Final Report to SCOR

SCOR WG134-The Microbial Carbon Pump (MCP) in the Ocean

Terms of Reference:

- Summarize representative microbial data on biomass, production and diversity of functional groups and overall microbial communities in the context of DOC dynamics along environmental gradients (productivity/temperature/salinity gradients such as estuarine to oceanic waters).
- Establish the current state of knowledge about microbial processes that utilize, generate and transform DOC, and identify essential scientific questions and suggest hypotheses regarding DOC accumulation through the microbial carbon pump.
- Identify the gaps in our understanding of marine DOC and the microbial community structure in different marine regions regarding bioactivity and storage of DOC.
- Document state-of-the-art techniques and parameters addressing microbial processing of organic carbon.
- Establish/standardize key protocols for the essential observations/measurements.
- Convene International Workshop(s) and publish a special volume in an internationally recognized peer-reviewed journal, or a protocol book (practical handbook) by a major publisher on measurements of the key parameters related to microbial processing of carbon in the ocean.
- Make recommendations for future research related to the microbial carbon pump in the ocean, toward development of a large-scale interdisciplinary research program.

SCOR Scientific Steering Committee (SSC) for MCP in the Ocean

Co-chairs:

Nianzhi Jiao

State Key Laboratory of Marine Environmental Science. Xiamen University, P. R. China

Tel & Fax: +86-592-2880150 Email: jiao@xmu.edu.cn

Farooq Azam

Scripps Institution of Oceanography, University of California, San Diego, US

Tel: +1-858-534-6850 Email: fazam@ucsd.edu

Other Full Members

Xosé Antón Álvarez-Salgado (Spain), Chen-Tung Arthur Chen (China-Taipei), Dennis Hansell (USA), Gerhard Herndl (Austria), Gerhard Kattner (Germany), Michal Koblížek (Czech Republic), Colin Stedmon (Denmark), Markus Weinbauer (France).

Associate Members

Ronald Benner (USA), Craig Carlson (USA), Feng Chen (USA), Sang-Jin Kim (Korea), David Kirchman (USA), Ingrid Obernosterer (France), Nagappa Ramaiah (India), Carol Robinson (UK), Richard Sempere (France), Meinhard Simon (Germany), Christian Tamburini (France), Steven Wilhelm (USA), Virginia Edgcomb(USA), Jizhong Zhou (USA), Susan Ziegler (Canada), Chuanlun Zhang(USA)

Part I. Progress on implementation of the project (2009-2012)

The SCOR WG134 on the MCP was founded in 2009, led by Prof. Nianzhi Jiao (China) and Prof. Farooq Azam (USA) and joined by 26 scientists from 12 countries. It had been successfully carried on for a four-year term by 2012, with a series of scientific progress achieved and terms of reference completed. The MCP theory is not only a conceptual framework which covers a broad range of disciplines, but also aims to seek a synthesis for future research on and an in depth understanding of the kinetics and mechanistic processes of dissolved organic matter (DOM) dynamics in the oceans. Thus the core aim of WG 134 is to obtain a better understanding of microbial and biogeochemical processes causing labile DOM (LDOM) degradation and alteration, along with the microbial and chemical formation and modification of refractory DOM (RDOM) in the ocean.

1. Overview on science highlights

The MCP concept was established with the publication of a featured article in *Nature Review Microbiology (NRM)* 2010, volume 8. In the paper, the background, rationale and application of the MCP concept were discussed, including representative microbial data on biomass, production and diversity of marine microbial communities in the context of DOM dynamics along environmental gradients, the current state of knowledge about microbial processes that utilize, generate and transform DOM, and essential scientific questions and hypotheses regarding DOC accumulation through the MCP. Moreover, the gaps in our understanding of marine DOC and the microbial community structure in different marine regions regarding bioactivity and future research directions were also addressed. It is noteworthy that this paper was highlighted on the cover and the contents of the issue as well as on the website of *Nature Reviews Microbiology*.

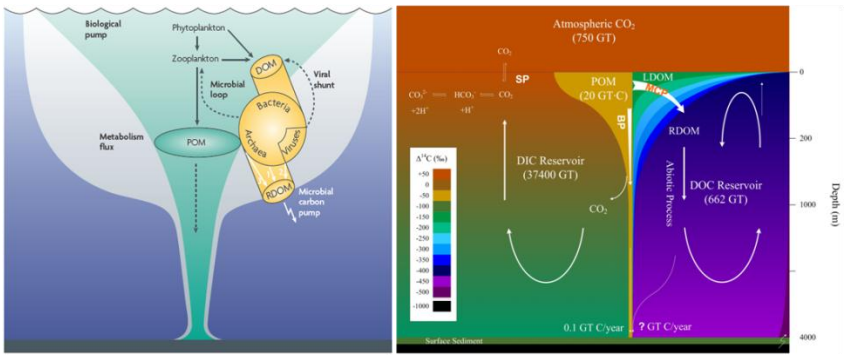


Figure 1. The conceptual framework of MCP and its relationship with the biological pump (left) and the major carbon reservoirs and carbon storage in the ocean (right) (Jiao et al. *Nature Review Microbiology* 2010 (8):593-599).

Not long after the publication of the MCP theory, a *Science News Focus* article (*SCIENCE* 328:1476-1477, 2010) addressed another story about the MCP: its origin, rationale, implications, applications, impacts, and prospects. In this article, the MCP is considered as "An invisible hand behind the vast carbon reservoir".

