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Editorial: The adaptation and response of aquatic animals in the context of global climate change

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Editorial on the Research Topic
The adaptation and response of aquatic animals in the context of global climate change

Anthropogenic climate change has brought on widespread changes in marine environments, including ocean warming, ocean acidification, the development and expansion of hypoxic zones. These environmental changes represent major threats to marine life, challenging the survival and adaptation of marine organisms. The adverse effects of these changes can interact in synergistic, additive or antagonistic ways (Huo et al., 2019a; Huo et al., 2019b; Small et al., 2020; Collins et al., 2021), evidencing different biological influence compared to their individual action (Huo et al., 2021a). Such influence can vary across populations and species as a consequence of differences in phenotypic plasticity and physiological tolerances shaped by their specific environmental and genetic backgrounds (Gaitán-Espitia et al., 2017a; Gaitán-Espitia et al., 2017b). These factors ultimately modulate the ecological response and evolutionary adaptation of marine organisms to climate change. From an ecological perspective, changes in the marine environment are likely to have significant negative phenotypic effects (e.g., physiology, behavior, gene/protein expression), across levels of biological organization (i.e., from individuals, populations, to species). These changes can alter the ingestion, digestion, respiration and growth of aquatic animals (Huo et al., 2018), potentially influencing demographic and genetic declines driven, for instance, by massive mortality (Huo et al., 2021b). From an adaptive evolution perspective, phenotypic plasticity appears to be a suitable strategy to cope with these changes, at least in the short-term, through behavioral, physiological, life-history and morphological adjustments (Gaitán-Espitia et al., 2017b). However, there are limits for plastic adjustments beyond which populations and species require genetic and cellular modifications to adapt to the unfavorable environmental conditions. These adaptive responses include microevolutionary changes of transcriptional, translational and post-translational mechanisms underpinning phenotypic responses (Huo et al., 2021b). Through the study of these mechanisms, we can gain better understanding of the costs and trade-offs of adaptive evolution in marine animals under climate change.

Our aim for this Research Topic in *Frontiers in Marine Science* was to bring together studies that enhance our understanding of the potential biological, ecological and evolutionary impacts of extreme environmental changes (individual and compound) on marine animals. This Research Topic comprises 17 scientific papers, which included reviews, original research and data reports, covering diverse taxa from unicellular foraminifera to more complex multicellular animals such as bivalves (hard Clam *Mercenaria mercenaria*, eastern oyster *Crassostrea Virginica*, Yesso scallop *Patinopecten yessoensis*, Zhikong scallop *Chlamys farreri* and bay scallop *Argopecten irradians*, Chilean scallop *Argopecten purpuratus*), holothurians (sea cucumber *Apostichopus japonicus*), and fishes (e.g., silver carp *Hypophthalmichthys molitrix*, spotted sea bass *Lateolabrax maculatus*, loaches *Triplophysa bleekeri*). The main research focus of these papers was associated with changes of key environmental drivers (e.g., temperature, oxygen, pH) and stressors closely linked to global climate change (e.g., seasonal cooling, fishing, microplastics and cadmium).

