

ICES WGCCBOCS REPORT 2017

SCICOM STEERING GROUP ON ECOSYSTEM PROCESSES AND DYNAMICS

ICES CM 2017/SSGEPD:14

REF. SCICOM

Interim Report of the ICES/PICES Working Group on Climate Change and Biologically- driven Ocean Carbon Sequestration (WGCCBOCS)

16–18 September 2017, Qingdao, China

19–22 September 2017, Beijing, China

23–27 September 2017, Vladivostok, Russia



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Recommended format for purposes of citation:

ICES. 2017. Interim Report of the ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS), 16–18 September 2017, Qingdao, China; 19–22 September 2017, Beijing, China; 23–27 September 2017, Vladivostok, Russia. ICES CM 2017/SSGEPD:14. 17 pp.

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Executive summary

In 2017, the ICES-PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS) organized a series of activities including a workshop in Qingdao, China (16–18 September), a conference in Beijing (Yanqi Lake), China (19–22 September), a business meeting and a session during the PICES-2017 annual meeting in Vladivostok, Russia (23–27 September). These activities aimed at improving the understanding of ocean carbon sequestration both theoretically and practically. These activities supported the goals of the WG that include promoting the practical and theoretical understanding of marine carbon export and sequestration and its potential impact on global climate.

The Yanqi Lake conference was co-chaired by five academicians from four countries, who were Nianzhi Jiao, Member of Chinese Academy of Sciences (CAS), Farooq Azam, Fellow of American Academy of Arts and Sciences, Louis Legendre, Fellow of the European Academy of Sciences, Curtis Suttle, Fellow of the Royal Society of Canada, and Zheng-tang Guo, Member of CAS. During the conference, the participants not only made cutting-edge presentations, but also discussed in-depth each presentation. During the WG business meeting that took place during the PICES-2017 Annual Meeting, Prof. Nianzhi Jiao introduced recent progress and activities since the WG meeting held in Hong Kong in June 2016. The WG members discussed the timeline for completing the Terms of Reference (ToRs), the feasibility of renewing the WG, and continued group writing. In addition, the WG held a theme session during the PICES 2017 meeting on "Anthropogenic effects on biogeochemical processes, carbon export and sequestration: Impact on ocean ecosystem services". There were 11 contributed talks, and the audience was about 50 participants.

As a result of these activities, the WG plans to draft three perspective papers, three invited review papers and a discussion forum in *National Science Review* (IF=8.8), and organize two special issues in *Science China-Earth Science*. Nianzhi Jiao also reported the key points to a meeting of the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Special Report on Ocean and Cryosphere, which was held in Fiji on 1–7 October 2017.

In addition, the three co-Chairs of the ICES -PICES WG, Louis Legendre, Richard B. Rivkin and Nianzhi Jiao published a high-profile "Food for Thought" paper entitled "Advanced experimental approaches to marine water-column biogeochemical processes" (*ICES J. Mar. Sci.*), which fulfils the objectives of WG ToR 3 (Promote international collaboration for developing new experimental approaches and facilities).

Other related WG activities since last progress report to ICES included a Chairs Meetings hold in Xiamen, China in December 2016, during which three co-Chairs reviewed the WG progress in 2016 and planned WG activities of 2017. In September and November 2016, co-Chair (Richard B. Rivkin) attended ICES Annual Science Meeting in Riga, Latvia and PICES Science Meeting in San Diego, USA, respectively. Co-Chairs (Louis Legendre and Richard B. Rivkin) and two WG members (Anderson and Hyun) meet during ASLO Aquatic Sciences Meeting in February 2017. Furthermore, the WG will organize a Theme Session at the ICES/PICES 2018 4th International Symposium: The Effects of Climate Change on the World's Oceans: Linking ocean acidification, hypoxia, and carbon sequestration with ecosystem dynamics under climate change.

1 Administrative details

<p>Working Group name ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS)</p> <p>Year of Appointment within the current cycle 2016</p> <p>Reporting year within the current cycle (1, 2 or 3) 2</p> <p>Chair(s) Nianzhi Jiao, China Louis Legendre, France Richard Rivkin, Canada</p> <p>Meeting venue Qingdao, China Beijing, China Vladivostok, Russia</p> <p>Meeting dates 16–18 September 2017 19–22 September 2017 23–27 September 2017</p>

2 Terms of Reference a) - z)

- (1) Document and identify current knowledge about the biologically - driven carbon pumps
- (2) Develop standard monitoring protocols
- (3) Promote international collaboration for developing new experimental approaches and facilities
- (4) Explore techniques for prediction of biologically mediated carbon sequestration in oceans
- (5) A science symposium

3 Summary of Work plan

Year 1

- (1) Hold an initial organizational meeting.
- (2) Review and document current understanding of the mechanisms the pumps, the estimate of the magnitude of the pumps, and the existing approaches.
- (3) Propose and plan the future directions of research and new approaches and facilities.
- (4) Develop conceptual models.