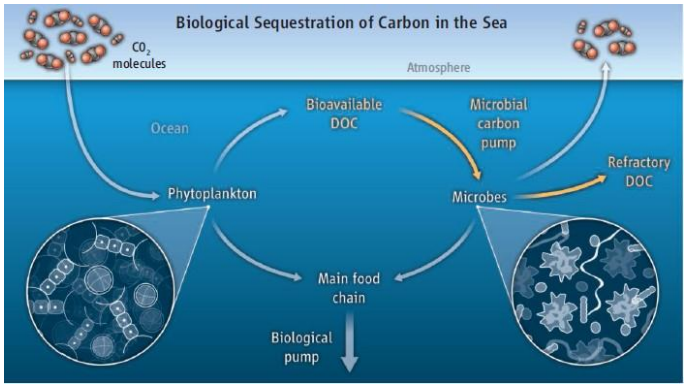


Figure 2. The so called "double-barrel pump" pointed that each year, the biological pump deposits some 300 million tons of carbon in the deep ocean sink. However, even more massive amounts are suspended in the water column as dissolved organic carbon, much of which is converted into refractory forms by the microbial carbon pump (R. Stone. *Science* 18 June 2010: Vol. 328. no. 5985, pp. 1476 -1477).

Meanwhile, the conceptual framework of MCP was adapted to land carbon sequestration by peer colleagues in soil science and Prof. Nianzhi Jiao proposed the idea of "Increasing the microbial carbon sink in the sea by reducing chemical fertilization on the land" (Figure 3).

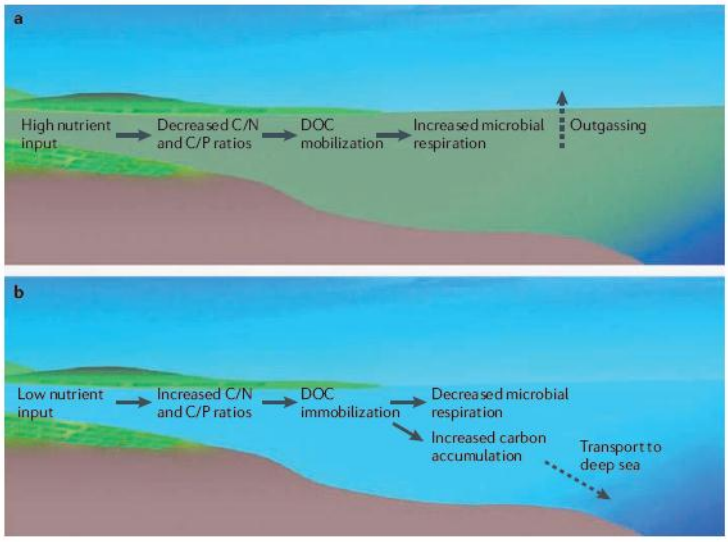


Figure 3. The key information delivered by the aforesaid paper: Microbial carbon processing scenarios under different environmental conditions. Figure a shows that microbial respiration of DOC is mobilized by enhanced terrestrial nutrient input, and b shows microbial carbon sequestration is enhanced by reducing terrestrial nutrient input (Jiao, et al. *Nature Reviews Microbiology*. 2011. 9(1):75.

In the current environment, most coastal waters suffer from excessive nutrients (nitrogen and phosphorus) discharge, which result in eutrophication and harmful algal blooms. More importantly, when nutrients are replete, dissolved organic carbon can be mobilized for microbial degradation and respiration. That is why the estuarine waters, being productive, but are often sources rather than "sinks" of atmospheric CO_2. Reducing nutrient input from the land would be a realistic way to increase microbial carbon sink in such coastal waters.

In correspondence, an article entitled "The microbial carbon pump and the oceanic recalcitrant dissolved organic matter pool" was published in *Nature Reviews Microbiology* 9, 555 (July 2011) (Figure 4).

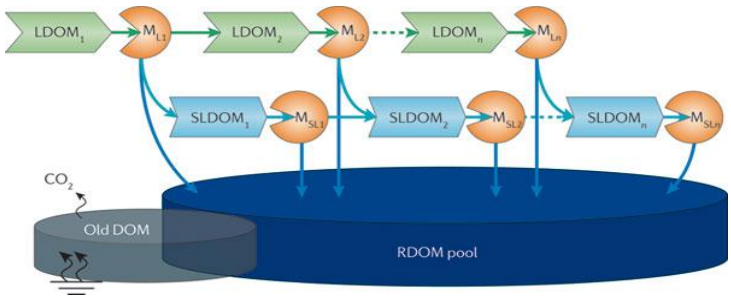


Figure 4. The successive microbial carbon pump processes for RDOM formation and subsequent contribution to

the oceanic RDOM pool. ML and MSL represent those microorganisms that can use labile dissolved organic matter (LDOM) or semi-labile DOM (SLDOM), respectively. The subscript numbers indicate the numerous compounds or microbes. Extents of recalcitrance are indicated by the colour sequence dark blue > light blue > green; grey indicates old DOM from seabed seeps or hydrothermal vents, which is not entirely recalcitrant, as some of these old compounds are readily available to microorganisms for respiration. Note that multiple processes are simplified here (for example, the back flows from SLDOM to LDOM) (Jiao et al, Nature Reviews Microbiology 9, 555, 2011).

