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Combined impacts of ocean climate change on invertebrates: a synopsis

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CO_2-driven ocean climate change (CC), i.e. ocean acidification and warming, is purported to directly affect organisms' physiological performance; however, a dearth in knowledge currently exists as to species physiological limits. Invertebrates constitute 95% of all animal species and are major components of all ecosystems; we thus provide a synopsis of future climatic physiological impacts on model molluscan, echinoderm and crustacean species. With regard to molluscs, negative impacts of elevated CO_2 include inhibition of larval development, 5% of *Crassostrea gigas* larvae developed into normal veliger under PCO_2 of 2270 μatm, even though no obvious effect was detected up to the trochophore stage; larval shell mineralization was completely inhibited in 45% of the CO_2-exposed larvae. In *Mytilus galloprovincialis*, embryogenesis was unaffected by exposure to high-CO_2 seawater up to the trochophore stage, but subsequent development was delayed when the shell began to form. Effects on echinoderms are more significant, as observed in the sea urchin *Hemicentrotus pulcherrimus* to individual and synergistic effects of elevated CO_2 (1000 μatm) and temperature over ambient (+2ºC) on reproduction and physiology during a 9-month continuous period. Findings demonstrate that elevated CO_2 exposure delayed ovarian maturation (approx.1 month), although a comparatively similar egg number was observed; low fecundity, i.e. low mature egg number (ca. 35% of the control) was observed in the high CO_2-high temperature treatment. Further physiological evidence includes complete spawning inhibition, as well as suppressed feeding (32%) and lowered metabolic rate (42%). High CO_2 exposure also suppressed the cryptic behaviour profiles (light avoidance 23% and chemoreception 50%) in sea urchins. Overall, we suggest the progressively increasing atmospheric and oceanic CO_2 and temperature may have negative impacts on the fecundity of sea urchins, and even may increase the extinction risk of this species.

Synergistic CC effects were also evaluated in several model crustaceans, representative of natant species in coastal marine ecosystems (copepods, palaemonid and penaeid prawns, and Antarctic krill). CC impacts include decreased physiological performance in terms of altered moulting frequency, decreased survival (50%) and reduced growth (palaemonids). Impacts on Antarctic krill were evaluated in both embryogenesis and adult stage. CC impacts (PCO_2 2000 μatm) on early development include 90% inhibition of development prior to the gastrula stage (within 24 h) and complete inhibition of larval hatching. Effects on adult krill, however, displayed a dichotomy in effects, when exposed to future oceanic conditions, with a doubling of growth rates in summer krill and a 2% 'shrinking' observed in winter krill. These findings are the first to demonstrate a comprehensive summary of CC impacts on Antarctic krill. Conversely, no significant effects were observed in physiology or early development in the copepod *Acartia tsuensis* through all life stages and subsequent generations (PCO_2 2380 μatm), thereby, highlighting species-specific responses/sensitivities. Other findings, however, show that in Penaeids, the synergistic effects of both high CO_2 and elevated temperature affect aerobic performance by reducing metabolic scope, and thus energetically-demanding activity, such as reduced swimming performance, as hypothesised by Pörtner and Farrell (2008). Collectively, these results demonstrate that CC impacts on organism physiology with unpredictable outcomes. Altered physiological functioning, may lead to decreased energy available for other energy sinks, such as somatic and gonadal growth, reproductive output and activity. Larval development is important in terms of success of subsequent generations and all such energetic sinks are directly quantifiable and provide insights into organism ecological performance and thus, repercussions of CC impacts. Further studies are thus advocated in order to predict fully physiological impacts of future oceanic conditions on ecosystems at species and community levels.