Biological mediated carbon cycling and sequestration in the ocean and climate change: A new dimension and perspective

Nianzhi Jiao
Institute of Microbes and Ecospheres, State Key Lab for Marine Environmental Sciences, Xiamen University
jiao@xmu.edu.cn

Acknowledgements
Members of the WG on the MCP, SCOR; Members of the joint PICES-ICES WG33; Members of the IME, XMU; Members of the 973 MCP projects, MOST
Outlines

1) Framework of Microbial Carbon Pump (MCP)
2) Impacts of MCP on climate change
3) Current status of the MCP studies
4) Future applications
Ocean Carbon: ~ 20x Land, 50x Atmospheric C
Play a significant role in climate changes

The Ocean is the largest carbon reservoir

Atmosphere
700 GT

Land
1,900 GT

Ocean
40,000 GT

uptake ~ 1/3 anthropogenic CO₂
Microbial Carbon Pump (MCP)

Jiao et al., 2010

Biological Pump
Diagram
Chisholm 2000
Microbial carbon pump (MCP) vs Biological pump (BP)

BP is based on physical transportation
MCP is based on microbial transformation

BP depends on vertical transport to depths
MCP is independent of water depth
Outlines

1) Framework of Microbial Carbon Pump (MCP)
2) Impacts of MCP on climate change
3) Current status of the MCP
4) Future applications
Since resistant to decomposition, RDOC accumulate

> 95% of marine OC is DOC;
> 95% of DOC is RDOC

DOC = CO$_2$ inventory
Equivalent  

Global warming  

Global cooling  

$\text{CO}_2$  

$\text{CO}_2$  

$\text{CO}_2$  

DOC  

DOC  

DOC
Evidence from the Proterozoic time

Macdonald et al. (2010), Science
Rothman et al. (2003), PNAS

\[ \delta_a = \delta_i + f \varepsilon \]
\[ \delta_i = -23.7\%; f = 0.94 \]

Blue: First Decoupling
Red: Second Decoupling

Size \( \geq 10^2-10^3 \) times of modern DOC
Turn-over Time \( \geq 10^4 \) years

Metazoan were not evolved yet
no grazing impacts
\( \rightarrow \) microbial C accumulated \( \rightarrow \) Viral lysis
\( \rightarrow \) tremendous DOC pool
Evidence in the current ocean

Hansell et al. 2009
Outlines

1) Framework of Microbial Carbon Pump (MCP)
2) Impacts of MCP on climate change
3) Current status of the MCP
4) Future applications
“微型生物碳泵”储碳新机制

Jiao et al., 2010
“海洋微型生物碳泵”；

Jiao et al., 2010

*Nature Reviews Microbiology* 作为其 featured Article

在其封面、目录、网站 Highlighted
MCP special issues
Science 评论 MCP为 “巨大碳库的幕后推手”

A key element of the carbon cycle is the microbial conversion of dissolved organic carbon into inedible forms. Can it also serve to sequester CO2?
Correspondences

Biosequestration of carbon by heterotrophic microorganisms

Ronald Benner

In their correspondence, Microbial production of recalcitrant organic matter in global soils: implications for productivity and climate policy, Nature Rev. Microbiol. 28 Nov 2010 (doi:10.1038/nrmicro2896-410), Liang and Baker point out similarities between the microbial production of recalcitrant non-living organic matter (RNOM) in soils and in sea water, as presented by Liu et al. (Microbial production of recalcitrant dissolved organic matter: a long-term carbon storage in the global ocean. Nature Rev. Microbiol. 8, 593–599 (2010)) in the conceptual framework of the microbial carbon pump. There is growing evidence indicating that RNOM derived from microorganisms is a large, and possibly dominant, global component of the non-living reduced carbon in water, sediments and soils. This realization has profound implications for our view of the role of microorganisms in biogeochemical cycles and the origins and cycling of RNOM in the environment.

Heterotrophic microorganisms in aquatic and terrestrial systems have an important role in organic matter decomposition. In this role, heterotrophic microorganisms remineralize carbon and are thereby a major source of carbon dioxide to the atmosphere. Bacteria and fungi are noted for their diverse enzymatic capabilities and their ability to degrade complex biopolymers, such as structural polysaccharides and lignins. These microorganisms are nature’s ultimate recyclers, growing and multiplying while decomposing life’s organic debris. Recent observations indicate a previously unrecognized functional role for heterotrophic microorganisms that transcend the classical role of carbon remineralization and nutrient regeneration. Microorganisms can grow rapidly during organic matter decomposition, and remnants of microbial biomass are released into the environment through a variety of processes, including cell division, lysis by viruses and phages, and protozoan grazing. These microbial remnants (including complex biomolecules with unique structural components such as lipopolysaccharides and haptophytes) that are recalcitrant and can remain in the environment for extended periods of time. The organic remnants left behind after the death of a large marine mammal can persist as molecular fossils in sediments for as long as 2,500 million years.

Correspondences

MCP is applicable to terrestrial environments

MCP in Soil
Trends in relative dominance of the BP and the MCP along environmental gradients
RDOCt vs RDOCc

Why deep ocean DOC can hold in the presence of hungry microbes?

