ICES WGCCBOCS REPORT 2018

ECOSYSTEM PROCESSES AND DYNAMICS STEERING GROUPS

ICES CM 2018/EPDSG:14

REF. SCICOM

Report of the ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS/WG-33)

28 October 2018

Yokohama, Japan

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2018. Report of the ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS), 28 October 2018, Yokohama, Japan. ICES CM 2018/EPDSG:14. 22 pp.

Contents

Executive summary

The Joint Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS) under the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES) was established in 2015. This WG has promoted interdisciplinary exchanges among the research communi- ties by bringing together experts who had expertise using observational, experimental and modelling approaches to characterize and assess the biologically-driven ocean car- bon pumps and their environmental and climate consequences. The WGCCBOCS had the objective of improving prediction and providing advice for climate policy and adaptation to a changing environment.

The WGCCBOCS organized a series of WG meetings to meet its Terms of Reference (ToRs), including (1) a kick-off meeting at Hong Kong, China (June 17, 2016); (2) a busi- ness meeting and workshop in Qingdao, China (September 16-18, 2017); (3) a business meeting in Vladivostok, Russia (PICES 2017 annual meeting, September 24, 2017); and (4) a business meeting in Yokohama, Japan (PICES 2018 annual meeting, October 28, 2018). In addition, the WGCCBOCS organized: a joint ICES-PICES Topic Session on "Anthro- pogenic effects on biogeochemical processes, carbon export and sequestration: Impact on ocean ecosystem services" during the PICES 2017' Annual Meeting in Vladivostok, Rus- sia (September 26, 2017); and a joint Theme Session on "Carbon uptake, ocean acidifica- tion, and ecosystems and human impacts" at the PICES/ICES/IOC/FAO 4th International Symposium on "The effects of climate change on the world's oceans" in Washington, DC, USA (June 4-8, 2018).

The WGCCBOCS also co-organized/supported the following five activities: two Gordon Research Conference on Ocean Biogeochemistry in Hong Kong, China (June 12-17, 2016, and July 8-13, 2018); a meeting of the International Advisory Committee (IAC) of the Marine Environmental Chamber System (MECS) at Shandong University, China (September 17, 2017); the Yanqi Lake Conference in Beijing, China (September 19-22, 2017); and a workshop on Biogenic Element Cycling Processes and Effects in Xiamen, China (November 8-9, 2018).

As a result of these activities, the WGCCBOCS successfully met its ToRs:

- **ToR (a):** Five review papers (Chen *et al.*, 2018; Jiao *et al.*, 2018a, 2018b, 2018c; Zhang *et al.*, 2018);
- **ToR (b):** One review paper (Robinson *et al.*, 2018);
- **ToR (c)**: One perspective paper, (Legendre *et al.*, 2017); and construction of an experimental facility (the Mini Marine Environmental Chamber System, Mini-MECS, 10-m high) on the Qingdao campus of Shandong University, China;
- **ToR (d)**: One perspective paper and one research paper (Wang *et al.*, 2018; Po- limene *et al.*, 2018);
- **ToR (e)**: Yanqi Lake Conference in Beijing, China (September 19-22, 2017).

In addition, three special topics in scientific journals were organized and published, and one of the co-Chairs (Nianzhi Jiao) is acting as a lead author for IPCC 6th Assessment

Special Report on Ocean and Cryosphere to fulfil the objective of providing advice for climate policy and adaptation to a changing environment.

1 Administrative details

Working Group name

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

Year of Appointment within the current cycle

2016

Reporting year within the current cycle (1, 2 or 3) 3

Chair(s)

Nianzhi Jiao, China

Louis Legendre, France

Richard Rivkin, Canada

Meeting venues and dates

Chairs Meeting for reviewing progress and planning WG activities; Xiamen, China; December 1, 2015 (co-Chairs Jiao, Legendre and Rivkin)

Kick-off meeting of ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS); Hong Kong, China; June 17, 2016 (~30 participants)

Gordon Research Conference on Ocean Biogeochemistry: The Biologically-Driven Ocean Carbon Pumps; Hong Kong, China; June 12-17, 2016 (180 participants)

Co-Chair Rivkin attended ICES Annual Science Conference; Riga, Latvia; September 19-23, 2016

Co-Chair Rivkin attended PICES Annual Meeting; San Diego, California, USA; November 2-13, 2016

Chairs Meeting for reviewing progress and planning WG activities; Xiamen, China; December 1, 2016 (co-Chairs Jiao, Legendre and Rivkin)

Review meeting for MECS (Marine Environmental Chamber System); Qingdao, China; December 6, 2016 (Profs. Jiao, Legendre, Rivkin and Suttle)

Co-Chairs Legendre and Rivkin and two WG members (Anderson and Hyun) meet during ASLO Aquatic Sciences Meeting; Honolulu, Hawaii, USA; February 26, 2017

Business meeting and workshop; Qingdao, China; September 16-18, 2017 (60 partici-pants)