A *Science* booklet on MCP including 10 papers previously published in *Science* and 10 new articles written by the WG134 members, in the form of "Supplement to *Science*", was distributed worldwide with the 13th of May 2011 issue of *Science*. Its electronic version is available on the *Science* website (http://science.imirus.com/Mpowered/book/vscim11/i2/p1) (Figure 5). In addition, a special session on MCP was published in Applied and Environmental Microbiology, with an illustration of the simplified MCP theory selected to be on the cover of AEM, Nov. 2011, Vol 77, No. 21 (Figure 5).

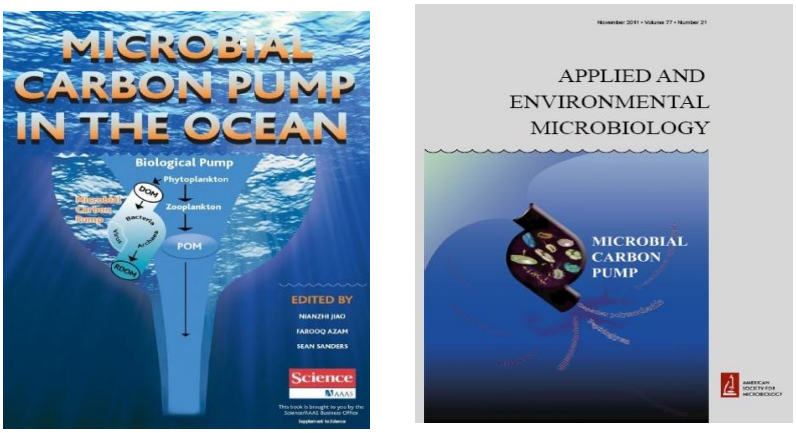


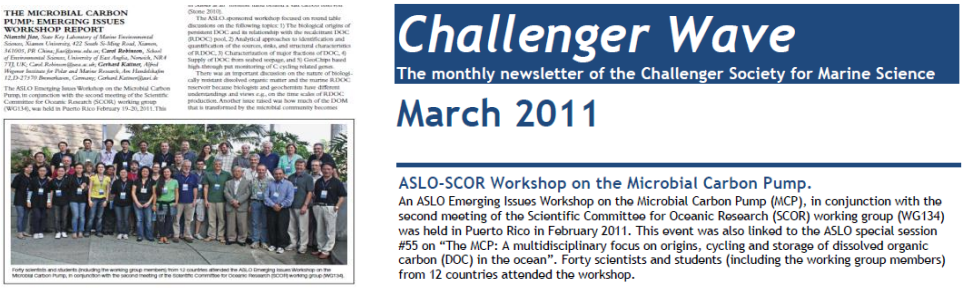
Figure 5. The MCP booklet supplemental to *Science (left) and* The *AEM* cover with MCP image(right).

Other representative publications and highlighting research are summarized here:

- Marine snows are indicated as active sites for microbial remineralization - Bochdansky, A.B., H.M. van Aken, G.J. Herndl, 2010: Role of macroscopic particles in deep-sea oxygen consumption. *Proc. Natl. Acad. Sci. USA*, 107: 8287-8291.
- ASLO Emerging issues workshop report, Limnology and Oceanography Bulletin 20 (2)

June 2011, 37-38 (Figure 6).

- ASLO–SCOR Workshop on the Microbial Carbon Pump, Challenger Society for Marine Science, Challenger Wave – March 2011: 8-9 (Figure 6).



THE MICROBIAL CARBON PUMP: EMERGING ISSUES WORKSHOP REPORT

Challenger Wave

The monthly newsletter of the Challenger Society for Marine Science

March 2011

ASLO-SCOR Workshop on the Microbial Carbon Pump.

An ASLO Emerging Issues Workshop on the Microbial Carbon Pump (MCP), in conjunction with the second meeting of the Scientific Committee for Oceanic Research (SCOR) working group (WG134) was held in Puerto Rico in February 2011. This event was also linked to the ASLO special session #55 on "The MCP: A multidisciplinary focus on origins, cycling and storage of dissolved organic carbon (DOC) in the ocean". Forty scientists and students (including the working group members) from 12 countries attended the workshop.

Figure 6. ASLO Emerging issues workshop report (left) and monthly newsletter Challenger Society for Marine Science (right) reporting MCP WG activities.

- Molecular biogeochemical provinces in the eastern Atlantic Ocean - Special Issue in *Biogeosciences*, 2011 (Editors: Boris Koch, Gerhard Kattner, Gerhard Herndl).
- *Publications*: Kawasaki, N., R. Sohrin, H. Ogawa, T. Nagata and R. Benner. 2011. Bacterial carbon content and the living and detrital bacterial contributions to suspended particulate organic carbon in the North Pacific Ocean. Aquat. Microb. Ecol. 62: 165-176. Kaiser, K., and R, Benner. 2012. Organic matter transformations in the upper mesopelagic zone of the North Pacific: chemical composition and linkages to microbial community structure. J. Geophys. Res., 117, C01023,doi: 10.1029/2011JC007141.

2. Academic Meetings and Research Activities

2.1 SCOR WG134 workshops

The first WG 134 meeting was held in Xiamen, China, from October 27 to 30 in 2009, under the theme of "Bridging Biology and Chemistry in Ocean Carbon Sequestration".

Figure 7. Open Science Meeting (left) and Closed Workshop (right) of WG134 1st meeting

The second meeting was held in Puerto Rico, USA during February 19-20 in 2011, along with the ASLO Emerging Issue Workshop on MCP (it was selected by ASLO as an emerging issue for the 2011 Aquatic Science Meeting).

