Proposition de sujet de thèse
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Effects of Marine Carbon Dioxide Removal on marine life

Laboratoire d'Océanographie de Villefranche (LOV) – UMR 7093

In order to align with the objectives of the Paris Agreement to limit global warming below 1.5°C, it is necessary to reduce greenhouse gas emissions and to remove large amounts of atmospheric carbon dioxide (CO_2) using carbon dioxide removal (CDR) techniques. While the potential of CDR is significant, a recent study has demonstrated that land-based CDR, such as reforestation/afforestation and bioenergy, will have limited effects on carbon storage if implemented in proportions that avoid negative impacts to biodiversity and food security (Deprez et al. 2024). The oceans might represent a more promising option due to their important capacity to store carbon through chemical, physical, and biological processes. This relieves the burden of utilizing increasingly scarce land and freshwater resources for CDR.

Marine Carbon Dioxide Removal (mCDR) is a set of techniques designed to combat climate change by exploiting or enhancing the ocean's capacity to remove CO_2 from the atmosphere and store it over the long term. These techniques range from protection and restoration actions to promote carbon storage in the sediment of blue carbon ecosystems (BCEs), to various marine geoengineering methods such as Ocean Alkalinity Enhancement (OAE) aimed at increasing CO_2 uptake by the ocean, and ocean fertilization which would promote carbon export to the deep ocean. While these techniques will be implemented on a large scale and included in the global carbon market, many questions remain regarding the understanding of the mechanisms involved, their effectiveness, their impact on ecosystems, and their contribution to the global greenhouse gas balance.

The present project focuses on OAE and its effect on marine organisms. OAE is a promising method for CDR due to its potential to increase CO_2 uptake by the ocean while simultaneously buffering acidification (Oschlies et al., 2023). It relies on the addition of alkaline substances to seawater or the removal of acid via electrochemistry to accelerate the oceanic carbon uptake. Adding alkalinity to the ocean favors the conversion of dissolved inorganic CO_2 into bicarbonates and carbonates; as a result, the CO_2 deficit in surface waters is quickly rebalanced via the dissolution of atmospheric CO_2 into the ocean. While the potential of this CDR method is significant, its efficiency and its effects on marine life are still highly debated (Bach et al. 2019).

The present project aims to assess the effects of OAE on both benthic organisms and pelagic communities. Because photosynthesis and calcification are two key metabolic parameters driven by carbonate chemistry conditions, OAE, which will shift the chemistry to higher alkalinity and pH, has the potential to differentially affect photosynthetic and calcifying organisms. Regarding benthic organisms, this project will investigate the effects of alkalinity enhancement resulting from the dissolution of commercial mollusk shells. This approach offers several advantages, as it involves recycling of a natural waste product from harvesting shellfish (mollusk shells) to the mitigation of ocean acidification by promoting carbon dioxide uptake. The kinetics of dissolution and the resulting effects of alkalinity enhancement on the physiology of juvenile mollusks will be investigated in flume experiments at the Laboratoire d'Oceanographie de Villefranche. The student will benefit from access to a state-of-the-art facility, including 8 flow-through flumes that will be completed before the start of the project.

The effects of OAE on pelagic communities will be investigated in mesocosms, consisting of 300 L high-density polyethylene tanks set up inside an experimental container located on site (Gazeau et al. 2021). The minicoms will be filled with natural plankton communities from the Bay of Villefranche and exposed to a gradient of alkalinity addition. The efficiency of alkalinity addition combined with the role of community metabolism for CO_2 uptake will be monitored during 6-week-long experiments. The effects on the plankton community will be determined by measuring primary production and calcification, as well as analyzing phytoplankton and bacteria community composition, abundances, and biomass changes.

The proposed studies will benefit from access to LOV facilities, as well as support from the project REPAIRS (Foundation Prince Albert II of Monaco) and other ongoing projects involving the supervision team. This PhD project will rely on state-of-the-art experimental facilities and a combination of ecological, chemical, physiological, and biogeochemical approaches to make significant advancements in our understanding of: 1) the efficiency of different OAE methods, and 2) their physiological and ecological effects on commercial mollusks and natural plankton communities. This project fit to the thematic of the *Institut de la Transition Energétique* as results from the project will be used to inform the public and policymakers about the potential benefits and side effects of OAE. Providing such information is critical as OAE will be implemented shortly on a large scale and included in the global carbon market without strong scientific knowledge on its effects for marine life.

The student will benefit from the supervision of Frédéric Gazeau and Steeve Comeau. F. Gazeau is a marine biogeochemist with extensive knowledge in carbonate chemistry and experience in conducting multi-driver experiments on pelagic and benthic communities using a wide range of experimental systems. S. Comeau is a marine biologist who studies the effects of carbonate chemistry modifications on benthic communities using both in situ and experimental studies. Both F. Gazeau and S. Comeau have expertise in carbon fluxes, particularly blue carbon. The student will also benefit from the expertise of J.-P. Gattuso at the LOV, who is a recognized world expert on OAE and Cale Miller from Utrecht University who is an expert in biogeochemistry.

Publications related to the project:
#Deprez, A., Leadley, P., Dooley, K., Williamson, P., Cramer, W., Gattuso, J.-P., Rankovic, A., Carlson, E. L., & Creutzig, F. (2024). Sustainability limits needed for CO2 removal. *Science*, *383*(6682), 484–486. https://doi.org/10.1126/science.adj6171

#Oschlies, A., et al. (Eds.): Guide to Best Practices in Ocean Alkalinity Enhancement Research, Copernicus Publications, State Planet, 2-oae2023, https://doi.org/10.5194/sp-2-oae2023, 2023

#Bach, L. T., et al. (2019). CO_2 Removal With Enhanced Weathering and Ocean Alkalinity Enhancement: Potential Risks and Co-benefits for Marine Pelagic Ecosystems. *Frontiers in Climate*, *1*. https://www.frontiersin.org/articles/10.3389/fclim.2019.00007

#Gazeau, F., et al.: Impact of dust addition on Mediterranean plankton communities under present and future conditions of pH and temperature: an experimental overview, Biogeosciences, 18, 5011–5034, https://doi.org/10.5194/bg-18-5011-2021, 2021.