

**Full title of the project (+ acronym):** Processes and Approaches of Coastal Ecosystem Carbon Sequestration (PACECS)

**Name of the Leader:** Yao Zhang

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**Theme / Main objectives:**

This research focuses on the carbon sink in coastal oceans. The majority of this research includes: (1) community structure and ecosystem function in the carbon cycle, with an emphasis on key processes concerning the particulate organic carbon (POC) sinking and the refractory dissolved organic carbon (RDOC) production; (2) physiological and molecular mechanisms of ocean carbon sinks, such as uptake, transformation, and release of carbon-containing chemical compound by microorganism at the gene and protein levels; the impact of human activities and input of terrestrial nitrogen and phosphorus on the above processes; (3) re-establishing the evolution process of ocean carbon sinks in geologic history with sedimentary records, which should record organic carbon from burial of sinking POC in sediments, the RDOC molecules, and the human activities and input of terrestrial sources; the relationship between ocean carbon sinks and global climate changes in ancient oceans; (4) establishing scenario models for carbon sink dynamics under global warming situation; providing theoretical and technical foundations for engineering ocean carbon sequestration in the future.

The objectives of this project is to obtain breakthroughs in the following aspects: (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, provide scientific and technological support and demonstration for China in terms of developing low-carbon economy and carbon emissions trading.

**Timetable of activities:** 1 July 2016 – 30 June 2021

**Major achievements:**

*½ page maximum, each highlight needs to be VERY short, bullet points, with a link to publication if possible*

**Subproject 1:**

- ✓ The phytoplankton and heterotrophic bacteria mix-system incubation experiments revealed bacterially-mediated transformations of phytoplankton-derived DOC at the chemical molecular level. (<https://onlinelibrary.wiley.com/doi/abs/10.1111/1462-2920.14646>)
- ✓ Field-based stable isotope probing analysis revealed a more important role of microbes in the transformation of one-carbon compounds in marine environments than hitherto assumed. (<https://www.nature.com/articles/s41598-018-33497-6>)
- ✓ Short-term exposure of plankton communities in eutrophic subtropical waters to elevated CO<sub>2</sub> concentration relevant to ocean acidification has little effect on primary productivity and trophic linkage to mesozooplankton. (<https://www.sciencedirect.com/science/article/pii/S0025326X19301833>)

**Subproject 2:**

- ✓ We developed a superfine pretreatment method and metabolomics analysis technique for insoluble organic samples.
- ✓ Glomalin-related soil protein (GRSP) produced by arbuscular mycorrhizal fungi was proved to be a stable

glycoprotein and can be transported by soil erosion and deposited in intertidal and marine sediments, and thus a significant component of the C and N pools in the coastal systems. (<https://www.sciencedirect.com/science/article/pii/S0043135418308406>)

- ✓ Part of carbon released by kelp was proved to be potentially recalcitrant and could contribute to the increase of long-term refractory DOC pool in the ocean. (<https://doi.org/10.1016/j.marpolbul.2018.10.048>)

#### **Subproject 3:**

- ✓ Inter-annual differences in pre-aged soil and fossil organic carbon (OC) fluxes imply that extreme climate events (e.g., floods) modulate the exhumation and export of old carbon to the ocean; the OC homogeneity in the pre-aged mineral soil-dominated watersheds facilitates robust predictions in terms of OC transport dynamics in the past (sediment cores) and in the future (<https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.1002/lno.10727>)
- ✓ The co-variation between the ladderane record and published records of low-oxygen tolerant foraminiferal microfossils and hypoxia events over the past 60 years suggested that sediment ladderanes are a useful indicator for past changes of oxygen depletion or hypoxia in the East China Sea. (<https://www.sciencedirect.com/science/article/abs/pii/S0043135419302684>)

#### **Subproject 4:**

- ✓ An optimality-based cellular model for major ocean N<sub>2</sub> fixer *Trichodesmium* was constructed and the results show that reduced nitrogenase efficiency will force the reduction of N<sub>2</sub> fixation of *Trichodesmium* by 27% under ocean acidification (RCP 8.5 scenario), which is very important to improve our understandings on N<sub>2</sub>-fixing-driven ocean carbon sequestration. (<https://www.nature.com/articles/s41467-019-09554-7>)
- ✓ A self-powered, highly efficient, and durable artificial upwelling system has been built and successfully tested in the Aoshan Bay, Jimo, Qingdao. The results showed that low temperature deep-water can be brought to the euphotic zone by injecting compressed air, which can change the nutrition distribution, regulate the nitrogen/phosphorus ratio, and stimulate the primary productivity locally.

