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Editorial: The changing carbonate systems in coastal, estuarine, shelf areas and marginal seas

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Editorial on the Research Topic
The changing carbonate systems in coastal, estuarine, shelf areas and marginal seas

Global atmospheric CO_2 concentrations have increased from 320 ppm in the 1960s to the present-day value of 420 ppm, primarily due to anthropogenic activities. This increase influences the seawater carbonate system, impacting the marine ecosystem. There are still gaps that need to be resolved for predicting how these marine systems respond to current and future CO_2 levels. Any actions to mitigate the change in pH will require adaptive management of multiple stressors across several spatial scales. Combined, these perspectives yield a more comprehensive picture of events during ocean acidification (OA).

This Research Topic brings together articles from different regions, including coastal, estuarine, and shelf areas and marginal seas, all susceptible to changing atmospheric conditions, riverine inputs, air-sea CO_2 exchanges, and multiple acid-base reactions that can alter carbonate chemistry. Articles on the long-term trends of CO_2 system descriptors and the interactions with calcifying organisms were also sought. The present Research Topic is primarily based on original articles devoted to carbonate systems in the marginal seas, but it is a pity that some interesting papers dealing with freshwater inflows, estuaries, and related coastal areas were not accepted.

Fransson et al. examined the effects of glacial and sea-ice meltwater on ocean acidification in the waters near the 79 North Glacier (79 NG) and the northeast Greenland shelf. The researchers investigated various ocean acidification factors and the influence of freshening, primary production, and air-sea CO_2 exchange. One of the key findings was that the biological removal of CO_2 through primary production played a crucial role in offsetting the negative impact of freshwater dilution on the aragonite saturation state (Ω_{Ar}), which is a measure of ocean acidification. This compensation effect was most pronounced in 2012, especially in the vicinity of the 79 NG front, where there was a significant presence of glacial meltwater and surface stratification. In 2016, a different scenario was observed, with a more homogenized water column due to sea-ice meltwater. In this case, the compensation effect of biological CO_2 removal on Ω_{Ar} was weaker compared to 2012. The study also suggests that in the future, with ongoing climate and ocean chemistry changes, the increasing influence of meltwater may surpass the mitigating effects of biological CO_2 removal. This could lead to unfavorable conditions for organisms that rely on calcium carbonate for their shells and skeletons. Thus, all the proposed factors need to be closely monitored as they could have significant implications for marine ecosystems and calcifying organisms in the face of ongoing environmental changes.

In a study by You et al., the researchers assessed ocean acidification in the Western Pacific using boron isotopic analysis in a large tropical coral core from Lanyu Islet in Southeast Taiwan. They used a well-preserved coral skeleton (Porites lobata) for detailed major and trace element analysis, including boron (B) and its isotopes ($\delta^{11}B$), as well as stable isotopes of oxygen (O) and carbon (C). Their primary objective was to investigate environmental changes during the period from 1991 to 1997. The coral records revealed a distinct temporal trend in sea surface temperatures (SSTs) based on elemental/calcium ratios on both annual and monthly scales. Notably, the most temperature-sensitive proxy, Mg/Ca-SSTs, indicated a significant warming trend during the study period. The researchers also observed subtle changes in the annual $\delta^{11}B$ record, corresponding to a pH decrease of approximately 0.2 units. This change was consistent with other coral records in the Pacific, *in-situ* measurements of pH and pCO_2, and model predictions, highlighting the impact of human-induced ocean acidification. When combined with Mg/Ca-SST data, the intra-annual coral data exhibited a clear seasonal cycle, with higher pH levels during the winter, aligning with surface ocean pCO_2 patterns. These chemical and isotopic findings in corals underscore the value of marine biogenic carbonates as informative tools for reconstructing oceanic pH changes.

Rivaro et al. investigated freshwater inflow into the Ross Sea in Antarctica, particularly through the eastern gate and along the Ross Ice Shelf. They conducted a survey during the austral summer of 2019-20 to assess the contribution of Amundsen Sea Water (ASW) to salinity variations. The researchers used data on total alkalinity (AT), pH, temperature, and salinity to analyze the properties of the carbonate system, including total inorganic carbon, pCO_2, and the calcium carbonate saturation state of aragonite and calcite (Ω), along with the Revelle factor. They also estimated anthropogenic carbon (C_{ant}) using the TrOCA method to gain insights into the carbon cycle and its impact on ocean acidification due to atmospheric CO_2 uptake. The study found that changes in the carbonate chemistry of surface waters were primarily influenced by physical properties. AT and pH were effective indicators of the entry of ASW, demonstrating limited mixing between different water masses in the shelf area. Additionally, shelf waters were enriched in C_{ant}, leading to levels lower than what was estimated for shelf waters generated in the western Ross Sea.

