SESSION 6: COASTAL BLUE CARBON ECOSYSTEM: CARBON RESOURCES EVALUATION, SOURCES-SINKS PROCESSES, AND MANAGEMENT COLLABORATION

Conveners: Dr. Jinzhou Du and Wen-Chen Chou

Rapporteurs: Xiaogang Chen and Mariche B. Natividad

Participants

Online: 6

On-site Number of participants: 31

1. Highlights of presentations

Oral Presenter 1 (Xiaogang Chen)

- This study used radon as a tracer and found that tidally driven seawater recirculation, rather than submarine groundwater discharge, is the dominant mechanism for porewater exchange in tropical seagrass meadows.
- The recirculation process drives substantial total alkalinity (TA) exports that greatly exceed local organic carbon burial, resulting in a net carbon sink capacity that far surpasses methane emissions. This underscores the underestimated climate mitigation potential of tropical seagrass meadows.

Discussion points:

- The significance of the TA:DIC ratio in evaluating carbon sink efficiency.
- Effects of salinity gradients and seasonal variability on seagrass carbon sequestration dynamics.

Oral Presenter 2 (Neven Cukrov)

- The Krka River estuary is a constantly stratified system with distinct freshwater, halocline, and saline layers, influenced by river input from carbonate-rich terrain, making it naturally supersaturated with dissolved inorganic carbon.
- The CoE MARBLE (Center of Excellence in Marine Robotics and Technology for Sustainable Blue Economy) project marks a new phase in estuarine research, establishing a high-tech underwater testing range with real-time, in situ sensor monitoring for blue carbon and carbon cycle studies, supporting innovation in underwater robotics and sustainable blue economy research.

Discussion points:

- Potential for expanding testing infrastructure to additional sites within the estuarine system.
- Opportunities to deploy a broader range of sensors—such as for CO_2, nutrients, and other biogeochemical parameters—to enhance monitoring and data collection capabilities.

Oral Presenter 3 (Bing Xu) – *Presentation not delivered.*

Oral Presenter 4 (Mohammad Rozaimi, online)

- Blue carbon has evolved (chronologically) from a scientific concept into an interdisciplinary platform (fundamental: biological, physical, and chemical; and applied: natural resource management, conservation, citizen science, policy, economics), bridging hard sciences with policy, economics, and conservation—yet key questions about scope, inclusion, and actors remain unresolved.

- Key takeaways: Blue carbon encompasses multiple sub-disciplines and has undergone significant historical development. Rebranding thematic areas, demonstrating measurable policy impacts, and investing in capacity building are essential for advancing the field.

Discussion points:

- No questions raised during the session.

Oral Presenter 5 (Jinqiu Du)

- Highlights the role of Coastal Blue Carbon Ecosystems as a nature-based climate solution, emphasizing their ecological importance and integration into global climate policy.
- The presentation emphasized the need for a cross-border collaboration framework along the Maritime Silk Road to improve the management of CBC ecosystems. This includes joint monitoring efforts, utilization of geographical proximity, harmonization of standards and methods, and coordinated scientific research.
- Challenges identified: No unified standards and methods, weak political and economic power
- Proposed strategies: Communication and exchange mechanisms (high-level government dialogue, knowledge sharing, and community public awareness); Stakeholder engagement mechanism (trading market mechanism, investment financing mechanism, ecological compensation mechanism); supervision and monitoring mechanism (convention, evaluation, and monitoring).

Discussion points:

- The global blue carbon market presents a promising opportunity, but quantification of carbon stocks is essential for effectively lobbying policymakers (e.g., demonstrating how much carbon is stored across thousands of seagrass meadows).
- It was suggested that integrating economic models and financial analysis into blue carbon strategies can boost their attractiveness to investors and governments by clearly illustrating the return on investment in coastal restoration and conservation.

Oral Presenter 6 (Yusi Wang)

- This study employed radium isotope tracers (^{223}Ra and ^{224}Ra) and modeling approaches to quantify submarine groundwater discharge (SGD) in Swan Lake, Shandong. The results revealed substantial fluxes of dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), and nitrous oxide (N_2O), underscoring the significant role of SGD in transporting materials to coastal ecosystems.
- Notably, recirculated saline groundwater discharge (RSGD) accounts for 95.53% of total SGD in the region, primarily influenced by local geotectonic and hydrological factors. The study provides critical insights into carbon cycling in lagoon-seagrass ecosystems, with Swan Lake exhibiting DIC fluxes that exceed those reported in some tropical systems.

Discussion points:

- Future research directions include the need for long-term monitoring and expanding the number of studies across different ecosystems to better understand temporal and spatial dynamics.
- It was noted that SGD rates should be interpreted as optimal values rather than normal or average estimates, considering site-specific variability and methodological limitations.

Oral Presenter 7 (Jian-Jhih Chen)

- The study emphasizes the significant role of dissolved organic carbon (DOC) in seagrass ecosystems, particularly in the context of the microbial carbon pump, which plays a key role in long-term carbon storage.

