PACECS Annual Report 2021

Processes and Approaches of Coastal Ecosystem Carbon Sequestration (PACECS)

1. Selected highlights

1.a.i. Selected scientific highlights since last report

Last report was submitted to SSC meeting, May/June 2020. Each highlight needs to be VERY short, bullet points, with a link to publication if applicable.

Subproject 1:

- ✓ Laterally transported particles from the surrounding margins provide a direct source of organic carbon and also allow for much new organic carbon production through dark carbon fixation. These particles, which provide a major energy source to dark ocean ecosystems, help resolve the mismatch in the regional carbon budget. (https://doi.org/ 10.1029/2020GL088971)
- ✓ Multiple single amplified genomes (SAGs) belonging to *Roseobacter* and *Alteromonas*, recovered from the hadal zone of the Mariana Trench were reported. The modification of cell surface-related proteins and transporters is the major direction of genomic evolution in *Roseobacter* and *Alteromonas* bacteria adapting to the hadal environment, and that prophages and transposons may be the key factors driving this process. (https://doi.org/10.3389/fmicb.2020.01739)
- ✓ The well-protected photosynthetic light reactions of both PSII and PSI endows the macroalga *Ulva lactuca* with a high capacity for physiological performance and carbon fixation. (https://doi.org/10.1016/j.algal.2020.102094)
- ✓ Planktonic ciliate communities in the East China Sea are dominated by aloricate oligotrichs and choreotrichs in terms of species number, abundance and carbon biomass. And planktonic ciliates are potentially reliable indicators of water masses in the marine systems with dynamic environmental variations. (https://doi.org/10.1016/j.marpolbul.2020.111253)
- ✓ The potential growth rate of the ecologically distinct prokaryotic subgroups [i.e., high nucleic acid (HNA) and low nucleic acid (LNA) cells] responded reversely along the nutrient gradient. Results revealed an elevated contribution of LNA cells to the prokaryotic community and a relatively greater virus-mediated mortality pressure on

total prokaryotes under more oligotrophic conditions.
(https://doi.org/10.3389/fmicb.2020.612053)

- ✓ The study sheds light on the transformation of different biological availability of organic carbon by coastal microorganisms which coupled with the regeneration of different form of inorganic nitrogen.
(https://doi.org/10.3389/fmicb.2020.01041)
- ✓ The microenvironments in the pelagic ocean represented by phytoplankton and organic particles are likely important niches that drive the cryptic speciation of the Roseobacter population, though microhabitats contributed by other less abundant pelagic hosts cannot be ruled out. (https://doi.org/10.1038/s41396-020-00743-7)
- ✓ Along an estuary to a basin transect of the Northern South China Sea, the active protistan communities were mainly driven by dispersal limitation, followed by drift and other ecological processes.
(https://doi.org/10.3390/ microorganisms9020351)
- ✓ In Liaohe Estuary, *nirS*-type denitrifiers were consistently more abundant and diverse than *nirK* and *nosZ*-type denitrifiers. The dominant genera of *nirK*, *nirS* and *nosZ*-type denitrifiers were *Sinorhizobium*, *Pseudomonas*, and *Azospirillum*. Salinity, nitrogen levels, and sediment grain size were the main factors affecting the denitrification process in this eutrophic estuary.
(https://doi.org/10.1080/01490451.2020.1822959)

Subproject 2:

- ✓ We found that certain part of the DOC released from growing Synechococcus can resist the utilization by bacterial community, providing a new understanding that Synechococcus can contribute to carbon sequestration in a dissolved form by producing directly the recalcitrant DOC. Moreover, the bacterial community could promote aggregate formation and sinking of Synechococcus, and thus may enhance the contribution of Synechococcus to the magnitude of the biological carbon pump in oceans.
(https://link.springer.com/article/10.1007/s10811-020-02343-6)

