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TECHNICAL COMMENT

Response to technical comment on 'meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms'

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Abstract

It has been proposed that crustaceans should be excluded from a comparison of biological responses to ocean acidification among organisms with different calcium carbonate ($CaCO_3$) forms in their calcified structures. We re-analysed our data without crustaceans and found high variation in organismal responses within $CaCO_3$ categories. We conclude that the $CaCO_3$ polymorph alone does not predict sensitivity, and a consideration of functional differences among organisms is necessary for predicting variation in response to acidification.

Keywords

Acidification, aragonite, calcification, calcium carbonate, crustaceans, Mg-calcite.

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RESPONSE

Accurately predicting which organisms will be vulnerable and/or resilient to ocean acidification requires a nuanced understanding of the sources of the variation in the biological responses. Kroeker *et al.* (2010) concluded that functional differences among organisms (e.g. degree of calcification, calcification processes, other biogenic substances associated with the calcified structures, regular moulting, intracellular pH regulation, etc.) are important considerations for predicting variation in responses to acidification. Andersson and Mackenzie (2011) note important differences between crustaceans and other organisms that use high-Mg calcite in their calcified structures, and emphasise that these differences need to be considered for meaningful comparisons among the responses of organisms using different mineral forms of calcium carbonate ($CaCO_3$).

Andersson and Mackenzie (2011) suggested that because of the complex mineralogy of crustaceans, they should be considered as a separate category in meta-analysis. We tested this by reanalyzing our data set without crustaceans. As in our original analysis, we found significant negative mean effects of acidification on organisms using aragonite and low-Mg calcite but we did not detect a significant mean effect on organisms using high-Mg calcite (Fig. 1). These results are contrary to the predictions based on the solubility of the pure mineral forms of $CaCO_3$ (Andersson *et al.* 2008). However, there remains considerable variation in the response in the high Mg-calcite category, which encompasses a broad diversity of organisms that differ considerably in their traits. It is likely that the functional differences in the organisms using high-Mg calcite (e.g. coralline algae with externally calcified skeletal structures and seastars with internally calcified ossicles) are critical in predicting an organism's sensitivity to acidification. We conclude that our results were not biassed by the inclusion of crustaceans as high-Mg calcifiers, and $CaCO_3$ polymorph does not predict sensitivity to acidification without considering the other biological variables.

Our original results were based on the standard 4 mol% $MgCO_3$ threshold for high-Mg calcite (Bøggild 1930). While there is species-specific variation in the amount of $MgCO_3$ in calcified structures, most decapod crustaceans, echinoderms and coralline algae have a $MgCO_3$ content substantially > 4 mol% (Chave 1954). We were unable to re-analyse the data with a 12 mol% $MgCO_3$ cut-off for high Mg-calcite designation based on the composition of the particular organism used in the experiments as suggested by Andersson and Mackenzie because these data are not reported in the primary literature. We agree that this information could increase the predictive power of the high-Mg calcite hypothesis. However, our analyses show that accurate predictions of organism's vulnerability to acidification will require consideration of other sources of biological variation as well.

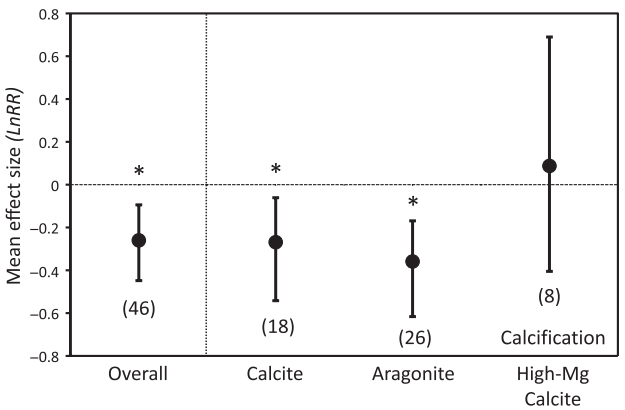

Figure 1 Variation in calcification response to ocean acidification amongst different polymorphs of calcium carbonate with crustaceans excluded from analysis. Mean effect size and 95% bias-corrected bootstrapped confidence interval are shown for organisms using calcite, aragonite and high-Mg calcite (based on a 4 mol% $MgCO_3$ content). The number of experiments used to calculate a mean effect size is shown in parentheses. The mean effect size is significant with the 95% confidence interval does not overlap zero (*).

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