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Editorial: Coralline algae: Past, present, and future perspectives

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Editorial on the Research Topic
Coralline algae: Past, present, and future perspectives

Following the success of the Frontiers in Marine Science Research Topic on "*Coralline Algae: Globally Distributed Ecosystem Engineers*," the Research Topic on "*Coralline Algae: Past, Present and Future Perspectives*" was launched to extend the opportunity for publishing further knowledge about these diverse ecosystem engineers across a broader time scale. In this Research Topic, an additional nine original research articles have been published, strengthening our understanding of coralline algae past, present, and future, including their biology, physiology and ecology. From reconstructing coralline algal assemblages during the Paleocene/Eocene thermal maximum, to understanding current trophodynamics and benthic-pelagic coupling in rhodolith beds, to assessing the adaptability of coralline algae to future warming, the original research articles in this Research Topic cover a time frame of 55.6 million years and span across an Atlantic biogeographical range from Brazil to the high Arctic. The wide biogeographical ranges and geological time scales covered in this Research Topic reflect the long evolutionary history and impressive distribution range of coralline algae as a group, and provide not only important insights about their past and present, but also about their potential adaptability to future warming conditions.

While calcification mechanisms in coralline algae have been widely studied, the onset of calcification during ontogenesis has remained elusive. Carvalho et al. fill a major knowledge gap in the biology of coralline algae, by investigating the initiation of calcification during development in *Lithophyllum corallinae*. Using a combination of optical, chemical and mechanical analytical tools the authors show that calcification commences after the third cell division (to eight cells), and that the interior cell walls are well calcified with magnesium calcite by the fourth cell division (to 16 cells). Their study is the first to assess nanomechanical properties of live coralline algae cells, and their work, combined with previous studies, draws a preliminary picture of the early stages of germinating spore development and the onset of calcification. Furthermore, the authors confirm the lack of calcification in the cell walls of the outermost part of the germinating spore, which they suggest facilitates the growth of the individual and indicates some level of control over the biomineralization process.

A surge of research in the past decades on the impact of ocean acidification and warming on coralline algae has shown that this group of organisms displays a wide range of responses to simulated climate change conditions. The mechanisms behind their responses have, until now, been poorly understood. The comprehensive study by Schubert et al. provides an in-depth evaluation of inter- and intra-specific differences in the photosynthetic and calcification mechanisms of Atlantic rhodolith species from different latitudes. The authors reported that calcification is a biologically-controlled process and strongly correlated to photosynthesis, but the strength of this correlation is species-specific. They conclude that there is no general pattern for all species, but rather high inter- and intra-specific variability in the mechanisms controlling photosynthesis and calcification that are driven by complex interactions between physiological and morphological traits (e.g. carbon concentrating mechanisms and branching morphology) and environmental conditions (e.g. light and temperature). These differences are likely to contribute to the wide range of responses to simulated climate change conditions that have been reported among coralline algae species.

The use of coralline algae as paleo-ecological proxies for reconstructing past climatic and environmental conditions in tropical, temperate and polar regions has received increasing attention in recent decades. Two studies in the current Research Topic address the use of coralline algae as proxies for sea ice reconstruction in the Arctic. Gould et al. report for the first time that *Clathromorphum compactum* continuously grows during the entire winter sea-ice season, and that approximately 25% of their annual growth occurs during this period, despite complete darkness under sea-ice cover. The implications of their study for sea-ice reconstruction are that anomalous sea-ice variability can still reliably be reconstructed using growth-band anomalies, but the sensitivity of the proxy likely varies geographically depending on the length and extent of the sea-ice season. The authors stress that a better understanding of the physiological processes supporting sustained growth during sea-ice cover is needed. Within the same context, Leclerc et al. conducted a study testing the utilization of tree-ring dating methods (dendrochronology) to improve sea-ice reconstruction using *C. compactum*, because previous studies had shown possible age model dating errors. The authors show that cross-dating techniques reduced dating errors and allowed for more precise climate reconstructions using *C. compactum*.

Research conducted on both the past and present of coralline algae biology can be projected to provide a glimpse of the expected future impacts of climate change on these organisms. Aguirre et al. reconstructed coralline algal assemblages in the south-central Pyrenees during the Paleocene/Eocene Thermal Maximum, ca. 55.6 Ma, when Earth experienced a warming event due to a massive release of CO_2 and subsequent ocean acidification (estimated surface water pH 7.8-7.6). The authors report that there was a drastic reduction in coralline algae abundance due to drastic changes in local paleoenvironmental conditions after the Paleocene/Eocene boundary that were unfavorable to coralline algal growth. Still, they did not find evidence that the warming event had led to a decrease in the abundance or diversity of coralline algae in the studied Pyrenean localities. Combining these results from the geological history of coralline algae with those of Pinna et al. who reported an overall good acclimation potential of the Mediterranean bioconstructor *Lithophyllum stictiforme* to warming seawater temperature, and those from Schubert et al. who report that fluctuating environmental conditions increase the tolerance of *Phymatolithon lusitanicum* to heat waves, evidence is mounting that coralline algae as a group are actually well equipped to acclimate to the changing environmental conditions expected in the near future. Aguirre et al. also point out the challenges associated with species identification of fossil specimens. The difficulties lie not only in the limited number of distinguishable characters preserved in the fossil record, but also in the inconsistent use of published species names, as well as in the cryptic diversity expressed among the coralline algae. Many studies have reported cryptic diversity in coralline algal communities, and in the current Research Topic, Kittle et al. report a new species of *Phymatolithon* (*P. abuqirensis*) from the Mediterranean, which brings the total number of described Mediterranean species in this genus to six. The authors stress that future research will be needed to assess the distribution of this newly described species throughout the Mediterranean. Furthermore, the study of Teper et al., using lipid, fatty acid and stable isotope analysis, showed that the trophodynamics of a sub-Artic rhodolith bed in Newfoundland are primarily controlled from the bottom up, by planktivores and detrivores. The study presents evidence of the specific diets and feeding relationships among dominant animal taxa in a rhodolith bed and encourages further explorations regarding the contributions of sediment and rhodolith-associated fauna to the habitat trophodynamics and the spatial and temporal variability of rhodolith-bed associated trophic relationships.

In summary, the Research Topics "*Coralline Algae: Globally Distributed Ecosystem Engineers*," and "*Coralline Algae: Past, Present and Future Perspectives*" have made a significant contribution to improving our understanding of past and present coralline algae biology, physiology, ecology, geological history, biogeography, biodiversity and genetics. These new insights not only narrow several current knowledge gaps, but also allow us to make predictions about the future perspectives of coralline algae under global climate change. Nevertheless, research on these important ecosystem engineers is still far behind that of other coastal habitats (e.g. coral reefs, kelp beds, seagrass beds, and mangroves), and many uncertainties regarding these habitats and their ecosystem functions and services still persist. In view of this and the increasing threats to marine benthic communities, we stress that increased research initiatives will be essential to provide a better understanding of the vital role coralline algae play in the oceans, which in turn will allow implementing and improving conservation efforts.

Authors contributions

The editorial was written by LH and NS, with contributions and critical revision from all remaining authors. All authors contributed to the article and approved the submitted version.

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