Meta-analysis reveals complex marine biological responses to the interactive effects of ocean acidification and warming

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# Meta-analysis reveals complex marine biological responses to the interactive effects of ocean acidification and warming

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## Abstract:
Ocean acidification and warming are considered two of the greatest threats to marine biodiversity, yet the combined effect of these stressors on marine organisms remains largely unclear. Using meta-analytical techniques we assessed the biological responses of marine organisms to the effects of ocean acidification and warming in isolation and combination. We found positive, neutral and negative biological responses that varied across taxonomic groups, life-history stages and trophic levels. Moreover, we found the combined stressors generally exhibited a stronger effect (either positive or negative) than when exposed to the stressors in isolation. Using a subset of fully factorial studies we show that the type of response (e.g. calcification, survival) determines whether multiple stressors interact in a predictable manner, or as an unpredictable ‘ecological surprise’. Interactions of the two stressors led to ‘ecological surprises’ more commonly than predictable outcomes. Additionally, although the analysis of our subset of data showed that ‘ecological surprises’ were common, meta-analysis of the full data set was not sensitive enough to detect these important interactions. The inherent variability associated with different taxonomic groups, life-history stages and trophic levels may make broad-scale meta-analyses less effective in detecting more specific ‘ecological surprises’. Given that the occurrence and importance of ‘ecological surprises’ are likely to intensify with increasing frequency of stressors interacting in marine systems, there is an urgent need to move towards a more robust, holistic and ecologically realistic approach to climate change experimentation that forewarns of the likely deleterious impacts to marine biodiversity and ecosystem functioning over the next century.
Meta-analysis reveals complex marine biological responses to the interactive effects of ocean acidification and warming

**Running title**: Interactions of warming and acidification

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ABSTRACT

Ocean acidification and warming are considered two of the greatest threats to marine biodiversity, yet the combined effect of these stressors on marine organisms remains largely unclear. Using meta-analytical techniques we assessed the biological responses of marine organisms to the effects of ocean acidification and warming in isolation and combination. We found positive, neutral and negative biological responses that varied across taxonomic groups, life-history stages and trophic levels. Moreover, we found the combined stressors generally exhibited a stronger effect (either positive or negative) than when exposed to the stressors in isolation. Using a subset of fully factorial studies we show that the type of response (e.g. calcification, survival) determines whether multiple stressors interact in a predictable manner, or as an unpredictable ‘ecological surprise’. Interactions of the two stressors led to ‘ecological surprises’ more commonly than predictable outcomes. Additionally, although the analysis of our subset of data showed that ‘ecological surprises’ were common, meta-analysis of the full data set was not sensitive enough to detect these important interactions. The inherent variability associated with different taxonomic groups, life-history stages and trophic levels may make broad-scale meta-analyses less effective in detecting more specific ‘ecological surprises’. Given that the occurrence and importance of ‘ecological surprises’ are likely to intensify with increasing frequency of stressors interacting in marine systems, there is an urgent need to move towards a more robust, holistic and ecologically realistic approach to climate change experimentation that forewarns of the likely deleterious impacts to marine biodiversity and ecosystem functioning over the next century.
INTRODUCTION

The concentration of atmospheric carbon dioxide (CO$_2$) has increased from 280ppm in pre-industrial times to a present day level of 387ppm (Feely et al. 2009). Over the last 100 years this has led to changes in global sea surface temperatures (+0.74°C) and ocean carbonate chemistry (Orr et al. 2005), which have included ocean acidification by 0.1 pH units (Caldeira & Wickett, 2003; Kleypas et al. 2006). By the year 2100 sea-surface temperatures are expected to rise by a further 1-4°C while increased CO$_2$ (aq) will result in the decreased availability of carbonate ions and a further reduction in pH by 0.3-0.5 units (Caldeira & Wickett, 2005; IPCC, 2007; Gooding et al. 2009). These changes in temperature and ocean carbonate chemistry are considered two of the greatest threats to marine biodiversity (Kleypas et al. 1999; Doney et al. 2009), leading to changes in the physiological performance of individual organisms which will in turn alter biotic interactions, community structure and ecosystem functioning.

A range of marine biological responses have already been observed in response to ocean warming including hypoxia (Pörtner & Knust, 2007), coral bleaching (Hoegh-Guldberg et al. 2007), species range shifts (Parmesan & Yohe, 2003; Root et al. 2003), changes to phenology (Walther et al. 2002), and reduced organism body size (Daufresne et al. 2009). Experimental manipulations simulating predicted future ocean temperatures have suggested that warming will also lead to increased metabolic costs for plants and animals (O’Connor et al. 2009), increased consumption rates (Sanford 1999) and changed food-web structure (Petchey et al. 1999). Observed responses of marine organisms to recent ocean acidification are limited (but see Iglesias-Rodriguez et al. 2008b; Moy et al. 2009), but are expected to become increasingly apparent in the next 50-100 years (Doney et al. 2009; Feely et al. 2009).
Experimental evidence, however, suggests that responses are likely to be highly varied (Hendriks et al. 2010; Kroeker et al. 2010) and will include hypercapnic suppression of metabolism (Christensen et al. 2011), acid-base balance disturbances (Miles et al. 2007), plus both positive and negative effects on skeleton formation (related to a decrease in carbonate saturation; Doney et al. 2009; Ries et al. 2009).

The vulnerability of marine species and ecosystems to individual climate stressors, particularly temperature, is well established (for reviews; Hoegh-Guldberg & Bruno, 2010; Richardson et al. 2012; Wernberg et al. 2012), despite this, the cumulative effect of warming and acidification remains unclear (Sala et al. 2000; Fabry et al. 2008). Recent meta-analyses, across ecological systems, have shown that multiple stressors can lead to ‘ecological surprises’ (sensu Paine et al. 1998) with responses dependent on the type of stressor as well as the ecological organisation investigated (e.g. population vs. community, autotroph vs. heterotroph) (Crain et al. 2008; Darling & Côté, 2008; Tylianakis et al. 2008). Moreover, the mechanism through which the stressor acts upon the organism will affect the response. Multiple stressors acting through a similar pathway may have an additive effect (Crain et al. 2008). In contrast, any stress-induced tolerances could lead to antagonisms (Blanck, 2002), while those stressors that act on different, but dependent mechanisms may act synergistically (Kneitel & Chase, 2004).

Organisms vary widely in their individual responses to ocean warming and acidification as a result of differences in their physiological and ecological characteristics (Dupont et al. 2008; Fabry, 2008). For example, many marine organisms possessing a calcium carbonate (CaCO$_3$) structure would be considered more susceptible to ocean acidification as this process will impair their capacity to produce calcified skeletons (Doney et al. 2009). Conversely, some
species, including some calcified species, will have the capacity to buffer against the deleterious effects of acidification by utilising acid-base compensation (e.g. fishes; Claiborne & Evans, 1992; Larsen et al. 1997), active mobility and metabolism (Widdicombe & Spicer, 2008; Whiteley, 2011) or energy reallocation (Wood et al. 2008; McDonald et al. 2009).

Elevated temperature (up to a limit) may positively enhance metabolism in ectotherms, resulting in faster growth and development (Byrne, 2011). Moreover, it has been speculated that warming could even ameliorate the negative impacts of acidification (McNeil et al. 2004; Kleypas & Yates, 2009). Therefore, the concurrent effect of temperature and ocean acidification via elevated CO$_2$ remains unclear, but is likely to lead to complex biological outcomes.

Species responses to ocean warming and acidification will also vary among life-history stages (Byrne, 2011). Early life-history stages are considered more susceptible to changes in both temperature and ocean acidification (Byrne, 2011). These stressors may, however, have positive and/or negative effects for the successful recruitment of juveniles to the adult population. Trophic level is also likely to determine how species respond due to differences in environmental sensitivity (Petchey et al. 2004; Raffaelli, 2004). Previous work has suggested the effects of multiple stressors are likely to act antagonistically in autotrophs, but synergistically in heterotrophs (Crain et al. 2008). Furthermore, since higher trophic levels contain less ‘biological insurance’ (sensu Yachi & Loreau, 1999), i.e. less taxonomic, physiological, and genetic diversity, they are predicted to be more susceptible to multiple environmental perturbations (Christensen et al. 2006) which could act upon them synergistically (Crain et al. 2008).
Studies of the biological effects of elevated temperature and acidification on marine organisms in isolation have provided some insight into the potential tolerance of species to these changing conditions (Gattuso et al. 2009). However, given that these stressors are unlikely to operate independently, there is now a need to gain a more ecologically realistic understanding of how the combined effects of temperature and acidification will affect marine biota. This is vital in order to inform future adaptative management strategies. Using a meta-analytical approach of the peer-reviewed literature we assessed the impacts and interactions of ocean acidification and warming on marine biological responses. Given that variability in the strength and direction of responses was expected, we classified data according to taxonomic groups, calcifiers and non-calcifiers, life-history stage and level of trophic organisation (autotroph and heterotroph) in terms of changes in rates of calcification, growth, photosynthesis, reproduction and survival. Specifically, we aimed to address three questions: (i) How do warming and acidification impacts interact? (ii) Do stressors combine in predictable ways or as ‘ecological surprises’? (iii) Can inherent biological variability be explained by predetermined categories?

MATERIAL AND METHODS

DATA SELECTION AND SUITABILITY CRITERIA

Searches for peer-reviewed articles in which studies explicitly investigated anthropogenic climate change using either elevated temperature, ocean acidification or elevated temperature and acidification were carried out using ISI Web of Science ©, Google Scholar; the European Project on Ocean Acidification (EPOCA) blog (http://oceanacidification.wordpress.com/), citation searches; analysis of reference lists in comprehensive reviews (Hendriks et al. 2010;
Kroeker *et al.* 2010; Wernberg *et al.* 2012), and then cross-referenced with the bibliographies of identified articles.

We limited our review to studies published between 1st January 1990 and 1st January 2012, as the majority of experimental climate change studies that manipulated climate change conditions in line with IPCC AR1 predictions and subsequent updates (IPCC, 1990, 2007) were published after 1990. Only controlled manipulative experiments were used for analysis. In addition, the control treatments of the environmental stressor (e.g., pH, CO$_2$, or temperature) needed to represent current ambient levels and were based on the authors’ opinion of ‘ambient’. The experimental organisms had to be subjected to elevated temperature alone, acidification alone, or both warming and acidification. When studies included environmental variables in addition to temperature and ocean acidification (such as light availability or nutrients), these responses were only considered at ‘ambient’ levels of the other environmental variables. To explore predicted future conditions for 2100, the manipulation treatments needed to conform to the IPCC IS92a “business-as-usual” emission scenario for the year 2100 (IPCC, 2007). We omitted studies that manipulated carbonate chemistry using acid addition, because it does not reproduce the changes in HCO$_3^-$ concentration that occur as a result of increased CO$_2$(aq) (Iglesias-Rodriguez *et al.* 2008a; 2008b; but see; Gattuso & Lavigne, 2009; Schulz *et al.* 2009). Finally, only studies that reported a measurable biological response were included.

As response variables we used calcification (or dissolution) rates, growth, photosynthesis, reproduction and survival (mortality was converted to survival by using 1 - mortality). There were insufficient data on other response variables (e.g. feeding rates, metabolism) to enable quantitative analysis. A number of articles included more than one species, response,
location, or treatment level. All of the species, responses, locations and treatment levels were included if they met the suitability criteria. This ensured that a broad range of responses could be fully explored, despite lessening the independence of the data from that particular study (Gurevitch et al. 1992). To maintain independence of data we included only one response, chosen at random, from studies reporting several responses that could be classified in the same category (eg. growth expressed as changes in length and biomass). Derived metrics from studies that included time-series data were based on the final time point of exposure. To investigate inherent biological variability, records were categorised according to taxonomy, life-history stage, level of trophic organisation (autotroph, heterotroph) and whether the organism possessed a CaCO$_3$ skeletal structure.

To enable a calculation of effect size, studies that met our initial criteria could only be used if they reported a mean response value, some form of variance (standard deviation, standard error or confidence interval), and a sample size. In some instances values were only reported in graphical form, and in these situations data were extracted using the program GraphClick (v. 3.0) (Neuchatel, Switzerland).

**DATA ANALYSIS**

Biological responses to ocean warming and acidification were measured for each experiment to establish the proportional change between the control and treatment means using response ratios. In their original metric response ratios are weighted towards positive responses, so the response ratios were log transformed to maintain symmetry in the analysis and ease the biological interpretation (Hedges *et al.* 1999). We chose a log response ratio (lnRR), over
other methods, to estimate the effect size because of the high capacity to detect true effects and there robustness to small sample sizes (Lajeunesse & Forbes, 2003).

We selected a weighted random-effects model to estimate a summary effect size. Random-effects analysis assumes that the true effect size differs between experiments and the estimated summary effect is the mean of the effects observed across the studies. This means that even if studies have a low weighting, the individual effect sizes from all of the studies will still be incorporated into the summary effect (Borenstein et al. 2009). This ensured that the biological variation inherent in the responses was properly accounted for. Both the within-study variance (inverse of the effect size variance) and the between-study variance ($\sigma^2_{\text{pooled}}$) were used to weight the studies. Therefore studies with higher replication and/or lower variance were considered more precise and weighted accordingly (Hedges & Olkin, 1985).

Statistical significance was attributed to each summary effect size by calculating a bias-corrected 95% confidence interval (CI) and comparing it with zero. If the summary effect size did not overlap zero then it was considered to be significantly different. A total heterogeneity statistic ($Q$) was used to ascertain that the variation observed was a combination of both true variation (between studies) and random error (within studies) (Borenstein et al. 2009). This was tested as the observed weighted sum of squares against a chi square distribution with $n - 1$ degrees of freedom, using the null hypothesis that observations share a common effect size.

Combinations of the treatment effect (CO$_2$/pH, temperature, temperature and CO$_2$/pH) and response variables (calcification, growth, photosynthesis, reproduction, and survival) were
used as the comparison groups in all analyses. Separate exploratory analyses were also used to test the differences between \textit{a priori} defined groups; it was appreciated that this form of multiple exploratory analyses on the same dataset is prone to Type I error, however, we aimed to use these analyses to identify the underlying patterns of the biological responses. The categorical moderators used were the different taxonomic groups (corals, crustaceans, crustose coralline algae, echinoderms, fishes, non-calcifying algae, molluscs, phytoplankton and seagrasses), calcifying and non-calcifying organisms, developmental stages (embryos, larvae, juveniles and adults), and trophic organisation (autotroph and heterotroph). This process applied a summary effect size and 95% CI to each of the different categories for comparison. To formally test for differences between these categories, a test for heterogeneity ($Q_M$) was used; this ascertains the total heterogeneity that can be explained by that particular categorical moderator (Gurevitch \textit{et al.} 1992). A significant $Q_M$ indicates that there is a difference between the categories. The taxonomic group of phytoplankton was initially divided into coccolithophores, cyanobacteria, diatoms, dinoflagellates and foraminifera, however, results were pooled again after detecting no difference using a test for heterogeneity ($Q_M$). Over all of the meta-analytical results, the summary effect sizes were not reported if there were fewer than five studies available for analysis, and categorical moderators were not reported if there were fewer than three studies. This was a pragmatic decision to ensure that a broad range of responses could be assessed, as some categories only had a few studies that met our criteria. Therefore, the categorical analyses did not always include all the observations from the full model.
INTERACTIONS BETWEEN MULTIPLE STRESSORS

Interactions between ocean warming and acidification were ascertained following the methodology of Darling and Côté (2008). The method involved using a weighted fixed-effect model to predict the combined effect of warming and acidification for each response variable. The effects of ocean warming and acidification are unlikely to operate independently, so we used a multiplicative model (± 95% CI) to predict the proportional change of their interaction (Morris et al. 2007; Crain et al. 2008). Although less conservative than an additive model (Folt et al. 1999), we considered a multiplicative model to be more appropriate since the underlying model of the metric lnRR is multiplicative (Hawkes & Sullivan, 2001; Morris et al. 2007), and this model is also thought to be more biologically realistic (Sih et al. 1998).