Year 2

- (5) Hold an annual meeting to review the progress.
- (6) Continue to develop new approaches.
- (7) Recommend improvements to numerical models for integrating biologically- driven carbon pump processes.

Year 3

- (1) Continue to develop and review the new approaches.
- (2) Continue to recommend improvements to numerical models and review their results concerning the biologically mediated sequestration of carbon in oceans.
- (3) Hold a scientific symposium to review the outcome of the WG, and draft the final report of the WG and the advice of climate policy to international organizations.

4 List of Outcomes and Achievements of the WG in this delivery period

- **Advisory product:** Nianzhi Jiao reported the key points of the WG to a meeting of the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Special Report on Ocean and Ecosystems, which was held from October 1-7, 2017.
- **Publication:** The three co-chairs published a high-profile "Food for Thought" paper, which fulfils the objectives of WG ToR (3):
Legendre, L., R. B. Rivkin, and N. Jiao (2017), Advanced experimental approaches to marine water-column biogeochemical processes, *ICES Journal of Marine Science*, fsx146, doi:10.1093/icesjms/fsx146.
- **Methological development:** A mesocosm and artificial upwelling system demo was set up at Aoshan Bay, Qingdao, China.
- **Methological development:** An experimental demo (Mini-MECS) for a planned large scale experimental system (MECS, the Marine Environmental Chamber System) was set up at Aoshan Bay, Qingdao, China.

- **Publications in drafting:** As a result of these meetings, the WG members are actively engaging in drafting three perspective papers, three invited review papers and a discussion forum in *National Science Review* (IF=8.8), and in organizing two special issues in *Science China-Earth Science* (details in progress report). These will be published in next few months and will be reported in the next year.

5 Progress report on ToRs

5.1 Yanqi Lake Conference, Beijing, Opening ceremony, 19 September 2017

The opening ceremony of the Yanqi Lake Conference was held at the Yanqi International Conference Center, Beijing, on 19 September.

The following invited experts participated in the opening ceremony of the Beijing conference and gave addresses: Dr. Hong Wang, Minister of the State Ocean Administration (the Chinese supervising agency for PICES-China), Academician Guanhua Xu, Former Minister the Ministry of Science and Technology of China; Dr. Hong Mei, Deputy Director of Academic Works and Publications Committee of the Academic Divisions of CAS; Dr. Salvatore Arico, Head of Ocean Science Section, Intergovernmental Oceanographic Commission of UNESCO; Mr. Xi Xu, Director of Beijing Municipal Human Resources and Welfare Bureau. Prof. Nianzhi Jiao and Prof. Zhengtang Guo, Members of CAS, co-chaired the opening ceremony.

In addition, Prof. Louis Legendre presented the first keynote speech on "Advanced experimental approaches to marine water-column biogeochemical processes", and Prof. Nianzhi Jiao presented the second keynote speech on "Land-ocean integrated study for carbon sequestration to cope with climate change".



The following invited guests were also present at the ceremony: Zuoyan Zhu, Member of CAS, former Associate Director of National Natural Science Foundation of China (NSFC), Editor-in-Chief of *Science China*; Ting Li, Director of Administration of the Academic Divisions of CAS; Bei Chen, Deputy Director of Beijing Municipal Human Resources and Social Security Bureau; Minhua Liu, Head of Organization department of Beijing municipal committee of CPC; Xin Li, Head of Experts Department of Beijing Municipal Human Resources and Social Security Bureau, The following invited members of CAS were also present: Academician Mu Mu, Academician Dake Chen, Academician Hongfu Yin, and Academician Zhonghe Zhou. More than 40 international renowned experts, including members of the ICES-PICES WG, and 50 Chinese scholars and students attended this international forum (Participants: Annex 1).

5.2 Yanqi Lake Conference, Beijing, 20 September 2017: Session 1 – Carbon sequestration mechanisms and processes

Led by Profs Nianzhi Jiao and Louis Legendre, session 1 on "Carbon sequestration mechanisms and processes" was held on 20 September 2017. This session included the following presentations: Microbial structuring of marine ecosystems: Significance for carbon cycling and climate change (Farooq Azam); Climate change and the cycling of refractory dissolved organic carbon in the ocean (Ronald Benner), Climate change: Response of phytoplankton to multiple stressors (Uta Passow), The biological pump under climate change (Marion Gehlen), and Heterotrophic prokaryotes control biologically-driven carbon sequestration in highly productive Amundsen Sea Polynya, Antarctica (Jung Ho Hyun). Each presentation lasted for 20 minutes, and followed by 5 minutes of discussion. After all presentations, there was a 60 min. general discussion of the topic of the session.



