



Impact of high $p\text{CO}_2$ on shell structure of the bivalve *Cerastoderma edule*



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ABSTRACT

Raised atmospheric emissions of carbon dioxide (CO_2) result in an increased ocean $p\text{CO}_2$ level and decreased carbonate saturation state. Ocean acidification potentially represents a major threat to calcifying organisms, specifically mollusks. The present study focuses on the impact of elevated $p\text{CO}_2$ on shell microstructural and mechanical properties of the bivalve *Cerastoderma edule*. The mollusks were collected from the Baltic Sea and kept in flow-through systems at six different $p\text{CO}_2$ levels from 900 μatm (control) to 24,400 μatm . Extreme $p\text{CO}_2$ levels were used to determine the effects of potential leaks from the carbon capture and sequestration sites where CO_2 is stored in sub-seabed geological formations. Two approaches were combined to determine the effects of the acidified conditions: (1) Shell microstructures and dissolution damage were analyzed using scanning electron microscopy (SEM) and (2) shell hardness was tested using nanoindentation. Microstructures of specimens reared at different $p\text{CO}_2$ levels do not show significant changes in their size and shape. Likewise, the increase of $p\text{CO}_2$ does not affect shell hardness. However, dissolution of ontogenetically younger portions of the shell becomes more severe with the increase of $p\text{CO}_2$. Irrespective of $p\text{CO}_2$, strong negative correlations exist between microstructure size and shell mechanics. An additional sample from the North Sea revealed the same microstructural-mechanical interdependency as the shells from the Baltic Sea. Our findings suggest that the skeletal structure of *C. edule* is not intensely influenced by $p\text{CO}_2$ variations. Furthermore, our study indicates that naturally occurring shell mechanical property depends on the shell architecture at μm -scale.

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1. Introduction

Growing emission of anthropogenically-derived CO_2 to the atmosphere and its subsequent uptake by the oceans are leading to climate change and ocean acidification (Caldeira and Wickett, 2003; Feely et al., 2004; Raven et al., 2005). The addition of CO_2 to the ocean is followed by an increase in bicarbonate and H^+ ions concentrations and a decrease in carbonate ions concentration (Orr et al., 2005; Feely et al., 2004). These changes are predicted to have severe potential environmental and ecological repercussions on regional and global scales (Orr et al., 2005; Kleypas et al., 2006; Fabry et al., 2008; Dupont et al., 2010). Since the pre-industrial period, CO_2 atmospheric concentration increased from 280 to over 400 ppm (IPCC, 2007; data available from www.esrl.noaa.gov/

[gmd/ccgg/trends/](http://www.esrl.noaa.gov/gmd/ccgg/trends/)) and ocean surface pH decreased by 0.1 units (Raven et al., 2005). According to the IS92a ocean acidification scenario, pH is predicted to further decrease by 0.3–0.4 units by 2100 (Meehl et al., 2007). In order to mitigate the emissions of CO_2 , a new strategy of carbon dioxide capture and sequestration (CCS) has been introduced (Steenvelde et al., 2006). For this technology CO_2 from the industrial processes is secured, injected and permanently stored in sub-seabed geological formations providing a long-term isolation from the atmosphere. Even though the benefits of CCS have been demonstrated (IEA, 2010), stocking large volumes of CO_2 below the ocean floor generates apprehension about potential leaks and the consequent extreme acidification of the surrounding waters (IPCC, 2005).

In the past, great interest has been addressed to the effects of ocean acidification on marine calcifying organisms (Delille et al., 2005; Ries et al., 2009; Dupont et al., 2010; Ragazzola et al., 2012; Xu et al., 2016). Low pH leads to a decrease of CO_3^{2-} which in turn affects seawater saturation state (Ω). Undersaturated conditions

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