Results were then compared to the combined warming and acidification observed responses (also calculated using a weighted fixed-effect model ± 95% CI). If the 95% CI of the predicted and observed responses did not overlap then they were considered significantly different. Observed effect sizes that were significantly higher were classed synergistic, significantly lower were antagonistic, and those that were non-significant were multiplicative.

To be included, studies had to have carried out a controlled factorial experiment that reported the outcomes of warming and acidification individually and in combination, with a control treatment (Underwood, 1997). Therefore, not all of the observations from the full model could be analysed. Multiple observations from the same study were included if separate factorial results were provided.

SENSITIVITY ANALYSES AND PUBLICATION BIAS

Sensitivity analysis was used to investigate the influence of any experimental study that demonstrated an unusually large effect size. This was achieved in a step-wise manner by
ranking each experiment by the magnitude of effect size, removing the largest one, and re-running the analysis. Likewise, if any study contributed five or more observations to a category, the study was omitted and the analyses re-run. If studies were considered to be driving the results, then they were omitted from the analysis of that response variable.

The number of studies with an effect size of zero that would be required to change the results of the meta analysis from significant to non-significant (‘file drawer problem’) was determined using Rosenberg’s failsafe number (Rosenberg, 2005). It was decided that if five or less studies (of zero effect size) were required to change the effect size, then that categorical analysis was not considered robust.

RESULTS

OVERALL BIOLOGICAL RESPONSES

Out of 196 peer-reviewed articles that investigated the biological responses of marine organisms to ocean warming and/or acidification 107 met our criteria, giving 623 unique observations (Table S1). Observations that did not meet the selection criteria are listed in Table S2, and the results from all the heterogeneity tests for overall within-effects ($Q$) and between categories ($Q_M$) are reported in Table S3.

Meta-analysis of the whole dataset revealed that calcification was negatively affected by ocean acidification and neutrally affected by ocean warming, although there was some tendency towards a negative response. Combined warming and acidification resulted in a highly significant negative response (Fig. 1). In contrast, the effects of ocean acidification and warming (both independently and combined) had no effect on growth (Fig. 1).
Independently, both ocean acidification and warming resulted in highly variable, but non-significant effects on photosynthesis. Conversely, concurrent acidification and warming revealed a significant positive effect on photosynthesis (Fig. 1).

The independent effects of ocean acidification and warming on reproduction and survival were of similar magnitude and negative. The combined effects of ocean warming and acidification were also negative and of greater magnitude than observed for the stressors in isolation (Fig. 1).

**TAXONOMIC GROUPS**

The combined effects of ocean warming and acidification on calcification varied between taxonomic groups ($Q_M = 7.92$, d.f.=2, $p=0.019$; Fig. 1). For corals and crustaceans there were neutral effects in response to warming and acidification both in isolation and combination. In echinoderms, acidification had a neutral effect on calcification while ocean warming and the two stressors combined resulted in significant negative effects with the concurrent effects tending towards a synergistic interaction.

Responses of crustaceans, echinoderms, molluscs and phytoplankton to the combined effects of warming and acidification varied in terms of growth ($Q_M = 14.27$, d.f.=3, $p=0.003$; Fig. 1). Across all taxa there was no significant effect of warming or acidification in isolation or combination, with the exception of the crustaceans, which displayed a significant negative response to the combined effects of these stressors. For the non-calcifiers (fish, non-calcareous algae and seagrass), there was no significant effect on growth as a result of
warming and acidification in isolation, although effects tended towards positive. Unfortunately there were insufficient studies to determine the combined effects of these stressors.

The combined effects of ocean warming and acidification had a significant positive effect on photosynthesis in phytoplankton (Fig. 1). Although, analysis of the combined stressors was not possible for the other primary producers they all showed responses of similar magnitude to ocean acidification and warming in isolation.

For both echinoderms and molluscs, ocean warming (in isolation) had a significant negative effect on reproduction, while for molluscs ocean acidification (in isolation) also had a negative effect. Combined warming and acidification had a significant negative effect on reproduction in both taxa (Fig. 1).

The combined effects of ocean warming and acidification negatively affected survival in crustaceans and molluscs (Fig. 1). Additionally, significant negative responses were also detected in corals and molluscs under warming conditions and for molluscs under high CO₂ conditions.

**CALCIFIERS/NON-CALCIFIERS**

Due to an insufficient number of studies investigating the concurrent effects of warming and acidification on non-calcifiers, comparisons with calcifiers of the combined impact of these stressors was not possible. Under future ocean chemistry conditions there was, however, significant difference in growth between calcifiers and non-calcifiers ($Q_m = 12.22$, d.f. =1,
p<0.001; Fig. 2), with growth significantly negatively affected in calcifiers and significantly positively affected in non-calcifiers. Calcifiers exhibited a significantly positive photosynthetic response to the combined effects of warming and acidification (Fig 2), primarily driven by phytoplankton (Fig 1). Where sufficient data existed to enable comparisons, warming and acidification, in isolation and combination, negatively affected survival in both calcifiers and non-calcifiers (Fig 2).

**LIFE-HISTORY STAGES**

Ocean warming (both independently and in conjunction with acidification) had a significant negative effect on calcification in juveniles, but not in adults. Heterogeneity tests, however, did not reveal significant differences between life history stages for either calcification or growth when exposed to the two stressors in isolation or combination (Table S3). The effects of ocean warming on survival differed significantly between life-history stages with both larvae and juveniles exhibiting more negative responses than adults ($Q_M = 23.62$, d.f. =2, p<0.001; Fig. 3). Although ocean acidification had a significant negative effect on the survival of larvae and adults, there was no significant difference in responses across life-history stages (Table S3). The combined effects of warming and acidification on survival showed a significant negative response for both larvae and juveniles.

**TROPHIC ORGANISATION**

Calcification in autotrophs was not significantly affected by either warming or acidification in isolation or combination. The combined effects of warming and acidification had, however, a significant negative effect on calcification in heterotrophs (Fig. 4). Conversely, the effects of warming and acidification did not significantly affect growth in heterotrophs,
while in autotrophs ocean warming and acidification had a significant positive effect on growth (Fig. 4). While there were insufficient data to investigate the combined effects of warming and acidification on survival in autotrophs, these stressors in isolation had significant negative effects. In heterotrophs survival was not affected by ocean acidification, but was significantly negatively affected by warming alone and the combined effects of warming and acidification.

INTERACTIONS BETWEEN MULTIPLE STRESSORS

For calcification, growth and survival, combined warming and acidification resulted in negative ‘ecological surprises’ when compared to the multiplicative null expectation model, with a synergistic effect on calcification and an antagonistic effect for both growth and survival (Fig. 5). The observed responses for photosynthesis and reproduction were accurately predicted by the model suggesting that these responses to future warming and acidification may be predictable.

SENSITIVITY ANALYSES AND PUBLICATION BIAS

To test the robustness of our analyses against large effect sizes, we removed each comparison step-wise and re-ran each analysis, omitting experiments if they changed the significance of either heterogeneity or the mean effect size of the response variables. This resulted in twelve experiments being omitted from subsequent analyses across several treatment-response variable scenarios (see Table S2 for more detail). We used Rosenthal’s fail-safe number to assess the importance of potential publication bias and found that our response variables were robust, with the lowest values being 82 and 99 additional studies being required to change the effect size (based on original experiment quantities of 33 and 7 respectively). No individual
study contributing more than five experiments changed the significance of either the heterogeneity or mean effect size of the response variables.

**DISCUSSION**

Meta-analysis of the full dataset revealed that the combined effects of ocean acidification and warming had significant negative effects on calcification, reproduction and survival, and a significant positive effect on photosynthesis. There was, as would be expected, variation amongst taxonomic groups, life-history stages, trophic levels, calcifiers and non-calcifiers. More importantly, our analyses showed that responses to ocean acidification and warming in isolation often differed from the results obtained when these stressors were combined. Our results highlight the need to move away from single-stressor studies towards more ecologically realistic research incorporating multiple stressors, in order to more fully understand how near-future anthropogenic change will affect marine biodiversity.

Analysis of the full dataset did not provide evidence that the combined stressors would result in truly synergistic or antagonistic interactions. However, examination of our subset of fully factorial studies showed that three out of five of our responses generated ‘ecological surprises’ (sensu Paine et al. 1998), where the outcome was not predictable from the sum of the individual stressors (i.e. multiplicative effects; Folt et al. 1999). We observed a synergistic effect on calcification and an antagonistic effect on both growth and survival, highlighting that stressor specificity, in addition to other factors, may be involved in driving interaction types (Crain et al. 2008). Our findings suggest that the effects of combined warming and acidification may commonly generate unpredictable interactions (i.e. synergies
and antagonisms) rather than interacting in a predictable manner, with implications for our ability to predict the future impacts of multiple stressors.

Ecological synergies are anticipated to have important implications for marine systems (Paine et al. 1998; Harley et al. 2006; Sutherland et al. 2006) as they can exacerbate adverse effects and reduce ecosystem resilience (Folke et al. 2004). Although antagonistic interactions will reduce the cumulative impact compared to synergies (Didham et al. 2007; Brook et al. 2008), they will also interact unpredictably. Such unpredictable outcomes are of particular concern because ‘ecological surprises’ may additionally affect biotic interactions (Tylianakis et al. 2008) and trophic complexity (Vinebrooke et al. 2004; Darling & Côté, 2008). Multiple stressors are thought to act synergistically when affecting different physiological mechanisms, since this results in ecological trade-offs. This is because synergies are fundamentally a negative functional interaction between traits (Kneitel & Chase, 2004). Alternatively, antagonisms will occur if an individual is exposed to an additional stressor that acts upon the same mechanism as a stressor for which that individual has already adapted or become acclimated to (Blanck, 2002; Christensen et al. 2006).

The negative synergistic response detected for calcification in echinoderms, for instance, is consistent with the pattern of ecological synergies and trade-offs (Kneitel & Chase, 2004) in that it may be attributed to an energy re-allocation strategy from somatic or reproductive growth (Melzner et al. 2009). For example, an infaunal brittlestar exhibited muscle wastage as an energetic trade-off to maintain calcification under ocean acidification conditions (Wood et al. 2008). Our observed antagonistic interaction between ocean warming and acidification for both growth and survival may be consistent with the pattern of developing a stress-tolerance for stressors acting on the same pathway (Christensen et al. 2006). For example,
acidification may induce a reduced body size, a common stress-tolerance trait (Vinebrooke et al. 2004), which makes organisms less susceptible to other stressors, or in this case elevated temperature. In our analyses, the impacts of ocean acidification on survival were more subtle, with neutral or weakly negative effects, while temperature appeared to be the overriding stressor. The only exception to this was in adults in our analysis across life-history stages. This pattern is consistent with previous work (eg. McDonald et al. 2009; Findlay et al. 2010).

Interestingly, despite establishing robust predictions for near-future changes in carbonate chemistry (Roleda et al. 2012), the underlying mechanisms of the biological responses still remain unclear (Gattuso & Hansson 2011; but see Pörtner, 2008). For instance, until recently the effects of ocean acidification on calcification responses were thought to reduce an organism’s potential to calcify and enhance the dissolution of their CaCO$_3$ shells (eg. Ries et al. 2009). Recent studies have, however, demonstrated that the net calcification loss found in many studies may not demonstrate constraints on calcification, but rather that the dissolving of exposed skeleton (gross dissolution) is greater than the skeletal growth beneath healthy tissue (gross calcification) (Ries, 2011; Rodolfo-Metalpa et al. 2011). It is therefore essential to understand the mechanisms through which warming and acidification act, as well as to establish the effect that the stressors have on biological responses.

Early life-history stages are generally considered more susceptible to environmental stressors (Pechenik, 1987), and larval and juvenile stages of marine organisms typically show high mortality rates (Gosselin & Qian, 1997; Hunt & Scheibling, 1997). Our results support the hypothesis that the threshold for deleterious warming may vary between developmental stages (Byrne et al. 2009; Byrne et al. 2010) with adult survival being significantly higher compared to either larvae or juveniles under predicted warming conditions. However,
insufficient studies limited a comparison of the effects of combined warming and acidification on survival across life-history stages. Previous work suggests that for survival the interaction between different types of stressors does not differ between life stages apart from embryos (Darling & Côté, 2008). Our results support these findings, but are perhaps more indicative of differences between life-history stages being less prominent than species-specific sources of heterogeneity (Fabry, 2008; Kurihara, 2008).

In our analyses, the combined effects of warming and acidification positively affected growth in autotrophs, probably due to the effect of temperature on metabolic rate, while CO$_2$, which is a substrate for photosynthesis, may also have indirectly lead to increased growth at higher CO$_2$ concentrations. There were no effects on calcification in autotrophs but in heterotrophs calcification was adversely affected, along with survival, by the combined stressors. In heterotrophs growth was unaffected. Collectively, the differences observed are likely attributed to different modes of energy acquisition, and associated indirect effects. For instance, in some autotrophs photosynthesis is expected to increase under near-future climate change (eg. Palacios & Zimmerman, 2007; Fu et al. 2008; Hall-Spencer et al. 2008), and indirectly, photosynthesis has the potential to stimulate calcification (Ries et al. 2009) and increase growth rates (eg. phytoplankton; Loehle, 1995). Moreover, the metabolism complexes of heterotrophs (respiration-limited) are more sensitive to ocean warming than the photosynthesis-limited metabolism of autotrophs (Lopez-Urrutia et al. 2006), and thus warming is predicted to lead to stronger consumer-driven control (O'Connor et al. 2009). There were insufficient data in our analysis to make comparisons between consumer trophic levels (herbivores, detritivores, consumers and top predators). Given the greater frequency of negative effects in response to single stressors at higher tropic levels (Christensen et al. 2006), biological responses and interactions to multiple stressors are also likely to differ
between consumer trophic levels (Vinebrooke et al. 2004). Therefore, a need clearly exists to incorporate trophic complexity within experimental manipulations (eg. O'Connor, 2009; Ferrari et al. 2011) of multiple stressors.