5.3 Yanqi Lake Conference, Beijing, 21 September 2017: Session 2 – Observation and modelling for carbon sequestration

Session 2 on "Observation and modelling for carbon sequestration" was led by Profs Guo and Richard Rivkin. This session included the following presentations: Sequestration of carbon and oxygen in high latitude, deep convection regions: process understanding from multidisciplinary, in-situ time-series (Douglas Wallace); Holocene paleo-landuse and influences on terrestrial carbon (Yanyan Yu); Visualizing bacterioplankton succession and bacterial polysaccharide utilization in a coastal sea (Rudolf Amann); Are we

able to model the microbial carbon pump? Current state and future directions (Luca Polimene); An extension of conditional nonlinear optimal perturbation approach and its applications (Mu Mu). Each presentation lasted for 20 minutes, and followed by 5 minutes of discussion. After all presentations, there was a 60 min general discussion of the topic of the session.



5.4 Yanqi Lake Conference Beijing, 22 September 2017: Session 3 – Core Measurements and Protocols

Session 3 on "Core Measurements and Protocols" was led by Profs. Carol Robinson and Curtis Suttle. This session included the following presentations: Viral mediated mortality in marine systems (Curtis Suttle); Perspectives in COD and DOC issues: from land to ocean, from science to policy (Nianzhi Jiao); Development and applications of high throughput metagenomics technologies to marine biogeochemistry (Jizhong Zhou); Plankton respiration - the known unknown? (Carol Robinson); Expectations for marine carbon protocols (Yao Zhang). Each presentation lasted for 20 minutes, and followed by 5 minutes of discussion. After all presentations, there was a 60 min. general discussion of the topic of the session.



5.5 Workshop on marine carbon sequestration, Qingdao, 17 September 2017: Mechanisms, Modelling and Protocols

Prof. Nianzhi Jiao hosted the opening, and gave a general introduction to the participants. The leaders from local host institutions also gave welcome speeches in the opening session. The aim prospective outputs (papers/reports) of the workshop were introduced by Profs Richard Rivkin, Louis Legendre and Nianzhi Jiao. The workshop focused on the following topics: marine carbon sequestration, mechanisms and processes; modelling for carbon sequestration; marine carbon sequestration protocols; and reports toward the needs for the IPCC special report on ocean carbon issues.



5.6 Scientific Field Tours, Qingdao 17 September 2017

Scientific field tours were led by Profs. Jihua Liu, Yao Zhang and Wei Fan. They included a field demo of a mesocosm and artificial upwelling system demo and the Mini-MECS (Marine Environmental Chamber System). The participants went to Aoshan Bay by ferry, and had on-site observations about the facilities while discussing.



5.7 MECS IAC Meeting, Qingdao, 17 September 2017

A meeting of the International Advisory Committee (IAC) of the Marine Environmental Chamber System (MECS) was held in Shandong University on 17 September 2017. The conveners were Drs. Lei Jia, Yanjun Liu and Jihua Liu. Prof. Yanjun Liu gave a report on the present status of the MECS introduced with a video. Prof. Louis Legendre, Chair of the IAC, led the discussion that followed the presentation.



5.8 Review of the MOST major project on the “Microbial Carbon Pump”, Qingdao, 16 September 2017

A meeting was held on 16 September 2017 to review the study of "Microbial Carbon Pump in China Seas", supported by the Ministry of Science and Technology (MOST). Highlights identified by the review panel will be published in the *National Science Review*, a leading journal that aims at reviewing cutting-edge developments across science and technology in China and around the world (with an impact factor 8.8).



5.9 National Science Review Interview, Beijing, 20 September 2017

An interview was convened by Zhonghe Zhou, Member of CAS, in Yanqi Lake on 20 September 2017. It involved seven representative scientists, who included members of Academy of Sciences: Profs. Nianzhi Jiao, Farooq Azam, Louis Legendre, Douglas Wallace, Carol Robinson, Chuanlun Zhang, and Dr. Luca Polimene. The interview focused on the microbial carbon pump, and the resulting "Forum" paper will be published in *National Science Review*.



5.10 WG Business Meeting, Vladivostok, 24 September 2017

A Business Meeting of the PICES – ICES WG was convened by Richard Rivkin and Nianzhi Jiao during the PICES 2017 Annual Meeting in the Far Eastern Federal University, Vladivostok, Russia, on 24 September 2017. Participants reviewed the work of the WG to date. Nianzhi Jiao and Rui Zhang provided a brief summary about FUTUR-China.