- ✓ The study shows that the degradation of green tide algal biomass is a long-term process that can have long-lasting effects on marine microbial processes and carbon cycling. The results indicate that although *U. prolifera* green tides disappeared in late summer every year, the long-term degradation of massive sank macroalgae would not only have a significant impact on marine microbial processes but also make an important contribution to the growth of the RDOC pool in the coastal ocean. (Chen et al., Water Research)
(https://doi.org/10.1016/j.watres.2020.116268)
- ✓ Combined with the multivariate statistical analysis, twenty-two differential metabolites were screened as relevant to the discrepancy in *Schizochytrium* sp. strains. The results showed relatively downregulated glycolysis and saturated fatty acids (SFA) synthesis, and upregulated TCA cycle, amino acids and polyunsaturated

fatty acids (PUFA) synthesis in DHA high yield strain. (https://doi.org/10.1016/j.jchromb.2020.122193)

- ✓ The study reported empirical geological and microbial evidence in the surface sediments for long-term effects of waterway management that began more than 700 years before the industrial revolution. We revealed a vast 12.4×10^3 km^2 region of trace metal accumulation, with sediment enrichment and sedimentary trace metals associated with microbial diversity changes. (https://doi.org/10.1016/j.jhazmat.2020.123164)
- ✓ The study demonstrated the ecological risks posed by trace metal pollution on mangrove patches and emphasized the importance of a more comprehensive survey for mangrove patch environments to achieve Sustainable Development Goals. （https://www.sciencedirect.com/science/article/pii/S0269749120366859?via%3Dihub）
- ✓ Bioavailability of canonical D-AAs and non-canonical D-AAs (NCDAAs) for marine microbes was analyzed. It was found that the NCDAAs are relatively more refractory than canonical D-AAs to microbial utilization. (https://doi.org/10.1016/j.scitotenv.2020.139216)

Subproject 3:

- ✓ The study introduces the concept of "biomolecular burial efficiency" and applies it in concert with conventional stable carbon isotopic approaches to explore the fates of different terrestrial organic carbon pools in the Pearl River–northern South China Sea and the Yellow River–Bohai Sea/Yellow Sea systems. Our findings reveal markedly different burial efficiencies of terrestrial organic carbon in these two fluvial–marine systems, with the former at ca. 25% but the latter more than 80%. （https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019JG005520）

Subproject 4:

- ✓ A new solar-powered, air-lifted artificial upwelling (AU) system was applied to study the potential effect on regional carbon removal. Comparison of the temperature and nutrient column between AU influenced site and the reference site suggests that the nutrient-rich bottom water has been successfully lifted to the surface. The growth of seaweeds was effectively stimulated by AU. The average weight of a single plant has increased by 8.98 g, and consequently an extra carbon removal potential of 14.8 thousand tons in Chinese coastal waters could be expected. (https://doi.org/10.1016/j.apor.2020.102260)

1.a.ii. Selected scientific highlights over last 5 years *(2016-2021)*

Subproject 1:

- ✓ Homeostasis in the lower epipelagic and mesopelagic nitrogen cycle is characterized by an interplay of contrasting life strategies of ammonia- and nitrite-oxidizing microbial assemblages with similar affinities maintaining nearly equal oxidation rates

of their respective nitrogen substrates in the energy-poor environment of the dark ocean. Our analysis suggests that chemoautotrophic nitrification is associated with a global carbon fixation rate of ~1×10^{13} to ~2×10^{13} mol C yr^{-1} in the dark ocean. (https://www.pnas.org/content/117/9/4823)

- ✓ Laterally transported particles from the surrounding margins provide a direct source of organic carbon and also allow for much new organic carbon production through dark carbon fixation. These particles, which provide a major energy source to dark ocean ecosystems, help resolve the mismatch in the regional carbon budget. (https://doi.org/ 10.1029/2020GL088971)
- ✓ Ocean acidification enhances coastal but inhibits pelagic photosynthetic carbon fixation of primary producers due to combined effects with other drivers, such as UV radiation and nutrients availability. (https://www.frontiersin.org/articles/10.3389/fmars.2019.00322/full)

Subproject 2:

