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Editorial: Marine biological materials: Functional mechanisms and environmental impacts from the molecular to the macro-scale

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Editorial on the Research Topic
Marine biological materials: Functional mechanisms and environmental impacts from the molecular to the macro-scale

Introduction

Marine organisms rely on a broad range of structurally and mechanically diverse materials for success in the world's oceans. Among many others, examples include structural materials involved in protection, locomotion, and nourishment (e.g., shells, skeletons, exoskeletons, claws and other feeding structures) and functional materials (e.g., adhesives, holdfasts, defensive secretions, signaling structures). In all cases, these materials are hierarchical with their success depending on multiple levels of biological complexity, from the molecular, to the nano- and micro-scales, to the whole organism scale. These materials have served, and continue to serve, as inspiration for biomimetic materials and approaches (e.g., nacre-inspired composites, exosuits, green fluorescent protein, hydrogels). Understanding the complexities of such materials may also allow us to address current and future major economic and ecological challenges (e.g., biofouling by marine adhesive organisms, shellfish aquaculture yields). A critical aspect of the study of marine biological materials is assessment of how environment affects functional properties and the mechanistic basis for such changes if they occur. Increases in global sea temperatures, reductions in pH (ocean acidification) and associated alterations in carbonate chemistry, variations in salinity and dissolved oxygen content, and anthropogenic noise and pollution, have all been documented to affect structural and functional materials, with the magnitude of the response often taxon-specific. In this Research Topic, we bring together a collection of articles that explore the relationship between environment and marine biological materials through a lens of either the *fundamental mechanisms of function of a material* or the *effects of environment on the material* (Figure 1). All studies incorporated an integrative approach, employing a range of experimental techniques to assess questions of interest at multiple levels of biological complexity.

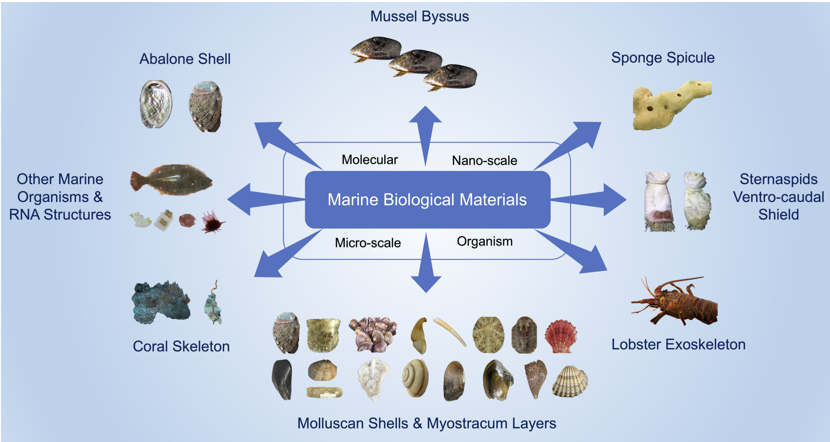

FIGURE 1
Marine organisms and biological materials investigated in this Research Topic.

Fundamental mechanisms of function of marine biological materials

Half of the articles within this Research Topic further our understanding of the basic mechanisms involved in biological materials synthesis and development, with each article focused on a different taxonomic group. Two studies assessed mineralized shell structure and composition within the context of evolutionary history. Dong et al. investigated the myostracum layer in 11 different living mollusks and compared them with that of a fossilized ammonoid. The authors found a high degree of conservation in structure (columnar prisms) and composition (aragonite) among the examined species. Ge et al. studied the ventro-caudal shields of two closely related tube-forming polychaetes. The authors found that the distinctive morphology and composition of the shields likely stems from difference in growth environment, resulting in differential gene regulation. The results emphasize the importance of genetic information in the analysis of biomineralization. In two additional studies, researchers employed novel proteomic techniques to characterize the function and properties of specific proteins involved in the biological material formation process. Work by Drake and Mass assessed the protein component of the sclerotized chitin skeleton of two species of black corals. Hundreds of proteins were identified with a clear compositional distinction from that of stony corals, namely a lack of acidic amino acids. Pozzolini et al. identified 21 diverse proteins, including cathepsins with silicateins and several lysosome enzyme-like proteins, within *Petrosia ficiformis* sponge silica spicules, and propose a lysosomal origin of silicification in these animals. Lastly, the work of Zhang et al. focused on materials at the molecular scale, assessing the role of Drosha, a ribonuclease enzyme. The authors found microRNA (miRNAs) and small interfering RNA (siRNAs) to play an important role in development and metamorphosis of Japanese flounder.