Meeting of the International Advisory Committee (IAC) of the Marine Environmental Chamber System (MECS); Qingdao, China; September 17, 2017 (60 participants)

Yanqi Lake Conference; Beijing, China; September 19-22, 2017 (80 participants)

Business meeting of ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS); Vladivostok, Russia; September 24, 2017 (30 participants)

Topic Session on "Anthropogenic effects on biogeochemical processes, carbon export and sequestration: Impact on ocean ecosystem services" during the PICES 2017 Annual Meeting; Vladivostok, Russia; September 26, 2017 (200 participants)

Theme Session on "Carbon uptake, ocean acidification, and ecosystems and human impacts" during the PICES/ICES/IOC/FAO 4th International Symposium on "The effects of climate change on the world's oceans"; Washington, DC, USA; June 4-8, 2018 (~60 participants)

Gordon Research Conference on Ocean Biogeochemistry: Biogeochemistry of Marine Interfaces; Hong Kong, China; July 8-13, 2018 (150 participants)

Business meeting of ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS), during the PICES annual meeting; Yokohama, Japan; October 28, 2018 (~30 participants)

Workshop on Biogenic Element Cycling Processes and Effects; Xiamen, China; November 8-9, 2018 (120 participants)

2 Terms of Reference a) – z)

a) Document and identify current knowledge about the biologically - driven cabon pumps;

b) Develop standard monitoring protocols;

c) Promote international collaboration for developing new experimental approaches and facilities;

d) Explore techniques for prediction of biologically mediated carbon sequestration in oceans;

e) A science symposium (including provide scientific advice to international organizations such as IPCC to aid in establishing climate policies).

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

(1) Hold an annual meeting to review the progress.

(2) Continue to develop new approaches.

(3) 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 Summary of Achievements of the WG during 3-year term

In response to ToR a)

Publication: Chen, J. M., L. Legendre, and R. Benner (2018), A recent project shows that the microbial carbon pump is a primary mechanism driving ocean carbon uptake, National Science Review, 5(4), 458-458, doi:10.1093/nsr/nwy006.

Publication: Jiao, N., *et al.* (2018a), Unveiling the enigma of refractory carbon in the ocean, National Science Review, 5(4), 459-463, doi:10.1093/nsr/nwy020.

Publication: Jiao, N., Z. Guo, L. Legendre, C. Suttle, R. Rivkin, and F. Azam (2018b), Editorial for the special issue on marine carbon sequestration and climate change, National Science Review, 5(4), 456-457, doi:10.1093/nsr/nwy068.

Publication: Jiao, N., H. Wang, G. Xu, and S. Aricò (2018c), Blue carbon on the rise: challenges and opportunities, National Science Review, 5(4), 464-468, doi:10.1093/nsr/nwy030.

Publication: Zhang, C., H. Dang, F. Azam, R. Benner, L. Legendre, U. Passow, L. Polimene, C. Robinson, C. A. Suttle, and N. Jiao (2018), Evolving paradigms in biological carbon cycling in the ocean, National Science Review, 5(4), 481-499, doi:10.1093/nsr/nwy074.

In response to ToR b)

Publication: Robinson, C., D. Wallace, J.-H. Hyun, L. Polimene, R. Benner, Y. Zhang, R. Cai, R. Zhang, and N. Jiao (2018), An implementation strategy to quantify the marine microbial carbon pump and its sensitivity to global change, National Science Review, 5(4), 474-480, doi:10.1093/nsr/nwy070.

In response to ToR c)

Publication: Legendre, L., R. B. Rivkin, and N. Jiao (2017), Advanced experimental approaches to marine water-column biogeochemical processes, ICES Journal of Marine Science, 75(1), 30-42. (A high-profile "Food for Thought" paper)

Methodological development: Construction of an experimental facility (the Mini Marine Environmental Chamber System, Mini-MECS, 10-m high) on the Qingdao campus of Shandong University, China;

In response to ToR d)

Publication: Polimene, L., R. B. Rivkin, Y.-W. Luo, E. Y. Kwon, M. Gehlen, M. A. Peña, N. Wang, Y. Liang, H. Kaartokallio, and N. Jiao (2018), Modelling marine DOC degradation time scales, National Science Review, 5(4), 468-474, doi:10.1093/nsr/nwy066.

Publication: Wang, N., Y.-W. Luo, L. Polimene, R. Zhang, Q. Zheng, R. Cai, and N. Jiao (2018), Contribution of structural recalcitrance to the formation of the deep oceanic dissolved organic carbon reservoir, Environ. Microbiol. Rep., 10(6), 711-717, doi:10.1111/1758-2229.12697.

In response to ToR e)

Special sections: The WGCCBOCS organized a topic-section with seven review papers in National Science Review (papers listed above), and two special topic sections in Sci- ence China Earth Science: Carbon cycling in the China Seas (Guest Editor: Nianzhi Jiao), including 11 papers; Microbial Oceanography (Guest Editor: Nianzhi Jiao), including 8 papers.