Figure 8. WG134 2nd meeting in conjunction with the ASLO Emerging Issues Workshop on the MCP

The third meeting of SCOR WG134 was held in Hanse Institute for Advanced Study (HWK) of Delmenhorst in Germany, during August 26 to 29 in 2012.

Figure 9. SCOR WG134 3rd meeting at HWK (Germany) in August 2012.

This meeting aimed at summarizing the microbial and geochemical research progress in recent years in the context of MCP and its impact on microbial oceanography research with specialization in DOM cycling and diagenetic alterations. In addition, future research activities within the conceptual framework of the MCP were discussed and put forward.

2.2 Meeting sessions convened/hosted by WG134 members

- The cross-disciplinary Workshop on “microbial carbon sequestration” (Beijing, China, 24-26, July, 2009).

- The “International Training Workshop on Organic Matter Characterization Using Spectroscopic Techniques” (Granada, Spain, 19-21, May, 2010)
- Special session entitled “Microbes and Carbon Cycling in the Ocean” at the First International Conference on Marine Science and Earth System (Shanghai, China, 27-30, June, 2010)

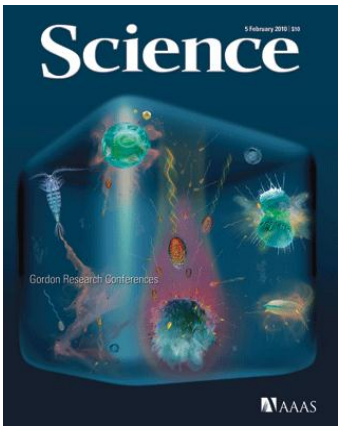


Figure 10. The image by Glynn Gorick; Roman Stocker; Justin Seymour interpreting the microbes-DOC interaction (Figure 10) selected for use as the cover of Science journal.

- Gordon Research Conference on Marine Microbes From Genes to Global Cycles (Tilton School, NH, USA, 4-9, July, 2010). The image by Glynn Gorick; Roman Stocker; Justin Seymour interpreting the microbes-DOC interaction (Figure 10) was selected as the cover image of issue Feb. 2010 on *Science*.
- Special session on Microbial Roles in Marine Carbon Cycling and Ocean Acidification Impacts during the AOGS 2010 Meeting (Hyderabad, India, 5-9, July, 2010).
- Special session on Marine Microbiology at ISME 13 (Seattle, USA, 22-27, August, 2010).
- Workshop on Aerobic Anoxygenic Heterotrophic Bacteria (AAPB) (Trebon, Czech Republic, 22-24, September, 2010).
- The 9th International Marine Biotechnology Conference (IMBC) with session of Biotic Carbon Sequestration (Qingdao, China, 8-12, October, 2010).
- The ASLO Aquatic Science Meeting Special Session 55 on the Microbial Carbon Pump in the Ocean (San Juan, Puerto Rico, 17-18, February, 2011).
- Chinese Science & Technology Association Forum on Marine Carbon Sink (Sanya, China, 15-16 Dec., 2011).
- The 2012 Ocean Science Meeting, special sessions of “Shedding Light on the Dark Ocean: Advances in Linking Physical and Microbial Oceanography to Biogeochemistry” and “Dissolved Organic Matter and the ‘Hidden’ Carbon Cycle” (Salt Lake City, Utah, USA, 20-24 February 2012).
- Special session on “Microbes and Carbon Cycling in the Ocean” at the Second

International Conference on Marine Science and Earth System (Shanghai, China, 2-4 July 2012).

- Special session on "The Global Ocean Ecosystem: Patterns, Drivers and Change" at the ASLO Aquatic Science Meeting (Lake Biwa, Japan, 09–13 July 2012).

2.3 Selective meetings participated by WG134 members:

- The AGU Chapman Conference on the Biological Carbon Pump of the Oceans (Brockenhurst, Hampshire, England, 14 September, 2009) and AGU Fall Meeting (San Francisco, USA, 13-17, December, 2010).
- The 11th International Estuarine Biogeochemistry Symposium (Atlantic Beach, NC, USA, 15-19, May, 2011).
- The Symposium on Aquatic Microbial Ecology SAME-12 (Rostock, Germany, 28 Aug - 2 Sep, 2011).
- The ISME 14th conference (Copenhagen, Denmark, 19 - 24 August, 2012).

3. Research activities

A variety of experiments were carried out through oceanographic cruises chaired or participated by our work group members:

- The 2010 Svalbard pelagic mesocosm experiments of European Project on Ocean Acidification, during time period of May 18 to July 16, 2010.
- Two cruises to the Western Pacific Warm Pool during 2010 and 2011 designed as pilot studies of the nutrient enrichment effects on MCP efficiency.
- Two cruises funded by the US National Science Foundation to the Ross Sea in January-March 2013 and the Gulf of Alaska in June-July 2013 with the aim to evaluate organic carbon dynamics in the meso- and bathypelagic ocean.
- A European Science Foundation project on the role of deep water autotrophic prokaryotes in the organic matter synthesis of the deep North Atlantic was launched in 2010.
- A MCP theory based proposal under this project was sponsored by the Ministry of

Science and Technology of China, and also the project of "Qualitative and Quantitative Evaluation of Processes Governing Microbial Carbon Pump in the Indian Ocean Regions" was provided by the Ministry of Earth Sciences of Government of India.