WG members reviewed the WG activities since the WG meeting in Hong Kong, June 2016, including activities during the WG science meetings in Qingdao and Beijing in September 2017, and the progress towards fulfilling ToRs. Co-chairs proposed time line for completing existing ToRs, including the progress reports to be submitted to both ICES and PICES. In addition, WG members continued group writing of manuscripts and reports that had been initiated during the WG science meetings in Qingdao and Beijing.



5.11 PICES Plenary Science Board Symposium (S1), Vladivostok, 25 September 2017

Prof. Nianzhi Jiao delivered a plenary talk entitled "Biological mediated carbon cycling and sequestration in the ocean and climate change" during the PICES Plenary Science Board Symposium, Vladivostok, 25 September 2017.



5.12 Theme Session S13 (Anthropogenic Effects), PICES Annual Meeting, Vladivostok, 26 September 2017

Profs. Richard B. Rivkin, Louis Legendre, Nianzhi Jiao and Dr. M. Robin Anderson convened Theme Session S13 during the PICES Annual Meeting, Vladivostok, 26 September 2017. It was a Joint PICES-ICES Session on "Anthropogenic effects on biogeochemical processes, carbon export and sequestration: Impact on ocean ecosystem services". Presentations were as follows: Localized high abundance of Marine group II archaea in the subtropical Pearl River Estuary: implication for their niche adaptation (Chuanlun Zhang); Anthropogenic blue carbon: assessing the contribution of seaweed aquaculture for carbon uptake and storage (M. Robin Anderson, given by Richard B. Rivkin); Viruses, carbon sequestration and the biological pump (Curtis Suttle); Climate change, phytoplankton export and carbon sequestration (Uta Passow); A model simulation of future biogeochemical conditions along the British Columbia Continental Shelf (Angelina Pena); Changes in plankton assemblages and role of microbial loop in biogeochemical carbon cycles associated with coastal upwelling in the Ulleung Basin, East Sea (Jung Ho Hyun); Response of spring diatoms to CO₂ availability in the western North Pacific (Koiji Suzuki); Silicate weathering and CO₂ consumption rates: new insights from rivers of the Primorskiy Krai (Russia) (Galina Yu Pavlovat); Development and applications of high throughput metagenomics technologies to marine biogeochemistry (Jizhong Zhou); Microbes and ocean biogeochemical processes (Richard B Rivkin).

5.13 Fulfilment of WG ToR 3 "Promote international collaboration for developing new experimental approaches and facilities"

The three co-Chairs of the PICES - ICES WG, Louis Legendre, Richard B. Rivkin and Nianzhi Jiao published a high-profile "Food for Thought" paper entitled "Advanced experimental approaches to marine water-column biogeochemical processes" (*ICES J. Mar Sci.* doi:10.1093/icesjms/fsx146, 1:13). This publication fulfils the objectives of WG ToR 3 (Promote international collaboration for developing new experimental approaches and facilities).

Abstract: This "Food for Thought" paper examines the potential uses of several novel scientific and technological developments, which are currently available or being developed, to significantly advance or supplement existing experimental approaches to study water-column biogeochemical processes (WCB-processes). After examining the complementary roles of observation, experiments and numerical models to study WCB-processes, we focus on the main experimental approaches of free-water *in situ* experiments, and at-sea and on-land meso- and macrocosms. We identify some of the incompletely resolved aspects of marine WCB-processes, and explore advanced experimental approaches that could be used to reduce their uncertainties. We examine three such approaches: free-water experiments of lengthened duration using bioArgo floats and gliders, at-sea mesocosms deployed several 100's m below the sea-surface using new biogeochemical sensors, and 50 m-tall on-land macrocosms. These approaches could lead to significant progress in concepts related to marine WCB-processes.

A new WG member

Dr. Pavel Tishchenko

The Pacific Oceanological Institute of the Far-Eastern Branch of Russian Academy of Sciences, Russia.

6 Revisions to the work plan and justification

N/A

7 Next meetings

4–8 June 2018, Washington D.C., USA

The 4th International Symposium on the Effects of Climate Change on the World's Oceans (Jointed organized by ICES, PICES and other organizations). Our WG will mainly contribute to Session 3: Carbon uptake, ocean acidification, and ecosystems and human impacts.

Annex 1: List of participants

Working Group Members			
Name	Institute	Country (of institute)	Email
Nianzhi Jiao	Associate Director of the Earth Science Division, Chinese Academy of Sciences (CAS). Chair Professor, Xiamen University Member of Chinese Academy of Sciences (CAS) Fellow of Third World Academy of Sciences (TWAS)	China	jiao@xmu.edu.cn
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