- Results show that tropical seagrass habitats exhibit higher benthic metabolic rates—including respiration, gross primary production (GPP), and net community production (NCP)—compared to adjacent bare sediments. These habitats function as net autotrophic systems and can serve as effective carbon sinks.
- DOC fluxes were notably higher in seagrass areas. Optical characterization of the DOC revealed that seagrass-derived DOC is fresh, bioavailable, and protein-like, in contrast to the degraded, recalcitrant dissolved organic matter (DOM) released from bare sediments.

Discussion points:

- Refractory DOC (RDOC) Sources: A question was raised regarding the differentiation of RDOC origins—specifically, riverine input, saline groundwater, and fresh groundwater. The presenter clarified that with the current ex-situ approach, it is not possible to distinguish these sources quantitatively. However, such distinctions might be achievable through in-situ measurements combined with advanced tracers or isotopic analyses.
- Seagrass Sugar Exudation: A request for clarification was made on the mechanism and extent of sugar exudation from seagrasses, particularly how it contributes to the DOC pool and microbial activity. The response likely emphasized the role of fresh, bioavailable DOC in promoting microbial processes, although more detailed metabolic tracing may be needed to fully quantify this pathway.

Oral Presenter 8 (Wen-Chen Chou)

- This presentation underscored the critical role of total alkalinity (TA) in supporting long-term carbon sequestration in coastal blue carbon ecosystems (CBCEs). The study explored the mechanisms influencing TA flux—namely, organic carbon metabolism, carbonate dissolution, and sulfate reduction—through case studies from Dongsha Island and Kenting seagrass meadows.
- Results demonstrated that seagrass meadows growing in organic carbon-rich reef sediments generate TA fluxes up to two orders of magnitude higher than those in organic carbon-poor terrestrial sediments.
- The research proposes incorporating TA outwelling into blue carbon assessments, as this may represent a larger carbon sink than in situ organic carbon burial. It also highlights the strategic value of restoring seagrass in high-OC reef sediment areas to optimize carbon sequestration and bolster coastal resilience.

Discussion Points:

- Sediment Type Influence: A question was raised about whether similar TA fluxes would occur if seagrass were established only on carbonate sediments, rather than in organic matter-rich reef sediments. This prompts further exploration of sediment composition in TA dynamics.
- Enhancing Alkalinity: It was noted that the addition of calcium carbonate ($CaCO_3$) to sediments could potentially enhance alkalinity, opening up new possibilities for sediment manipulation strategies to boost carbon sequestration.

Oral Presenter 9 (Hongbin Liu)

- This study employed 16S rRNA amplicon sequencing, metagenomics, and metatranscriptomics to investigate the microbial communities associated with the root systems of *Halophila ovalis*, a dominant seagrass species in Hong Kong. Key bacterial groups enriched in the rhizosphere included Bacteroidetes, *Vibrio* spp., Arcobacter, *Roseibium*, and *Reinekea*.
- Functional analyses revealed that these bacteria contribute to nitrogen fixation, sulfide detoxification, and flavonoid degradation, all of which support seagrass resilience under

environmental stress. Notably, symbiotic bacteria showed enhanced saccharide transporter expression and flavonoid-degrading enzyme activity, which may help reduce phototoxic stress.
- The study proposes the application of these beneficial microbes as bio-agents for seagrass sediment remediation, offering an innovative approach to seagrass restoration and climate change mitigation through microbial symbiosis.

Discussion points:

- Nitrogen Fixation and Competition: A question was raised regarding competition for nitrogen fixation among sulfide-tolerant bacteria. The presenter clarified that nitrogen fixation is primarily carried out by *Vibrio* spp. in this system.
- Nitrogen Limitation Strategy: It was also discussed that in nitrogen-limited sediments, these bacteria may utilize atmospheric nitrogen primarily for their growth, but in doing so, indirectly support seagrass health through enhanced nutrient cycling.

Oral Presenter 10 (Mariche Bandibas Natividad)

- This study underscores the critical role of seagrass meadows as primary drivers of coastal ecosystem metabolism, demonstrating consistently higher gross primary production (GPP) and community respiration (CR) compared to adjacent bare sediments or the water column. These metabolic rates were especially elevated during the warm season, reinforcing the function of seagrass meadows as net carbon sinks across different seasonal conditions.
- A key takeaway is the importance of integrating both organic carbon metabolism and carbonate dynamics in blue carbon accounting, emphasizing that a comprehensive assessment of seagrass carbon sequestration must go beyond traditional organic carbon metrics to include processes like calcification and alkalinity fluxes for more accurate evaluations.

Discussion points:

- A question was raised on how calcification in seagrass meadows influences pCO_2 levels in seawater and its subsequent impact on adjacent coral reef ecosystems. It was noted that calcification increases pCO_2 due to the release of CO_2 during the formation of calcium carbonate. This can locally elevate CO_2 concentrations, potentially affecting water chemistry and reducing the buffering capacity of the surrounding environment. For coral reefs, which are sensitive to pH and carbonate saturation states, this localized increase in pCO_2 could stress calcifying organisms and influence coral health and growth rates. However, in landscapes where seagrass and corals coexist, seagrass meadows may provide local buffering to adjacent coastal ecosystems. Through photosynthesis, seagrasses can reduce pCO_2 and increase pH levels during daylight hours, helping mitigate acidification stress on nearby coral reefs. This dual role—both as a source (via calcification) and sink (via photosynthesis) of CO_2—underscores the complex biogeochemical interactions within these ecosystems.