Despite our subset of data, derived from experiments where both temperature and acidification were manipulated in isolation and combination, revealing ‘ecological surprises’ (Fig 5), analysis of our complete dataset did not reveal either synergistic or antagonistic interactions with combined warming and acidification. Broad-scale meta-analyses may therefore be ineffective in detecting the more specific ‘ecological surprises’, due to the inherent variability associated with different taxonomic groups, trophic levels and life-history stages. The implications of this are that any inferred additive interaction between acidification and warming may underestimate synergisms, and overestimate antagonisms (although conservatively) (Didham et al., 2007). Compared to additive interactions, mitigation measures on synergisms will result in greater than expected returns, however, antagonisms will lead to challenges for management because they will require multiple stressors to be mitigated before considerable recovery can be seen. In contrast to our findings, a previous synthesis of interactions between a broad range of stressors found that the overall interaction effect across all studies in marine systems was synergistic (Crain et al. 2008). However, a subsample of their more robust, fully factorial studies, resulted in over half of their studies having predictable additive interactions. Their study included only three examples of the combined impacts of temperature and ocean acidification, but our conflicting results further reinforce the role that stressor identity has in determining multiple stressor interactions. Additionally, since marine systems are subject to multiple interacting stressors (Halpern et al. 2007), it is possible that the addition of a third stressor would introduce further adverse consequences (eg. Przeslawski et al. 2005).
Although we identified and incorporated the available literature that met our selection criteria, the number of studies was limited across taxonomic groups, trophic levels and life stages leading to restrictions on the analyses we could undertake and highlighting the need for further research effort in this area. Additionally, despite a recognised tradition for effective experimental design in marine ecology (Underwood, 1997), a recent review highlighted that almost half of marine climate change experiments had design weaknesses or deficiencies (Wernberg et al. 2012). In that meta-analysis, 91% of studies either lacked treatment replication or carried out a form of pseudo-replication. We found that a third of the studies we investigated were also limited by experimental design, particularly pseudo-replication. This increases the likelihood of Type I errors, i.e. false positives (Hurlbert, 1984). Given the intense scrutiny that climate change science receives it is essential that climate change ecologists, along with all scientists, design their experiments in order to eliminate potential artifacts as a result of poor experimental design.

Substantial progress has been made in determining the impacts of climate change on marine systems, but several key areas require concerted research effort before marine climate change ecologists can provide the evidence required to inform adaptive management strategies. Studies that investigate the biological responses of individual species to multiple stressors will continue to provide insight into the potential tolerance of species to these changing conditions (Gattuso et al. 2009). However, it is likely that over multiple generations phenotypic plasticity and/or genetic evolution will influence the ability of marine organisms to develop a stress-tolerance (Ferrari et al. 2011). Therefore, areas of natural variable pH and temperature, such as CO2 vent systems (eg. Hall-Spencer et al. 2008) or areas of upwelling (eg. Bakun, 1990), may provide a method of ecosystem validation to investigate whether prolonged exposure to stressors can promote adaptation. Moreover, physiological studies are
needed to investigate the pathways driving the biological responses of marine organisms, in
order to better understand the magnitude, direction and interaction of the effects of multiple
stressors.

Individual species are responding idiosyncratically to anthropogenic climate change, and it is
likely that the temporal and spatial association between species interacting at different trophic
levels will also be affected (Harrington et al. 1999; Walther et al. 2002). Since the
complexity of biotic interactions makes it difficult to extrapolate from single-species studies
to community or ecosystem levels (Walther et al. 2002). Future studies will need to establish
the links between climatic impacts at an individual, population, community and ecosystem
level (Harley, 2006). This can be achieved by increasing both the trophic complexity and
number of stressors, with the aim to scale up to investigations with natural communities and
ecosystems. Such large-scale ecosystem level experiments would not only increase our
knowledge of the functioning and resilience of marine ecosystems, but provide explicit
evidence to policymakers on the effectiveness of conservation and management strategies in
response to climate change.

In conclusion, our findings highlight a complex set of outcomes when the combined effects
of ocean warming and acidification on marine organisms are considered. Specifically, we
established that the magnitude, direction and interaction of the effects of multiple stressors
varies between response type probably as a result of the pathways driving the biological
response. Responses also differ between taxonomic groups, trophic levels and life stages.
Most importantly, in our subset of data we identified ‘ecological surprises’ that were not
found in our broad-scale dataset, reinforcing the need for more robust assessments in this
field. However, two of our responses (photosynthesis and reproduction) did interact in a
predictable manner. Understanding the variation of these additive responses will enable more accurate assessment of the likely outcomes of mitigation measures. Importantly, we must also consider further abiotic and biotic stressors in the marine environment that are likely to also interact with warming and acidification (Halpern et al. 2007). Understanding how multiple stressors will impact and interact on different trophic levels also represents a major challenge in the marine biosciences. Experimental manipulation of multiple stressors will provide a sound scientific basis to inform climate change adaptive management strategies, but more generally will also enhance our understanding of the functioning and resilience of marine ecosystems.

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SUPPORTING INFORMATION

808 Table S1 Experiments included in meta-analysis

810 Table S2 Selection criteria for exclusion from meta-analysis

812 Table S3 Heterogeneity tests – within groups (Q) and between groups (QM)
FIGURE CAPTIONS

Figure 1 The mean effect of ocean acidification (clear circles), ocean warming (grey circles), and combined ocean acidification and warming (black circles) on calcification, growth, photosynthesis, reproduction and survival for different taxonomic groups. The mean log response ratio and ±95% confidence intervals are shown for overall (combined results), calcifiers (calcifying algae, corals, crustaceans, echinoderms, molluscs and phytoplankton) and non-calcifiers (fishes, non-calcified algae, seagrass). The number of observations in each analysis is shown in parentheses. The zero line indicates no effect, and significance (*) of mean effects is determined when the ±95% confidence interval does not overlap zero.

Figure 2 The mean effect of ocean acidification (clear circles), ocean warming (grey circles), and combined ocean acidification and warming (black circles) on growth, photosynthesis and survival for calcifying and non-calcifying organisms. The mean log response ratio and ±95% confidence intervals are shown for calcifiers and non-calcifiers. The number of observations in each analysis is shown in parentheses. The zero line indicates no effect, and significance (*) of mean effects is determined when the ±95% confidence interval does not overlap zero.

Figure 3 The mean effect of ocean acidification (clear circles), ocean warming (grey circles), and combined ocean acidification and warming (black circles) on calcification, growth and survival in different life-stages. The mean log response ratio and ±95% confidence intervals are shown for embryos, larvae, juveniles and adults. The number of observations in each analysis is shown in parentheses. The zero line indicates no effect, and significance (*) of mean effects is determined when the ±95% confidence interval does not overlap zero.
Figure 4 The mean effect of ocean acidification (clear circles), ocean warming (grey circles), and combined ocean acidification and warming (black circles) on calcification, growth, photosynthesis, reproduction and survival for different levels of trophic organisation. The mean log response ratio and ±95% confidence intervals are shown for autotrophs and heterotrophs. The number of observations in each analysis is shown in parentheses. The zero line indicates no effect, and significance (*) of mean effects is determined when the ±95% confidence interval does not overlap zero.

Figure 5 The mean effect of combined ocean warming and acidification as a predicted multiplicative null expectation model (clear circles), and observed responses (filled circles) for different response variables. The mean log response ratio and ±95% confidence intervals are shown for calcification, growth, photosynthesis, reproduction and survival. The number of observations in each analysis is shown in parentheses by the associated response variable. The zero line indicates no effect, significance of mean effects is determined when the ±95% confidence interval does not overlap each other, and each significant response variables is denoted *.
**Calcifiers**

| Mean effect size (lnRR) | Survival | Photosynthesis | Growth |
|-------------------------|----------|----------------|--------|
| -1.8                    | *        |                | (143)  |
| -1.2                    |          |                | (26)   |
| -0.6                    |          |                | (25)   |
| 0                       |          |                |        |
| 0.6                     |          |                |        |
| 1.2                     |          |                |        |

**Non-Calcifiers**

| Mean effect size (lnRR) | Survival | Photosynthesis | Growth |
|-------------------------|----------|----------------|--------|
| -0.6                    |          |                | (35)   |
| -0.4                    |          |                | (16)   |
| -0.2                    | *        |                | (6)    |
| 0                       |          |                |        |
| 0.2                     |          |                |        |
| 0.4                     |          |                |        |
| 0.6                     |          |                |        |
| 0.8                     |          |                |        |

*Significant differences*
Growth

-1.2

Mean effect size (lnRR)