- **RDOCt** _Rcalcitrance of the RDOC under certain environmental conditions_
- **RDOCc** _RDOC compounds are very diverse. There are thousands of different molecules generated from the successive microbial processing of organic matter. Each individual molecule could be at extremely low concentration which is below the microbial uptake threshold._

Jiao et al., 2014 Biogeoscience
RDOC t rather than RDOCc is the majority of deep-sea RDOC pool

Jiao et al., Science 2015,
An appreciable fraction of bacterial DOM has molecular and structural properties that are consistent with those of refractory molecules in the ocean, indicating a dominant role for bacteria in shaping the refractory nature of marine DOM. The rapid production of chemically complex and persistent molecules from simple biochemicals demonstrates a positive feedback between primary production and refractory DOM formation. It appears that carbon sequestration in diverse and structurally complex dissolved molecules that persist in the environment is largely driven by bacteria.
(a) Fourier transform ion cyclotron resonance mass spectrum of Synechococcus SPE-DOM, (b) van Krevelen diagram of all assigned molecular formulas of Synechococcus (CB0101) SPE-DOM and (c) van Krevelen diagrams of the distribution of CHNO formulas. Note: size of bubbles represent relative abundance.
First meeting of “Ocean Biogeochemistry” on Biological driven carbon pumps
HK, China
2016.6.12-17
1) Framework of Microbial Carbon Pump (MCP)
2) Impacts of MCP on climate change
3) Current status of the MCP studies
4) Applications and future direction
MCP is applicable to different environments

Implication for policy

Correspondence

Microbial production of recalcitrant organic matter in global soils: implications for productivity and climate policy

Chao Liang and Teri C. Balken

In their recent article (Microbial production of recalcitrant organic matter in global soils: implications for productivity and climate policy), Liang et al. (2019) discuss the importance of microbial production of recalcitrant organic matter (ROM) in global soils and its implications for productivity and climate policy. The authors highlight the role of ROM in soil carbon storage and its potential impact on climate change.

In their study, the authors use a combination of field observations and modeling to estimate the contribution of ROM to global soil carbon storage. They find that ROM can account for a significant portion of soil carbon, with estimates ranging from 4% to 10% of total soil carbon. This suggests that efforts to increase soil carbon through agriculture and land management practices should also consider the role of ROM.

The implications of these findings are significant for policy makers and stakeholders interested in climate change mitigation and adaptation. The authors recommend further research to better understand the dynamics of ROM and its role in soil carbon storage.

Liang et al. (2019) highlight the need for continued research to better understand the factors influencing ROM formation and decomposition, as well as the potential for management strategies to enhance ROM formation. This research could inform the development of policies to support the conservation and enhancement of soil carbon.

Correspondence

Chao Liang and Teri C. Balken

Additional research is needed to further understand the role of ROM in soil carbon storage and its implications for climate change. Future studies should focus on improving our understanding of ROM formation, decomposition, and the factors influencing these processes. This could help inform the development of strategies to increase soil carbon and mitigate climate change.
A proposal for practice: Increase Carbon sequestration in the coastal water by reducing fertilization on the land

Jiao et al., 2010
Nutrients can be a double edged sword. Maximum output of the sum of “BP+MCP” is the goal to achieve for carbon sequestration.

Jiao et al., 2014
Figure 1 | NO$_3^-$ concentration as a function of DOC or POC concentration among Earth’s major ecosystems. Data were gathered from ecosystems in tropical, temperate, boreal and arctic regions, and include data sets collected on local, watershed, regional, national and global scales. a, Soils. b, Groundwaters, streams and rivers. c, Human-disturbed streams and rivers are waterways within the USA, which are predominantly influenced by agricultural activities. d, Lakes, ponds and wetlands. e, Estuaries, bays and coastal margins. f, Seas and oceans: the separation of the pattern reflects biogeochemical differences in C richness among distinct ocean provinces. See Table 1 for statistical analyses and Supplementary Table 1 for references used. Axes are truncated for best observation of data.

全国30多个涉海单位的科技人员秉承“自发、自愿、贡献、分享”的原则共同组建的“全国海洋碳汇联盟（COCA）”于2013年9月17日在三亚揭牌成立。
海洋碳汇时间序列监测站--东山站

海洋碳汇时间序列监测站

南海海上石油平台碳汇联合监测站

三亚崖城南山终端联合监测站

西沙海洋碳汇联合监测站

舟山海洋碳汇联合监测站

渤海海上石油平台碳汇联合监测站

养殖环境海洋碳汇监测站
2014年 发起建立“China Future Alliance”
PICES --- FUTURE-China

2015年10月
Marine Environmental Chamber System (MECS)

Mini MECS at Shandong University (Qingdao Campus)
MECS for Ecosystem-level Scenario Studies
Such as BP vs MCP at different conditions ...
Seek optimum combined conditions for maximum output of the sum of “BP+MCP”
BP is very strong in the current ocean but was very weak in the ancient ocean, resulting in accumulation of DOM. MCP was very strong in ancient time, and DOM reservoir is 100 times larger than the current one. Therefore, MCP plays a significant role in climate change (Ridgwell, 2011).
Shifts in biogenic carbon flow from particulate to dissolved forms under high carbon dioxide and warm ocean conditions

Kim et al., 2011, Geophysical Research Letters

BP ↔ MCP
• Global cooling ↔ Global warming
Thanks for your attention!