- ✓ We found that certain part of the DOC released from growing *Synechococcus* can resist the utilization by bacterial community, providing a new understanding that Synechococcus can contribute to carbon sequestration in a dissolved form by producing directly the recalcitrant DOC. Moreover, the bacterial community could promote aggregate formation and sinking of *Synechococcus*, and thus may enhance the contribution of *Synechococcus* to the magnitude of the biological carbon pump in oceans. (https://link.springer.com/article/10.1007/s10811-020-02343-6)
- ✓ The study shows that the degradation of green tide algal biomass is a long-term process that can have long-lasting effects on marine microbial processes and carbon cycling. The results indicate that although *U. prolifera* green tides disappeared in late summer every year, the long-term degradation of massive sank macroalgae would not only have a significant impact on marine microbial processes but also make an important contribution to the growth of the RDOC pool in the coastal ocean. (Chen et al., Water Research) (https://doi.org/10.1016/j.watres.2020.116268)
- ✓ Glomalin-related soil protein (GRSP) is a widespread glycoprotein found to have strong ability of sequestering heavy metals in soils. This study was initiated to investigate the interconnection of metal loading in GRSP between sediments and suspended solids, focusing on the mobilization mechanisms of GRSP in mangrove wetland. The new finding provided insights into the ecological functions of GRSP and the heavy metal cycling in wetland environments. (https://www.sciencedirect.com/science/article/pii/S0043135418308406)

Subproject 3:

- ✓ The study carries out dual carbon isotope analyses to study the composition and flux of Yellow River particulate organic carbon. Quantifications on contemporary, pre-aged and fossil organic carbon fluxes were reached by using mixing model, and our results show that the Yellow River particulate organic carbon composition exhibits

minor temporal variability on both seasonal and inter-annual scales while the overall flux of each source component changes dramatically under the control of hydrological conditions. (https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lno.10727)

- ✓ The study applies the bulk and molecular carbon isotopes (^{13}C and ^{14}C) to examine the spatiotemporal variations in particulate OC composition and age in the Yellow River under the impacts of natural and human-induced hydrological variability during 2015-2016. Our results reveal the predominance of pre-aged OC at the upstream site and strong intra-annual variations in modern and pre-aged OC at the downstream site which are caused by both natural and human-induced hydrological events. (https://pubs.acs.org/doi/abs/10.1021/acs.est.8b04705)

Subproject 4:

- ✓ By integrating experimental results with a physiological-level model, Luo et al. (2019) quantitatively reveal that the ocean acidification (OA) overall negatively impacts the N_2 fixation of the major marine N_2 fixer, Trichodesmium, mainly caused by reducing efficiency of nitrogenase enzyme. They also project that the potential of Trichodesmium N_2 fixation will decline on average by 27% in the global ocean in the 21st century under RCP 8.5. (https://www.nature.com/articles/s41467-019-09554-7)

1.b. Publications since last report

Please add all publications since last report to the table below (see notes for details on "Class" and "Activity" fields).

***Publication** with DOI*	***Class 1, 2, 3***	***Activity****
Subproject 1 :		
Shen, J; Jiao, N; Dai, M; Wang, H; Qiu, G; Chen, J; Li, H; Kao, S.J.; Yang, J.Y. T.; Cai, P.; Zhou, K.; Yang, W.; Zhu, Y.; Liu, Z.; Chen, M.; Zuo, Z.; Gaye, B.; Wiesner, M. G.; Zhang, Y. Laterally transported particles from margins serve as a major carbon and energy source for dark ocean ecosystems. Geophysical Research Letters, **2020.9.28**, 47(18), e2020GL088971.* ***DOI: 10.1029/2020GL088971.***	*Class 2*	
Chen, M.; Song, Y.; Feng, X.; Tang, K.; Jiao, N.; Tian, J.; Zhang, Y. Genomic characteristics and potential metabolic adaptations of hadal trench Roseobacter and Alteromonas bacteria based on single-cell genomics analyses. Frontiers in Microbiology, **2020.7.24**, 11, 1739.* ***DOI: 10.3389/fmicb.2020.01739.***	*Class 2*	
Zhang, D.; Beer, S.; Li, H.; Gao, K. Photosystems I and II in Ulva lactuca are well protected from high incident sunlight. Algal Research, **2020.12**, 52, 102094.* ***DOI: 10.1016/j.algal.2020.102094.***	*Class 2*	
Yang, J., Huang, S., Fan, W., Warren, A., Jiao, N., Xu, D. Spatial distribution patterns of planktonic ciliate communities*	*Class 2*	