Calcification

Survival

-2.5
ST1 - Experiments included in meta-analysis
Each row represents an individual experiment that was included for meta-analysis. Columns 'B - F' describes the experiment as: the manipulated stressor, taxonomic group, species, trophic level and life-stage. Columns 'G - K' describe the number of times each response (Calcification, growth, photosynthesis, reproduction and survival) was tested.
| Source                        | Manipulation Group | Taxonomic Group        |
|-------------------------------|--------------------|------------------------|
| Aline et al., 2006            | CO2                | Corals                 |
| Anestis et al., 2007          | Temperature       | Molluscs               |
| Anlauf et al., 2011           | CO2                | Corals                 |
| Anlauf et al., 2011           | CO2                | Corals                 |
| Anlauf et al., 2011           | Temperature       | Corals                 |
| Anlauf et al., 2011           | Temperature       | Corals                 |
| Anlauf et al., 2011           | Temperature and CO2| Corals                 |
| Anthony et al., 2008          | CO2                | Corals                 |
| Anthony et al., 2008          | CO2                | Corals                 |
| Anthony et al., 2008          | CO2                | Crustose Coralline Algae|
| Anthony et al., 2008          | Temperature       | Corals                 |
| Anthony et al., 2008          | Temperature       | Corals                 |
| Anthony et al., 2008          | Temperature       | Crustose Coralline Algae|
| Anthony et al., 2008          | Temperature and CO2| Corals                 |
| Anthony et al., 2008          | Temperature and CO2| Corals                 |
| Anthony et al., 2008          | Temperature and CO2| Crustose Coralline Algae|
| Arnold et al., 2009           | CO2                | Crustaceans            |
| Barcelos e Ramos et al., 2010 | CO2                | Phytoplankton          |
| Borchard et al., 2011         | CO2                | Phytoplankton          |
| Borchard et al., 2011         | Temperature and CO2| Phytoplankton          |
| Brennand et al., 2010         | CO2                | Echinoderms            |
| Brennand et al., 2010         | Temperature       | Echinoderms            |
| Brennand et al., 2010         | Temperature and CO2| Echinoderms            |
| Byrne et al., 2009            | CO2                | Echinoderms            |
| Byrne et al., 2009            | CO2                | Echinoderms            |
| Byrne et al., 2009            | Temperature       | Echinoderms            |
| Byrne et al., 2009            | Temperature       | Echinoderms            |
| Byrne et al., 2009            | Temperature and CO2| Echinoderms            |
| Byrne et al., 2009            | Temperature and CO2| Echinoderms            |
| Byrne et al., 2010            | CO2                | Echinoderms            |
| Byrne et al., 2010            | CO2                | Echinoderms            |
| Byrne et al., 2010            | CO2                | Echinoderms            |
| Byrne et al., 2010            | CO2                | Echinoderms            |
| Byrne et al., 2010            | CO2                | Echinoderms            |
| Byrne et al., 2010            | CO2                | Echinoderms            |
| Byrne et al., 2010            | CO2                | Molluscs               |
| Byrne et al., 2010            | Temperature       | Echinoderms            |
| Byrne et al., 2010            | Temperature       | Echinoderms            |
| Byrne et al., 2010            | Temperature       | Echinoderms            |
| Byrne et al., 2010            | Temperature       | Echinoderms            |
| Byrne et al., 2010            | Temperature       | Echinoderms            |
| Byrne et al., 2010            | Temperature       | Echinoderms            |
| Byrne et al., 2010            | Temperature       | Echinoderms            |
| Reference                      | Treatment          | Organism       |
|-------------------------------|--------------------|----------------|
| Byrne et al., 2010            | Temperature        | Molluscs       |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Byrne et al., 2010            | Temperature and CO2| Echinoderms   |
| Catarino et al., 2011         | CO2                | Echinoderms   |
| Chan et al., 2011             | CO2                | Echinoderms   |
| Chen and Gao, 2011            | CO2                | Phytoplankton |
| Christensen et al., 2011      | Temperature        | Echinoderms   |
| Clarke et al., 2009           | CO2                | Echinoderms   |
| Clarke et al., 2009           | CO2                | Echinoderms   |
| Clarke et al., 2009           | CO2                | Echinoderms   |
| Clarke et al., 2009           | CO2                | Echinoderms   |
| Comeau et al., 2009           | CO2                | Molluscs       |
| Comeau et al., 2010           | CO2                | Molluscs       |
| Connell and Russell, 2010     | CO2                | Macroalgae     |
| Connell and Russell, 2010     | Temperature        | Macroalgae     |
| Connell and Russell, 2010     | Temperature and CO2| Macroalgae     |
| Crawley et al., 2010          | CO2                | Corals         |
| Crim et al., 2011             | CO2                | Molluscs       |
| Cullen and Sherrell, 2005     | CO2                | Phytoplankton  |
| de Kluijver et al., 2010      | CO2                | Phytoplankton  |
| Diaz Pulido et al., 2011      | CO2                | Corals         |
| Diaz Pulido et al., 2011      | CO2                | Macroalgae     |
| Donelson et al., 2010         | Temperature        | Fishes         |
| Doo et al., 2011              | CO2                | Echinoderms   |
| Dupont et al., 2008           | CO2                | Echinoderms   |
| Dupont et al., 2010           | CO2                | Echinoderms   |
| Dupont et al., 2010           | CO2                | Echinoderms   |
| Edmunds et al., 2001          | Temperature        | Corals         |
| Edmunds, 2011                 | CO2                | Corals         |
| Engel et al., 2005            | CO2                | Phytoplankton  |
|Epelbaum et al., 2009          | Temperature        | Tunicates      |
|Epelbaum et al., 2009          | Temperature        | Tunicates      |
|Epelbaum et al., 2009          | Temperature        | Tunicates      |
|Feng et al., 2008              | CO2                | Phytoplankton  |
|Feng et al., 2008              | Temperature        | Phytoplankton  |
|Feng et al., 2008              | Temperature and CO2| Phytoplankton  |
|Fernandez et al., 2011         | CO2                | Molluscs       |
|Findlay et al., 2008           | CO2                | Molluscs       |
|Findlay et al., 2008           | Temperature        | Molluscs       |
|Findlay et al., 2008           | Temperature and CO2| Molluscs       |
|Findlay et al., 2009           | CO2                | Crustaceans    |
|Findlay et al., 2009           | CO2                | Crustaceans    |
|Findlay et al., 2010           | CO2                | Crustaceans    |
|Findlay et al., 2010           | CO2                | Crustaceans    |
| Authors and Year | CO2 | Organism | Authors and Year | CO2 | Organism | Authors and Year | CO2 | Organism |
|------------------|-----|----------|------------------|-----|----------|------------------|-----|----------|
| Findlay et al., 2010 | CO2 | Crustaceans | Findlay et al., 2010 | Temperature | Crustaceans |
| Findlay et al., 2010 | Temperature | Crustaceans |
| Findlay et al., 2010 | Temperature | Crustaceans |
| Findlay et al., 2010 | Temperature | Crustaceans |
| Findlay et al., 2010 | Temperature and CO2 | Crustaceans |
| Findlay et al., 2010 | Temperature and CO2 | Crustaceans |
| Findlay et al., 2010 | Temperature and CO2 | Crustaceans |
| Franke and Clemmesen, 2011 | CO2 | Fishes |
| Franke and Clemmesen, 2011 | CO2 | Fishes |
| Fredersdorf et al., 2009 | Temperature | Macroalgae |
| Fredersdorf et al., 2009 | Temperature | Macroalgae |
| Fu et al., 2007 | CO2 | Phytoplankton |
| Fu et al., 2007 | CO2 | Phytoplankton |
| Fu et al., 2007 | Temperature | Phytoplankton |
| Fu et al., 2007 | Temperature | Phytoplankton |
| Fu et al., 2007 | Temperature and CO2 | Phytoplankton |
| Fu et al., 2007 | Temperature and CO2 | Phytoplankton |
| Fu et al., 2008 | CO2 | Phytoplankton |
| Fu et al., 2008 | CO2 | Phytoplankton |
| Fu et al., 2008 | Temperature | Phytoplankton |
| Fu et al., 2008 | Temperature | Phytoplankton |
| Fu et al., 2008 | Temperature and CO2 | Phytoplankton |
| Fu et al., 2008 | Temperature and CO2 | Phytoplankton |
| Gao and Zheng, 2010 | CO2 | Crustose Coralline Algae |
| Garcia et al., 2011 | CO2 | Cyanobacteria |
| Gattuso et al., 1998 | CO2 | Corals |
| Gaylord et al., 2011 | CO2 | Molluscs |
| Gazeau et al., 2011 | CO2 | Molluscs |
| Gazeau et al., 2011 | CO2 | Molluscs |
| Gooding et al., 2009 | CO2 | Echinoderms |
| Gooding et al., 2009 | Temperature | Echinoderms |
| Gooding et al., 2009 | Temperature and CO2 | Echinoderms |
| Grossart et al., 2006 | CO2 | Bacteria |
| Gutow and Franke, 2001 | Temperature | Crustaceans |
| Hauty et al., 2009 | CO2 | Crustaceans |
| Havenhand and Schlegel, 2009 | CO2 | Molluscs |
| Havenhand and Schlegel, 2009 | CO2 | Molluscs |
| Havenhand et al., 2008 | CO2 | Echinoderms |
| Havenhand et al., 2008 | CO2 | Echinoderms |
| Hoffman et al., 2003 | Temperature | Macroalgae |
| Hoffman et al., 2003 | Temperature | Macroalgae |
| Holcomb et al., 2010 | CO2 | Corals |
| Hutchins et al., 2007 | CO2 | Bacteria |
| Iglesias Rodriguez et al., 2008 | CO2 | Phytoplankton |
| Imsland et al., 2007 | Temperature | Fishes |
| Imsland et al., 2007 | Temperature | Fishes |
| Isla et al., 2008 | Temperature | Crustaceans |
| Israel and Hophy, 2002 | CO2 | Macroalgae |
| Israel and Hophy, 2002 | CO2 | Macroalgae |
| Israel and Hophy, 2002 | CO2 | Macroalgae |
| Authors               | Year     | CO2/Other Factors | Organism                           |
|----------------------|----------|-------------------|------------------------------------|
| Israel and Hophy, 2002 |          | CO2               | Macroalgae                         |
| Israel and Hophy, 2002 |          | CO2               | Macroalgae                         |
| Jury et al., 2010    |          | CO2               | Corals                             |
| Kim et al., 2006     |          | CO2               | Phytoplankton                       |
| Kim et al., 2006     |          | CO2               | Phytoplankton                       |
| Koch et al., 2007    | Temperature | CO2               | Seagrass                           |
| Koch et al., 2007    | Temperature | CO2               | Seagrass                           |
| Kranz et al., 2009   |          | CO2               | Bacteria                           |
| Kubler et al., 1999  |          | CO2               | Macroalgae                         |
| Kurihara et al., 2004 |         | CO2               | Echinoderms                        |
| Kurihara et al., 2004 |         | CO2               | Echinoderms                        |
| Kurihara et al., 2004 |         | CO2               | Echinoderms                        |
| Kurihara et al., 2004 |         | CO2               | Echinoderms                        |
| Kurihara et al., 2008 |         | CO2               | Crustaceans                        |
| Langer et al., 2006  |          | CO2               | Phytoplankton                       |
| Leclercq et al., 2000 |         | CO2               | Corals                             |
| Lischka et al., 2011 |         | Temperature       | Molluscs                           |
| Lischka et al., 2011 |         | Temperature and CO2 | Molluscs                         |
| Liu et al., 2008     |          | Temperature       | Cnidarians                         |
| Melzner et al., 2011 | CO2      | Molluscs           |                                    |
| Munday et al., 2009  | CO2      | Temperature       | Molluscs                           |
| O’Connor, 2009       |          | Temperature       | Macroalgae                         |
| Parker et al., 2010  | CO2      | Molluscs           |                                    |
| Parker et al., 2010  | CO2      | Molluscs           |                                    |
| Parker et al., 2010  | CO2      | Molluscs           |                                    |
| Parker et al., 2010  | CO2      | Molluscs           |                                    |
| Parker et al., 2010  | Temperature | Molluscs         |                                    |
| Parker et al., 2010  | Temperature | Molluscs         |                                    |
| Parker et al., 2010  | Temperature | Molluscs         |                                    |
| Parker et al., 2010  | Temperature | Molluscs         |                                    |
| Parker et al., 2010  | Temperature and CO2 | Molluscs |                                    |
| Parker et al., 2010  | Temperature and CO2 | Molluscs |                                    |
| Parker et al., 2010  | Temperature and CO2 | Molluscs |                                    |
| Parker et al., 2010  | Temperature and CO2 | Molluscs |                                    |
| Pistevos et al., 2011 | CO2      | Bryozoans          |                                    |
| Pistevos et al., 2011 | CO2      | Bryozoans          |                                    |
| Pistevos et al., 2011 | Temperature | Bryozoans     |                                    |
| Pistevos et al., 2011 | Temperature | Bryozoans     |                                    |
| Pistevos et al., 2011 | Temperature and CO2 | Bryozoans |                                    |
| Pistevos et al., 2011 | Temperature and CO2 | Bryozoans |                                    |
| Price et al., 2011   | CO2      | Macroalgae        |                                    |
| Price et al., 2011   | CO2      | Macroalgae        |                                    |
| Przeslawski et al., 2005 |         | Temperature       | Molluscs                           |
| Putnam et al., 2008  |          | Temperature       | Corals                             |
| Putnam et al., 2008  |          | Temperature       | Corals                             |
| Riebesell et al., 2000 |         | CO2               | Phytoplankton                       |
| Riebesell et al., 2000 |         | CO2               | Phytoplankton                       |
| Ries et al., 2009    | CO2      | Annelids           |                                    |
| Author(s)                        | Year       | CO2 Type       | Species               |
|---------------------------------|------------|----------------|-----------------------|
| Ries et al., 2009               |            | CO2            | Corals                |
| Ries et al., 2009               |            | CO2            | Crustaceans           |
| Ries et al., 2009               |            | CO2            | Crustaceans           |
| Ries et al., 2009               |            | CO2            | Crustose Coralline Algae |
| Ries et al., 2009               |            | CO2            | Echinoderms           |
| Ries et al., 2009               |            | CO2            | Molluscs              |
| Ries et al., 2009               |            | CO2            | Molluscs              |
| Ries et al., 2009               |            | CO2            | Molluscs              |
| Ries et al., 2009               |            | CO2            | Molluscs              |
| Ries et al., 2010               |            | CO2            | Corals                |
| Rodolfo Metalpa et al., 2010    |            | CO2            | Temperature           |
| Rodolfo Metalpa et al., 2010    |            | Temperature    | Corals                |
| Rodolfo Metalpa et al., 2010    |            | Temperature    | Corals                |
| Roleda et al., 2011             |            | CO2            | Macroalgae            |
| Russell et al., 2009            |            | CO2            | Crustose Coralline Algae |
| Russell et al., 2009            |            | CO2            | Macroalgae            |
| Russell et al., 2011            |            | CO2            | Crustose Coralline Algae |
| Russell et al., 2011            |            | CO2            | Macroalgae            |
| Schmidt et al., 2011            |            | Temperature    | Phytoplankton         |
| Schmidt et al., 2011            |            | Temperature    | Phytoplankton         |
| Schmidt et al., 2011            |            | Temperature    | Phytoplankton         |
| Schram et al., 2011             |            | CO2            | Echinoderms           |
| Sciandrea et al., 2003          |            | CO2            | Phytoplankton         |
| Shirayama and Thornton, 2005    |            | CO2            | Echinoderms           |
| Shirayama and Thornton, 2005    |            | CO2            | Echinoderms           |
| Shirayama and Thornton, 2005    |            | CO2            | Molluscs              |
| Spielmeyer and Pohnert, 2011    |            | CO2            | Phytoplankton         |
| Spielmeyer and Pohnert, 2011    |            | CO2            | Phytoplankton         |
| Spielmeyer and Pohnert, 2011    |            | CO2            | Phytoplankton         |
| Stumpp et al., 2011             |            | CO2            | Echinoderms           |
| Stumpp et al., 2011             |            | CO2            | Echinoderms           |
| Suffrian et al., 2008           |            | CO2            | Cyanobacteria         |
| Suffrian et al., 2008           |            | CO2            | Phytoplankton         |
| Suffrian et al., 2008           |            | CO2            | Phytoplankton         |
| Suffrian et al., 2008           |            | CO2            | Phytoplankton         |
| Suwa et al., 2010               |            | CO2            | Corals                |
| Suwa et al., 2010               |            | CO2            | Corals                |
| Talmage and Gobler, 2009        |            | CO2            | Molluscs              |
| Talmage and Gobler, 2009        |            | CO2            | Molluscs              |
| Talmage and Gobler, 2009        |            | CO2            | Molluscs              |
| Talmage and Gobler, 2011        |            | CO2            | Molluscs              |
| Talmage and Gobler, 2011        |            | CO2            | Molluscs              |
| Authors                          | Parameter     | Organism      |
|---------------------------------|---------------|---------------|
| Talmage and Gobler, 2011         | Temperature   | Molluscs      |
| Talmage and Gobler, 2011         | Temperature   | Molluscs      |
| Talmage and Gobler, 2011         | Temperature   | Molluscs      |
| Talmage and Gobler, 2011         | Temperature   | Molluscs      |
| Talmage and Gobler, 2011         | Temperature   | Molluscs      |
| Talmage and Gobler, 2011         | Temperature and CO2 | Molluscs |
| Talmage and Gobler, 2011         | Temperature and CO2 | Molluscs |
| Talmage and Gobler, 2011         | Temperature and CO2 | Molluscs |
| Thom, 1996                       | CO2           | Seagrass      |
| Thom, 1996                       | CO2           | Seagrass      |
| Thomsen and Melzner, 2010        | CO2           | Molluscs      |
| Tortell et al., 2008             | CO2           | Phytoplankton |
| Vilchis et al., 2005             | Temperature   | Molluscs      |
| Vilchis et al., 2005             | Temperature   | Molluscs      |
| Walther et al., 2010             | CO2           | Crustaceans   |
| Walther et al., 2011             | CO2           | Crustaceans   |
| Wood et al., 2008                | CO2           | Echinoderms   |
| Wood et al., 2009                | CO2           | Echinoderms   |
| Wood et al., 2011                | Temperature   | Echinoderms   |
| Zou, 2005                        | CO2           | Macroalgae    |
| Organism               | Trophic Level | Life Stage | Calcification | Growth | Photosynthesis | Reproduction |
|-----------------------|---------------|------------|---------------|--------|----------------|--------------|
| Porites lobata        | Autotroph     | Adult      |               |        |                |              |
| Mytilus galloprovincialis | Heterotroph | Adult      |               |        |                |              |
| Porites panamensis    | Autotroph     | Adult      |               |        |                |              |
| Porites panamensis    | Autotroph     | Lagvae     | 1             |        |                |              |
| Porites panamensis    | Autotroph     | Lagvae     | 1             |        |                |              |
| Porites panamensis    | Autotroph     | Lagvae     |               |        |                |              |
| Porites panamensis    | Autotroph     | Lagvae     |               |        |                |              |