One theme that emerges from this Research Topic is the importance of understanding the multiple biological levels involved in the ecological responses and adaptive evolution of marine organisms, here from genes to organismal phenotypes and population dynamics. Padilla-Gamiño et al. explored this issue by reviewing the impacts of ocean acidification on processes of sexual reproduction (e.g., gametogenesis, fertilization, and reproductive resource allocation) in five economically and ecologically important marine invertebrate groups, including cnidarians, crustaceans, echinoderms, molluscs and ascidians. They found that the fertilization rate declined as pH fell, indicating the negative impacts on future generations in the context of a rapidly changing oceans. Similar to ocean acidification, warming oceans are expected to induce detrimental effects on marine organisms. Yuan et al. found that increasing temperatures induce major metabolic reprogramming and lipid remodeling in loaches fish *Triplophysa bleekeri*, highlighting potential physiological costs induced by climate change. Another important driver modulating life in marine environments is oxygen availability. Li X. et al. demonstrated that low oxygen conditions (i.e., hypoxia stress) trigger tissue damage and changes in the immune defense and oxygen transport in the silver carp *Hypophthalmichthys molitrix*. In other fish species (e.g., spotted sea bass *Lateolabrax maculatus*), Ren et al. found that this type of environmental stress altered the HIF signal network system, suppressing the cell cycle process. Environmental drivers such as pH, temperature, and oxygen, however, do not change in isolation but co-vary among them and have interactive effects. For instance, Huo et al. showed that the immune system, digestion, and antioxidant levels in the sea cucumber *Apostichopus japonicus* were affected differently by individual and combined changes in temperature and dissolved oxygen. Similarly, Li C. et al. found that the interaction of air exposure and elevated temperatures, can ultimately influence the regulation of the cell cycle, apoptosis, and proline accumulation in the eastern oyster *Crassostrea virginica* as part of its adaptive response. The immune and apoptotic response has been also been documented in other marine animals such as scallops when limited oxygen interacts with transient heat (Mao et al.).

Although global warming is the dominant trend, there are regions in which temperatures are decreasing (e.g., upwelling areas along the East South Pacific coast). Ramajo et al. showed that populations of scallops (*Argopecten purpuratus*) in upwelling areas decreased their growth and gross calcification rates when exposed to cooling waters and low oxygen conditions. Such interactive effects directly impact traits that are relevant for the fitness and dynamics of natural populations of these marine invertebrates.

Temperature, dissolved oxygen and pH are environmental factors of great interest and discussion. In addition to those factors, global climate change has also exacerbated the effects of other stressors on marine organisms. For instance, toxic algal blooms of *Karenia mikimotoi* are more regularly impacting populations of the abalone *Haliotis discus*. These effects are exacerbated when hypoxic conditions are present, significantly reducing survival rate and the activation of oxidative stress (Zhang Y. et al.). Another important anthropogenic stressor that is more frequently documented in the literature is derived from marine and coastal pollution. Zhang C. et al. examined the effects of dietary ingestion of microplastics and cadmium in the sea cucumber *Apostichopus japonicus*, finding that the interactive exposure can lead to oxidative stress, the inflammatory response in the intestine, and the activation of the intestinal immune defense system. These studies contributed to the goal of expanding our understanding of how marine organisms respond to upcoming environmental challenges mainly from molecular and physiological aspects. The identified changes in biological processes in these studies provide fundamental information for deciphering the adaptive regulatory mechanisms employed by marine animals when exposed to environmental stress and climate change.

Another theme that emerged from this Research Topic is the importance of understanding the mechanisms underpinning adaptative evolution. As species face new and changing environments, they must evolve to avoid extinction. Hu Z. et al. emphasized the significance of heat shock protein 70 genes expansion as part of the adaptive evolutionary responses of the hard Clam *Mercenaria mercenaria* to heat and hypoxic environments. Mao et al. identified that heat shock proteins could likely have helped in correct protein folding to aid the adaption of the scallops to the altered environment. Ren et al. suggested that alternative splicing events have been probably shaped by natural selection as part of the hypoxia adaptation in the spotted sea bass *Lateolabrax maculatus*. In addition to internal regulation at the molecular level, phenotypic change, mediated by natural selection, is also an important strategy for adaptation to environmental stress. Such phenotypic changes can show intra-specific variation due to genotype-by-environmental interactions. For example, the purple strain of the sea cucumber *A. japonicus* can tolerate a wider range of temperatures and higher salinity levels than those of the green morph (Bin et al., 2018). Yao et al. characterized the types, quantities and expression of TGFβ signaling pathway members in *A. japonicus* and provided information for pigmentation, as it is a key trait for understanding environmental adaptability and species stability. Hu W. et al. concentrated on the Oxudercinae fishes distributed in the intertidal mudflats, one of the ecosystems with the most drastic changes in salinity, temperature, and oxygen content. Hu W. et al. identified the morphological features of corneal epithelial cells as the visual adaptation mechanisms for Oxudercinae species to adjust to varied environments. Phenotypic evolution and gene regulation together enable species to better adapt to environmental stress and change.