in the East China Sea: potential indicators of water masses. Marine Pollution Bulletin, ***2020.7****, 156, 111253.* ***DOI: 10.1016/j.marpolbul.2020.111253.***		
Hu, C.; Chen, X.; Yu, L.; Xu, D.; Jiao, N.* Elevated contribution of low nucleic acid prokaryotes and viral lysis to the prokaryotic community along the nutrient gradient from an estuary to open ocean transect. Frontiers in Microbiology* ***2020.12.15****, 11, 612053.* ***DOI: 10.3389/fmicb.2020.612053.***	*Class 2*	
Xie, R.; Wang, Y.; Chen, Q.; Guo, W.; Jiao, N; Zheng, Q. Coupling between carbon and nitrogen metabolic processes mediated by coastal microbes in Synechococcus-derived organic matter addition incubations. Frontiers in Microbiology,* ***2020.5.25****, 11, 1041.* ***DOI: 10.3389/fmicb.2020.01041.***	*Class 2*	
Wang, X.#; Zhang, Y.#; Ren, M.#; Xia, T.; Chu, X.; Liu, C.; Lin, X.; Huang, Y.; Chen, Z.; Yan, A.; Luo, H. Cryptic speciation of a pelagic Roseobacter population aarying at a few thousand nucleotide sites, The ISME Journal,* ***2020.12****, 14(12), 3106-3119.* ***DOI: 10.1038/s41396-020-00743-7.***	*Class 2*	
Li, R., Hu, C., Wang, J., Sun, J., Wang, Y., Jiao, N., Xu, D. Biogeographical Distribution and Community Assembly of Active Protistan Assemblages Along an Estuary to a Basin Transect of the Northern South China Sea. Microorganisms,* ***2021.2.10****, 9(2), 351.* ***DOI: 10.3390/ microorganisms9020351.***	*Class 2*	
Ming, H., Fan, J., Chen, Q., Su, J., Song, J., Yuan, J., Shi T.; Li, B. Diversity and Abundance of Denitrifying Bacteria in the Sediment of a Eutrophic Estuary. Geomicrobiology Journal,* ***2020.9****, 1-11.* ***DOI: 10.1080/01490451.2020.1822959.***	*Class 2*	
Subproject 2 :		
Zhang, Z†, Tang, L†, Liang, Y, Li, G, Li, H, Rivkin, R, Jiao, N, and Zhang, Y. The relationship between two Synechococcus strains and heterotrophic bacterial communities and its associated carbon flow. Journal of Applied Phycology,* ***2021.1.7****, 33:953–966.* ***DOI: 10.1007/s10811-020-02343-6.***	*Class 2*	
Chen, J.; Li, H., Zhang, Z.; He, C.; Shi, Q.; Jiao, N.; Zhang, Y.* DOC dynamics and bacterial community succession during long-term degradation of Ulva prolifera and their implications for the legacy effect of green tides on refractory DOC pool in seawater. Water Research,* ***2020.10.15****, 185, 116268.* ***DOI: 10.1016/j.watres.2020.116268.***	*Class 2*	
Yang, J.; Song, X.; Wang, L.; Cui, Q.* Comprehensive analysis of metabolic alterations in Schizochytrium sp. strains with different DHA content, Journal of Chromatography B,* ***2020.12.1****, 1160, 122193.* ***DOI: 10.1016/j.jchromb.2020.122193.***	*Class 2*	