#### **Capacity building activities:**

- ✓ The subprojects 1 and 2 teams jointly organized the session "Ocean carbon sink and the coupling of regional carbon, nitrogen, and sulfur cycle in response to global changes" during the geological microbiology symposium in Shanghai from June 8 to 11, 2018.
- ✓ The project team held a seminar to integrate and discuss the Medium-term progress of the four subprojects in Qingdao on July 29, 2018.
- ✓ The project team conducted the internal Medium-term inspection in Qingdao on July 30, 2018. The project leader, professor Yao Zhang, reported the overall progress of the project, and the subproject leaders reported the progress of the four subprojects. The advisory committee gave many constructive suggestions.
- ✓ The Ministry of Science and Technology held the Medium-term inspection meeting in Beijing from September 2 to 3, 2018.
- ✓ The subprojects 1, 2, and 4 teams jointly organized the first Artificial Upwelling System Test in the Aoshan Bay, Jimo, Qingdao from April 18 to 25, 2018.
- ✓ The subprojects 1, 2, and 4 teams jointly organized the second Artificial Upwelling System Test in the Aoshan Bay, Jimo, Qingdao from May 3 to 10, 2018.
- ✓ The subprojects 1, 2, and 4 teams jointly organized the third Artificial Upwelling System Test in the Aoshan Bay, Jimo, Qingdao from June 18 to 25, 2018.
- ✓ The subprojects 1, 2, and 4 teams jointly held a series of seminars to discuss the Artificial upwelling system in

Qingdao, Weihai, and Xiamen from October 29 to November 2, 2018.

- ✓ The subprojects 1, 2, and 4 teams jointly organized the fourth Artificial Upwelling System Test in the Aoshan Bay, Jimo, Qingdao from January 15 to 21, 2019.
- ✓ The subprojects 1, 2, and 4 teams jointly organized the fifth Artificial Upwelling System Test in the Aoshan Bay, Jimo, Qingdao from March 9 to 12, 2019.
- ✓ 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.

#### **Upcoming activities:**

- ✓ The project team will hold the annual internal inspection meeting in 2019.
- ✓ The project team will basically finish establishing the demonstration area for increasing coastal ocean's carbon sinks based on artificial upwelling in the Aoshan Bay, Jimo, Qingdao.
- ✓ The project team will hold a meeting and invite a board of experts to discuss and demonstrate part of the main core measurements protocols aiming at establishing an index system for carbon storage.

#### **Data Management:**

*Please note this will be placed on the endorsed project webpage*

##### **- Name and e-mail of the person in charge of data management:**

Ms. Yingnan Fu, Senior technician, [fuyingnan@xmu.edu.cn](mailto:fuyingnan@xmu.edu.cn)

Ms. Xiabing Xie, Technician, [xiexiabing@xmu.edu.cn](mailto:xiexiabing@xmu.edu.cn)

##### **- Name of the data centre where your project data are stored:**

"Data Management Centre".

##### **- Direct Web link where the project data are available:**

<http://ime.xmu.edu.cn/bluecarbonmcp/data.asp>

#### **List of 2018/19 publications:**

##### **Subproject 1**

1. Deng W., Peng L., Jiao N., Zhang Y. Differential incorporation of one-carbon substrates among microbial populations identified by stable isotope probing from the estuary to South China Sea. *Scientific Reports*, 8:15378, 2018. (SCI, IF =4.122)
2. Hou L., Xie X., Wan X., Kao S., Jiao N., Zhang Y. Niche differentiation of ammonia and nitrite oxidizers along a salinity gradient from the Pearl River estuary to the South China Sea, *Biogeosciences*, 15: 5169-5187, 2018. (SCI, IF =3.441)
3. Li Y., Tang K., Zhang L., Zhao Z., Xie X., Chen C-T.A., Wang D., Jiao N., Zhang Y. Coupled Carbon, Sulfur, and Nitrogen Cycles Mediated by Microorganisms in the Water Column of a Shallow-Water Hydrothermal Ecosystem, *Frontiers in Microbiology*, 9: 2718, 2018. (SCI, IF =4.019)
4. Duan Y., Xie N., Song Z., Ward C.S., Yung C.-M., Hunt D.E., Johnson Z.I., Wang G. A High-resolution Time-series Reveals Seasonal Patterns of Planktonic Fungi at a Temperate Coastal Ocean Site (Beaufort, North Carolina, USA). *Applied and Environmental Microbiology*, 2018. (SCI, IF =3.633)
5. Carol R., Wallace D., Hyun J.H., Polimene L., Benner R., Zhang Y., Cai R., Zhang R., Jiao N. An implementation strategy to quantify the marine microbial carbon pump and its sensitivity to global change, *National Science Review*, nwy070, 2018. (SCI, IF =9.408)
6. Jiao N., Wang H., Xu G., Aricò S. Blue Carbon on the Rise: Challenges and Opportunities. *National Science*