| Porites panamensis    | Autotroph     | Lagvae     |               |        |                |              |
| Porites panamensis    | Autotroph     | Lagvae     |               |        |                |              |
| Acropora intermedia   | Autotroph     | Adult      | 1 1           |        |                |              |
| Porites lobata        | Autotroph     | Adult      | 1 1           |        |                |              |
| Porolithon onkodes     | Autotroph     | Adult      | 1 1           |        |                |              |
| Acropora intermedia   | Autotroph     | Adult      | 1 1           |        |                |              |
| Porites lobata        | Autotroph     | Adult      | 1 1           |        |                |              |
| Porolithon onkodes     | Autotroph     | Adult      | 1 1           |        |                |              |
| Homarus gammarus       | Heterotroph   | Lagvae     | 12            |        |                |              |
| Emiliania huxleyi     | Autotroph     | Culture    | 2             |        |                |              |
| Emiliania huxleyi     | Autotroph     | Culture    | 2             |        |                |              |
| Emiliania huxleyi     | Autotroph     | Culture    | 1             |        |                |              |
| Tripneustes gratilla  | Heterotroph   | Lagvae     | 2             |        |                |              |
| Tripneustes gratilla  | Heterotroph   | Lagvae     | 1             |        |                |              |
| Tripneustes gratilla  | Heterotroph   | Lagvae     | 2             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Adult      |               |        |                | 2            |
| Heliocidaris erythrogramma | Heterotroph | Embryos    | 2             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Adult      | 1             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Embryos    | 1             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Adult      | 2             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Embryos    | 2             |        |                |              |
| Centrostephanus rodgersii | Heterotroph | Adult      | 1             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Adult      | 1             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Adult      | 4             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Juvenile   | 2             |        |                |              |
| Heliocidaris tuberculata | Heterotroph | Adult      |               |        |                | 2            |
| Patiriella regularis  | Heterotroph   | Adult      | 1             |        |                |              |
| Tripneustes gratilla  | Heterotroph   | Adult      | 2             |        |                |              |
| Haliotis coccoradiata | Heterotroph   | Adult      | 2             |        |                |              |
| Centrostephanus rodgersii | Heterotroph | Adult      | 1             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Adult      | 2             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Adult      | 8             |        |                |              |
| Heliocidaris erythrogramma | Heterotroph | Juvenile   | 2             |        |                |              |
| Heliocidaris tuberculata | Heterotroph | Adult      | 1             |        |                |              |
| Patiriella regularis  | Heterotroph   | Adult      | 2             |        |                |              |
| Tripneustes gratilla  | Heterotroph   | Adult      | 1             |        |                |              |
| Species                          | Life Form         | Stage            | Count |
|---------------------------------|-------------------|------------------|-------|
| Haliotis coccoradiata           | Heterotroph       | Adult            | 2     |
| Centrostephanus rodgersii       | Heterotroph       | Adult            | 1     |
| Heliocidaris erythrogramma      | Heterotroph       | Adult            | 2     |
| Heliocidaris erythrogramma      | Heterotroph       | Adult            | 8     |
| Heliocidaris erythrogramma      | Heterotroph       | Juvenile         | 4     |
| Heliocidaris tuberculata        | Heterotroph       | Adult            | 2     |
| Patiriella regularis            | Heterotroph       | Adult            | 2     |
| Tripneustes gratilla            | Heterotroph       | Adult            | 2     |
| Haliotis coccoradiata           | Heterotroph       | Adult            | 4     |
| Arbacia dufresnei               | Heterotroph       | Larvae           | 1     |
| Dendraster excentricus          | Heterotroph       | Larvae           | 12    |
| Phaeocystis globosa             | Autotroph         | Culture          | 1     |
| Ophionereis schayeri            | Heterotroph       | Adult            |       |
| Evechinus chloroticus           | Heterotroph       | Larvae           | 1     |
| Pseudoechinus huttoni           | Heterotroph       | Larvae           | 1     |
| Stereochinus neumayeri          | Heterotroph       | Larvae           | 1     |
| Tripneustes gratilla            | Heterotroph       | Larvae           | 1     |
| Limacina helicina               | Heterotroph       | Adult            | 1     |
| Cavolinia inflexa               | Heterotroph       | Larvae           | 1     |
| Turf Algae                      | Autotroph         | Adult            | 1     |
| Turf Algae                      | Autotroph         | Adult            | 1     |
| Turf Algae                      | Autotroph         | Adult            | 1     |
| Acropora formosa                | Autotroph         | Adult            | 2     |
| Haliotis kamtschatkana          | Heterotroph       | Larvae           | 1     |
| Natural Assemblage Phytoplankton| Autotroph         | -                | 8     |
| Total phytoplankton             | Autotroph         | Culture          | 2     |
| Acropora intermedia             | Autotroph         | Adult            | 6     |
| Lobophora papenfussii           | Autotroph         | Adult            | 6     |
| Acanthochromis polyacanthus     | Heterotroph       | Adult            | 2     |
| Centrostephanus rodgersii       | Heterotroph       | Larvae           | 2     |
| Ophiothrix fragilis             | Heterotroph       | Larvae           | 12    |
| Crossaster papposus             | Heterotroph       | Juvenile         | 1     |
| Crossaster papposus             | Heterotroph       | Larvae           | 1     |
| Porites astreoides              | Autotroph         | Larvae           | 1     |
| Porites spp.                    | Autotroph         | Adult            | 1     |
| Emiliania huxleyi               | Autotroph         | -                | 2     |
| Botryllis schlosseri            | Heterotroph       | Adult            | 1     |
| Botryllis schlosseri            | Heterotroph       | Juvenile         | 1     |
| Botrylloides violaceus          | Heterotroph       | Juvenile         | 1     |
| Emiliania huxleyi               | Autotroph         | Culture          | 1     |
| Emiliania huxleyi               | Autotroph         | Culture          | 1     |
| Emiliania huxleyi               | Autotroph         | Culture          | 1     |
| Ruditapes decussatus            | Heterotroph       | Juvenile         | 2     |
| Patella vulgata                 | Heterotroph       | Adult            |       |
| Patella vulgata                 | Heterotroph       | Adult            |       |
| Patella vulgata                 | Heterotroph       | Adult            |       |
| Semibalanus balanoides          | Heterotroph       | Adult            |       |
| Semibalanus balanoides          | Heterotroph       | Embryos          | 1     |
| Elminius modestus               | Heterotroph       | Juvenile         | 1     |
| Semibalanus balanoides          | Heterotroph       | Juvenile         | 1     |
| Species                        | Trophic Category | Stage     | Quantity |
|-------------------------------|------------------|-----------|----------|
| Semibalanus balanoides        | Heterotroph      | Juvenile  | 1        |
| Elminius modestus             | Heterotroph      | Juvenile  | 1        |
| Semibalanus balanoides        | Heterotroph      | Juvenile  | 1        |
| Semibalanus balanoides        | Heterotroph      | Juvenile  | 1        |
| Elminius modestus             | Heterotroph      | Juvenile  | 1        |
| Semibalanus balanoides        | Heterotroph      | Juvenile  | 1        |
| Clupea harengus               | Heterotroph      | Adult     | 1        |
| Clupea harengus               | Heterotroph      | Embryos   | 1        |
| Alaria esculenta              | Autotroph        | Adult     | 3        |
| Alaria esculenta              | Autotroph        | Juvenile  | 4        |
| Prochlorococcus               | Autotroph        | Culture   | 1        |
| Synechococcus                 | Autotroph        | Culture   | 1        |
| Prochlorococcus               | Autotroph        | Culture   | 1        |
| Synechococcus                 | Autotroph        | Culture   | 1        |
| Prochlorococcus               | Autotroph        | Culture   | 1        |
| Synechococcus                 | Autotroph        | Culture   | 1        |
| Heterosigma akashiwo          | Autotroph        | Culture   | 1        |
| Prorocentrum minimum          | Autotroph        | Culture   | 1        |
| Heterosigma akashiwo          | Autotroph        | Culture   | 1        |
| Prorocentrum minimum          | Autotroph        | Culture   | 1        |
| Heterosigma akashiwo          | Autotroph        | Culture   | 1        |
| Prorocentrum minimum          | Autotroph        | Culture   | 1        |
| Corallina sessilis            | Autotroph        | Adult     | 1        |
| Trichodesmium erythraeum      | Autotroph        | Culture   | 1        |
| Stylophora pistillata         | Autotroph        | Adult     | 4        |
| Mytilus californianus         | Heterotroph      | Larvae    | 2        |
| Crassostrea gigas             | Heterotroph      | Adult     | 1        |
| Crassostrea gigas             | Heterotroph      | Embryos   | 1        |
| Pisaster ochraceus            | Heterotroph      | Juvenile  | 1        |
| Pisaster ochraceus            | Heterotroph      | Juvenile  | 1        |
| Pisaster ochraceus            | Heterotroph      | Juvenile  | 1        |
| Community                     | Heterotroph      | Culture   | 1        |
| Idotea metallica              | Heterotroph      | Adult     | 2        |
| Gammarus locusta              | Heterotroph      | Adult     | 2        |
| Crassostrea gigas             | Heterotroph      | Adult     | 1        |
| Crassostrea gigas             | Heterotroph      | Larvae    | 1        |
| Heliocidaris erythrogramma    | Heterotroph      | Adult     | 1        |
| Heliocidaris erythrogramma    | Heterotroph      | Larvae    | 1        |
| Alaria marginata              | Autotroph        | Adult     | 1        |
| Fucus gardneri                | Autotroph        | Adult     | 1        |
| Astrangia pociula             | Autotroph        | Adult     | 1        |
| Trichodesmium spp             | Heterotroph      | Culture   | 3        |
| Emilianiia huxleyi            | Autotroph        | Culture   | 3        |
| Gadus Morhua                  | Heterotroph      | Adult     | 1        |
| Gadus Morhua                  | Heterotroph      | Juvenile  | 1        |
| Pseudocalanus sp.             | Heterotroph      | Adult     | 2        |
| Cystoseira sp                 | Autotroph        | Adult     | 1        |
| Enteromorpha linza            | Autotroph        | Adult     | 1        |
| Pterocladia capillaceae       | Autotroph        | Adult     | 1        |
| Species                      | Type          | Stage    | Quantity |
|------------------------------|---------------|----------|----------|
| Sollieria sp.                | Autotroph     | Adult    | 2        |
| Spatoglossum sp.             | Autotroph     | Adult    | 1        |
| Ulva sp.                     | Autotroph     | Adult    | 2        |
| Madracis auretenra           | Autotroph     | Adult    | 1        |
| Nitzschia spp.               | Autotroph     | Community| 1        |
| Skeletonoma costatum         | Autotroph     | Community| 1        |
| Halodule wrightii            | Autotroph     | Adult    | 2        |
| Thalassia testudinum         | Autotroph     | Adult    | 4        |
| Trichodesmium spp            | Heterotroph   | Culture  | 1        |
| Lomentaria articulata        | Autotroph     | Adult    | 1        |
| Echinometra mathaei          | Heterotroph   | Adult    | 1        |
| Echinometra mathaei          | Heterotroph   | Larvae   | 1        |
| Hemicentrotus pulcherreimus  | Heterotroph   | Adult    | 1        |
| Hemicentrotus pulcherreimus  | Heterotroph   | Larvae   | 1        |
| Palaemon pacificus           | Heterotroph   | Adult    | 2        |
| Emiliania huxleyi            | Autotroph     | Culture  | 8        |
| Community                    | Autotroph     | Mixed    | 2        |
| Limacina helicina            | Heterotroph   | Juvenile | 2        |
| Limacina helicina            | Heterotroph   | Juvenile | 2        |
| Limacina helicina            | Heterotroph   | Juvenile | 4        |
| Aurelia aurita               | Heterotroph   | Juvenile |          |
| Mytilis edulis               | Heterotroph   | Adult    | 1        |
| Amphiprion percula           | Heterotroph   | Larvae   | 12       |
| Sargassum filipendula        | Autotroph     | Adult    | 4        |
| Crassostrea gigas            | Heterotroph   | Adult    | 3        |
| Crassostrea gigas            | Heterotroph   | Larvae   | 3        |
| Saccostrea glomerata         | Heterotroph   | Adult    | 3        |
| Saccostrea glomerata         | Heterotroph   | Larvae   | 3        |
| Crassostrea gigas            | Heterotroph   | Adult    | 1        |
| Crassostrea gigas            | Heterotroph   | Larvae   | 1        |
| Saccostrea glomerata         | Heterotroph   | Adult    | 1        |
| Saccostrea glomerata         | Heterotroph   | Larvae   | 1        |
| Crassostrea gigas            | Heterotroph   | Adult    | 3        |
| Crassostrea gigas            | Heterotroph   | Larvae   | 3        |
| Saccostrea glomerata         | Heterotroph   | Adult    | 3        |
| Saccostrea glomerata         | Heterotroph   | Larvae   | 3        |
| Celleporella hyalina         | Heterotroph   | Adult    | 1        |
| Celleporella hyalina         | Heterotroph   | Larvae   | 1        |
| Celleporella hyalina         | Heterotroph   | Adult    | 1        |
| Celleporella hyalina         | Heterotroph   | Larvae   | 1        |
| Celleporella hyalina         | Heterotroph   | Adult    | 1        |
| Celleporella hyalina         | Heterotroph   | Larvae   | 1        |
| Celleporella hyalina         | Heterotroph   | Adult    | 1        |
| Halimeda opuntia             | Autotroph     | Adult    | 1        |
| Halimeda taenicola           | Autotroph     | Adult    | 1        |
| Bembicium nanum              | Heterotroph   | Embryos  |          |
| Stylophora pistillata        | Autotroph     | Adult    | 1        |
| Stylophora pistillata        | Autotroph     | Larvae   | 1        |
| Emiliania huxleyi            | Autotroph     | Culture  | 2        |
| Gephyrocapsa oceanica        | Autotroph     | Culture  | 2        |
| Hydroides crucigera          | Heterotroph   | Adult    | 2        |
| Species                        | Trophic State | Life Stage | Quantity |
|-------------------------------|---------------|------------|----------|
| *Oculina arbuscula*           | Autotroph     | Adult      | 2        |
| *Callinectes sapidus*         | Heterotroph   | Adult      | 2        |
| *Homarus americanus*          | Heterotroph   | Adult      | 2        |
| *Penaeus plebejus*            | Heterotroph   | Adult      | 2        |
| *Halimeda incrassata*         | Autotroph     | Adult      | 2        |
| *Neogoniolithon sp.*          | Autotroph     | Adult      | 2        |
| *Arbacia punctulata*          | Heterotroph   | Adult      | 2        |
| *Eucidaris tribuloides*       | Heterotroph   | Adult      | 2        |
| *Argopecten irradians*        | Heterotroph   | Adult      | 2        |
| *Crassostrea virginica*       | Heterotroph   | Adult      | 2        |
| *Crepidula fornicata*         | Heterotroph   | Adult      | 2        |
| *Littorina littorea*           | Heterotroph   | Adult      | 2        |
| *Mercenaria mercenaria*       | Heterotroph   | Adult      | 2        |
| *Mya arenaria*                | Heterotroph   | Adult      | 2        |
| *Mytilus edulis*              | Heterotroph   | Adult      | 2        |
| *Strombus alatus*             | Heterotroph   | Adult      | 2        |
| *Urosalpinx cinerea*          | Heterotroph   | Adult      | 2        |
| *Oculina arbuscula*           | Autotroph     | Adult      | 4        |
| *Cladocora caespitosa*        | Autotroph     | Adult      | 2        |
| *Cladocora caespitosa*        | Autotroph     | Adult      | 2        |
| *Cladocora caespitosa*        | Autotroph     | Adult      | 2        |
| *Macroystus pyrifer*          | Autotroph     | Adult      | 1        |
| *Lithophyllum sp.*            | Autotroph     | Adult      | 1        |
| *Feldmannia spp.*             | Autotroph     | Adult      | 1        |
| *Lithophyllum sp.*            | Autotroph     | Adult      | 1        |
| *Feldmannia spp.*             | Autotroph     | Adult      | 1        |
| *Amphistegina radiata*        | Autotroph     | Adult      | 2        |
| *Calcarina hispida*           | Autotroph     | Adult      | 1        |
| *Heterostegina depressa*      | Autotroph     | Adult      | 1        |
| *Luidia clathrata*            | Heterotroph   | Adult      | 1        |
| *Emiliania huxleyi*           | Autotroph     | Culture    | 1        |
| *Echinometra mathaei*         | Heterotroph   | Juvenile   | 1        |
| *Hemicentrotus pulcherrimus*  | Heterotroph   | Juvenile   | 1        |
| *Strombus luhuanus*           | Heterotroph   | Juvenile   | 1        |
| *Emiliania huxleyi*           | Autotroph     | Culture    | 2        |
| *Phaeodactylum tricornutum*   | Autotroph     | Culture    | 1        |
| *Thalassiosira pseudonana*    | Autotroph     | Culture    | 1        |
| *Strongylometrotus purpuratus*| Heterotroph   | Embryos    | 1        |
| *Strongylometrotus purpuratus*| Heterotroph   | Larvae     | 1        |
| *Cyanobacteria*               | Autotroph     | Culture    | 2        |
| *Diatoms*                     | Autotroph     | Culture    | 2        |
| *Dinoflagellates*             | Autotroph     | Culture    | 2        |
| *Prymnesiophytes*             | Autotroph     | Culture    | 2        |
| *Acropora digitifera*         | Autotroph     | Larvae     | 1        |
| *Acropora tenuis*             | Autotroph     | Larvae     | 1        |
| *Argopecten irradians*        | Heterotroph   | Larvae     | 1        |
| *Crassostrea virginica*       | Heterotroph   | Larvae     | 1        |
| *Mercenaria mercenaria*       | Heterotroph   | Larvae     | 1        |
| *Argopecten irradians*        | Heterotroph   | Larvae     | 1        |
| *Mercenaria mercenaria*       | Heterotroph   | Larvae     | 1        |
| Species                        | Trophic Type | Life Stage | Count |
|-------------------------------|--------------|------------|-------|
| Argopecten irradians          | Heterotroph  | Juvenile   | 1     |
| Argopecten irradians          | Heterotroph  | Larvae     | 1     |
| Crassostrea virginica         | Heterotroph  | Juvenile   | 1     |
| Mercenaria mercenaria         | Heterotroph  | Juvenile   | 1     |
| Mercenaria mercenaria         | Heterotroph  | Larvae     | 1     |
| Argopecten irradians          | Heterotroph  | Juvenile   | 1     |
| Argopecten irradians          | Heterotroph  | Larvae     | 1     |
| Mercenaria mercenaria         | Heterotroph  | Larvae     | 1     |
| Nereocystis luetkeana         | Autotroph    | Adult      | 4     |
| Zostera marina                | Autotroph    | Adult      | 3     |
| Mytilus edulis                | Heterotroph  | Adult      | 2     |
| **Phytoplankton Assemblage**  |              |            |       |
| Haliotis fulgens              | Heterotroph  | Adult      | 1     |
| Haliotis rufescens            | Heterotroph  | Adult      | 1     |
| Hyas araneus                  | Heterotroph  | Larvae     | 3     |
| Hyas araneus                  | Heterotroph  | Larvae     | 4     |
| Amphiura filiformis           | Heterotroph  | Adult      | 1     |
| Amphiura filiformis           | Heterotroph  | Adult      |       |
| Ophiocten sericeum            | Heterotroph  | Adult      | 1     |
| Hizikia fusiforme             | Autotroph    | Adult      | 1     |
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ST2 - Selection criteria for exclusion in meta-analysis

