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# A review of transgenerational effects of ocean acidification on marine bivalves and their implications for sclerochronology

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ABSTRACT

Ocean acidification can negatively impact marine bivalves, especially their shell mineralization processes. Consequently, whether marine bivalves can rapidly acclimate and eventually adapt in an acidifying ocean is now increasingly receiving considerable attention. Projecting the fate of this vulnerable taxonomic group is also pivotal for the science of sclerochronology – the study which seeks to deduce records of past environmental changes and organismal life-history traits from various geochemical properties of periodically layered hard tissues (bivalve shells, corals, fish otoliths, etc.). In this review, we provide a concise overview of the long-term and transgenerational responses of marine bivalves to elevated $pCO_2$ manifested at different levels of biological organization, with a specific focus on responses of geochemical properties (stable carbon and oxygen isotopes, minor and trace elements and microstructures) of their shells. Without exception, positive transgenerational responses to an elevated $pCO_2$ scenario projected for the year 2100 have been found in all five bivalve species hitherto studied, under the umbrella of two non-genetic mechanisms (increased maternal provisioning and epigenetic inheritance), suggesting that marine bivalves have remarkable transgenerational phenotypic plasticity which allows them to respond plastically and acclimate rapidly in an acidifying ocean. Rapid transgenerational acclimation, especially in terms of physiological processes, however, hinders a reliable interpretation of proxy records. Transgenerationally acclimated bivalves can actively modify the calcification physiology in response to elevated $pCO_2$, which in turn affects the processes of almost all geochemical proxies preserved in their shells. In particular, stable carbon isotopes, metabolically regulated elements (Na, K, Cu, Zn, Fe, etc.), and shell microstructures can be highly biased. In this context, we propose a number of challenges and opportunities the field of sclerochronology may face.

## 1. Introduction

The global atmospheric carbon dioxide ($CO_2$) concentration is increasing at an unprecedented rate during the last decades, reaching up to 410 ppm in 2018 – a rise by about 41% since the industrial revolution higher than at any time during the past 800,000 years (Blunden et al., 2018). Approximately one third of atmospheric $CO_2$ has been dissolved into the oceans, forming carbonic acid ($H_2CO_3$) and eventually decreasing the seawater pH, the carbonate ($CO_3^{2-}$) concentration and the calcium carbonate ($CaCO_3$) saturation state (Caldeira and Wickett, 2003). Surface ocean pH already has declined by 0.1 pH units since 1750 and is projected to decline by another 0.3–0.4 units by the end of the 21st century (IPCC, 2013). Unprecedented rapid decline in ocean pH, known as ocean acidification (OA), will have widespread implications for marine calcifying organisms and ecosystems that they support (Orr et al., 2005; Fabry et al., 2008; Kroeker et al., 2013). The fate of marine bivalves in an acidifying ocean is of particular concern, considering their high ecological and economical importance in global coastal ecosystems (Gosling, 2003), and their sensitivity to OA, according to ample evidence of negative impacts at almost all levels of biological organization

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