Assessment report: One of the co-Chairs (Nianzhi Jiao) is acting as a lead author for IPCC 6th Assessment Special Report on Ocean and Cryosphere to fulfil the objective of providing advice for climate policy and adaptation to a changing environment.

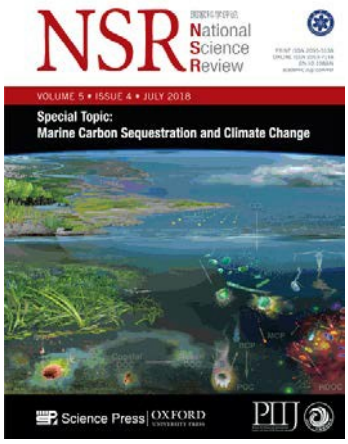

Figure 1. Cover image of the Special Topic: Marine Carbon Sequestration and Climate Change in National Science Review organized by WGCCBOCS.

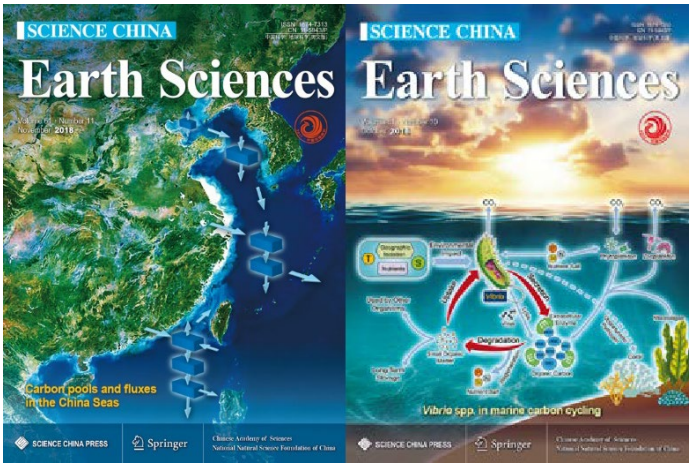

Figure 2. Cover images of two special topic sections in Science China Earth Science organized by WGCCBOCS.

5 Final report on ToRs, workplan and Science Implementation Plan

As an element in global biogeochemical cycles, carbon plays a fundamental role in biotic and abiotic processes in the ocean, which intertwine to mediate the chemistry and redox status of carbon in the ocean and the atmosphere. The interactions between abiotic and biogenic carbon (e.g. CO_2, $CaCO_3$, organic carbon) in the ocean are complex, and there is a half-century-old enigma about the existence of a huge reservoir of recalcitrant dissolved organic carbon (RDOC) that equates to the magnitude of the pool of atmospheric CO_2. The concepts of the biological carbon pump (BCP) shaped our understanding of the ma- rine carbon cycle. The more recent concept of the microbial carbon pump (MCP), which is closely connected to those of the BCP, explicitly considers the significance of the ocean's RDOC reservoir and provides a mechanistic framework for the exploration of its for- mation and persistence.

In response to ToR a)

The WGCCBOCS reviewed our current understanding of different biologically-driven carbon pumps in the ocean. The BCP is the mechanism by which carbon-containing com- pounds are exported via biological processes from the surface to the deep ocean. Carbon transported to the deep ocean (e.g. >1000 m) is sequestered on timescale s of >100 years to 1000 years (i.e. the residence time of deep ocean waters). Based on the latest estimation, about 0.3% of the ocean's primary production is transported to the interior of the ocean (below the euphotic zone) via the BCP and buried in marine sediments, some of which eventually forms a major reservoir of organic matter that persists for hundreds of mil- lions of years in rock formations.

The MCP addresses the dissolved organic carbon (DOC) pool, specifically the recalcitrant (R) DOC, which constitutes the majority of DOC and persists in the ocean for up to 4000–6000 years. Accounting for a global ocean inventory of 662 Gt C, the RDOC pool is almost equal to the carbon dioxide pool (750 Gt C) in the atmosphere. Therefore, the biogeo- chemical behavior of the RDOC pool has important implications for the ocean carbon cycle and climate.

The magnitude of these pumps depends on the balance between the rate at which aggre- gates form and sink on the one hand and the rate at which they are remineralized and produce RDOC on the other hand, which has a major impact on ocean carbon flux. The contribution of the MCP to carbon storage was considered to be relatively high in the oligotrophic ocean, polar regions and the mesopelagic waters. In addition, particle ag- gregating and scavenging processes are common in the water column, which is closely related to physical processes (such as stratification, mixing and currents) and chemical conditions (e.g. pH, salinity, oxygen). Modelling of MCP vs BCP indicated that the im- portance of the MCP relative to BP may increase under global-warming scenarios. It is important and extremely valuable to quantify the BP and MCP in modern and ancient oceans in order to better understand the coupling between the ocean carbon cycle and global climate in the Earth's history.

