# CoralChange
# Factors controlling carbonate production and destruction of cold-water coral reefs of the NE Atlantic

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Final Summary Report

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**1. Summary description of project context and objectives**

Uptake of anthropogenic $CO_2$ by the oceans is altering seawater chemistry with potentially serious consequences for calcifying organisms due to the reduction of seawater pH and carbonate ion concentration (ocean acidification, OA). Calcium carbonate (CaCO3)-rich ecosystems, such as shallow and deep-sea coral reefs, coralline and shellfish beds, are of central importance as they directly respond to climate change, contribute to structural complexity, create habitat for associated organisms, significantly contribute to biogeochemical cycles, and provide diverse services to human society. Thus, their damage or loss due to adverse conditions will have serious repercussions. Their survival and sustainability directly depends on the balance between constructive (accretion) and destructive processes (physical, chemical, and biological erosion). Cold-water corals (CWC) are thought to be particularly vulnerable to OA because they inhabit deep and cold waters where the aragonite saturation state (Ωa) is low. Given global climate change, two important questions are (1) what are the environmental controls of reef framework growth? and (2) how might cold-water corals be affected by environmental change? This project addressed these questions by studying the biological erosion (bioerosion) processes of carbonate substrates in coastal and deep-sea environments in the warm-temperate setting of the Azores region; and by studying growth dynamics of important cold-water corals in the Azores and their relationship to environmental factors. The project also included laboratory experiments on the effects of predicted increases in carbon dioxide partial pressure ($pCO_2$) on the calcification, basal metabolism (measured as respiration rates) and gene expression responses of CWC species. The parasitic behaviour of zoanthids associated with CWC was also investigated as it raises questions on their importance as a natural cause of coral mortality, and on how can they affect coral population structure. The ultimate goal of the project is to improve predictions of how these cold-water corals will respond to future environmental changes and whether reefs will be able to maintain a positive balance between carbonate construction and destruction processes.

**2. A description of the main S&T results**

**2.1 Bioerosion studies** Bioerosion studies conducted in shallow and deep-sea areas revealed that the biological degradation (bioerosion) of shells and coral skeletons are much faster in shallow-water environments than the deep-sea, probably related to the lack of light and primary production, and slow settlement rates by zoospores and larvae of boring organisms in deep-sea areas. Bioerosion studies using a shallow-water hydrothermal vent field as a OA natural laboratory, indicated that the post-mortem integrity of mollusc shells and coral skeletons was highly vulnerable to dissolution under predicted conditions of ocean acidification for the year 2300 (pH = 7.4). Increased dissolution rates will reduce the lifespan of these biogenic structures and may have significant ecological consequences.

**2.2. CWC growth studies** CWC growth studies included investigations on the skeletal density of cold-water scleractinian corals in three geographic regions: the NE Atlantic continental margin of Ireland and Scotland, the central NE Atlantic region of the Azores and in the NW Mediterranean. Coral skeletal density is an important growth characteristic that determines the strength of the corals and its ability to sustain physical pressure and bioerosion but has rarely been directly addressed in CWC growth/calcification studies. Results of this study showed important differences between CWC species and geographic regions which are probably related to their different growth form (solitary/colonial) and structure and arrangement of the carbonate ion crystals. Geographic differences in *L. pertusa* bulk density and porosity were significantly

correlated with sea-water temperature and depth. Bulk density was higher at greater depth and lower sea-water temperature, while porosity followed an inverse trend, with lower porosity at greater depth, and lower temperature. These results suggest that sea-water temperature (and potentially global warming) is a more important determinant factor of coral skeletal density than carbonate chemistry, at least under the current ocean chemistry conditions.
Radiocarbon dating of black coral *Leiopathes* sp, an important component of coral garden communities in the Azores, revealed that colonies had very low growth rates (5-30 $\mu m.y^{r-1}$) and high colony lifespans (264 - 2,322 years), indicating that colony and population recovery from damage or removal by fishing or other anthropogenic activities may take centuries to millennia.