4. Academic Honors

- WG134 member **Ronald Benner** was awarded the Einstein Professorship of the Chinese Academy of Sciences (CAS) in 2010 and was elected a Fellow of the American Geophysical Union (AGU) in 2011.
- WG134 member **Gerhard Herndl** received the Wittgenstein-Prize, the highest Austrian science honor and prize (1.5M €), 2010.
- WG134 chair **Nianzhi Jiao** was elected a member of the Chinese Academy of Sciences (CAS) in 2011.
- WG134 member **Chen-Tung Arthur Chen** was reappointed a vice chair of the International Geosphere Biosphere Programme in 2011.
- WG134 memb**er Virginia Edgcomb** was awarded the 2012 Seymour H. Hutner Prize in Protistology by International Society for Protistologist.
- WG134 member **Michal Koblizek** has continued his service to the Czech National Committee of the Intergovernmental Oceanographic Commission, UNESCO.
- WG 134 co-chair **Farooq Azam** is selected by the ASM to receive the 2013 D. C. White Award for interdisciplinary research and mentoring.

Part II. Follow-up activities and progresses of SCOR WG 134 (2013-2014)

1. IMBER IMBIZO III conference

1.1 Topical workshop on MCP

A MCP based topical workshop 2, "Impacts of anthropogenic perturbations on ocean carbon sequestration via BP and MCP" was convened by Prof. Nianzhi Jiao, Prof. Farooq Azam, Prof.

Figure 11. A cartoon video of MCP was presented at the conference (left), the conveners and audiences interacting during the workshop discussion (right).

Carol Robinson, and Prof. Helmuth Thom as, at the IMBER IMBIZO III conference held in January 2013, India. **The functioning of the MCP at molecular to food web scales and its vulnerability to human perturbations was the subject of this workshop. We gladly point out that this workshop attracted scientists from multiple disciplines including microbial ecology, biogeochemistry, organic chemistry, climate science, fisheries and marine economy.** All together we shared exciting ideas and discussed methods to integrate MCP into the oceans and global carbon cycle through innovative carbon sequestration models. Three scientific sessions in total covered topics of the nature of DOC, microbial processing of DOC and genetic diversity, the interaction between MCP and BP and their responses to anthropogenic perturbation, and large temporal and spatial scale dynamics and links to humanity. During the meeting, a keynote presentation from workshop 2 was given by Prof. Farooq Azam: Microbial carbon pump and ecosystem connectivity. The scientific highlights in this presentation focused mainly on the opportunity exploring the linkages and interaction between MCP and Biological Pump (BP). Prof. Nian zhi Jiao addressed the importance of reducing the use of chemical fertilization on the land which could lead to an enhancement of the MCP as a carbon sink in eutrophic coastal waters during the plenary session. Results of microbiological and photochemical transformation of organic carbon during an in situ iron and phosphate addition experiment conducted by Prof. Carol Robinson indicated that the important role of both microbial and biological carbon pump to organic carbon under changing nutrient conditions.

In particularly, participants agreed that its pivotal role in determining food web structure allows relatively minor anthropogenic or climatic perturbations to potentially cause major shifts in the ocean's role in sequestering carbon and thus in regulating the climate. A few key questions concerning the MCP theory were well discussed by the workshop attendees: how does carbon transform through both MCP and BP and how do these two pumps interact with each other. The following keywords accomplished during the discussion session of the meeting are noteworthy: anthropogenic perturbation, land and atmospheric nutrients uploading, higher trophic levels, and natural scenarios from estuary to deep ocean, and upwelling and eddy habitats. It was suggested the future work should focus on the quantity, rate and proportion of the role MCP plays, through a combination of multiple efforts from genes to ecosystems, and from observation to modeling.

1.2 Outcome highlights

A summary report of the MCP workshop and a template for writing the synthesis paper on MCP was accomplished during the meeting synthesis session; an introduction to a national Chinese research project "Processes and mechanisms of microbial carbon sequestration in the ocean" was submitted as one of the science highlights from the IMBER IMBIZO III (http://www.imber.info/index.php/Products/Newsletters/Issue-n-24-August-2013).

A special issue on MCP in the journal of Biogeosciences (BG) was aimed to bring together articles arising from this workshop.

Topics to be investigated include the organisms and microbial processes which produce and transform dissolved organic carbon in the ocean, organisms and processes influencing the interaction between the BP and the MCP, and the impact of anthropogenic perturbations such as nutrient addition and ocean acidification on oceanic carbon transformation, export and sequestration. **To date a total of 10 papers have been accepted for publish under the BG special issue of "The impact of anthropogenic perturbations on open ocean carbon transformation, export and sequestration", they are:**

- Dang H, Jiao N (2014) Perspectives on the microbial carbon pump with special reference to microbial respiration and ecosystem efficiency in large estuarine systems. *Biogeosciences* 11: 3887-3898.
- Jiao N, Luo T, Zhang R, Yan W, Lin Y, et al. (2014) Presence of *Prochlorococcus* in the

aphotic waters of the western Pacific Ocean. *Biogeosciences* 11: 2391-2400.