In response to ToR b)

The WGCCBOCS reviewed the current progress on quantification of marine carbon sequestration. The rate of carbon sequestration by the BCP can be estimated from the POC sinking flux measured in sediment traps. In last decade, considerable progress on the identification and quantification of the composition of RDOM, the characterization of specific biochemical compounds in RDOM, the development of proxies of RDOM, the determination of loss of labile DOC and accumulation of RDOC by incubation experiments, the identification and quantification of RDOC production and loss pathways using large-scale manipulation experiments. Coordinating these approaches will require multi-component programs of systematic experimentation linked with conceptual and numerical modelling.

In response to ToR c)

The WGCCBOCS proposed and described three novel advanced experimental approaches: free-water experiments of lengthened duration using bioArgo floats and gliders, at-sea mesocosms deployed several 100s m below the sea-surface using new biogeochemical sensors, and 50 m-tall on-land macrocosms were examined for the potential uses for study biologically-driven ocean carbon pumps, as well as their interactions.

In response to ToR d)

This ToR concerned modelling of biologically-driven carbon sequestration by the ocean, focusing on new practically modelling schemes for MCP. Assessing the capacity of the ocean to store atmospheric CO_2 is one of the major challenges for oceanographers. Being the most recentlyrecognized and described mechanism of biogenic carbon sequestration in the ocean (and more recently in terrestrial soils), the MCP is also the least investigated and represented in marine ecosystem models. The general absence of RDOC and its dy- namics in (most) marine ecosystem models may reflect the assumptions that the contri- bution of marine biota to global carbon sequestration is mainly through the BCP and that the majority of RDOC reacts at time scales (millennia) exceeding those investigated with current ecosystem and climate models. One of the main challenges with modelling DOC accumulation beyond the seasonal time scale is to represent the turnover time of the various pools of RDOC, which is formed of a large number of highly diverse molecules with a continuum spectrum of degradation rates. **To meet the prediction part of ToR (d)**, the WGCCBOCS proposed a conceptual framework capable of representing the continuum spectrum of DOC degradation rates in a tractable way, using one state variable representing the bulk DOC concentration and a degradation function. This model can be either considered as a standalone box model or as a spatial unit (i.e. a subunit of a larger model grid) of a 3D domain. The WGCCBOCS also constructed a model to study the previously published data that describes deep oceanic DOC degradation experiments, suggesting that the recalcitrance of RDOC is largely related to its chemical properties, whereas dilu- tion plays a minor role in determining the persistence of deep-ocean DOC.

In response to ToR e)

To meet the policy advice component of ToR (e) and based on above progress, the WGCCBOCS and policy makers from Chinese government and UNESCO highlighted the challenges and opportunities of blue carbon (i.e. carbon sequestrated by marine ecosys-

tems). Blue carbon does not only include mangrove, seagrass and salt marsh ecosystems, but also the enormous invisible blue carbon biomes composed of tiny but extremely abundant microbes, including phytoplankton, bacteria, archaea and viruses, which contribute a large fraction of the world's blue carbon. The MCP is a major contributor to the very large marine refractory DOC (RDOC) reservoir, which is equivalent in amount to the total inventory of CO_2 in the atmosphere. In addition, the MCP effects exist in all wa- ter environments and even soil environments, connecting with the visible blue carbon ecosystems since part of the blue carbon that the macro-biomes release as DOC in the water can be further transformed into RDOC by the MCP.

To meet the symposium/workshops component of ToR (e), the WGCCBOCS organized meetings and theme sessions during PICES Annual Science Conferences. In addition, WGCCBOCS co-Chairs Nianzhi Jiao and Louis Legendre created the Gordon Research Conference (GRC) on Ocean Biogeochemistry, which provides a unique platform to the international community of marine biogeochemists for scientific exchanges on ocean carbon sink and other forefront ideas. WGCCBOCS co-Chairs Nianzhi Jiao and Louis Legendre, along with other scientist, established a high-end international academic forum, the Yanqi Lake Conference, under the auspice of the Chinese Academy of Sciences (Beijing, China, September 19–22, 2017). The speakers included: Dr. Hong Wang, Minister of the State Ocean Administration; Academician Guanhua Xu, Former Minister the Ministry of Science and Technology of China; and Dr. Salvatore Arico, Head of Ocean Science Section, Intergovernmental Oceanographic Commission of UNESCO. The major theme of this first Yanqi Lake Conference was Climate Change and Biologically-driven Ocean Carbon Sequestration. It addressed three major topics: Marine carbon sequestration mechanisms and processes, Numerical modelling for forecasting marine carbon sequestration, and Marine carbon protocols. Different from other ocean science meetings, this conference emphasized land-ocean interaction, science-technology integration, ancient-modern-ocean comparisons, and science-policy connections. These meetings/symposiums resulted in one special section in National Science Review and two special topics in Science China Earth Sciences (see above).

6 Summary of Working Group self-evaluation and conclusions

A copy of the full Working Group self-evaluation is given in Annex 3.

