Microbial Carbon Sequestration in the Ocean: The Big Role of Small Bugs in Mitigating Global Climate Change

— An Interview with Prof. JIAO Nianzhi

Ocean is the largest carbon reservoir on Earth. By taking up about one-third of all human carbon emissions, it has effectively reduced atmospheric carbon dioxide and eased global climate change.

Scientists have studied extensively on the mechanisms of CO_2 absorption in the ocean, or the so-called "carbon pumps", from physical to chemical and biological pumps. Microbes, traditionally regarded as organic matter decomposers, had been long neglected until a few years ago Prof. JIAO Nianzhi from Xiamen University proposed the concept "microbial carbon pump (MCP)" illustrating that these tiny marine inhabitants are also producers of refractory dissolved organic carbon, a persistent form of matter which can be stored in the ocean for thousands of years and thus constitute an ideal carbon pool. Today, the MCP concept has been widely accepted as a promising sequestration strategy, and Prof. JIAO is working hand in hand with scientists from all over the world under the Scientific Committee on Oceanic Research (SCOR) Working Group 134 to better understand how to use these magic creatures for preserving carbon in the deep blue.

During an interview with BCAS reporter XIN Ling on June 4, Prof. JIAO introduced the rationale of MCP and its advantages over other carbon pumps. He also envisioned the potential application of MCP. In his words, "the problem we're facing is huge, from a bug in the ocean to climate change on Earth".

Prof. JIAO Nianzhi is an outstanding scientist in microbial ecology and ocean carbon cycling. Before joining Xiamen University as Cheung Kong Chair Professor in 2000, he had conducted research at the CAS Institute of Oceanology, the MIT, the University of Tokyo and the National Institute for Environmental Studies of Japan. He was elected Member of the Chinese Academy of Sciences in 2011. (Photo: BCAS)

***BCAS:** What is the scientific background of the MCP theory?*

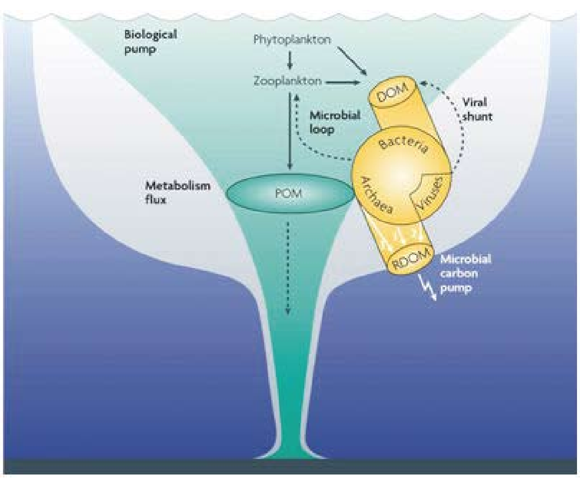
Prof. JIAO: There are several known mechanisms for the ocean to store carbon dioxide. One is called the "solubility pump". After carbon dioxide dissolves in water, there is a natural physical process to transport dissolved inorganic carbon from the ocean's surface to its interior. However, many studies have confirmed that as atmospheric CO_2 continue to accumulate and heat up the Earth, the solubility of CO_2 in the ocean will decrease and the reservoir becomes less effective. For instance, in the last century, the solubility pump contributed to around 80% of all anthropogenic CO_2 uptake by the ocean. Today the contribution rate is less than 50%. Besides, the chemical reactions between CO_2 and water have led to ocean acidification and many negative consequences for marine ecosystems such as the death of coral reefs.

A second mechanism is called the "carbonate pump".

When marine organisms die, a fraction of their calcium carbonate skeletal coverings will be transported to the bottom of the ocean and buried there for long term storage. However, a formerly ignored fact is that in forming calcium carbonate, the organism will also release a same equivalent of carbon dioxide as a result of biochemical reaction, and heterotrophs are a releaser rather than absorber of carbon. Now the mechanism is often referred to as the "carbonate counter-pump".

A third mechanism, the "biological pump", is well known and can be manipulated for human purpose. A famous case is iron fertilization. We all know there are very few nutrient substances in the barren ocean. If we introduce proper trace elements into the ocean, they can remarkably enhance the ocean's biological productivity and gear up the biological pumps. The notion was first proposed in the late 1980s by US oceanographer John Martin, the man who declared that "give me half a tanker of iron and I'll give you the next ice age". However, iron fertilization will induce phytoplankton blooms and could trigger marine ecological disasters including red tide, the death of fishes from toxic materials, as well as invisible but fatal changes in the structure and function of the marine community. Iron fertilization has also been proven to indirectly accelerate ocean acidification.

The "microbial carbon pump" or MCP, as we proposed, refers to the transformation of dissolved organic carbon (DOC) in the water from labile to refractory states driven by microbes including bacteria, archaea, phytoplankton and viruses. The labile DOC is biologically available while refractory DOC is hard to digest and thus accumulate to a huge carbon reservoir, constituting carbon sequestration in the ocean.



