Biomineralization mechanisms of white and red corals grown through Mineral Accretion Technology: Exploring opportunities for coral restoration (BioMAT-COR)

Prof. Manuel Rigo, Dr. Paolo Montagna, Dr. Frine Cardone, Dr. Lorenzo Bramanti

The European Union Nature Restoration Law (2024/1991) mandates Member States to implement effective, area-based restoration measures to halt and reverse biodiversity loss in terrestrial and marine ecosystems (Hering et al., 2023). Cold-water corals (CWC), including red coral (*Corallium rubrum*) and white corals (*Madrepora oculata* and *Desmophyllum pertusum*), are prime candidates for active restoration efforts, as these habitat-forming species are important ecosystem engineers that support high local biodiversity through the three-dimensionally (3D) complex habitats they create (Roberts et al., 2009, 2006). By increasing the availability of hard substratum and enhancing overall habitat heterogeneity, they promote local species richness (Henry & Roberts 2007; Bongiorni et al. 2010) and provide essential habitat for commercial fish species (Costello et al.,2005; Söffker et al.,2011; Baillon et al. ,2012). However, this structural complexity is at risk from climate-driven shifts, particularly ocean acidification (Büscher et al., 2022) and physical damages resulting from the activity of demersal trawling (Fosså et al. 2002; Hall-Spencer et al. 2002). For *Corallium rubrum*, another source of disturbance is the fishery activity, which impacts on this species due to its high economic value for the jewellery industry (Tsounis et al 2010).
The BioMAT-COR project seeks to investigate the **potential application of Mineral Accretion Technology (MAT)**—a method successfully employed to enhance tropical coral growth through low-voltage direct electrical currents applied between submerged metal electrodes (anode and cathode)—**for the restoration of white deep-water and red corals**. While MAT has proven effective for shallow-water coral reef restoration (Sapater and Yap, 2002), its efficacy in deep-sea ecosystems and red corals remains largely unexplored (Strömberg et al., 2010; Benedetti et al., 2011).
BioMAT-COR aims to provide a **mechanistic understanding of biomineralization processes in deep-water corals grown under MAT conditions**, both in controlled laboratory experiments and natural environments. Specifically, the project will explore mechanisms enhancing coral growth, such as the creation of favourable chemical environments (e.g., elevated pH and carbonate saturation states) around the cathode, the inorganic precipitation of calcium carbonate facilitating larval settlement, and the potential enhancement of the coral pH-upregulation mechanisms (McCulloch et al., 2012) under MAT conditions.
The research will involve comprehensive monitoring and analysis of several parameters to evaluate the success of MAT treatment on the corals, including growth parameters such as skeletal density, linear extension and calcification rates. Additionally, to assess the vitality and well-being of the corals under MAT treatment, parameters such as coral survival rates, tissue integrity, polyp activity, reproduction rates and recruitment will be investigated. These measurements will enable the development of an integrated and comprehensive biomineralization model.
Growth data from MAT-treated corals will be complemented by specific geochemical analyses of coral skeletons and compared against control samples. Analyses will include stable isotopes ($\delta^{18}O$, $\delta^{13}C$, $\delta^{11}B$) and trace elements (B, Li, Mg, Ca, Sr, Ba, and U), reconstructing the chemical conditions of the calcifying fluid (pH and carbonate ion concentration), thus providing **insights into the full carbonate chemistry parameters**, such as alkalinity, dissolved inorganic carbon (DIC), and saturation state of the **micrometer space where corals precipitate their skeleton**.
Through the integration of experimental approaches and detailed geochemical analysis, BioMAT-COR will **evaluate MAT's feasibility as a restoration method for deep-water coral habitats**. The project's outcomes will offer critical scientific insights that may guide future coral **restoration practices and innovative conservation strategies**, enhancing ecosystem resilience to climate change and anthropogenic stressors.
The BioMAT-COR project will be structured into three phases:

1. **Methodological Training**: Conducted at LECOB-Observatoire Océanologique de Banyuls-sur-Mer (France), supervised by Dr. Lorenzo Bramanti, where MAT is currently employed on red corals. This phase will establish best practices and refine protocols suitable for deep-water coral applications.
2. **Experimental Trials**: Carried out at Stazione Zoologica Anton Dohrn in Naples, Italy, under the supervision of Dr. Frine Cardone. Here, MAT will be applied to white deep-water corals under controlled aquarium conditions.
3. **Geochemical Analyses**: Performed collaboratively at the Department of Geosciences (University of Padova), Institute of Polar Sciences (CNR, Bologna), and Laboratory for Climate and Environmental Sciences (France), supervised by Prof. Manuel Rigo, Dr. Paolo Montagna and Dr. Eric Douville. Analyses will include stable isotope and trace element measurements.