The ICES/PICES joint Working Group on Climate Change and Biologically-driven Ocean Car-bon Sequestration (WGCCBOCS), established in 2016 and co-chaired by Nianzhi Jiao, Louis Legendre and Richard Rivkin, has organized 11 meetings/workshops/ symposiums and published nine peer reviewed papers, including a topic-section with seven review papers in National Science Review, and one high-profile "Food for Thought" paper in ICES Journal of Marine Science. Through these activities, the WGCCBOCS successfully met its Terms of Reference: summarized current progress and knowledge about the bio- logically - driven carbon pumps in the ocean, provided guidance for development of standard monitoring protocols, develop model including microbial carbon pump and addressed future scientific directions. With the high quality international collaboration promoted by WGCCBOCS, a new Working Group about Blue Carbon (i.e. the carbon captured and sequestered by marine ecosystems) was proposed.

Annex 1: List of participants

Working Group Members

Name	Institute	Country (of institute)	Email
Nianzhi Jiao (Co-Chair)	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
Louis Legendre (Co-Chair)	Professor emeritus at the Pierre & Marie Curie University Paris 06, France, and Laval University, Canada Fellow of the Royal Society of Canada, Academy of Sciences Fellow of the European Academy of Sciences.	France	legendre@obs-vlfr.fr
Richard Rivkin (Co-Chair)	University Research Professor, Department of Ocean Sciences Memorial University of Newfoundland, Canada	Canada	rrivkin@mun.ca
Rudolf Amann	Professor, Max Planck Institute for Microbial Microbiology, University of Bremen, Germany	Germany	ramann@mpi-bremen.de
Marion Gehlen	Researcher, Laboratoire des Sciences du Climat et de l'Environnement, France	France	gehlen@lsce.saclay.cea.fr
Hermanni Kaartokallio	Professor, Finnish Institute of Marine Research, Finland	Finland	hermanni@fimr.fi
Luca Polimene	Researcher, Plymouth Marine Laboratory, UK	UK	luca@pml.ac.uk
Carol Robinson	Professor, University of East Anglia, UK	UK	carol.robinson@uea.ac.uk
Nannan Wang	Ph. D. Xiamen University	China	nannan_wangpearl@126.com
Yao Zhang	Professor, Xiamen University	China	yaozhang@xmu.edu.cn
Jung-Ho Hyun	Professor, Hanyang University, South Korea	Korea	hyunjh@hanyang.ac.kr
Eun Young Kwon	Professor, IBS Center for Climate Physics. Pusan National University, Korea	Korea	ekwon76@snu.ac.kr
Yawei Luo	Associate Professor, Xiamen University	China	ywluo@xmu.edu.cn

Uta Passow	Professor, University of California Santa Barbara Santa Barbara, USA	USA	uta.passow@lifesci.ucsb.edu
Curtis Suttle	Distinguished University Scholar, Earth & Ocean Sciences, Microbiology & Immunology, and Botany, University of British Columbia, Canada Fellow of the Royal Society of Canada, Academy of Sciences	Canada	csuttle@eos.ubc.ca
Fengping Wang	Professor, Laboratory of Microbial Oceanography, Shanghai Jiao Tong University	China	fengpingw@sjtu.edu.cn
Chuanlun Zhang	Professor, Southern University of Science and Technology	China	zhangcl@sustc.edu.cn
Rui Zhang	Professor, Xiamen University	China	ruizhang@xmu.edu.cn
Robin Anderson	Professor, Fisheries and Oceans Canada	Canada	Robin.Anderson@dfo-mpo.gc.ca
Corina Brussaard	Professor, Royal Netherlands Institute for Sea Research	the Netherlands	Corina.Brussaard@nioz.nl
Adrian Burd	Professor, University of Georgia	USA	adrianb@uga.edu
Yngvar Olsen	Professor, Norwegian University of Science and Technology	Norway	yngvar.olsen@ntnu.no
Yanbin Guo	Xiamen University	China	elgyb@163.com
Angelica Peña	Professor, Fisheries and Oceans Canada, Institute of Ocean Sciences	Canada	angelica.pena@dfo-mpo.gc.ca
Koji Suzuki	Professor, Faculty of Environmental Earth Science, Hokkaido University	Japan	kojis@ees.hokudai.ac.jp
Youhei Yamashita	Professor, Faculty of Environmental Earth Science, Hokkaido University	Japan	amashiy@ees.hokudai.ac.jp
Keun-Hyung Choi	Professor, Department of Oceanography and Ocean Environmental Sciences, Chungnam National University	Korea	eunhchoi@cnu.ac.kr

Chair Invited Participants

Name	Institute	Country (of institute)	Email
Farooq Azam	Distinguished Professor at Scripps Institution of Oceanography, USA Fellow of the American	USA	fazam@ucsd.edu