Impacts of climate change are evident in natural systems all over the world (Gaitan-Espitia and Hobday, 2021). The studies in this Research Topic explored this context across diverse biogeographic backgrounds around the globe, from the poles to the tropics. As a result of climate change and other anthropogenic pressures, marine ecosystems have been strongly impacted, reducing their ecological stability (e.g., 75% in coral reefs globally) (Bruno and Selig, 2007; Hu et al., 2020). Zhang X. et al. used the Ecopath with Ecosim model to investigate the effects of ocean warming and fishing on the coral reef ecosystem surrounding the Xisha Islands in the South China Sea. According to their findings, ocean warming and fishing caused the overall catch to decline by 3.79% and 4.74%, respectively, by the middle of the century compared to 2009. Some groups (i.e., medium and large carnivorous fish), tend to be less affected by ocean warming when the fishing effort is reduced. Yu et al. explored the hypoxia avoidance behavior of six common reef-dependent species found in the northeastern sea areas of China (i.e., rockfishes *Sebastes schlegelii* and *Hexagrammos otakii*, filefish *Thamnacomus modestus*, flatfish *Pseudopleuronectes yokohamae*, sea cucumber *Stichopus japonicus*, and crab *Charybdis japonica*). The findings demonstrated that reduced DO levels enhanced the habitat affinity to preferred habitat types for the two habitat-specific rockfishes, decreased the usage of preferred habitats of sea cucumber and filefish, and had no effects on crab habitat usage. Similar to the tropics, the Antarctic region biota is currently facing major threats from complicated environmental changes (Convey and Peck, 2019). As Antarctic marine animals are facing a stable and limited range of low seawater temperatures (Carter et al.), slight variations in thermal environment can result in differences in the spatial distribution of species and populations (Bilyk and DeVries, 2011; Sandersfeld et al., 2017; Morley et al., 2020). Li Q. et al. presented the relationships between foraminiferal molecular diversity and environmental variables in the Antarctic region, discovering that both, water depth and temperature have distinct effects on abundant and rare foraminiferal subcommunities. Specifically, the foraminiferal alpha diversity of the most abundant subcommunity was positively correlated with water depth and negatively correlated with temperature, whereas the alpha diversity of the rarest subcommunity did not exhibit a linear relationship with any of these environmental factors. Carter et al. investigated the upper thermal limits (CTmax) of seven marine ectotherm Antarctic species (Chordata 3 spp., Arthropoda 2 spp., and Echinodermata 2 spp.) and discovered that basal mortality was influenced by seasonal temperature change in the intertidal zone, with echinoderms having greater CTmax than Chordata and Arthropod species. These papers help to our understanding of how future environmental changes will affect biodiversity from the tropics to the poles.

The study of ecological responses and adaptive evolution in marine animals facing environmental stress will unavoidably get more attention as global changes are increasing in frequency, magnitude and duration all across the globe. Each of the articles summarized in this Research Topic have made a major contribution to this area and contributed a piece of the puzzle to advance our comprehension. Moreover, this Research Topic points to new directions and highlights the many knowledge gaps that still remain to be addressed in this area of research. This Research Topic highlights the urgent need for continued investigation into these complex interactions. Future directions in this field include encouraging integrated evaluation of multiple environmental stressors, comparative multi-species research, cross-regional and cross-temporal investigations. This Research Topic also highlights that understanding the impact of climate change on aquatic animals requires interdisciplinary collaboration, including ecology, biology, genetics, oceanography, and climate science. Collaborations between researchers from different fields can provide a more comprehensive understanding of the complex interactions between climate change and aquatic ecosystems, as well as identify potential solutions and management strategies. We strongly hope that this topic will attract the attention of the broader scientific community interested in climate change biology, bringing together researchers with expertise in diverse and complementary fields.

Author contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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