Available Financial Resources: PRIN Rigo-Montagna, HE-Redress project, LIFE-Dream project

Collaborations: Istituto di Scienze Polari (ISP-CNR), Stazione Zoologica Anton Dohrn (SZN), LECOB-Observatoire Océanologique de Banyuls-sur-Mer (France), Laboratory for Climate and Environmental Sciences (LSCE, France)

References

Baillon, S., Hamel, J.-F., Wareham, V. E., & Mercier, A. (2012). Deep cold-water corals as nurseries for fish larvae. *Frontiers in Ecology and the Environment, 10*(7), 351-356. https://doi.org/10.1890/120022

Benedetti, A., Bramanti, L., Tsounis, G., Faimali, M., Pavanello, G., Rossi, S., Gili, J.M., Santangelo, G. (2011). Applying cathodically polarised substrata to the restoration of a high value coral. *Biofouling*, 27(7), 799-809.

Bongiorni, L., Shafir, S., Angel, D., & Rinkevich, B. (2010). Survival, growth and gonad development of three coral species on a mid-water rope nursery in the Red Sea. *Marine Ecology Progress Series, 408*, 81-93. https://doi.org/10.3354/meps08565

Büscher, J. V., Wisshak, M., Form, A. U., & Riebesell, U. (2022). Ocean acidification and warming affect the structural integrity of cold-water corals. *Scientific Reports, 12*, 1589. https://doi.org/10.1038/s41598-022-05658-3

Costello, M. J., McCrea, M., Freiwald, A., Lundälv, T., Jonsson, L., Bett, B. J., & van Weering, T. C. (2005). Role of cold-water Lophelia pertusa coral reefs as fish habitat in the NE Atlantic. *Cold-water Corals and Ecosystems*, 771-805. https://doi.org/10.1007/3-540-27673-4_38

Fosså, J. H., Mortensen, P. B., & Furevik, D. M. (2002). The deep-water coral Lophelia pertusa in Norwegian waters: distribution and fishery impacts. *Hydrobiologia, 471*, 1-12. https://doi.org/10.1023/A:1016504430684

Hall-Spencer, J., Allain, V., & Fosså, J. H. (2002). Trawling damage to Northeast Atlantic ancient coral reefs. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 269*(1490), 507-511. https://doi.org/10.1098/rspb.2001.1910

Henry, L. A., & Roberts, J. M. (2007). Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the Porcupine Seabight, NE Atlantic. *Deep-Sea Research Part I: Oceanographic Research Papers, 54*(4), 654-672. https://doi.org/10.1016/j.dsr.2006.12.006

Hering, D., Borja, A., & Carstensen, J. (2023). Implementing the EU Nature Restoration Law: challenges and opportunities. *Environmental Science & Policy, 138*, 101-110. https://doi.org/10.1016/j.envsci.2023.01.004

McCulloch, M., Falter, J., Trotter, J., & Montagna, P. (2012). Coral resilience to ocean acidification and global warming through pH up-regulation. *Nature Climate Change, 2*, 623-627. https://doi.org/10.1038/nclimate1473

Roberts, J. M., Wheeler, A. J., Freiwald, A., & Cairns, S. D. (2009). Cold-water corals: the biology and geology of deep-sea coral habitats. *Cambridge University Press.*

Roberts, J. M., Wheeler, A., & Freiwald, A. (2006). Reefs of the deep: The biology and geology of cold-water coral ecosystems. *Science, 312*(5773), 543-547. https://doi.org/10.1126/science.1119861

Sapater, E., & Yap, H. T. (2002). Growth and survival of coral transplants with and without mineral accretion technology. *Marine Pollution Bulletin, 44*(10), 1076-1081. https://doi.org/10.1016/S0025-326X(02)00224-5

Söffker, M., Sloman, K. A., & Hall-Spencer, J. M. (2011). In situ observations of fish associated with coral reefs off Ireland. *Deep-Sea Research Part I: Oceanographic Research Papers, 58*(8), 818-825. https://doi.org/10.1016/j.dsr.2011.06.002

Strömberg, S. M., Lummer, M., Backhaus, J., & Nilsson, S. K. (2010). Electrochemical stimulation of coral calcification: a potential tool for reef restoration. *Journal of Experimental Marine Biology and Ecology, 395*(1-2), 153-160. https://doi.org/10.1016/j.jembe.2010.09.012

Additional information on MAT: https://newheavenreefconservation.org/projects/mineral-accretion