- Review, nwy030, 2018. (SCI, IF =9.408)
7. Song Z., Stajich J.E., Xie Y., Liu X., He Y., Chen J., Hicks G.R., Wang G. Comparative analysis reveals unexpected genome features of newly isolated Thraustochytrids strains: on ecological function and PUFAs biosynthesis. *BMC Genomics*, 19 (1): 541, 2018. (SCI, IF = 3.730)
  8. Xie N., Sen B., Song Z., Zhao Y., Chen Z., Shi W., Zhang Y., Zhang J., Johnson Z.I., Wang G. High phylogenetic diversity and abundance pattern of labyrinthulomycete protists in the coastal waters of the Bohai Sea. *Environmental Microbiology*, 2018. (SCI, IF = 4.974)
  9. Zheng, Q., Chen, Q., Xu, Y., Suttle, C. A., & Jiao, N. A virus infecting marine photoheterotrophic alphaproteobacteria (*Citromicrobium* spp.) defines a new lineage of ssDNA viruses. *Frontiers in Microbiology*, 9:1418, 2018. (SCI, IF = 4.019)
  10. Zheng Q., Wang Y., Xie R., Lang A.S., Liu Y.T., Lu J.Y., Zhang X.D., Sun J., Suttle C.A., Jiao N.Z. Dynamics of heterotrophic bacterial assemblages within *Synechococcus* cultures. *Applied and Environmental Microbiology*. 84: e01517-17, 2018. (SCI, IF = 3.633)
  11. Wang G., Bai M., Xie Y., et al. Perspective and significance of unicellular protists in ocean carbon sink. *Microbiology China*, 45(4):886-892, 2018. (in Chinese)
  12. Xu K., Hutchins D.A., Gao K.S. Coccolith arrangement follows Eulerian mathematics in the coccolithophore *Emiliana huxleyi*. *PeerJ* 6: e4608, 2018. (SCI, IF =2.118)
  13. Chen M, Lu Y, Jiao N, Tian J, Kao S-J, Zhang Y. Biogeographic drivers of diazotrophs in the western Pacific Ocean[J]. *Limnology and Oceanography*, 9999, 1–19, 2019. (SCI, IF = 3.595)
  14. Wang T, Jin P, Wells M L, et al. Insensitivities of a subtropical productive coastal plankton community and trophic transfer to ocean acidification: Results from a microcosm study. *Marine Pollution Bulletin*, 141: 462-471, 2019. (SCI, IF = 3.241)
  15. Wang Y, Liu Y, Wang J, et al. Seasonal dynamics of bacterial communities in the surface seawater around subtropical Xiamen Island, China, as determined by 16S rRNA gene profiling. *Marine Pollution Bulletin*, 142: 135-144, 2019. (SCI, IF = 3.241)
  16. Li Q, Huisman J, Bibby T S, et al. Biogeography of Cyanobacterial *isiA* Genes and Their Link to Iron Availability in the Ocean. *Frontiers in Microbiology*, 10: 650, 2019. (SCI, IF = 4.019)
  17. Zheng, Q., Chen, Q., Cai, R. et al. Molecular characteristics of microbially mediated transformations of *Synechococcus*-derived dissolved organic matter as revealed by incubation experiments. *Environmental Microbiology*, 2019. (SCI, IF = 4.974)