Ingrosso et al. investigated the factors influencing the absorption of anthropogenic carbon dioxide (C_{ant}) in the Ross Sea, an area known for its capacity to absorb carbon due to its cold waters, high primary productivity, and unique circulation on the Antarctic continental shelf. The researchers focused on the carbonate system to assess the current levels of anthropogenic carbon and understand how physical and biological processes regulate C_{ant} sequestration along the shelf-slope continuum. They found that the Winter Water mass, formed during convective events, contained high levels of C_{ant} due to the mixing of layers during the cold season. In contrast, the older and less-ventilated Circumpolar Deep Water entering the Ross Sea had minimal anthropogenic carbon contributions. The study also revealed variations in C_{ant} content between different areas, such as polynyas and the shelf break, influenced by their distinct hydrographic and biological characteristics. The intense microbial activity in these regions consumed a significant portion of particulate organic carbon, leading to the release of CO_2 into the intermediate and deep layers of the continental shelf zone. The findings underscored the importance of summer biological activity over the Ross Sea shelf in facilitating the transfer of anthropogenic CO_2 between organic and inorganic carbon pools. This process contributed to ocean acidification in the upper mesopelagic zone and the long-term sequestration of C_{ant} in the deep ocean.

Hassoun et al. conducted a comprehensive review of ocean acidification (OA) research in the Mediterranean region using data from the United Nations' International Atomic Energy Agency's Ocean Acidification International Coordination Center (OA-ICC) database and an extensive survey. Their analysis revealed several important knowledge gaps in understanding OA trends and biological impacts in the semi-enclosed and densely populated Mediterranean Sea. These gaps are attributed to disparities in OA research capabilities among Mediterranean countries and the intricate, long-term interactions among biological, chemical, and physical factors. The study highlighted an uneven distribution of OA research efforts across the region, with the Algero-Provencal and Ionian sub-basins being the least studied areas. Furthermore, the carbonate system in coastal zones remains inadequately quantified, and there is a scarcity of long-term time series data in the Mediterranean, making it challenging to assess OA trends along the coast. While certain groups of organisms, such as autotrophs (algae, phanerogams, phytoplankton), mollusks, and corals, have received considerable attention in research, others, including microbes, small mollusks (particularly pteropods), and sponges, have been relatively understudied. Despite available resources and agreements for enhanced and coordinated OA governance, there is a lack of consistent OA policies in the Mediterranean Sea. To address these challenges, the article offers recommendations based on their literature review and insights from the Mediterranean OA scientific community.

Curbelo-Hernández et al. conducted an analysis of the carbon dioxide (CO_2) system, anthropogenic carbon (C_{ant}) inventory, and air-sea CO_2 fluxes (F_{CO2}) in the waters surrounding the Macaronesian archipelago. They found that variations in CO_2 levels were primarily influenced by temperature changes, biological activity, and advection processes driven by differences in the Canary Upwelling System, mixed layer depth, mesoscale activity, and circulation patterns. Surface CO_2 levels ($f_{CO2,sw}$) were found to be influenced by biological production and the injection of CO_2-rich water in tropical waters, while temperature fluctuations played a significant role in subtropical waters. The study also examined the factors that control changes in the total inorganic carbon normalized to a constant salinity (NCT) in the upper ocean. The research revealed an increase in the uptake and storage of anthropogenic carbon compared to preexisting levels, as calculated using the TrOCA 2007 approach, which served as an upper limit for NCT. The importance of the organic carbon pump diminished in subtropical waters, while the carbonate pump had minimal contribution. Regarding F_{CO2}, the area behaved as a CO_2 sink during the winter, but strong outgassing was observed over the Cape Blanc filament. To enhance understanding in this region, the authors compared their data with existing datasets (SOCAT and GLODAP) and provided a new set of equations for calculating $f_{CO2,sw}$, C_{ant}, and F_{CO2} in the Macaronesian area.

All these studies emphasize the urgency of addressing ocean acidification and its multifaceted impacts on marine ecosystems. They call for continued monitoring, research, and international cooperation to better understand and mitigate the effects of rising CO_2 levels on our oceans and the life they support.

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