A diagram of the microbial carbon pump (MCP, yellow color) and the classical biological pump (green color) as well as relevant biological processes involved in carbon cycle in the ocean. (Photo courtesy Prof. Jiao Nianzhi)

BCAS: *It must be hard to understand at first: in people's intuition, microbes are decomposers that give off carbon dioxide to the air. How can they store carbon instead?*

Prof. JIAO: Yes, it was difficult in the beginning. A key fact here is when microbes decompose marine organisms for food, they also have to protect themselves from being degraded by extracellular enzyme present in the marine environment. By synthesizing D-amino acids, microbes build up very strong cell walls to resist the degradation of enzymes. When they die, the D-amino acids in them are released into the ocean and become refractory dissolved organic carbon (RDOC), which is left unused and thus accumulated over time to form a great carbon reservoir. This new role of microbes, totally different from its traditional one as decomposers, is very important in understanding the MCP.

BCAS: *How did such a novel idea occur to you at first?*

Prof. JIAO: It was about ten years ago when my group was looking into the global distribution of aerobic anoxygenic phototrophic bacteria (AAPB), an old group of bacteria with newly discovered ecological significances. We came to a conclusion that was opposite to that in the literature. So we spent a lot of time digging into different methods and data sets, and finally revealed the specific linkage between AAPB and DOC. As a result, the MCP concept was developed which then began to receive more and more recognition from around the world.

BCAS: *What are you and your coworkers doing in SCOR Working Group 134?*

Prof. JIAO: Together we are making difference. We have put efforts to perfect and promote the MCP framework. We are also developing the MCP, with a multidisciplinary strength pooling the best biologists, chemists and paleoclimate experts in the field together. Now, our group is a consortium of 26 scientists from 12 countries. By far we have convened three WG meetings, in Xiamen, San Juan and Delmenhorst respectively, as well as a number of independent workshops and sessions.

BCAS: *How is the MCP superior to other carbon pumps?*

Prof. JIAO: A big difference is that the MCP is non-sinking, while physical and biological pumps more or less depend on the sinking process. The solubility pump is dependent on the transportation of water mass from surface to depths. The biological pump depends on the sinking of particulate organic carbon in the water column. In contrast,

Prof. Jiao at discussion with SCOR WG members. (Photo courtesy Prof. Jiao Nianzhi)

the MCP is non-sinking so carbon can be kept at any depth of the water, even in surface waters. More importantly, the MCP is a naturally occurring process that works at very low cost and without any known negative biological or ecological consequences.

The MCP has been used to explain many mysteries. For instance, now we know that 95% of organic carbon in the ocean is in the form of dissolved organic carbon (DOC) and 95% of the DOC is recalcitrant DOC (RDOC). The vast existence of RDOC explains the gap between the ocean's huge carbon storage and the limited amount of particulate organic carbon known on the sea floor.

The MCP is also the key to accounting for the paradox that some marine areas are rich in organic carbon but poor in biological productivity. That's because the organic carbon produced by phytoplankton is labile and can be easily converted to carbon dioxide. Only carbon that goes through the MCP can become refractory and stable in the marine environment.

A piece of evidence for the MCP comes from paleoclimate study. During the Proterozoic, our planet was ruled by bacteria and the oceans held 500 times as much DOC as today, which was most likely generated by the MCP. The dramatic increase of carbon in the ocean and decrease in the atmosphere had exacerbated climate changes to the biggest ice age called the "snowball Earth" .

BCAS: *Where does the RDOC go eventually?*

Prof. JIAO: Some of the RDOC evolve into aggregates and finally sink to the bottom of the ocean. Some rise to the water surface amid ocean circulation to be degraded by ultraviolet light. As long as the marine environment is stable and free from major natural or human-induced perturbations, the RDOC will be accumulated over time. The average age of RDOC in the current ocean is about 5,000 years. From this perspective, the ocean is endowed with much higher carbon sequestration efficiency than terrestrial carbon sinks, by separating CO_2 from the atmosphere for as long as possible.

BCAS: *How do you see the potential applications of MCP?*

Prof. JIAO: The MCP is especially applicable to waters with eutrophication problems, like the coastal oceans of China. In such environment, the biological pump does not fit in because it will facilitate ecological disasters like harmful algal blooms and other invisible threats. What we should do is to reduce the nutrient level in the ocean by curbing chemical fertilization on the land, and develop the MCP for carbon sequestration.

The MCP can also play a part in the carbon sequestration in estuarine waters. The sinking-process-based biological pump is inefficient due to the shallow water depth, the strong mixing process and the severe resuspension of particles in estuarine waters. The MCP is not confined to such physical conditions thanks to its non-sinking nature.

I think an integrative consideration of the biological pump and the MCP will help us identify the responses of marine carbon sinks to climate changes, as well as the practices conducive to carbon sequestration in the ocean.

The problem we're facing is huge, from a bug in the ocean to climate change on Earth. I'm looking forward to more communications and collaborations with scientists from all related fields. I also hope that we can find a way to convey these ideas to policymakers and seek for implementation opportunities as soon as possible.