Oral Presenter 11 (Hon-Kit Lui)

- This study explores the role of submarine groundwater discharge (SGD) in shaping coastal carbon dynamics, revealing a complex process where CO_2-supersaturated groundwater, upon discharge, contributes to CO_2-undersaturated conditions in the receiving coastal waters.
- Although SGD introduces high levels of dissolved inorganic carbon (DIC) and is initially a CO_2 source, it carries nutrients that stimulate photosynthetic activity, leading to carbon fixation, alkalinity generation, and ultimately, enhanced CO_2 sequestration.

- The CO_2 buffering capacity of SGD, particularly when derived from carbonate rock weathering, underscores its dual role: while groundwater itself is supersaturated with CO_2, its discharge can lower seawater pCO_2, contributing to carbon sink conditions.
- This transformation from a CO_2 source to a sink highlights the potential of SGD-influenced coastal zones to serve as net sinks for atmospheric CO_2, depending on biogeochemical interactions and ecological responses.

Discussion points:

- Clarification on high CO_2 and DO levels: These may be attributed to high metabolic activity within the coastal ecosystem. Such elevated levels are a natural phenomenon, particularly in systems with dynamic biological and chemical exchanges.
- Weak carbon sink at night: During the nighttime, photosynthetic CO_2 uptake ceases, leading to reduced carbon sequestration efficiency. This results in the coastal system acting as a very weak sink or even a net source during dark hours, emphasizing the diurnal variability in carbon fluxes.

Oral Presenter 12 (Chen Yu Da)

- This study quantifies the flux of submarine groundwater discharge (SGD) and dissolved organic carbon (DOC) in a Croatian karst seagrass bed, revealing that SGD-derived DOC significantly contributes to the carbon dynamics of these ecosystems.
- Fluorescence analysis revealed that humic-like and protein-like dissolved organic matter (DOM) are the dominant DOC components from SGD, with implications for long-term oceanic carbon storage due to their persistence and reactivity in marine systems. These results reinforce the importance of integrating groundwater-derived organic matter into blue carbon assessments, especially in karst coastal systems where SGD is prominent.

Discussion points:

- No questions were raised during the presentation session.

Oral Presenter 13: Najamuddin (online) – *Unable to present.*

2. Session summary

Session 6 of the conference, moderated by Prof. Jinzhou Du and Prof. Wen-Chen Chou, focused on the carbon resource evaluation, carbon source-sink processes, and management collaboration in coastal blue carbon ecosystems. The session featured 11 presentations that covered a wide range of topics, including the role of seawater recirculation in seagrass beds, the carbon cycle in the Krka River Estuary, and the importance of alkalinity in seagrass meadows. These presentations provided valuable insights into the complex biogeochemical processes and the regulatory role of seagrass habitats in coastal systems.

Key findings highlighted the significance of submarine groundwater discharge in carbon fluxes, the seasonal variability in organic metabolism and carbonate dynamics, and the presence of nitrogen-fixing and sulfide-oxidizing symbiotic bacteria in seagrass root systems. The discussions emphasized the need for integrated approaches to carbon management, interdisciplinary collaboration, and the development of comprehensive models to better understand and predict carbon dynamics in these ecosystems.

In their concluding remarks, Prof. Du and Prof. Chou expressed their enthusiasm for future collaborations and outlined potential areas for research, including the formulation of policies and management strategies, the

establishment of international research networks, and the continued exploration of the overlooked role of alkalinity in blue carbon assessments. The session concluded with a strong commitment to advancing blue carbon research for global environmental sustainability.

3. Suggestions for IMBeR 3.0 from this session (one or two bullet points):

- ✓ **Integrate Coastal Blue Carbon Processes and Submarine Groundwater Discharge (SGD) into Global Carbon Models and in the Current Blue Carbon Assessment**
  Current blue carbon assessments primarily focus on particulate organic carbon, often overlooking carbonate dynamics and the role of submarine groundwater discharge (SGD). IMBeR 3.0 can play a critical role in facilitating interdisciplinary collaboration and guiding research priorities that bridge land–sea interactions, with a focus on total alkalinity (TA) fluxes, SGD, and seagrass–coral ecosystem interactions. Encouraging the inclusion of these processes will improve the accuracy of global carbon budgets and support evidence-based nature-based climate solutions.

- ✓ **Foster Interdisciplinary and Regional Frameworks for Blue Carbon Governance**
  Encourage cross-border collaboration, unified methodologies, and the integration of socioeconomic dimensions—including carbon markets, policy mechanisms, and stakeholder engagement—to enhance blue carbon implementation, particularly in dynamic and interconnected coastal zones.