	Academy of Arts and Sciences.		
Salvatore Arico	Head of ocean science section, Intergovernmental Oceanographic Commission (IOC) of UNESCO	UNESCO	s.arico@unesco.org
John Batt	Aquatron Laboratory, Dalhousie University, Canada	Canada	john.batt@dal.ca
Ronald Benner	Professor, University of South Carolina, USA Fellow of the American Geophysical Union.	USA	benner@mailbox.sc.edu
Bei Chen	Deputy Director of Beijing Municipal Human Resources and Social Security Bureau	China	
Dake Chen	Chair Professor, Second Institute of Oceanography, SOA, China Member of Chinese Academy of Sciences (CAS)	China	dchen@sio.org.cn
Ge Chen	Professor, Ocean University of China	China	gechen@ouc.edu.cn
Hong Cui	Editor, China Science Daily	China	cuihong@scichina.org
Junyi Chen	Journalist, China Ocean News	China	
Ruanhong Cai	Ph. D. Xiamen University	China	crh1987@163.com
Hongyue Dang	Professor, Xiamen University	China	danghy@xmu.edu.cn
Wei Fan	Associate Professor, Zhejiang University	China	wayfan@163.com
Yingnan Fu	Xiamen University	China	fuyingnan@xmu.edu.cn
Zhengtang Guo	Chair Professor, Institute of Geology and Geophysics, Chinese Academy of Sciences (CAS) Vice President of University of CAS. Member of Chinese Academy of Sciences (CAS)	China	ztguo@mail.iggcas.ac.cn
Chen He	Ph. D. China University of Petroleum	China	395811500@qq.com
Ran Huang	Journalist, China Ocean News	China	
Xiaoke Hu	Professor, Yantai Institute of Costal Zone Research, Chinese Academy of Sciences (CAS)	China	xkhu@yic.ac.cn
Yaodong He	Professor, Tianjin University	China	
Chao Li	Professor, China University of Geosciences (Wuhan)	China	chaoli@cug.edu.cn
Jihua Liu	Associate Professor, Shandong University	China	liujihua1982@foxmail.com

Ting Li	Director of Administration of the Academic Divisions of Chinese Academy of Sciences (CAS)	China	
Xin Li	Head of Specialist Department of Beijing Municipal Human Resources and Social Security Bureau	China	
Yantao Liang	Assistant Professor, Qingdao Institute of Bioenergy and Bioprocess Technology, Chinese Academy of Sciences (CAS)	China	iangyt@qibebt.ac.cn
Hong Mei	Associate Director of Academic Works and Publications Committee of the Academic Divisions of Chinese Academy of Sciences (CAS). Member of Chinese Academy of Sciences (CAS)	China	hfyin@cug.edu.cn
Mu Mu	Professor, Institute of Oceanology, Chinese Academy of Sciences (CAS) Member of Chinese Academy of Sciences (CAS) Fellow of Third World Academy of Sciences (TWAS)	China	mumu@qdio.ac.cn
Xiaolin Ren	Ph. D. Institute of Geology and Geophysics, Chinese Academy of Sciences (CAS)	China	602668318@qq.com
Quan Shi	Professor, China University of Petroleum	China	sq@cup.edu.cn
Ronghui Su	Deputy Director of Administration of the Academic Divisions of Chinese Academy of Sciences (CAS)	China	
Kai Tang	Associate Professor, Xiamen University	China	tangkai@xmu.edu.cn
Douglas Wallace	Canada Excellence Research Chair. Professor of Oceanography, Dalhousie University, Canada	Canada	douglas.wallace@dal.ca
Hong Wang	Minister of the State Oceanic Administration (SOA), China	China	
Haibin Wu	Professor, Institute of Geology and Geophysics, Chinese Academy of Sciences (CAS)	China	Haibin-wu@mail.igcas.ac.cn
Jianjing Wei	Editor, China Science Daily	China	
Qiaodan Weng	Xiamen University	China	jordanxmu@foxmail.com
Xiaoxue Wang	Professor, South China Sea Institute Oceanology, Chinese	China	xxwang@scsio.ac.cn

	Academy of Sciences (CAS)		
Guanhua Xu	Former Minister of Ministry of Science and Technology (MOST) China. Member of Chinese Academy of Sciences (CAS)	China	xghzy@public.bta.net.cn
Jie Xu	Professor, South China Sea Institute of Oceanology, Chinese Academy of Sciences (CAS)	China	xujie@scsio.ac.cn
Xi Xu	Director of Beijing Municipal Human Resources and Social Security Bureau	China	
Xiuling Xu	Managing Editor, National Science Review Editorial Office, Science China Press	China	
Hongfu Yin	Professor, China University of Geosciences (Wuhan) Member of Chinese Academy of Sciences (CAS)	China	hfyin@cug.edu.cn
Xiaotong Yu	Xiamen University	China	yu-xiaotong@163.com
Yanyan Yu	Associate Professor, Institute of Geology and Geophysics, Chinese Academy of Sciences (CAS)	China	yyy@mail.iggcas.ac.cn
Jizhong Zhou	Professor, University of Oklahoma, USA	USA	jzhou@ou.edu
Nannan Zhang	Xiamen University	China	nancy@xmu.edu.cn
Qian Zhang	University of Chinese Academy of Sciences (CAS)	China	
Qiang Zheng	Associate Professor, Xiamen University	China	zhengqiang@xmu.edu.cn
Weijie Zhao	News Editor, National Science Review Editorial Office, Science China Press	China	
Yongyu Zhang	Professor, Qingdao Institute of Bioenergy and Bioprocess Technology, Chinese Academy of Sciences (CAS)	China	zhangyy@qibebt.ac.cn
Yujiao Zhang	Xiamen University	China	zyjhandy@163.com
Zhonghe Zhou	Associate Director of the Earth Science Division, Chinese Academy of Sciences (CAS) Director, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences (CAS) Member of Chinese Academy of Sciences (CAS)	China	zhouzhonghe@ivpp.ac.cn