Wang, S.; Lan, C.; Wang, Z.; Wan, W.; Cui, Q.; Song, X., PUFA-synthase-specific PPTase enhanced the polyunsaturated fatty acid biosynthesis via the polyketide synthase pathway in Aurantiochytrium. Biotechnology for biofuels ***2020.08.31****, 13, 152.* ***DOI:10.1186/s13068-020-01793-x***	*Class 2*	
Wang, S.; Lan, C.; Wang, Z.; Wan, W.; Zhang, H.; Cui, Q.; Song, X., Optimizing Eicosapentaenoic Acid Production by Grafting a Heterologous Polyketide Synthase Pathway in the Thraustochytrid Aurantiochytrium. J Agric Food Chem ***2020.08.24****, 68, 11253-11260.* ***DOI:10.1021/acs.jafc.0c04299***	*Class 2*	
Zhang, H.; Cui, Q.; Song, X., Research advances on arachidonic acid production by fermentation and genetic modification of Mortierella alpina. World J Microbiol Biotechnol ***2020.12.20****, 37, 4* ***DOI: 10.1007/s11274-020-02984-2***	*Class 2*	
Hong, H.; Li, J.; Wang, Q.; Lu, H.; Liu, J.; Dong, Y.; Zhang, J.; Li, J.; Mark, A. W.; Huang, B.; Yan, C.* The legacy of trace metal deposition from historical anthropogenic river management: A regional driver of offshore sedimentary microbial diversity. Journal of Hazardous Materials,* ***2020.12.5****, 400, 123164.* ***DOI: 10.1016/j.jhazmat.2020.123164.***	*Class 2*	
Hong, H.; Wu, S.; Wang, Q.; Qian, L.; Lu, H.; Liu, J.; Lin, H.; Zhang, J.; Xu, W.; Yan, C. Trace metal pollution risk assessment in urban mangrove patches: Potential linkage with the spectral characteristics of chromophoric dissolved organic matter. Environmental Pollution,* ***2021.3.1****, 272, 115996.* ***DOI: 10.1016/j.envpol.2020.115996.***	*Class 2*	
Chen, S.; Lin; R.; Lu; H.; Wang, Q.; Yang, J.; Liu, J.; Yan, C. Effects of phenolic acids on free radical scavenging and heavy metal bioavailability in Kandelia obovata under cadmium and zinc stress. Chemosphere,* ***2020.6****, 249, 126341.* ***DOI: 10.1016/j.chemosphere.2020.126341.***	*Class 2*	
Wang, R.; Zhang, Z.; Sun, J.; Jiao, N.* Differences in bioavailability of canonical and non-canonical D-amino acids for marine microbes, Science of the Total Environment,* ***2020.9.1****,733, 139216.* ***DOI: 10.1016/j.scitotenv.2020.139216.***	*Class 2*	
Subproject 3 :		
Hou, P., Yu, M., Zhao, M., Montluçon, D. B., Su, C., Eglinton, T. I.* Terrestrial biomolecular burial efficiencies on continental margins. Journal of Geophysical Research: Biogeosciences,* ***2020.8****, 125(8), e2019JG005520.* ***DOI: 10.1029/2019JG005520.***	*Class 2*	
Chu, M.; Sachs, J. P.; Zhang, H.; Ding, Y.; Zhao, M. Spatiotemporal variations of organic matter sources in two mangrove-fringed estuaries in Hainan, China. Organic Geochemistry,* ***2020.9****, 147, 104066.* ***DOI: 10.1016/j.orggeochem.2020.104066.***	*Class 2*	

Subproject 4 :		
Fan, W.; Zhang, Z.; Yao, Z; Xiao, C.; Zhang, Y.; Zhang, Y.; Liu, J.; Di, Y.; Chen, Y.; Pan, Y. A sea trial of enhancing carbon removal from Chinese coastal waters by stimulating seaweed cultivation through artificial upwelling, Applied Ocean Research,* ***2020.8****, 101, 102260.* ***DOI: 10.1016/j.apor.2020.102260.***	*Class 2*	

**If appropriate, please list the IMBeR activity through / by / from / during which the publication arose*

*******Notes on publications********

Publications are logged in the IMBeR Zotero library which is publicly accessible online - https://www.zotero.org/groups/2448334/imber_library_2/library

[Due to space limitations, publications from 1999-2017 are in a separate Zotero library - https://www.zotero.org/groups/38770/imber_library_1/library]

Publications are categorised by "Class" and linked to "Activities":

Class 1 publications are specifically generated through/by/from/during ***IMBeR activities*** - for example, arising from IMBIZOs and IMBeR conferences such as the IMBeR open science meeting and the IMBeR CJK symposia and from the activities of the working groups, regional programmes and the SPIS scoping teams.