## Subproject 2

18. Jiao N, Liang Y, Zhang Y, Liu J, Zhang Y, Zhang R, Zhao M, Dai M, Zhai W, Gao K, Song J, Yuan D, Li C, Lin G, Huang X, Yan H, Hu L, Zhang Z, Wang L, Cao C, Luo Y, Luo T, Wang N, Dang H, Wang D, Zhang S. Carbon pools and fluxes in the China Seas and adjacent oceans. *Science China Earth Sciences*, 61: 1535–1563, 2018. (SCI, IF = 2.058)
19. Guo R, Liang Y, Xin Y, et al. Insight into the pico-and nano-phytoplankton communities in the deepest biosphere, the Mariana Trench[J]. *Frontiers in Microbiology*, 9, 2018. (SCI, IF =4.019)
20. Li H, Zhang Y, Liang, Y, Chen, J, Zhu, Y, Zhao, Y, Jiao, N. Impacts of maricultural activities on characteristics of dissolved organic carbon and nutrients in a typical raft-culture area of the Yellow Sea, North China. *Marine Pollution Bulletin* 137, 456–464, 2018. (SCI, IF =3.241)
21. Song, X., et al., Artificial creation of *Chlorella pyrenoidosa* mutants for economic sustainable food production. *Bioresour Technol.* 268:340-345, 2018. (SCI, IF =5.807)
22. Wang, Q., Mei, D., Chen, J., Lin, Y., Liu, J., Lu, HL, & Yan, CL. Sequestration of heavy metal by glomalin-related soil protein: Implication for water quality improvement in mangrove wetlands. *Water Research*, 148,

- 142-152, 2019. (SCI, IF = 7.051)
23. Chi X., Wang L., Guo R., Zhao D., Li J., Zhang Y., and Jiao N. RuBisCO large-subunit gene primers for assessing the CO<sub>2</sub>-assimilating planktonic community structure in Jiaozhou Bay, China. *FEMS Microbiology Letters*: fny140-fny140, 2018. (SCI, IF = 1.735)
  24. Mou S., Li G., Li H., Li F., Shao Z., Li J. et al. Differential physiological responses of the coastal cyanobacterium *Synechococcus* sp. PCC7002 to elevated pCO<sub>2</sub> at lag, exponential, and stationary growth phases. *Science China Earth Sciences*, 2018. (SCI, IF =2.058)
  25. Wang Q., Li J., Chen J., Hong H., Lu H., Liu J., Dong Y., Yan C. Glomalin-related soil protein deposition and carbon sequestration in the Old Yellow River delta. *Science of the Total Environment*, 625: 619-626, 2018. (SCI, IF = 4.610)
  26. Zhang, H., et al. Heavy ion mutagenesis combined with triclosan screening provides a new strategy for improving the arachidonic acid yield in *Mortierella alpina*. *BMC Biotechnol*, 18(1): 23, 2018. (SCI, IF = 2.605)
  27. Zhang Z., Tang L., Zhang Y. Algae-bacteria interactions and their ecological functions in the ocean. *Microbiology China*, 45(9): 2043–2053, 2018. (in Chinese)
  28. Wang Z, Zhang Z, Li C, Hu Z, Zhao H, Zhang Y. *Marinicaulis aureum* sp. nov., isolated from a culture of the green alga *Ulva prolifera*, and emended description of the genus *Marinicaulis*. *Antonie van Leeuwenhoek* 1-7, 2018. (SCI, IF = 1.588)
  29. Tang L., Zhang Z., Zhou C. et al. *Roseicyclus marinus* sp. nov., isolated from a *Synechococcus* culture, and emended description of the genus *Roseicyclus*. *Int J Syst Evol Micr*, 2018. (SCI, IF = 1.932)
  30. Wang Q., Lu H.L., Chen J.Y., Hong H.L., Liu J.C., Li J.W., Yan C.L. Spatial distribution of glomalin-related soil protein and its relationship with sediment carbon sequestration across a mangrove forest. *Science of the Total Environment* 613: 548-556, 2018. (SCI, IF =4.610)
  31. Zhang Y, He P, Li H, et al. *Ulva prolifera* green-tide outbreaks and their environmental impact in the Yellow Sea, China. *National Science Review*, 0: 1–14, 2019. (SCI, IF =9.408)
  32. Cui G, Wang Z, Hong W, et al. Enhancing tricarboxylate transportation-related NADPH generation to improve biodiesel production by *Aurantiochytrium*. *Algal Research*, 40: 101505, 2019. (SCI, IF = 3.745)
  33. Yang L, Tang L, Li H, et al. Unique microbial communities inhabiting underground seawater in an intertidal area utilized for industrialized aquaculture, as compared with the coastal water. *Geomicrobiology Journal*, 2019. (SCI, IF = 1.433)
  34. Zhang Z, Hu Z, et al. *Ulvibacterium marinum* gen. nov., sp. nov., a novel marine bacterium of the family Flavobacteriaceae, isolated from a culture of the green alga *Ulva prolifera*. *Antonie van Leeuwenhoek*, 2019. (SCI, IF = 1.588)
  35. Wang Z, Zhang Z, et al. *Algihabitans albus* gen. nov., sp. nov., isolated from a culture of the green alga *Ulva prolifera*. *Int J Syst Evol Microbiol*, 2019. (SCI, IF = 1.932)
  36. Wang Z, Zhang Z, et al. *Alginatibacterium sediminis* gen. nov., sp. nov., a novel marine gammaproteobacterium isolated from coastal sediment. *International Journal of Systematic and Evolutionary Microbiology*. *Int J Syst Evol Microbiol*, 2019. (SCI, IF = 1.932)
  37. Li H, Zhang Y, Chen J, et al. Nitrogen uptake and assimilation preferences of the main green tide alga *Ulva prolifera* in the Yellow Sea, China. *Journal of Applied Phycology* 31, 625-635, 2018. (SCI, IF =2.401)

