MICB425 – Microbial Ecological Genomics
Name: Wei Ting Lin (Jonah)
ID: 30616130

"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). Additional couplings between climate change and ocean carbon cycle processes are listed in Table 1.

Marine Carbon Cycle Process	Major Forcing Factors	Response + = positive feedback – = negative feedback and Quantitative Potential	Start	Re-equilibration Time Scale (kyr)	Likelihood	Comment
Biological export production of organic carbon and changes in organic carbon cycling	Warming, ocean circulation, nutrient supply, radiation, atmospheric CO_2, pH value	(Sum of effects not clear) +/– medium	immediate	0.001–10	*Likely*	Complex feedback chain, reactions can be fast for surface ocean, nutrient supply from land works on longer time scales, patterns of biodiversity and ecosystem functioning may be affected
Biological export production of calcium carbonate	Warming, atmospheric CO_2, pH value	(Sum of effects not clear) +/– small	immediate	0.001–1	*Likely*	Complex feedback chain, extinction of species likely, patterns of biodiversity and ecosystem functioning may be affected
Seawater buffering	Atmospheric CO_2, ocean circulation	– high	immediate	5–10	*Virtually certain*	System response, leads to ocean acidification
Changes in inorganic carbon chemistry (solubility, dissociation, buffer factor)	Warming, atmospheric CO_2, ocean circulation	+ medium	immediate	5–10	*Virtually certain*	Positive feedback dependent on 'bottleneck' ocean mixing
Dissolution of calcium carbonate sediments	pH value, ocean circulation	– high	immediate	40	*Virtually certain*	Patterns of biodiversity and ecosystem functioning in deep sea may be affected
Weathering of silicate carbonates	Atmospheric CO_2, warming	– medium	immediate	100	*Likely*	Very long-term negative feedback

Table 1. Couplings between climate change and ocean carbon cycle processes (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). Additional sources of nitrogen compounds (NO_X, NO_3, and N_2O) from both manmade and natural sources can be found in Table 2. Note that the majority of anthropogenic sources for nitrogen are three to four times that of natural sources, which indicates the significance of human impact on the nitrogen cycle. The results of these human impacts on the nutrient cycles demonstrate that humans can significantly impact the nutrient cycles as much as microbes and that the survival of microbial species also becomes increasingly dependent on humanity as time progresses.

Table 2. Global sources (TgN/yr) of NO_X, NH_3, and N_2O for the 1990s (Denman et al. 2007).

Source	NO_x		NH_3		N_2O	
	TAR[a]	AR4[b]	TAR[a]	AR4[a]	TAR[c]	AR4
Anthropogenic sources						
Fossil fuel combustion & industrial processes	33 (20–24)	25.6 (21–28)	0.3 (0.1–0.5)	2.5[d]	1.3/0.7 (0.2–1.8)	0.7 (0.2–1.8)[d]
Aircraft	0.7 (0.2–0.9)	–[e] (0.5–0.8)	-	-	-	-
Agriculture	2.3[f] (0–4)	1.6[g]	34.2 (16–48)	35[g] (16–48)	6.3/2.9 (0.9–17.9)	2.8 (1.7–4.8)[g]
Biomass and biofuel burning	7.1 (2–12)	5.9 (6–12)	5.7 (3–8)	5.4[d] (3–8)	0.5 (0.2–1.0)	0.7 (0.2–1.0)[g]
Human excreta	–	–	2.6 (1.3–3.9)	2.6[g] (1.3–3.9)	–	0.2[g] (0.1–0.3)[h]
Rivers, estuaries, coastal zones	–	–	–	–	–	1.7 (0.5–2.9)[i]
Atmospheric deposition	–	0.3[g]	–	–	–	0.6[i] (0.3–0.9)[h]
Anthropogenic total	**43.1**	**33.4**	**42.8**	**45.5**	**8.1/4.1**	**6.7**
Natural sources						
Soils under natural vegetation	3.3[f] (3–8)	7.3[j] (5–8)	2.4 (1–10)	2.4[g] (1–10)	6.0/6.6 (3.3–9.9)	6.6 (3.3–9.0)[g]
Oceans	–	–	8.2 (3–16)	8.2[g] (3–6)	3.0/3.6 (1.0–5.7)	3.8 (1.8–5.8)[k]
Lightning	5 (2–12)	1.1–6.4 (3–7)	–	–	–	–
Atmospheric chemistry	<0.5	–	–	–	0.6 (0.3–1.2)	0.6 (0.3–1.2)[c]
Natural total	**8.8**	**8.4–13.7**	**10.6**	**10.6**	**9.6/10.8**	**11.0**
Total sources	**51.9** (27.2–60.9)	**41.8–47.1** (37.4–57.7)	**53.4** (40–70)	**56.1** (26.8–78.4)	**17.7/14.9** (5.9–37.5)	**17.7** (8.5–27.7)

Notes:

[a] Values from the TAR: NO_x from Table 4.8 with ranges from Tables 4.8 and 5.2; NH_3 from Table 5.2, unless noted.

[b] Parentheses show the range of emissions used in the model runs described in Table 7.9. See text for explanation. Where possible, the best estimate NO_x emission is based on satellite observations. None of the model studies includes the NO_x source from oxidation of NH_3, which could contribute up to 3 TgN yr^{-1}. The source of NO_x from stratosphere-troposphere exchange is less than 1 TgN yr^{-1} in all models, which is well constrained from observations of N_2O-NO_x correlations in the lower stratosphere (Olsen et al., 2001).

[c] Values are from the TAR, Table 4.4; Mosier et al. (1998); Kroeze et al. (1999)/Olivier et al. (1998): a single value indicates agreement between the sources and methodologies of the different studies.

[d] Van Aardenne et al. (2001), range from the TAR.

[e] The aircraft source is included in the total for industrial processes. The parentheses indicate values used in model runs.

[f] The total soil NO_x emissions estimate of 5.6 provided in Table 4.8 of the TAR was distributed between agriculture and soil NO_x according to the proportions provided in the TAR, Table 5.2.

[g] Bouwman et al. (2001, Table 1); Bouwman et al. (2002) for the 1990s; range from the TAR or calculated as ±50%.

[h] Estimated as ±50%.

[i] Kroeze et al. (2005); Nevison et al. (2004); estimated uncertainty is ±70% from Nevison et al. (2004).

[j] All soils, minus the fertilized agricultural soils indicated above.

[k] Nevison et al. (2003, 2004), combining the uncertainties in ocean production and oceanic exchange.

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 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).

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 researches that simulate processes performed by many microbes in addition to the removal of greenhouse gases, albeit on a smaller scale. Some of these researches 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?

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