	Foreign Associate member of National Academy of Science, USA		
Zuoyan Zhu	Former Associate Director of NSFC, Editor-in-Chief of Science. Member of Chinese Academy of Sciences (CAS)	China	zhuzy@ nsfc.gov.cn
Fangli Qiao	Professor, Secretary General and Deputy Director General of First Institute of Oceanography (FIO), State Oceanic Administration (SOA)	China	qiaofl@fio.org.cn
Guangshui Na	Professor, National Marine Environmental Monitoring Center (NMEMC)	China	gsna@nmemc.org.cn
Jinhui Wang	Professor, East China Sea Environmental Monitoring Center, East China Sea Branch of State Oceanic Administration (SOA)	China	wangjinhui@eastsea.gov.cn
Se-Jong Ju	Professor, Deep-Sea and Seabed Mineral Resources Research Center, Korea Institute of Ocean Science and Technology	Korea	sjju@kiost.ac.kr
Sinjae Yoo	Jeju International Marine Science Center for Research & Education, Korea Institute of Ocean Science and Technology (KIOST)	Korea	sjyoo@kiost.ac.kr
Mark Wells	Professor; School of Marine Sciences, University of Maine	USA	mlwells@maine.edu

Annex 2: Draft resolution for a new Working Group

DRAFT

A **Working Group on Blue Carbon** (WGBC), chaired by Nianzhi Jiao, China, will be established and will work on ToRs and generate deliverables as listed in the Table below.

	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2019	Oct	Xiamen, China	Interim report by Dec 2019	
Year 2020	Oct	Xiamen, China	Interim report by Dec 2020	
Year 2021	Oct	Qingdao, China	Final report by Dec 2021	

ToR descriptors

ToR	Description	Background	Science Plan codes	Duration	Expected Deliverables
a	Identify current knowledge gaps in blue carbon in the inshore and offshore oceans, and propose new research directions	Science Requirements		2 years	Review paper
b	Plan the development of long-term time series monitoring stations for observations of water-column blue carbon in representative coastal and offshore waters	Science Requirements		2 years	Dataset
c	Propose integrated experimental studies for better understanding water-column blue carbon sequestration under paleo-, current and future environmental conditions	Science Requirements		2 years	Research papers
d	Hold annual workshops and business meetings			3 years	Review papers; Reports

Summary of the Work Plan

Year 1	Meetings to address Blue Carbon knowledge gaps and plan the long term time series stations.
Year 2	Propose and start the integrated experimental studies
Year 3	Meetings to review the progress and write review/research papers

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the global climate change, especially with regard to the role of ocean in the global carbon sequestration. Consequently, these activities are considered to have a very high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 20–25 members and guests.
Secretariat facilities	Standard support
Financial	None
Linkages to ACOM and groups under ACOM	
Linkages to other committees or groups	
Linkages to other organizations	

Annex 3: WGCCBOCS self-evaluation 2016-2018

1) Working Group name:

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

2) Year of appointment: 2016

3) Current Chairs:

Nianzhi Jiao, China

Louis Legendre, France

Richard Rivkin, Canada

4) Venues, dates and number of participants per meeting.

- Kick-off meeting of ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS); Hong Kong, China; June 17, 2016 (~30 participants)
- Gordon Research Conference on Ocean Biogeochemistry: The Biologically-Driven Ocean Carbon Pumps; Hong Kong, China; June 12-17, 2016 (180 participants)
- Business meeting and workshop; Qingdao, China; September 16-18, 2017 (60 participants)
- Meeting of the International Advisory Committee (IAC) of the Marine Environmental Chamber System (MECS); Qingdao, China; September 17, 2017; (60 participants)
- Yanqi Lake Conference; Beijing, China; September 19-22, 2017 (80 participants)
- Business meeting of ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS); Vladivostok, Russia; September 24, 2017 (30 participants)
- Topic Session on "Anthropogenic effects on biogeochemical processes, carbon export and sequestration: Impact on ocean ecosystem services" during the PICES 2017 Annual Meeting; Vladivostok, Russia; September 26, 2017 (200 participants)
- Theme Session on "Carbon uptake, ocean acidification, and ecosystems and human impacts" during the PICES/ICES/IOC/FAO 4th International Symposium on "The effects of climate change on the world's oceans"; Washington, DC, USA; June 4-8, 2018 (~60 participants)
- Gordon Research Conference on Ocean Biogeochemistry: Biogeochemistry of Marine Interfaces, Hong Kong, China; July 8-13, 2018 (150 participants)
- Business meeting of ICES/PICES Working Group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS), during the PICES annual meeting; Yokohama, Japan; October 28, 2018 (~30 participants)
- Workshop on Biogenic Element Cycling Processes and Effects; Xiamen, China; November 8-9, 2018 (120 participants)