### Subproject 3

38. Tao S., Eglinton T.I., Zhang L., Yi Z., Montluçon D.B., McIntyre C., Yu M., Zhao, M.X. Temporal variability in composition and fluxes of Yellow River particulate organic matter. *Limnology and Oceanography*. 63: S119-S141, 2018. (SCI, IF = 3.595)
39. Yu M., Guo Z., Wang X., Eglinton T.I., Yuan Z., Xing L., Zhang H., Zhao M.X. Sources and radiocarbon ages of

aerosol organic carbon along the east coast of China and implications for atmospheric fossil carbon contributions to China marginal seas. *Science of the Total Environment*. 619-620: 957-965, 2018. (SCI, IF = 4.610)

40. Yuan Z., Xiao X., Wang F., Xing L., Wang Z., Zhang H., Xiang R., Zhou L., Zhao M. Spatiotemporal temperature variations in the East China Sea shelf during the Holocene in response to surface circulation evolution, *Quaternary International*, 482: 46-55, 2018. (SCI, IF = 2.163)
41. Zhao Z, Cao Y, Fan Y, et al. Ladderane Records over the Last Century in the East China Sea: Proxies for Anammox and Eutrophication Changes. *Water Research*, 156: 297-304, 2019. (SCI, IF = 7.051)
42. Yu M, Eglinton T I, Haghipour N, et al. Impacts of Natural and Human-Induced Hydrological Variability on Particulate Organic Carbon Dynamics in the Yellow River. *Environmental Science & Technology*, 53(3): 1119-1129, 2019. (SCI, IF = 6.653)

#### Subproject 4

43. Wang Nannan, Luo Ya-Wei, Polimene Luca, Zhang Rui, Zheng Qiang, Cai Ruanhong, Jiao Nianzhi. Contribution of structural recalcitrance to the formation of the deep oceanic dissolved organic carbon reservoir. *Environmental Microbiology Reports*, 10(6), 2018. (SCI, IF = 2.885)
44. Yongfa Qiang, Fan Wei, Canbo Xiao, Richard B. Rivkin, Yiwen Pan, Jiaping Wu, Jenhwa Guo, Ying Chen. Behaviors of bubble-entrained plumes in air-injection artificial upwelling[J]. *Journal of Hydraulic Engineering*, 144(7), 2018. (SCI, IF = 2.080)
45. Canbo Xiao, Wei Fan, Yongfa Qiang, Zhenyu Xu, Yiwen Pan, Ying Chen, A tidal pump for artificial downwelling: Theory and experiment. *Ocean Engineering*, 151:93-104, 2018. (SCI, IF = 2.214)
46. Yongfa Qiang, Fan Wei, Canbo Xiao, Richard B. Rivkin, Yiwen Pan, Jiaping Wu, Jenhwa Guo, Ying Chen. Effects of operating parameters and injection method on the performance of an artificial upwelling by using airlift pump. *Applied Ocean Research*, 121, 2018. (SCI, IF = 1.950)
47. Luo Yawei, Shi Dalin, Kranz S A, et al. Reduced nitrogenase efficiency dominates response of the globally important nitrogen fixer *Trichodesmium* to ocean acidification. *Nature Communications*, 10(1): 1521, 2019. (SCI, IF = 12.353)
48. Zhenyu Xu, Wei Fan, Canbo Xiao, Zhongzhi Yao, Yongfa Qiang, Ying Chen, Experimental and numerical study of current-induced artificial upwelling, *Applied Ocean Research*. 87, 26–37, 2019. (SCI, IF = 1.950)
49. Canbo Xiao, Wei Fan, Zhongzhi Yao, Yongfa Qiang, Yiwen Pan, Ying Chen, On the total entrained flow rate of artificial downwelling, *Ocean Engineering*. 181, 13–28, 2019. (SCI, IF = 2.214)