- Jiao N, Zhang Y, Zhou K, Li Q, Dai M, et al. (2014) Revisiting the CO2 "source" problem in upwelling areas; a comparative study on eddy upwellings in the South China Sea. *Biogeosciences* 11: 2465-2475.
- Koch BP, Kattner G, Witt M, Passow U (2014) Molecular insights into the microbial formation of marine dissolved organic matter: recalcitrant or labile? *Biogeosciences* 11: 4173-4190.
- Li Y, Luo T, Sun J, Cai L, Liang Y, et al. (2014) Lytic viral infection of bacterioplankton in deep waters of the western Pacific Ocean. *Biogeosciences* 11: 2531-2542.
- Liu J, Jiao N, Tang K (2014) An experimental study on the effects of nutrient enrichment on organic carbon persistence in the western Pacific oligotrophic gyre. *Biogeosciences* 11: 5115-5122.
- Mitra A, Flynn KJ, Burkholder JM, Berge T, Calbet A, et al. (2014) The role of mixotrophic protists in the biological carbon pump. *Biogeosciences* 11: 995-1005.
- Romanou A, Romanski J, Gregg WW (2014) Natural ocean carbon cycle sensitivity to parameterizations of the recycling in a climate model. *Biogeosciences* 11: 1137-1154.
- Zhang Y, Xie X, Jiao N, Hsiao SSY, Kao SJ (2014) Diversity and distribution of amoA-type nitrifying and nirS-type denitrifying microbial communities in the Yangtze River estuary. *Biogeosciences* 11: 2131-2145.
- Jiao N, Robinson C, Azam F, et al., (2014) Mechanisms of microbial carbon sequestration in the ocean-future research directions. *Biogeosciences* 11: 5285-5306.

Research highlights from the BG special issue on MCP:

- For the first time coauthors of this MCP synthesis paper has brought to light in a relatively clear way, **the nature and controls of DOC in the ocean- linking RDOC at multiple dimensions: temporal (age) and spatial (depth) transformations of RDOC (Figure 12).**

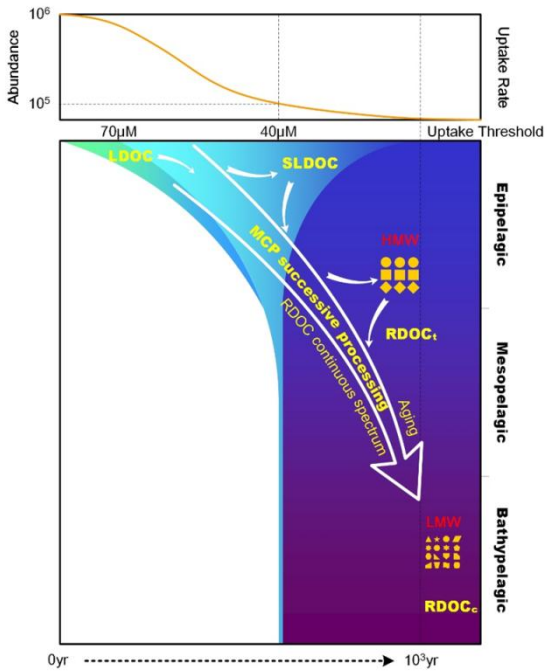


Figure 12. Linking RDOC at multiple dimensions: temporal (age) and spatial (depth) transformations of RDOC. Lower panel: successive microbial processing of organic carbon results in the generation of RDOC of different recalcitrance and different potential residence time; MCP – microbial carbon pump; $RDOC_t$ – RDOC compounds that are resistant to microbial consumption in certain environments, but subject to further cleaving and decomposition when the situation changes; $RDOC_c$ – composed of diverse small molecules which are inaccessible to microbial uptake due to their low concentration. Upper panel: microbial response (in terms of abundance or uptake rate) to DOC availability as a reference to conceptualize the microbial uptake threshold for $RDOC_c$, microbial abundance corresponding to DOC concentrations of 40μM in the deep and 70μM in the surface oceans; LDOC – labile DOC, a fraction of DOC, which is immediately accessible to microbial utilization; SLDOC – semi-labile DOC, a fraction of DOC, which resides mainly in the upper layer but which becomes labile when transported to deep water.

- **Interactions between POC and DOC sequestration** - the contribution of the MCP to carbon storage could be expected to be relatively high in the oligotrophic ocean. A similar transition from dominance of the BP to dominance of the MCP might be expected along a latitudinal gradient from polar regions to the tropics and from surface waters to the mesopelagic (Figure 13, Figure 14).

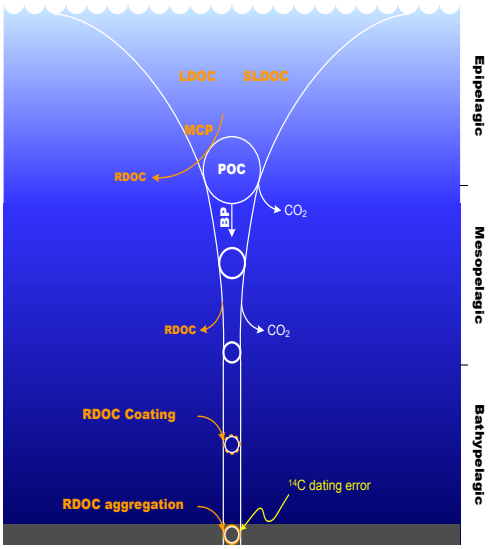


Figure 13. Transformation of DOC and POC through decomposition and scavenging processes that could influence carbon sequestration and ^{14}C dating (see text for details). MCP – microbial carbon pump, BP – biological pump, POC – particulate organic carbon, DOC – dissolved organic carbon, LDOC – labile DOC, SLDOC – semilabile DOC, RDOC – refractory DOC, RDOC coating – the process of RDOC attaching to the exterior of or being incorporated into a particle, RDOC aggregation – the process of RDOC molecules accumulating and combining.