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. *

Publications:

The WGCCBOCS has published nine peer reviewed papers, including a topic-section with seven review papers in National Science Review, and one high-profile "Food for Thought" paper in the ICES Journal of Marine Science, and one research paper in Environmental Microbiology Reports.

- Chen, J. M., L. Legendre, and R. Benner (2018), A recent project shows that the microbial carbon pump is a primary mechanism driving ocean carbon uptake, National Science Review, 5(4), 458-458, doi:10.1093/nsr/nwy006.
- Jiao, N., *et al.* (2018a), Unveiling the enigma of refractory carbon in the ocean, National Science Review, 5(4), 459-463, doi:10.1093/nsr/nwy020.
- Jiao, N., Z. Guo, L. Legendre, C. Suttle, R. Rivkin, and F. Azam (2018b), Editorial for the special issue on marine carbon sequestration and climate change, National Science Review, 5(4), 456-457, doi:10.1093/nsr/nwy068.
- Jiao, N., H. Wang, G. Xu, and S. Aricò (2018c), Blue carbon on the rise: challenges and opportunities, National Science Review, 5(4), 464-468, doi:10.1093/nsr/nwy030.
- Legendre, L., R. B. Rivkin, and N. Jiao (2017), Advanced experimental approaches to marine water-column biogeochemical processes, ICES Journal of Marine Science, 75(1), 30-42.
- Polimene, L., R. B. Rivkin, Y.-W. Luo, E. Y. Kwon, M. Gehlen, M. A. Peña, N. Wang, Y. Liang, H. Kaartokallio, and N. Jiao (2018), Modelling marine DOC degradation time scales, National Science Review, 5(4), 468-474, doi:10.1093/nsr/nwy066.
- Robinson, C., D. Wallace, J.-H. Hyun, L. Polimene, R. Benner, Y. Zhang, R. Cai, R. Zhang, and N. Jiao (2018), An implementation strategy to quantify the marine microbial carbon pump and its sensitivity to global change, National Science Review, 5(4), 474-480, doi:10.1093/nsr/nwy070.
- Zhang, C., H. Dang, F. Azam, R. Benner, L. Legendre, U. Passow, L. Polimene, C. Robinson, C. A. Suttle, and N. Jiao (2018), Evolving paradigms in biological carbon cycling in the ocean, National Science Review, 5(4), 481-499, doi:10.1093/nsr/nwy074.
- Wang, N., Y.-W. Luo, L. Polimene, R. Zhang, Q. Zheng, R. Cai, and N. Jiao (2018), Contribution of structural recalcitrance to the formation of the deep oceanic dissolved organic carbon reservoir, *Environ. Microbiol. Rep.*, *10*(6), 711-717, doi:10.1111/1758-2229.12697.

Special issues:

- Science China Earth Science: Carbon cycling in the China Seas (Guest Editor: Nianzhi Jiao), including 11 papers.
- Science China Earth Science: Microbial Oceanography (Guest Editor: Nianzhi Jiao), including eight papers.

Advisory products:

- One of the co-Chairs (Nianzhi Jiao) is a lead author for IPCC 6th Assessment Special Report on Ocean and Cryosphere to fulfil the objective of providing advice for climate policy and adaptation to a changing environment.

Modelling outputs:

The WGCCBOCS proposed a conceptual framework capable of representing the continuum spectrum of DOC degradation rates in a tractable way, using one state variable representing the bulk DOC concentration and a degradation function. This model can be either considered as a standalone box model or as a spatial unit (i.e. a subunit of a larger model grid) of a 3D domain. The WGCCBOCS also con- structed another model to study the previously published data that describes deep oceanic DOC degradation experiments, suggesting that the recalcitrance of RDOC is largely related to its chemical properties, whereas dilution plays a minor role in determining the persistence of deep-ocean DOC.

Methodological developments:

- A mesocosm and artificial upwelling system demo was set up at Aoshan Bay, Qingdao, China.
- An experimental demonstrations (Mini-MECS,) for a planned large scale experimental system (MECS, the Marine Environmental Chamber System) was built on the Qingdao campus of Shandong University, China.

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)

Yes.

Blue carbon, i.e. the carbon captured and sequested by marine ecosystems, is recognized as an impartant carbon pool in global carbon cycling by scientists, governments and the public. Better integrated reviews and research are necessary to understand its significance for science and society.

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

(*If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat*.)

12) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?

13) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)