Each row represents an individual observation that was omitted from subsequent analysis. Therefore, some studies may include a number of observations, in which some are included (and listed within ST1) and some are omitted. Columns 'B - F' describes the experiment as: the manipulated stressor, response, taxonomic group, species and life-stage. Columns 'G - L' describe the reason that particular experiment did not meet the criteria. Stressor Level describes when either the CO2/pH or temperature manipulation was greater than the IPCC 2100 predictions (i.e. >0.5 pH reduction, >1300ppm CO2, or >5 °C increase). Response indicates that the particular response variable of that experiment did not have a sufficient number to be quantitatively assessed. Fieldwork indicates that the experiment was carried out in the field and therefore omitted because of possible confounding factors. No Variance highlights that either the study did not provide a form of uncertainty (either standard deviation, standard error or confidence interval) or that the study only had 1 replicate. Carbonate Chemistry indicates that the carbonate chemistry of the experiment was manipulated using an HCL Addition rather than manipulating the DIC. Other reason highlights a reason that the experiment was omitted that did not fall into one of the preceding categories.
Source | Manipulation Group
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Albright et al., 2008, Coral Reefs, 27:485–490 | CO2
Anestis et al., 2007, Am. J. Physiol-Reg. I., 293:R911-21 | Temperature
Anthony et al., 2008, Proc. Nat. Acad. Sci., 105:17442-6 | Temperature and CO2
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Brennand et al., 2010, Plos One, 5:e11372 | Temperature
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| Response | Taxonomic Group |
|----------|----------------|
| Growth   | Corals         |
| Survival | Corals         |
| Survival | Molluscs       |
| Photosynthesis | Corals    |
| Photosynthesis | Corals    |
| Photosynthesis | Crustose Coralline Algae |
| Bleaching | Corals         |
| Bleaching | Corals         |
| Bleaching | Crustose Coralline Algae |
| Calcification | Corals      |
| Calcification | Corals      |
| Calcification | Crustose Coralline Algae |
| Photosynthesis | Corals   |
| Photosynthesis | Corals   |
| Photosynthesis | Crustose Coralline Algae |
| Bleaching | Corals         |
| Bleaching | Corals         |
| Bleaching | Crustose Coralline Algae |
| Bleaching | Corals         |
| Bleaching | Corals         |
| Bleaching | Crustose Coralline Algae |
| Calcification | Corals   |
| Calcification | Corals   |
| Calcification | Crustose Coralline Algae |
| Photosynthesis | Corals  |
| Photosynthesis | Corals  |
| Photosynthesis | Crustose Coralline Algae |
| Growth   | Phytoplankton  |
| Photosynthesis | Phytoplankton |
| Fitness  | Annelids       |
| Fitness  | Annelids       |
| Growth   | Annelids       |
| Growth   | Annelids       |
| Survival | Annelids       |
| Survival | Annelids       |
| Fitness  | Molluscs       |
| Fitness  | Molluscs       |
| Growth   | Molluscs       |
| Growth   | Molluscs       |
| Fitness  | Molluscs       |
| Growth   | Molluscs       |
| Survival | Molluscs       |
| Survival | Echinoderms    |
| Survival | Echinoderms    |
| Metric          | Organism   |
|----------------|------------|
| Survival       | Crustaceans|
| Biodiversity   | Phytoplankton|
| Survival       | Corals     |
| Growth         | Corals     |
| Calcification  | Phytoplankton|
| Calcification  | Phytoplankton|
| Calcification  | Phytoplankton|
| Fitness        | Echinoderms|
| Fitness        | Echinoderms|
| Abundance      | Echinoderms|
| Development    | Crustaceans|
| Reproduction   | Crustaceans|
| Abundance      | Seagrass   |
| Development    | Molluscs   |
| Reproduction   | Molluscs   |
| Growth         | Tunicates  |
| Growth         | Tunicates  |
| Survival       | Tunicates  |
| Survival       | Tunicates  |
| Photosynthesis | Corals     |
| Survival       | Corals     |
| Feeding        | Molluscs   |
| Fitness        | Molluscs   |
| Feeding        | Fishes     |
| Interaction Strength | Fishes |
| Survival       | Fishes     |
| Survival       | Fishes     |
| Survival       | Fishes     |
| Survival       | Fishes     |
| Survival       | Crustaceans|
| Survival       | Crustaceans|
| Survival       | Crustaceans|
| Survival       | Crustaceans|
| Survival       | Crustaceans|
| Survival       | Crustaceans|
| Development    | Crustaceans|
| Calcification  | Crustaceans|
| Growth         | Crustaceans|
| Survival       | Crustaceans|
| Calcification  | Crustaceans|
| Growth         | Crustaceans|
| Survival       | Crustaceans|
| Calcification  | Corals     |
| Growth         | Fishes     |
| Reproduction   | Fishes     |
| Survival       | Fishes     |
| Photosynthesis | Macroalgae|
| Reproduction   | Macroalgae|
| Reproduction   | Fishes     |
Growth Phytoplankton
Growth Phytoplankton
Calcification Corals
Calcification Molluscs
Calcification Molluscs
Growth Molluscs
Reproduction Molluscs
Feeding Echinoderms
Feeding Echinoderms
Feeding Echinoderms
Abundance Bacteria
Development Crustaceans
Reproduction Crustaceans
Abundance Annelids
Abundance Arthropods
Abundance Community
Abundance Echinoderms
Abundance Molluscs
Biodiversity Annelids
Biodiversity Arthropods
Biodiversity Community
Biodiversity Molluscs
Abundance Annelids
Abundance Arthropods
Abundance Community
Abundance Echinoderms
Abundance Molluscs
Biodiversity Annelids
Biodiversity Arthropods
Biodiversity Community
Biodiversity Molluscs
Abundance Annelids
Abundance Arthropods
Abundance Community
Abundance Echinoderms
Abundance Molluscs
Fitness Molluscs
Abundance Phytoplankton
Photosynthesis Phytoplankton
Abundance Phytoplankton
Photosynthesis Phytoplankton
Abundance Phytoplankton
Photosynthesis Phytoplankton
Feeding Molluscs
Feeding Molluscs
| Category   | Species                      |
|------------|------------------------------|
| Fitness    | Molluscs                     |
| Growth     | Molluscs                     |
| Growth     | Molluscs                     |
| Survival   | Molluscs                     |
| Survival   | Molluscs                     |
| Survival   | Crustaceans                  |
| Reproduction | Macroalgae                |
| Survival   | Macroalgae                  |
| Symbionts  | Corals                       |
| Symbionts  | Corals                       |
| Symbionts  | Corals                       |
| Symbionts  | Corals                       |
| Symbionts  | Corals                       |
| Growth     | Phytoplankton                |
| Growth     | Phytoplankton                |
| Growth     | Phytoplankton                |
| Growth     | Fishes                       |
| Growth     | Fishes                       |
| Reproduction | Crustaceans              |
| Reproduction | Crustaceans              |
| Fitness    | Crustaceans                  |
| Reproduction | Crustaceans              |
| Growth     | Macroalgae                   |
| Growth     | Macroalgae                   |
| Growth     | Macroalgae                   |
| Growth     | Macroalgae                   |
| Growth     | Macroalgae                   |
| Growth     | Macroalgae                   |
| Growth     | Macroalgae                   |
| Reproduction | Crustaceans              |
| Survival   | Crustaceans                  |
| Abundance  | Crustose Coralline Algae     |
| Abundance  | Macroalgae                   |
| Abundance  | Molluscs                     |
| Abundance  | Molluscs                     |
| Calcification | Corals                       |
| Growth     | Corals                       |
| Growth     | Corals                       |
| Growth     | Crustaceans                  |
| Growth     | Crustose Coralline Algae     |
| Reproduction | Corals                       |
| Reproduction | Corals                       |
| Abundance  | Seagrass                     |
| Abundance  | Seagrass                     |
| Growth     | Seagrass                     |
| Photosynthesis | Seagrass                 |
| Photosynthesis | Seagrass                 |
| Abundance  | Annelids                     |
| Abundance  | Crustaceans                  |
Abundance Crustaceans
Abundance Crustaceans
Abundance Crustaceans
Abundance Molluscs
Abundance Molluscs
Growth Macroalgae
Growth Crustose Coralline Algae
Growth Macroalgae
Reproduction Crustose Coralline Algae
Reproduction Echinoderms
Reproduction Echinoderms
Calcification Molluscs
Growth Molluscs
Growth Molluscs
Feeding Crustaceans
Growth Crustaceans
Growth Phytoplankton
Calcification Corals
Photosynthesis Corals
Calcification Phytoplankton
Calcification Phytoplankton
Photosynthesis Phytoplankton
Photosynthesis Phytoplankton
Fitness Molluscs
Fitness Molluscs
Fitness Molluscs
Reproduction Cnidarians
Survival Cnidarians
Calcification Corals
Calcification Crustose Coralline Algae
Calcification Crustose Coralline Algae
Calcification Crustose Coralline Algae
Calcification Crustose Coralline Algae
Calcification Crustose Coralline Algae
Calcification Corals
Calcification Corals
Calcification Corals
Calcification Corals
Calcification Corals
Growth Crustaceans
Growth Crustaceans
Reproduction Crustaceans
Growth Molluscs
Growth Molluscs
Fitness Fishes
Fitness Fishes
Fitness Fishes
Fitness Fishes
Fitness Fishes
Fitness Fishes
Fitness Fishes
Fitness Crustaceans
Interaction Strength Crustaceans
Growth Molluscs
Reproduction Molluscs
Growth Molluscs
Reproduction Molluscs
Growth Molluscs
Reproduction Molluscs
Growth Molluscs
Reproduction Molluscs
Growth Molluscs
Reproduction Molluscs
Growth Molluscs
Reproduction Molluscs
Growth Bryozoans
Reproduction Bryozoans
Growth Bryozoans
Reproduction Bryozoans
Growth Bryozoans
Reproduction Bryozoans
- Macroalgae
Fitness Molluscs
Fitness Molluscs
Fitness Molluscs
Survival Molluscs
Survival Molluscs
Survival Molluscs
Growth Corals
Calcification Corals
Photosynthesis Corals
Calcification Corals
Photosynthesis Corals
Calcification Annelids
Calcification Corals
Calcification Crustaceans
Calcification Crustaceans
Calcification Crustaceans
Calcification Crustose Coralline Algae
Calcification Crustose Coralline Algae
Calcification Echinoderms
| Process         | Organism               |
|-----------------|------------------------|
| Calcification   | Echinoderms            |
| Calcification   | Molluscs               |
| Calcification   | Molluscs               |
| Calcification   | Molluscs               |
| Calcification   | Molluscs               |
| Calcification   | Molluscs               |
| Calcification   | Molluscs               |
| Calcification   | Corals                 |
| Calcification   | Corals                 |
| Calcification   | Bryozoaans             |
| Calcification   | Corals                 |
| Calcification   | Corals                 |
| Growth          | Molluscs               |
| Calcification   | Corals                 |
| Calcification   | Corals                 |
| Calcification   | Corals                 |
| Photosynthesis  | Corals                 |
| Growth          | Phytoplankton          |
| Reproduction    | Macroalgae             |
| Feeding         | Echinoderms            |
| Growth          | Molluscs               |
| Abundance       | -                      |
| Biodiversity    | -                      |
| Fitness         | Phytoplankton          |
| Fitness         | Phytoplankton          |
| Photosynthesis  | Phytoplankton          |
| Photosynthesis  | Phytoplankton          |
| Photosynthesis  | Phytoplankton          |
| Photosynthesis  | Corals                 |
| Photosynthesis  | Corals                 |
| Photosynthesis  | Corals                 |
| Photosynthesis  | Phytoplankton          |
| Survival        | Echinoderms            |
| Survival        | Echinoderms            |
| Survival        | Molluscs               |
| Abundance       | Phytoplankton          |
| Growth          | Phytoplankton          |
| Growth          | Phytoplankton          |
| Growth          | Phytoplankton          |
| Growth          | Phytoplankton          |
| Growth          | Phytoplankton          |
| Growth          | Phytoplankton          |
| Fitness         | -                      |
| Abundance       | Phytoplankton          |
| Growth          | Corals                 |
| Survival | Corals |
|----------|--------|
| Growth   | Macroalgae |
| Growth   | Macroalgae |
| Survival | Molluscs |
| Growth   | Molluscs |
| Growth   | Molluscs |
| Growth   | Molluscs |
| Survival | Molluscs |
| Growth   | Molluscs |
| Growth   | Molluscs |
| Growth   | Molluscs |
| Survival | Molluscs |
| Growth   | Molluscs |
| Growth   | Molluscs |
| Growth   | Molluscs |
| Fitness  | 0      |
| Photosynthesis | Seagrass |
| Growth   | Molluscs |
| Calcification | Corals |
| Reproduction | Molluscs |
| Calcification | Molluscs |
| Development | Crustaceans |
| Growth   | Crustaceans |
| Development | Crustaceans |
| Growth   | Crustaceans |
| Development | Crustaceans |
| Growth   | Crustaceans |
| Calcification | Crustaceans |
| Calcification | Crustaceans |
| Calcification | Crustaceans |
| Survival  | Cnidarians |
| Survival  | Cnidarians |
| Survival  | Cnidarians |
| Calcification | Echinoderms |
| Growth   | Echinoderms |
| Survival  | Echinoderms |
| Fitness   | Echinoderms |
| Growth   | Echinoderms |
| Fitness   | Echinoderms |
| Growth   | Echinoderms |
| Calcification | Corals |
| Abundance | -      |
| Calcification | Phytoplankton |
| Calcification | Phytoplankton |
| Growth   | Phytoplankton |
| Growth  | Phytoplankton |
|---------|---------------|
| Growth  | Seagrass      |
| Photosynthesis | Seagrass |
| Calcification | Phytoplankton |
| Growth  | Phytoplankton |
| Organism                  | Life Stage | Stressor Level | Other Response |