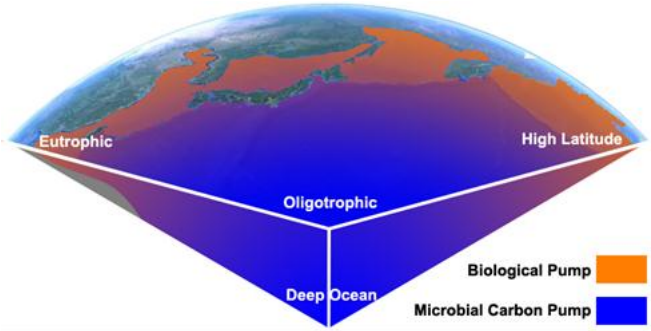


Figure 14. A demonstration of trends in the relative dominance of the BP and the MCP along environmental gradients.

2. The IMBER Open Science Conference (OSC) 2014

2.1 Special meeting session on MCP

In June this year, IMBER held its Open Science Conference 2014, under theme "Future Oceans: Research for marine sustainability, multiple stressors, drivers, challenges and solutions" in Bergen, Norway. The conference included a wide range of topics related to marine biogeochemistry and ecosystem research, from ocean acidification to management of fisheries, and the human dimensions of global marine change. The special session of "Microbial and geochemical perspectives of global carbon cycling and climate change: from genes to ecosystems, from ancient to current" under the conference session B - Lower Trophic

Level Processes and Dynamics, was convened and hosted by Prof. Farooq Azam, Prof. Carol Robinson and Prof. Nianzhi Jiao successfully. It brought marine scientists interested in biogeochemical behaviour of microbial processes that underlie RDOC production which is critical for models of global carbon cycling under climate change. **An overarching goal of this session is to conceptually integrate the activities of the MCP and the biological carbon pump. A total of 16 oral presentations and 5 poster presentations covering topics of molecular biomarkers and isotopic tracers linking water column carbon sequestration and sediment records; field observations and in-situ manipulation experiments to explore the mechanisms explaining the variability in carbon sequestration under a range of nutrient, temperature and CO_2 regimes; and ecosystem modeling of RDOC production based on ecological parameters, were contributed and presented during the conference.**

Figure 15. Prof. Nianzhi Jiao and Prof. Farooq Azam hosting the MCP special session

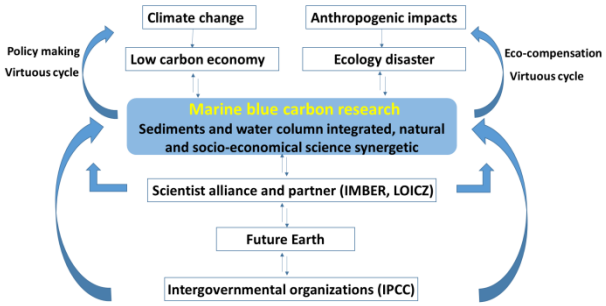


Figure 16. Paradigm of the "Mechanisms and magnitude of Blue Carbon storage in the ocean"

2.2 "Mechanisms and magnitude of Blue Carbon storage in the ocean"- a proposal for the IMBER Position Paper

As a follow-up to the IMBER OSC, Prof. Nianzhi Jiao (China), Prof. Farooq Azam (USA), Prof. Louis Legendre (France) and Prof. Helmulth Thomas (Canada) prepared a proposal for the "IMBER Position Paper", i.e. to add a new subsection to Section 3.1 (Developing a new research plan) entitled "Mechanisms and magnitude of Blue Carbon storage in the ocean". The main challenge/aim is, to identify the mechanisms of capture and storage/sequestration of carbon by marine organisms and ecosystems (i.e. Blue

Carbon), both inshore and offshore, and to quantify these mechanisms in order to provide natural-science bases to social and economic alternatives to the present human practices that cause the decline of Blue Carbon sinks (see Figure 16).

3. The 15th International Symposium on Microbial Ecology (ISME-15)

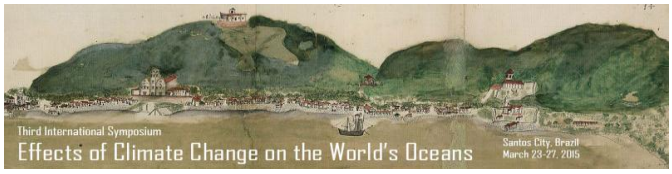
As the local organizers of the ISME 15th conference (held in South Korea in August 2014), WG members Prof. Kang-Jin Kim and Prof. Nian zhi Jiao were involved not only as the conference local organizers, but also convened the invited oral session IS23 - Microbial carbon sequestration (conveners, Nian zhi Jiao and Richard Bardgett , session). Particularly, Prof. Farooq Azam also gave the invited talk entitled "Microbial microscale interactions: Implications for carbon sequestration in the ocean".