Effects of environment on marine biological materials

The other half of the articles within this Research Topic assessed the effects of environment, broadly speaking, on the formation and properties of marine biological materials. Three of the articles assessed biological materials in mollusks. Huang and Zhang provide a broad review of molluscan shell biomineralization, with a focus on the shell organic matrix, including shell matrix proteins (SMPs), and their effect on minerology. The authors place this work within the context of changes in seawater chemistry over geologic time (e.g., shifts between calcitic and aragonitic seas), encouraging the field to consider the role of environment on biomineralization. Ji et al. characterized shell structure and protein composition and activity following exposure to extreme heat, finding that proteins remained bioactive in mineralization even after exposure to 200°C. The third article on mollusks, by Zhao et al., documented the effects of anthropogenic noise on mussel byssal attachment. The authors showed diminished mechanical properties and down-regulation of genes involved in byssus formation when mussels were exposed to simulated anthropogenic noise. Lowder et al., assessed the effects of reduced pH (ocean acidification) on the mineralized exoskeleton of a crustacean, the California spiny lobster. Exoskeleton mineral content and mechanical properties were reduced at low pH, but in a complex and body-region-dependent manner in which reduced mineral content did not correlate directly with reductions in mechanical properties. A final study, Xu et al., assessed phototrophic microbial communities within the Baltic Sea using 16S rRNA. The authors were able to correlate phototrophic abundance and composition with a broad range of environmental conditions including temperature, pH, salinity, and dissolved oxygen content.

Conclusions and future directions

The collection of articles presented within this Research Topic demonstrate the diversity of biological materials within the marine realm, with materials from seven distinct taxonomic groups represented (Figure 1). Within the field, studies that assess *fundamental mechanisms* of biological material synthesis and development inform work of researchers assessing the *effects of environment* and vice versa. We propose three recommendations for work on marine biological materials, which, taken individually or in combination, may advance the field. *First*, projects should couple functionality of materials at the whole organism level with the mechanistic basis for that functionality at the meso-, micron-, and molecular scales. For example, researchers might quantify the degree of protection a shell provides against predator attack with characterization of the structure, mechanical properties, and composition of the shell. Importantly, this work should be published together in a single, comprehensive study to enable direct links between levels of complexity. *Second*, researchers should embrace biological variability. Variability among individuals is inherent to biological systems and in fact is the basis for evolution by natural selection. As demonstrated in this Research Topic, researchers studying biological materials include marine biologists, geoscientist, physicists, molecular biologists, engineers, statisticians, among others. Each field brings their own views, and researchers unfamiliar with biological variability may view anomalous results as unwanted outliers, removing them from the dataset. Assuming experiments were run with care, however, these outliers can often provide valuable insight on the range of properties that are possible and may suggest the potential for adaptation within a population. *Lastly*, and particularly for studies on the effects of environment, researchers should publish negative results. There is often a publication bias towards results that show significant or dramatic effects of environment on materials properties, as these results are viewed as more exciting or important within the field. Negative findings, however, are integral to our understand of how these materials respond to environmental change and may inform decisions on where conservation or aquaculture efforts should be focused.

Author contributions

GD wrote the first draft of the manuscript. All authors contributed to manuscript revisions, and read and approved the submitted version.

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