Class 2 publications are on topics relevant to the IMBeR Science Plan that benefitted from some interaction with IMBeR or ***IMBeR activities***, for example by IMBeR symposium attendees, past and present SSC members, working group, regional programme and endorsed project members, or national contacts.

Class 3 publications are on topics relevant to the IMBeR Science Plan but for which there is no direct link to or benefit from an IMBeR activity. These might include publications by SSC members, working group, regional programme or endorsed project members or members of the IMBeR international community that were written as part of the normal scientific activity of the authors and would have occurred irrespective of IMBeR's existence. You can report Class 3 publications, but they will no longer be logged in the IMBeR database.

[See https://drive.google.com/open?id=1OQWn41KJvQ-LyWJlkiYnc5qZ2IuNQOrg or https://pan.ecnu.edu.cn/p/DTrpUb4QiFAYoQ4 for further information on "What is an IMBeR publication?".]

Why list 'Class' and 'Activity'? This helps us to declare authentically which publications IMBeR has helped to generate, and it makes it easier for us to demonstrate the value of the Regional Programmes, the Working Groups, the Endorsed Projects, and IMBeR in general, and it helps us to justify support for IMBeR activities when we can list tangible outputs.

1.c. Events, Meetings, and Workshops

List all international and national events, meetings and workshops. Describe the level of participation: e.g. chairing session/workshop, organising meeting. Include Endorsed Project meetings and workshops.

Format: Title of event. Date. Location. Description of participation. Any other pertinent details.

- ✓ The subprojects 1 and 4 teams jointly organized the cruise of Dongji Island in Zhoushan, from September 22 to 28, 2020. The microbial DNA, RNA and protein samples have been collected.
- ✓ The project team held a seminar to integrate and discuss the annual progress of the four subprojects in Xiamen on November 20-22, 2020.
- ✓ The leaders and the principal researchers of this project discussed the collaborative integration of organic carbon sinks at the land-sea interface in Ocean University of China on December 5, 2020.
- ✓ The Ministry of Science and Technology held the annual meeting in GuangZhou on December 15-16, 2020.

2. International collaboration and links

The project team and Dalhousie University have jointly carried out long-term large-scale ecological simulation experiments using the Aquatron experimental system since September 2016 and obtained a series of important understandings of the microbial carbon pump processes and mechanism.

3. Input to management, policy and governance

Add anything that in line with the IMBeR Grand Challenge III: Improving and achieving sustainable ocean governance

Ocean is the largest carbon pool on earth, serving as the buffer of global climate change, absorbing about 1/3 of CO_2 produced by human activities. Carbon sink captured by marine ecosystem is called the "Blue Carbon Sink" (hereinafter referred to as "blue carbon"), which is one of the most important mechanisms for the sea to store carbon. The initial form of blue carbon is visible plant carbon sequestration in the coastal zone. As a matter of fact, the invisible microorganisms (phytoplankton, bacteria, archaea, and protozoa), which have always been ignored, account for 90% of the marine biomass and constitute the main component of blue carbon. The marginal sea covers one third of the total territory of China, and it is of urgent need to explore the immense potential of carbon sinks. This project aims at the key processes and mechanisms of the carbon sequestration in coastal ecosystems and ways to increase ocean carbon sink: (1) key processes and regulatory mechanisms of ocean carbon sink and its relationship with environment and global climate changes; (2) an index system for carbon storage including a series of physical-chemical and biological indices and parameters and main core measurements protocols; (3) demonstrations of increasing carbon sink and engineering carbon sequestration in the ocean. These outputs will support the sustainable development of marine ecosystem and national carbon emissions trading.

4. Planned activities for next year

- ✓ The project team is preparing for the acceptance check which is organized by the expert committee of the national science and technology in 2021.9.
- ✓ The project team will hold a meeting and invite a board of experts to discuss and demonstrate part of the main core measurement protocols aiming at establishing an index system for carbon storage.