

The Future of Marine Invertebrates in Face of Global Climate Change

Wang You-Ji*

College of Fisheries and Life Science, Shanghai Ocean University, Shanghai 201306, China

*Corresponding author: Wang You-Ji, College of Fisheries and Life Science, Shanghai Ocean University, Shanghai 201306, China, Tel : +021 61900505; E-mail: yj_wang@shou.edu.cn

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Global Warming and Sea Temperature Rise

Average sea surface temperature is now 0.6°C warmer than at the start of the industrial revolution [1], and a further increase of 3-6°C is forecasted by the end of this century because of elevated levels of atmospheric carbon dioxide [2,3]. The effects of global warming on marine species include range shifts, population collapses, local extinctions, and phase shifts, which result from individual physiological and behavioural responses to increasing temperature throughout the species' geographic range [3-9]. For ectothermic organisms, habitat temperature is a critically important environmental factor because of the effects of temperature on all biological processes, from molecular to physiological to behavioural [8,10-12]. Local adaptation to thermal gradients can cause populations in different parts of the geographic range to exhibit different responses to temperature variation [11,13-15]. Obviously, forecasting the response of animals to global climate change drivers must encompass more than just physiological sensitivity, e.g., the animal's ability to buffer the effects of climate change through behavior. Consequently, comparing the effects of temperature increases in different populations is essential for generating robust predictions about the impact of global warming on animal community at large spatial scales.

Carbon Dioxide and Ocean Acidification

The ongoing increase of anthropogenic CO₂ in the atmosphere causes an accumulation of CO₂ in the oceans and an acidification trend, which develops in parallel with global warming [1,9,12,16-18]. The associated ocean acidification leads to questions about its effect on marine ecosystems in times of ocean warming [12,19]. Our understanding of the biological and ecological consequences of ocean acidification is, however, still in its infancy [20,21]. Reductions in seawater pH have been demonstrated to affect the physiological and developmental processes of a number of marine organisms [19,20,22-24] through reduced internal pH (acidosis) and increased CO₂ (hypercapnia) [19,25]. CO₂ has also been shown to cause behavioural alterations in anti-predator behaviour [26-28]. A few studies have provided us with insights into foreseeable effects, or inform us about how predator-prey interactions may be altered in fish [29], given that so far, simultaneous changes of feeding behavior and physiology of invertebrate predators are still incomplete. Determining how ocean acidification might affect the feeding behavior and physiology of benthic organisms is critical to predicting how these impacts might propagate through the food chain. For reliable conclusions concerning the impact of CO₂ on the physiology and fitness of crustaceans in the near future, it is necessary to include realistic CO₂ concentrations in those studies, as postulated for 2100 (710 ppm) or beyond (3000 ppm), and combine them with changing temperatures.

Combined Effects of Temperature and Ocean Acidification

Simultaneous changes in multiple climate variables have the potential to yield surprising biological responses that could not be predicted by responses to single climate variables alone [30]. These stressors are likely to have deleterious interactive effects; increased temperature has a stimulatory effect on physiological processes (until thresholds are reached) while hypercapnia has a suppressive, narcotic effect [12,25]. Shallow-water coastal crustaceans, such as the edible crab *Cancer pagurus* and the spider crab *Hias araneus*, are considered at risk, because of increased sensitivity to the synergistic effects of temperature and hypercapnia [31-33]. Furthermore, sensitivity to CO₂ may be highest where a species experiences extreme temperatures [31] and lives close to the border of its temperature dependent distribution range, e.g. along a latitudinal gradient. Although both warming and acidification represent serious threats to marine life, little information exists on the effect of enhanced CO₂ levels in combination with global warming on the feeding behavior and physiology of crustaceans. Only Walther found that the spider crab *Hias araneus* from different latitudes showed different tolerance to the combination of ocean acidification and warming [34]. Most of the studies on the biological action of environmental stressors have concentrated on the action of single factor against organisms, while the combined effects are less well known, in particular whether warming increases the susceptibility to other forms of stress such as ocean acidification. Therefore, establishing principles on how multiple environmental stressors jointly interact from a physio-ecological perspective are needed to provide theoretical support for environmental-specific regulations that are established to protect aquatic ecosystems. In assessing risk to marine biota from climate change it is critical to investigate interactive effects of stressors in multifactorial experiments as this better reflects the real world scenario [19,25].

Estuarine and coastal marine systems are among the most ecologically and economically important habitats in the world. In many cases, benthic invertebrates including molluscs are the most important components of the coastal ecosystems. Molluscs are also major commercial fisheries worldwide [35]. Given the importance of coastal habitats, research aiming to predict changes in the coastal systems in face of climate change is urgently needed. The effects of acidification on marine invertebrates have not been well studied, and recent studies are most related to the calcification response of corals and coccolithophores [36,37]. There is now a critical need to test the consequences of ocean acidification on ecologically and commercially important benthic invertebrates at climate-relevant CO₂ levels under warming conditions.

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