**2.3 CWC experiments** Aquaria-based experiments included two experiments to compare the physiological responses of the azooxanthellate solitary coral *Desmophyllum dianthus,* and the gorgonian *Dentomuricea* sp. at ambient $pCO_2$ levels (460 µatm, pHT 8.01) with those predicted for 2100 under the worst case scenario (997 µatm, pHT 7.70). The objective of these studies was to investigate physiological consequences of elevated $pCO_2$ at both the organism level (calcification, respiration) and the gene expression level in order to better assess the degree of physiological plasticity of these organisms to future OA. Results of these experiments revealed that calcification rates were not significantly impacted by reduced pH for both coral species, although respiration rates were slightly enhanced under acidified conditions for *D. dianthus*, but depressed for *Dentomuricea* sp. In addition, there was a noticeable increase in tissue necrosis in *Dentomuricea* sp. under lower pH conditions, but no observable difference for *D. dianthus*. Gene expression profiles demonstrated that there were several physiological processes (e.g. stress response, metabolism) that were impacted by elevated $pCO_2$ but were not detected at the organismal level. These results suggest that studies that focus solely on organismal processes (e.g. calcification) may fail to detect important impacts of elevated $pCO_2$ on the physiology of CWCs, and may wrongly conclude that there will be no impact of predicted increases of OA on CWCs. Thus, future studies on OA should include a wider range of physiological and cellular processes, which may help to better understand the ability of CWCs to adapt to future OA scenarios.

**2.4 Parasitic zoanthids of CWCs** Zoanthids are a group of cnidarians that are often found in association with CWCs in the Azores. Analyses of molecular data (mtDNA COI and 16S rDNA) coupled with ecological and morphological characteristics, identified 4 putative new species to Science of zoanthids associated with CWCs. Zoanthids associated with octocorals showed evidence of a parasitic relationship, where the zoanthid progressively eliminates gorgonian tissue and uses the gorgonian axis for structure and support and sclerites for protection. The parasitic behaviour of these octocoral-associated zoanthids raises questions on their importance as a natural cause of coral mortality, and on how can they affect coral population structure.

**3. Potential impact (including the socio-economic impact of the project)**
There is presently a heavy international policy focus on the impacts of climate change, including ocean acidification, on marine ecosystems within Europe. The Marine Board-ESF Position Paper on the Impacts of Climate Change on the European Marine and Coastal Environment – Ecosystems indicated that presenting ocean acidification issues to policy makers is a key issue and challenge. A key recommendation by EU is investing in research to try to understand the consequences of, and eventually help mitigate ocean acidification.
The CoralChange project contributes to this international effort by providing a more accurate quantification of climate change impacts on carbonate marine ecosystems by studying effects of OA on bioerosion, an important, but overlooked disintegration process of $CaCO_3$ ecosystems; and on cold-water coral physiology including growth/calcification. Data generated by the project can

be used into modelling of ecosystem functions and carbon geochemistry under different environmental settings; and thus contribute to predictions assessing the integrity of ecosystems to changing environmental conditions. This is essential to provide advice to policy makers on the relative benefits of mitigating global stressors, in order to maintain ecosystem structure and function.

Project outputs include advice that can be used directly by environmental managers from government, NGOs, and international bodies in order to better preserve $CaCO_3$ ecosystems. These outputs are relevant to policy design at EU and international level, in particular under the EU Marine Strategy Framework Directive, EU Habitats Directive and Natura 2000, OSPAR and the Barcelona Conventions; United Nations Convention on the Law of the Sea and Convention on Biological Diversity. At the regional level, data generated by this project can be used within the "Directiva-Quadro - Estratégia Marinha" to help predict the impacts of ocean acidification on marine ecosystems, habitats and organisms in the Azores in the future, contributing to a better description of the potential changes in the health status of marine ecosystems; improving the effectiveness in monitoring interventions; and helping to identify mitigation actions. Data can also be used as part of the "Programa de Medidas" of the Directiva-Quadro to raise public awareness of the consequences of ocean acidification on marine biota. Results of these studies are particularly useful to the Comissão Regional para a Avaliação das Alterações Climáticas, created by the Secretaria Regional do Ambiente e do Mar, in the assessment of impact of global climate change in the Azores region.