microbes in terms of their dependency on the microbes' roles in global catalysis and environmental transformations. Not only are humans capable of impacting the major nutrient cycles on Earth in a smaller timescale, they also possess technologies capable of imitating some of the biogeochemical processes that microbes perform. One major example would be the Haber-Bosch process that enables the mass production of synthetic nitrogen fertilizers in order to satisfy the increasing demand for food. With human ingenuity, technologies that are capable of reversing the negative effects of human activities on the major nutrient cycles should also be possible. The development of technologies that can utilize renewable energy to transform the byproducts of industrial processes into useful resources show some promising results for the future of humanity. These observations demonstrate that one day humanity can survive without being fully dependent on the global catalysis and environmental transformations that microbes currently provide. However, this brings up the question: Given that human currently have significant impacts on the major nutrient cycles, can microbial life still easily live without humans in the future?

References

Chaban VV, Prezhdo OV. 2016. The Haber Process Made Efficient by Hydroxylated Graphene. https://arxiv.org/ftp/arxiv/papers/1603/1603.08041.pdf (Retrieved Feb.14.2017).

Crab R, Avnimelech Y, Defoirdt T, Bossier P, Verstraete W. 2007. Nitrogen removal techniques in aquaculture for a sustainable production. *AQUACULTURE*. 270:1-14.

Denman *et al*. 2007. Couplings Between Changes in the Climate System and Biogeochemistry. IPCC. https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter7.pdf (Retrieved Feb.12.2017).

Ferreira *et al*. 2016. pH effects on nodulation and biological nitrogen fixation in calopogonium mucunoides. *Brazilian Journal of Botany* 39(4):1015-1020.

Figueiredo JL, Órfão JJM, and Cunha AF. 2010. Hydrogen production via methane decomposition on Raney-type catalysts. *International Journal of Hydrogen Energy*. 35(18):9795-9800.

Fowler D, Coyle M, Skiba U, *et al*. 2013. The global nitrogen cycle in the twenty-first century. *Philosophical Transactions of the Royal Society of London. Series B*. 368(1621):20130164.

Hartmann A, Burris RH. 1987. Regulation of nitrogenase activity by oxygen in azospirillum brasilense and azospirillum lipoferum. *Journal of Bacteriology* 169(3):944-948.

Ho *et al*. 2016. Biotic interactions in microbial communities as modulators of biogeochemical processes: Methanotrophy as a model system. *Frontiers in Microbiology* 7:1285.

Rao CNR, Dey S. 2017. Solar thermochemical splitting of water to generate hydrogen. Proc Natl Acad Sci USA. 114(51):13385-13393.

Smil V. 2011. Nitrogen cycle and world food production. *World Agriculture*. 2:9-13.

Yadav *et al*. 2014. Carbonic anhydrase mediated carbon dioxide sequestration: Promises, challenges and future prospects. *Journal of Basic Microbiology*. 54(6):472-481.