"What controls microbial carbon sequestration in the ocean? A multiple perspective"- Interesting scientific puzzles concerning carbon sequestration in the ocean remaining unanswered were proposed by Prof. Nian zhi Jiao during his oral presentation, "Why huge organic carbon reservoirs could hold under either anoxic or oxygenated environments in the earth history? Why oligotrophic ocean gyres hold large organic carbon reservoirs? Why nutrient-rich estuarine waters as well as productive upwelling areas are often sources rather than sinks of CO2? " His talk thus, is intended to address the above concerns with field observations, lab experiments as well as theoretical speculations and testable hypothesis. Particular scenarios of environmental constrains such as the effects of nutrient availability on the lability of dissolved organic carbon (DOC) to microbes was illustrated. For example, the common sense that the more nutrients the more carbon fixation may not apply to carbon preservation in the ocean. Excess nutrients could facilitate phytoplankton production as well as microbial uptake of

DOC, and therefore can enhance both bacterial production and bacterial respiration. As a result, it can be either positive or negative for the preservation of DOC pool depending on the context of environmental conditions.

Other MCP related meetings convened or to be convened:

- Prof. Nianzhi Jiao, Prof. Chuanlun Zhang and Prof. Holly Simon together convened the **AGU session OS005**-- From mountains to the ocean: Physical, chemical and microbial impacts on carbon fluxes, in December 2013, San Francisco, USA.
- Prof. Nianzhi Jiao, together with Prof. Louis Legendre et al. will together convene a "biological carbon pump" related workshop at the "Third Symposium of Effects of Climate Change on the World's Oceans", in March 2015, Santos city, Brazil.



Appendix:

China Future Ocean Alliance

China Future Ocean Alliance (CFO in short) is a global neutral and independent scientific association, which will provide an international, open forum for marine researchers and research end-users to share their knowledge and experience. CFO is intended to address the concerns of both researchers and governmental policy-makers in marine science. Through its knowledge sharing network, we can not only highlight CFO partners' scientific achievements, but also synthesize and integrate "future ocean"-related research. To foster collaborative, interdisciplinary research that addresses human-natural marine science issues, to provide guidance for decision makers,

managers and communities towards marine sustainability, and the ultimately sustainable development of the ocean at all scales, are what the CFO pursues.
CFO had its first kick-off meeting in Tsing Tao, China, August this year, concurrently hosted with a CAS (Chinese academy of science) forum on future directions of marine sciences in China. More than 100 scientists from most if not all, the marine institutions in China presented at the meeting. One of the significant outputs of this meeting is the establishment of "China Future Ocean Alliance", and the other is our proposed "China Blue Carbon Plan" which will potentially be a guide for the future directions in marine carbon sink research (especially in coastal areas) in China. The committee members of the alliance have consented to its objective of "cross-disciplinary integration, synergistic innovation, resource sharing and facing the future".

Pan-China Ocean Carbon Alliance, COCA

As one of the predecessors of CFO, COCA is also a national organization, which was initiated by CAS Academician research group, and supported by the State Oceanic Administration, China Association for Science and Technology, Chinese Academy of Sciences, Ministry of Environmental Protection (Chinese Research Academy of Environmental Sciences), the National Climate Committee, etc. The COCA members consists of marine science and technology personnel from 21 domestic research institutes including Xiamen University, and enterprises including China National Offshore Oil Corporation (CNOOC). COCA originally emerged in an attempt to foster the prime MCP conditions, which will thus enhance the carbon absorption and storage capabilities within the ocean surrounding the Chinese coast. The final goal of COCA is to seek for ocean carbon storage mechanisms by uniting national strengths and make the best of both carbon emission reduction and sink increase through "policy-industry-research" cooperation strategy.

Three goals of COCA:

1) To build an international monitoring station for ocean carbon sink research

Using the world famous ocean time series station ALOHA in the Northern Pacific and BATS in the Northern Atlantic Ocean as benchmarks, a Chinese Coastal Ocean Time Series Station (COTS) under human activities influence is being constructed through jointly cooperation with CNOOC and other marine research institutes. It will act as a monitor and research base for Chinese coastal ocean carbon sink study.

2) To establish a standing international forum of ocean carbon pumps

The ongoing application of an International Forum for Ocean Carbon Pumps has received approval from the Gordon Research Conference Selection & Scheduling (S&S) Committee. This forum aims to appeal international colleagues, collect think tank in relevant fields of marine science and serve as incubator for the formation of "Ocean Carbon Sink International protocols and Standards" (see below).

3) To create the international technical protocols for measuring ocean carbon sink

The fulfillment of initiating a technical protocol draft for ocean carbon sink which has not been addressed to date, will be another ultimate goal through the synergetic and combined contribution from all said scientific organizations and actions centering on the MCP study on a global scale.

Chinese open program-2011 Collaborative Innovation Cluster on marine carbon sink

The 2011 Collaborative Innovation Cluster on marine carbon sink focuses on research in the wide range of in depth understanding of biological processes and mechanisms of the MCP theory, systematically assessing the potentials of carbon storage in Chinese coastal waters, and its controlling factors through biological, chemical and physical pathways. The program will be supported by the National 2011 Program of China, a highly innovative program initiated by the Ministry of Education of China. It will act as another international platform for jointly and interdisciplinary ocean carbon research, focusing on comparative studies between ancient and modern marine environments. Research facilities have been developed including coastal marine station, BP-MCP research and monitoring station, off shore platform for BP-MCP time series study, and university class research vessel. By putting the MCP theoretical framework into practical field and laboratory studies, we hope to ultimately

provide a new, integrated view of microbial mediated carbon flow in the marine environment to further fill knowledge gaps in oceanic carbon sequestration.