|--------------------------|------------|----------------|----------------|
| Porites astreoides      | Larvae     |                |                |
| Porites astreoides      | Larvae     |                |                |
| Mytilus galloprovincialis | Adult    |                |                |
| Acropora intermedia     | Adult      |                |                |
| Porites lobata          | Adult      |                |                |
| Porolithon onkodes      | Adult      |                |                |
| Porolithon onkodes      | Adult      |                |                |
| Acropora intermedia     | Adult      |                |                |
| Porites lobata          | Adult      |                |                |
| Porolithon onkodes      | Adult      |                |                |
| Porolithon onkodes      | Adult      |                |                |
| Acropora intermedia     | Adult      |                |                |
| Porites lobata          | Adult      |                |                |
| Porolithon onkodes      | Adult      |                |                |
| Acropora intermedia     | Adult      |                |                |
| Porites lobata          | Adult      |                |                |
| Porolithon onkodes      | Adult      |                |                |
| Acropora intermedia     | Adult      |                |                |
| Porites lobata          | Adult      |                |                |
| Porolithon onkodes      | Adult      |                |                |
| Acropora intermedia     | Adult      |                |                |
| Porites lobata          | Adult      |                |                |
| Nereis virens           | Adult      |                |                |
| Nereis virens           | Adult      |                |                |
| Nereis virens           | Adult      |                |                |
| Nereis virens           | Juvenile   |                |                |
| Nereis virens           | Adult      |                |                |
| Nereis virens           | Adult      |                |                |
| Crassostrea gigas       | Adult      |                |                |
| Crassostrea gigas       | Juvenile   |                |                |
| Crassostrea gigas       | Juvenile   |                |                |
| Mytilus edulis          | Adult      |                |                |
| Littorina littorea      | Adult      |                |                |
| Littorina littorea      | Adult      |                |                |
| Littorina littorea      | Adult      |                |                |
| Tripneustes gratilla    | Larvae     |                |                |
| Tripneustes gratilla    | Larvae     |                |                |
| Species                          | Form       |
|---------------------------------|------------|
| Phaeodactylum tricornutum       | Culture    |
| Thalassiosira weissflogii       | Culture    |
| Heliocidaris erythrogramma      | Adult      |
| Heliocidaris erythrogramma      | Adult      |
| Heliocidaris erythrogramma      | Embryos    |
| Heliocidaris erythrogramma      | Adult      |
| Heliocidaris erythrogramma      | Embryos    |
| Heliocidaris tuberculata        | Adult      |
| Patiriella regularis            | Adult      |
| Tripneustes gratilla           | Adult      |
| Haliotis coccoradiata           | Adult      |
| Centrostephanus rodgersii      | Adult      |
| Heliocidaris tuberculata        | Adult      |
| Tripneustes gratilla           | Adult      |
| Centrostephanus rodgersii      | Adult      |
| Heliocidaris erythrogramma      | Adult      |
| Heliocidaris tuberculata        | Adult      |
| Patiriella regularis            | Adult      |
| Tripneustes gratilla           | Adult      |
| Haliotis coccoradiata           | Adult      |
| Heliocidaris tuberculata        | Adult      |
| Delisea pulchra                 | Adult      |
| Arbacia dufresnei               | Larvae     |
| Arbacia dufresnei               | Larvae     |
| Dendraster excentricus          | Larvae     |
| Acropora muricata               | Adult      |
| Ophionereis schayeri            | Adult      |
| Ophionereis schayeri            | Adult      |
| Ophionereis schayeri            | Adult      |
| Evechinus chloroticus           | Larvae     |
| Pseudoechinus huttoni           | Larvae     |
| Sterechinus neumayeri           | Larvae     |
| Tripneustes gratilla            | Larvae     |
| Favia fragum                    | Juvenile   |
| Chlamydomonas reinhardtii       | -          |
| Cavolinia inflexa               | Larvae     |
| Turf Algae                      | Adult      |
| Turf Algae                      | Adult      |
| Turf Algae                      | Adult      |
| Haliotis kamtschatkana          | Larvae     |
| Haliotis kamtschatkana          | Larvae     |
| Pseudochromis fuscus            | Adult      |
| Pseudochromis fuscus            | Adult      |
| Pseudochromis fuscus            | Adult      |
| Nematode community              | Adult      |
| Nematode community              | Adult      |
| Pagurus bernhardus              | Adult      |
| Species                        | Life Cycle | Notes |
|-------------------------------|------------|-------|
| Pagurus bernhardus            | Adult      |       |
| Acropora intermedia           | Adult      |       |
| Ammonia tepida                | Culture    |       |
| Ammonia tepida                | Culture    |       |
| Centrostephanus rodgersii     | Larvae     |       |
| Echinogammarus marinus        | Embryos    | *     |
| Zostera marina                | Adult      |       |
| Littorina obtusata            | Embryos    |       |
| Littorina obtusata            | Adult      |       |
| Botryllis schlosseri          | Juvenile   |       |
| Botrylloides violaceus        | Juvenile   |       |
| Botryllis schlosseri          | Juvenile   |       |
| Botrylloides violaceus        | Juvenile   |       |
| Turbinaria mesenterina        | Adult      |       |
| Turbinaria mesenterina        | Adult      |       |
| Ruditapes decussatus          | Juvenile   |       |
| Pseudochromis fuscus          | Adult      |       |
| Pomacentrus amboinensis       | Juvenile   |       |
| Pomacentrus chrysurus         | Juvenile   |       |
| Pomacentrus moluccensis       | Juvenile   |       |
| Pomacentrus nagasakiensis     | Juvenile   |       |
| Elminius modestus             | Adult      |       |
| Semibalanus balanoides        | Adult      |       |
| Semibalanus balanoides        | Juvenile   |       |
| Semibalanus balanoides        | Juvenile   |       |
| Semibalanus balanoides        | Juvenile   |       |
| Semibalanus balanoides        | Juvenile   |       |
| Semibalanus balanoides        | Juvenile   |       |
| Semibalanus balanoides        | Juvenile   |       |
| Oculina patagonica            | Adult      |       |
| Clupea harengus               | Embryos    |       |
| Clupea harengus               | Adult      |       |
| Alaria esculenta              | Juvenile   |       |
| Alaria esculenta              | Adult      |       |
| Gadus Morhua                  | Adult      |       |
| Species / Assemblage        | Stage   |
|----------------------------|---------|
| Heterosigma akashiwo       | Culture |
| Prorocentrum minimum       | Culture |
| Acropora sp                | Adult   |
| Crassostrea gigas          | Adult   |
| Mytilus edulis             | Adult   |
| Crassostrea gigas          | Embryos |
| Crassostrea gigas          | Adult   |
| Pisaster ochraceus         | Juvenile*|
| Pisaster ochraceus         | Juvenile*|
| Pisaster ochraceus         | Juvenile*|
| Community                  | Culture |
| Idotea metallica           | Adult   |
| Idotea metallica           | Adult   |
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Community                  | Community*|
| Acosta excavata            | Adult   |
| Phytoplankton Assemblage   | -       |
| Phytoplankton Assemblage   | -       |
| Phytoplankton Assemblage   | -       |
| Phytoplankton Assemblage   | -       |
| Phytoplankton Assemblage   | -       |
| Haliotis laevigata         | Juvenile*|
| Haliotis rubra             | Juvenile*|
| Species                        | Life Stage | Notes |
|-------------------------------|------------|-------|
| Haliotis laevigata            | Juvenile   | *     |
| Haliotis laevigata            | Juvenile   | *     |
| Haliotis rubra                | Juvenile   | *     |
| Haliotis laevigata            | Juvenile   | *     |
| Haliotis rubra                | Juvenile   | *     |
| Gammarus locusta              | Adult      |       |
| Fucus gardneri                | Adult      | *     |
| Fucus gardneri                | Adult      | *     |
| Pavona clavus                 | Adult      | *     |
| Pavona gigantea               | Adult      | *     |
| Pocillopora damicornis        | Adult      | *     |
| Pocillopora elegans           | Adult      | *     |
| Porites lobata                | Adult      | *     |
| Emiliania huxleyi             | Culture    |       |
| Emiliania huxleyi             | Culture    |       |
| Emiliania huxleyi             | Culture    |       |
| Gadus Morhua                  | Adult      | *     |
| Gadus Morhua                  | Juvenile   | *     |
| Pseudocalanus sp.             | Adult      |       |
| Pseudocalanus sp.             | Adult      |       |
| Pseudocalanus sp.             | Adult      | *     |
| Enteromorpha linza            | Adult      | *     |
| Hypnea cornuta                | Adult      | *     |
| Hypnea musciformis            | Adult      | *     |
| Padina pavonia                | Adult      | *     |
| Porphyra sp.                  | Adult      | *     |
| Pterocladia cappillacea       | Adult      | *     |
| Sargassum vulgare             | Adult      | *     |
| Ulva sp.                      | Adult      | *     |
| Monoporeia affinis            | Adult      | *     |
| Monoporeia affinis            | Adult      | *     |
| Lithophyllum, pallescens, Hydrolithon sp., Porolithon sp. | Community |
| Turf Algae                    | Community  |       |
| Dendrostrea sandwichensis     | Community  |       |
| Serpulorbis sp.               | Community  |       |
| Montipora capitata            | Community  |       |
| Montipora capitata            | Community  |       |
| Pocillopora damicornis        | Juvenile   |       |
| Balanus sp.                   | Community  |       |
| Lithophyllum, pallescens, Hydrolithon sp., Porolithon sp. | Community |
| Montipora capitata            | Community  |       |
| Pocillopora damicornis        | Adult      |       |
| Halodule wrightii             | Adult      | *     |
| Thalassia testudinum          | Adult      | *     |
| Thalassia testudinum          | Adult      | *     |
| Halodule wrightii             | Adult      | *     |
| Thalassia testudinum          | Adult      | *     |
| Polychaetes                   | Community  | *     |
| Amphipods                     | Community  |       |
| Decapods Community | Isopods Community | Tanaids Community | Bivalves Community | Gastropods Community |
|--------------------|-------------------|-------------------|--------------------|----------------------|
| Lomentaria articulata Adult | Porolithon gardineri Community | Non-calcifying algae Community | Porolithon gardineri Community | Echinometra mathaei Adult |
| Hemicentrotus pulcherrimus Adult | Crassostrea gigas Adult | Crassostrea gigas Adult | Mytilus galloprovencialis Embryos | Palæmon pacificus Adult |
| Palæmon pacificus Adult | Marginopora kudakajimensis Culture | Porites compressa, Montipora verucosa Adult | Porites compressa, Montipora verucosa Adult | Calcidiscus leptoporus Culture |
| Coccolithus pelagicus Culture | Calcicidiscus leptoporus Culture | Coccolithus pelagicus Culture | Limacina helicina Juvenile | Aurelia aurita Adult |
| Limacina helicina Juvenile | Limacina helicina Juvenile | Limacina helicina Juvenile | Aurelia aurita Juvenile | Lophelia pertusa Adult |
| Aurelia aurita Juvenile | Lithophyllum cabiocularis Adult | Lithophyllum cabiocularis Adult | Lithophyllum cabiocularis Adult | Lithophyllum cabiocularis Adult |
| Lithophyllum cabiocularis Adult | Lithophyllum cabiocularis Adult | Lithophyllum cabiocularis Adult | Lithophyllum cabiocularis Adult | Lithophyllum cabiocularis Adult |
| Lithophyllum cabiocularis Adult | Porites compressa Adult | Porites compressa Adult | Porites compressa Adult | Acropora verweyi Adult |
| Porites compressa Adult | Porites compressa Adult | Acropora verweyi Adult | Galaxea fascicularia | Pavona cactus Adult |
| Acropora verweyi Adult | Galaxea fascicularia Adult | Pavona cactus Adult | Turbinaria reniformis Adult | Amphibalanus amphitrite Juvenile |
| Pavona cactus Adult | Turbinaria reniformis Adult | Turbinaria reniformis Adult | Amphibalanus amphitrite Larvae | Amphibalanus amphitrite Adult |
| Turbinaria reniformis Adult | Amphibalanus amphitrite Adult | Mytilus edulis Adult | Mytilus galloprovencialis Juvenile | Mytilus edulis Adult |
| Mytilus galloprovencialis Juvenile | Mytilus edulis Adult | Mytilus edulis Adult | Mytilus edulis Adult | Mytilus edulis Adult |
| Mytilus edulis Juvenile | Mytilus edulis Juvenile | Mytilus edulis Juvenile | Mytilus edulis Juvenile | Mytilus edulis Juvenile |
| Ostorhinchus cyanosoma Adult | Ostorhinchus cyanosoma Adult | Ostorhinchus cyanosoma Adult | Ostorhinchus cyanosoma Adult | Ostorhinchus cyanosoma Adult |
| Ostorhinchus doederleini Adult | Ostorhinchus doederleini Adult | Ostorhinchus doederleini Adult | Ostorhinchus doederleini Adult | Ostorhinchus doederleini Adult |
Ostorhinchus cyanosoma  
Adult  

Ostorhinchus doederleini  
Adult  

Ampithoe longimana  
Adult  

Ampithoe longimana  
Adult  

Saccostrea glomerata  
Larvae  

Saccostrea glomerata  
Adult  

Saccostrea glomerata  
Larvae  

Saccostrea glomerata  
Adult  

Saccostrea glomerata  
Adult  

Crassostrea gigas  
Larvae  

Saccostrea glomerata  
Larvae  

Crassostrea gigas  
Adult  

Saccostrea glomerata  
Adult  

Crassostrea gigas  
Larvae  

Saccostrea glomerata  
Larvae  

Crassostrea gigas  
Adult  

Saccostrea glomerata  
Adult  

Mytilus galloprovincialis  
Adult  

Perna canaliculus  
Adult  

Mytilus galloprovincialis  
Adult  

Perna canaliculus  
Adult  

Celleporella hyalina  
Larvae  

Celleporella hyalina  
Adult  

Celleporella hyalina  
Larvae  

Celleporella hyalina  
Adult  

Celleporella hyalina  
Larvae  

Celleporella hyalina  
Adult  

Community  
Bembicium nanum  
Embryos  

Dolabrifera brazieri  
Embryos  

Siphonaria denticulata  
Embryos  

Bembicium nanum  
Embryos  

Dolabrifera brazieri  
Embryos  

Siphonaria denticulata  
Embryos  

Acropora cervicornis  
Adult  

Stylophora pistillata  
Adult  

Stylophora pistillata  
Adult  

Stylophora pistillata  
Adult  

Stylophora pistillata  
Adult  

Stylophora pistillata  
Adult  

Hydroides crucigera  
Adult  

Oculina arbuscula  
Adult  

Callinectes sapidus  
Adult  

Homarus americanus  
Adult  

Penaeus plebejus  
Adult  

Halimeda incrassata  
Adult  

Neogoniolithon sp.  
Adult  

Arbacia punctulata  
Adult  

* indicates species that are not present in the sample.
| Species                        | Life Stage | Notes |
|-------------------------------|------------|-------|
| Eucidaris tribuloides         | Adult      | *     |
| Argopecten irradians          | Adult      | *     |
| Crassostrea virginica         | Adult      | *     |
| Crepidula fornicata           | Adult      | *     |
| Littorina littorea            | Adult      | *     |
| Mercenaria mercenaria         | Adult      | *     |
| Mya arenaria                  | Adult      | *     |
| Mytilus edulis                | Adult      | *     |
| Strombus alatus               | Adult      | *     |
| Urosalpinx cinerea            | Adult      | *     |
| Oculina arbuscula             | Adult      | *     |
| Cladocora caespitosa          | Adult      | *     |
| Myriapora truncata            | Adult      |       |
| Balanophyllia europaea        | Adult      |       |
| Cladocora caespitosa          | Adult      | *     |
| Patella caerulea              | Adult      | *     |
| Cladocora caespitosa          | Adult      |       |
| Balanophyllia europaea        | Adult      |       |
| Balanophyllia europaea        | Adult      |       |
| Cladocora caespitosa          | Adult      |       |
| Emiliana huxleyi              | Culture    |       |
| Macrocytus pyriferi           | Adult      | *     |
| Pisaster ochraceus            |            |       |
| Nucella canaliculata          |            |       |
| Amphistegina radiata          | Adult      | *     |
| Heterostegina depressa        | Adult      | *     |
| Amphistegina radiata          | Adult      | *     |
| Calcarina hispida             | Adult      | *     |
| Heterostegina depressa        | Adult      | *     |
| Acropora eurystoma            | Adult      |       |
| Acropora eurystoma            | Adult      |       |
| Emiliania huxleyi             | Culture    |       |
| Emiliania huxleyi             | Culture    |       |
| Echinometra mathaei           | Juvenile   |       |
| Hemicentrotus pulcherrimus     | Juvenile   |       |
| Strombus luhuanus             | Juvenile   |       |
| Community                     | Culture    | *     |
| Emiliania huxleyi             | Culture    | *     |
| Phaeodactylum tricornutum     | Culture    | *     |
| Thalassiosira pseudonana      | Culture    | *     |
| Emiliania huxleyi             | Culture    | *     |
| Phaeodactylum tricornutum     | Culture    | *     |
| Thalassiosira pseudonana      | Culture    | *     |
| Strongylocentrotus purpuratus | Larvae     | *     |
| Acropora digitifera           | Larvae     | *     |
| Species                              | Life Stage | Notes |
|-------------------------------------|------------|-------|
| Acropora digitifera                 | Larvae     | *     |
| Acropora tenuis                     | Larvae     | *     |
| Nereocystis luetkeana               | Juvenile   | *     |
| Saccharina latissima                | Juvenile   | *     |
| Argopecten irradians                | Larvae     |       |
| Argopecten irradians                | Larvae     | *     |
| Crassostrea virginica               | Larvae     | *     |
| Mercenaria mercenaria               | Larvae     | *     |
| Argopecten irradians                | Larvae     | *     |
| Crassostrea virginica               | Juvenile   | *     |
| Mercenaria mercenaria               | Juvenile   | *     |
| Argopecten irradians                | Juvenile   | *     |
| Argopecten irradians                | Juvenile   | *     |
| Crassostrea virginica               | Juvenile   | *     |
| Mercenaria mercenaria               | Juvenile   | *     |
| Nereocystis luetkeana               | Adult      | *     |
| Zostera marina                      | Adult      | *     |
| Mytilus edulis                      | Adult      | *     |
| Corallium rubrum                    | Adult      | *     |
| Haliotis rufescens                  | Adult      |       |
| Crassostrea gigas                   | Larvae     | *     |
| Hyas araneus                        | Larvae     |       |
| Hyas araneus                        | Larvae     |       |
| Hyas araneus                        | Larvae     |       |
| Hyas araneus                        | Larvae     |       |
| Hyas araneus                        | Larvae     |       |
| Hyas araneus                        | Larvae     |       |
| Hyas araneus                        | Larvae     |       |
| Hyas araneus                        | Larvae     |       |
| Aurelia labiata                     | Juvenile   | *     |
| Aurelia labiata                     | Juvenile   | *     |
| Aurelia labiata                     | Juvenile   | *     |
| Amphiura filiformis                 | Adult      | *     |
| Amphiura filiformis                 | Adult      | *     |
| Amphiura filiformis                 | Adult      | *     |
| Ophiocent sericeum                  | Adult      | *     |
| Ophiocent sericeum                  | Adult      | *     |
| Ophiocent sericeum                  | Adult      | *     |
| Emiliania huxleyi                   | Culture    |       |
| Gephyrocapsa oceanica               | Culture    |       |
| Emiliania huxleyi                   | Culture    |       |
| Species                  | Stage      |
|-------------------------|------------|
| Gephyrocapsa oceanica   | Culture    |
| Zostera marina          | Adult *    |
| Zostera marina          | Adult *    |
| Emiliania huxleyi       | Culture    |
| Emiliania huxleyi       | Culture    |
| Fieldwork | No Variance | Carbonate Chemistry: HCl addition | Other Reason |
|-----------|-------------|----------------------------------|--------------|
|           |             | *                                | Publication Bias |
|           |             | *                                | Publication Bias |
|           |             | *                                | Publication Bias |
|           |             | *                                |                |
Upper Thermal Limit

Repeat of Ries et al., 2009
Repeat of Ries et al., 2009
Publication Bias

Publication Bias
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ST3 - Heterogeneity Tests - Within Groups (Q) and Between Groups (Qm)
Heterogeneity statistics for each model in the different response variables. Separate analyses were conducted to compare similarity in effect size between each group.
### Statistical Model

|                  | d.f | Q            | P            |
|------------------|-----|--------------|--------------|
| **Full model:**  |     |              |              |
| CO2              | 89  | 66.38891     | 0.965091     |
| Calcifiers / Non-Calcifiers |     |              |              |
| Between groups   | -   | -            | -            |
| Within groups    | -   | -            | -            |
| Taxonomic Groups |     |              |              |
| Between groups   | 6   | 10.11529     | 0.11988      |
| Within groups    | 81  | 56.15998     | 0.983939     |
| Life Stages      |     |              |              |
| Between groups   | 2   | 0.98711      | 0.610453     |
| Within groups    | 67  | 57.27249     | 0.795732     |
| Autotroph / Heterotroph |     |              |              |
| Between groups   | 1   | 0.000917     | 0.975848     |
| Within groups    | 88  | 66.388       | 0.958555     |

|                  | d.f | Q            | P            |
|------------------|-----|--------------|--------------|
| **Full model:**  |     |              |              |
| Temperature      | 12  | 6.706097     | 0.876409     |
| Calcifiers / Non-Calcifiers |     |              |              |
| Between groups   | -   | -            | -            |
| Within groups    | -   | -            | -            |
| Taxonomic Groups |     |              |              |
| Between groups   | 2   | 3.673571     | 0.159329     |
| Within groups    | 10  | 2.99407      | 0.981563     |
| Life Stages      |     |              |              |
| Between groups   | 1   | 3.373508     | 0.066253     |
| Within groups    | 9   | 3.294133     | 0.951484     |
| Autotroph / Heterotroph |     |              |              |
| Between groups   | 1   | 2.856914     | 0.090982     |
| Within groups    | 11  | 3.849183     | 0.974123     |

|                  | d.f | Q            | P            |
|------------------|-----|--------------|--------------|
| **Full model:**  |     |              |              |
| Temperature and CO2 | 13  | 10.30223     | 0.669053     |
| Calcifiers / Non-Calcifiers |     |              |              |
| Between groups   | -   | -            | -            |
| Within groups    | -   | -            | -            |
| Taxonomic Groups |     |              |              |
| Between groups   | 2   | 7.282403     | 0.026221     |
| Within groups    | 11  | 2.93331      | 0.991578     |
| Life Stages      |     |              |              |
| Between groups   | 1   | 3.325488     | 0.068214     |
| Within groups    | 10  | 6.890225     | 0.735766     |
| Autotroph / Heterotroph |     |              |              |
| Between groups   | 1   | 3.21096      | 0.073147     |
| Within groups    | 12  | 7.09127      | 0.851524     |
### Statistical Model

|                            | d.f | Q    | P    |
|---------------------------|-----|------|------|
| **Full model:**           |     |      |      |
| CO2 Growth                | 184 | 79.50974 | 1   |
| Calcifiers / Non-Calcifiers |     |      |      |
| Between groups            | 1   | 12.22165 | 0.000472 | 1   |
| Within groups             | 183 | 67.28809 | 1   |
| Taxonomic Groups          |     |      |      |
| Between groups            | 8   | 16.57577 | 0.034843 | 1   |
| Within groups             | 170 | 61.44674 | 1   |
| Life Stages               |     |      |      |
| Between groups            | 3   | 2.465172 | 0.481618 | 1   |
| Within groups             | 134 | 56.87432 | 1   |
| Autotroph / Heterotroph   |     |      |      |
| Between groups            | 1   | 0.581635 | 0.445672 | 1   |
| Within groups             | 183 | 78.9281 | 1   |

|                            | d.f | Q    | P    |
|---------------------------|-----|------|------|
| **Full model:**           |     |      |      |
| Temperature Growth        | 40  | 22.86788 | 0.986448 |      |
| Calcifiers / Non-Calcifiers |     |      |      |
| Between groups            | 1   | 1.795096 | 0.180306 |      |
| Within groups             | 39  | 21.07279 | 0.991504 |      |
| Taxonomic Groups          |     |      |      |
| Between groups            | 6   | 5.951578 | 0.428636 |      |
| Within groups             | 31  | 16.74605 | 0.982598 |      |
| Life Stages               |     |      |      |
| Between groups            | 2   | 0.351527 | 0.838816 |      |
| Within groups             | 33  | 21.11176 | 0.945629 |      |
| Autotroph / Heterotroph   |     |      |      |
| Between groups            | 1   | 1.674628 | 0.19564 |      |
| Within groups             | 39  | 21.19326 | 0.991013 |      |

|                            | d.f | Q    | P    |
|---------------------------|-----|------|------|
| **Full model:**           |     |      |      |
| Temperature and CO2 Growth | 25  | 16.04101 | 0.913602 |      |
| Calcifiers / Non-Calcifiers |     |      |      |
| Between groups            | 1   | - | - | - |
| Within groups             | 25  | 10.01303 | 0.996617 |      |
| Taxonomic Groups          |     |      |      |
| Between groups            | 3   | 14.26619 | 0.002564 |      |
| Within groups             | 21  | 1.712536 | 1   |      |
| Life Stages               |     |      |      |
| Between groups            | 1   | 7.130137 | 0.00758 |      |
| Within groups             | 18  | 6.308307 | 0.994778 |      |
| Autotroph / Heterotroph   |     |      |      |
| Between groups            | 1   | 6.543602 | 0.010526 |      |
| Within groups             | 24  | 9.497408 | 0.996327 |      |
### Statistical Model

| d.f | Q       | P       |
|-----|---------|---------|
| **Full model:** | CO2 Photosynthesis | 50 | 24.34661 | 0.999166 |

Calcifiers / Non-Calcifiers

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | 1 | 1.355637 | 0.244295 |
| Within groups  | 49 | 22.99097 | 0.999435 |

Taxonomic Groups

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | 4 | 4.600559 | 0.33079 |
| Within groups  | 42 | 18.75501 | 0.999267 |

Life Stages

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | - | - | - |
| Within groups  | 26 | 18.8692 | 0.841904 |

Autotroph / Heterotroph

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | - | - | - |
| Within groups  | 50 | 24.34661 | 0.999166 |

### Statistical Model

| d.f | Q       | P       |
|-----|---------|---------|
| **Full model:** | Temperature Photosynthesis | 25 | 4.014843 | 0.999999 |

Calcifiers / Non-Calcifiers

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | 1 | 0.054102 | 0.816073 |
| Within groups  | 24 | 3.96074 | 0.999999 |

Taxonomic Groups

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | 3 | 0.541265 | 0.909737 |
| Within groups  | 22 | 3.473578 | 0.999998 |

Life Stages

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | 2 | 0.235583 | 0.888881 |
| Within groups  | 18 | 3.769427 | 0.999846 |

Autotroph / Heterotroph

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | - | - | - |
| Within groups  | 25 | 4.014843 | 0.999999 |

### Statistical Model

| d.f | Q       | P       |
|-----|---------|---------|
| **Full model:** | Temperature and CO2 Photosynthesis | 6 | 4.125859 | 0.659649 |

Calcifiers / Non-Calcifiers

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | - | - | - |
| Within groups  | 6 | 4.125859 | 0.659649 |

Taxonomic Groups

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | - | - | - |
| Within groups  | 6 | 4.088998 | 0.664634 |

Life Stages

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | - | - | - |
| Within groups  | 1 | 2.78E-17 | 1 |

Autotroph / Heterotroph

| d.f | Q       | P       |
|-----|---------|---------|
| Between groups | - | - | - |
| Within groups  | 6 | 4.125859 | 0.659649 |
| Statistical Model          | d.f | Q           | P          |
|---------------------------|-----|-------------|------------|
| **Full model:** CO2       | 32  | 15.00094    | 0.995389   |
| **Calcifiers / Non-Calcifiers** |     |             |            |
| Between groups            | 1   | 3.170592    | 0.074975   |
| Within groups             | 31  | 11.83035    | 0.999263   |
| **Taxonomic Groups**      |     |             |            |
| Between groups            | 1   | 3.483788    | 0.061973   |
| Within groups             | 30  | 3.979337    | 1          |
| **Life Stages**           |     |             |            |
| Between groups            | 2   | 0.059077    | 0.970894   |
| Within groups             | 30  | 14.94187    | 0.990064   |
| **Autotroph / Heterotroph** |   |             |            |
| Between groups            | 32  | 14.73757    | 0.996086   |

| Statistical Model          | d.f | Q           | P          |
|---------------------------|-----|-------------|------------|
| **Full model:** Temperature | 32  | 26.74311    | 0.729845   |
| **Calcifiers / Non-Calcifiers** |     |             |            |
| Between groups            | 1   | 1.414748    | 0.23427    |
| Within groups             | 31  | 25.32836    | 0.75284    |
| **Taxonomic Groups**      |     |             |            |
| Between groups            | 4   | 11.58831    | 0.02069    |
| Within groups             | 26  | 15.07243    | 0.955995   |
| **Life Stages**           |     |             |            |
| Between groups            | -   | -           | -          |
| Within groups             | 32  | 14.81015    | 0.995903   |
| **Autotroph / Heterotroph** |   |             |            |
| Between groups            | 1   | 8.004761    | 0.004665   |
| Within groups             | 31  | 18.73835    | 0.959136   |

| Statistical Model          | d.f | Q           | P          |
|---------------------------|-----|-------------|------------|
| **Full model:** Temperature and CO2 | 31  | 41.92531    | 0.091087   |
| **Calcifiers / Non-Calcifiers** |     |             |            |
| Between groups            | -   | -           | -          |
| Within groups             | 31  | 41.92531    | 0.091087   |
| **Taxonomic Groups**      |     |             |            |
| Between groups            | 1   | 0.037652    | 0.846143   |
| Within groups             | 29  | 41.8552     | 0.057864   |
| **Life Stages**           |     |             |            |
| Between groups            | 1   | 17.88687    | 2.34E-05   |
| Within groups             | 30  | 24.03844    | 0.770282   |
| **Autotroph / Heterotroph** |   |             |            |
| Between groups            | -   | -           | -          |
| Within groups             | 31  | 41.92531    | 0.091087   |
### Statistical Model: CO2 Survival

| d.f | Q      | P      |
|-----|--------|--------|
|     | 21.07494 | 0.738085 |

#### Calcifiers / Non-Calcifiers

| Between groups | 1 | 0.344861 | 0.557037 |
| Within groups  | 25| 20.73008 | 0.70756  |

#### Taxonomic Groups

| Between groups | 4 | 9.11735 | 0.058232 |
| Within groups  | 22| 11.95759| 0.958249 |

#### Life Stages

| Between groups | 2 | 5.22956 | 0.073184 |
| Within groups  | 24| 15.84539| 0.893576 |

#### Autotroph / Heterotroph

| Between groups | 1 | 2.737702 | 0.098006 |
| Within groups  | 25| 18.33724 | 0.827744 |

### Statistical Model: Temperature Survival

| d.f | Q      | P      |
|-----|--------|--------|
|     | 29.24892 | 0.082972 |

#### Calcifiers / Non-Calcifiers

Between groups: 1 | 1.324548 | 0.249778 |
Within groups: 19 | 27.92437 | 0.084895 |

#### Taxonomic Groups

Between groups: 3 | 2.643547 | 0.449906 |
Within groups: 14 | 25.28083 | 0.031894 |

#### Life Stages

Between groups: 2 | 23.62438 | 7.41E-06 |
Within groups: 18 | 5.624542 | 0.997496 |

#### Autotroph / Heterotroph

Between groups: 1 | 0.221652 | 0.637784 |
Within groups: 19 | 29.02727 | 0.065557 |

### Statistical Model: Temperature and CO2 Survival

| d.f | Q      | P      |
|-----|--------|--------|
|     | 14.67871 | 0.197683 |

#### Calcifiers / Non-Calcifiers

Between groups: - | - | - |
Within groups: 11 | 14.67871 | 0.197683 |

#### Taxonomic Groups

Between groups: 1 | 0.013307 | 0.908162 |
Within groups: 10 | 14.6654 | 0.144745 |

#### Life Stages

Between groups: 1 | 3.006553 | 0.082928 |
Within groups: 10 | 11.67216 | 0.307597 |

#### Autotroph / Heterotroph

Between groups: - | - | - |
Within groups: 11 | 14.67569 | 0.197831 |