Supplementary Material

Effects of ocean acidification on Antarctic marine organisms: a meta-analysis

Table S1: Database search strategy with main themes (top line) and synonyms below. Searches were conducted using 'and' between columns and 'or' between rows for each column e.g. ocean or marine and acid* or pH and "Southern Ocean". For Scopus database " " were replaced with { }.

ocean	acid*	"Southern Ocean"
marine	pH	Antarctic*
pelagic	?CO2	
coast*	DIC	
nearshore	"carbon dioxide"	
	"dissolved inorganic carbonate chemistry"	
	"carbonate chemistry"	

Supplementary Document 1: References for papers included in the meta-analysis

Bednaršek, N., Tarling, G. A., Bakker, D. C. E., Fielding, S., and Feely, R. A. (2014). Dissolution dominating calcification process in polar pteropods close to the point of aragonite undersaturation. *PLoS ONE*, 9(10):1–14.

Black, J. G, Stark, J. S., Johnstone, G. J., McMinn, A., Boyd, P., McKinlay, J., Wootherspoon, S., and Runcie, J. W. (2019). *In situ* behavioural and physiological responses of Antarctic microphytobenthos to ocean acidification. *Scientific Reports*, 9: 1890.

Bylenga, C. H., Cummings, V. J., and Ryan, K. G. (2015). Fertilisation and larval development in an Antarctic bivalve, *Laternula elliptica*, under reduced pH and elevated temperatures. *Marine Ecology Progress Series*, 536:187–201.

Bylenga, C. H., Cummings, V. J., and Ryan, K. G. (2017). High resolution microscopy reveals significant impacts of ocean acidification and warming on larval shell development in *Laternula elliptica*. *PLoS ONE*, 12(4).

Byrne, M., Ho, M. A., Koleits, L., Price, C., King, C. K., Virtue, P., Tilbrook, B., and Lamarek, M. (2013). Vulnerability of the calcifying larval stage of the Antarctic sea urchin *Sterechinus neumayeri* to near-future ocean acidification and warming. *Global Change Biology*, 19(7):2264–2275.

Clark, D., Lamare, M., and Barker, M. (2009). Response of sea urchin pluteus larvae (Echinodermata: Echinoidea) to reduced seawater pH: a comparison among a tropical, temperature, and a polar species. *Marine Biology*, 156:1125-1137.

Coad, T., McMinn, A., Nomura, D., and Martin, A. (2016). Effect of elevated CO_2 concentration on microalgal communities in Antarctic pack ice. *Deep-Sea Research Part II*, 131:160–169.

Cross, E. L., Peck, L. S., and Harper, E. M. (2015). Ocean acidification does not impact shell growth or repair of the Antarctic brachiopod *Liothyrella uva* (Broderip, 1833). *Journal of Experimental Marine Biology and Ecology*, 462:29–35.

Davidson, A. T., McKinlay, J., Westwood, K., Thomson, P. G., van den Enden, R., de Salas, M., Wright, S., Johnson, R., and Berry, K. (2016). Enhanced CO_2 concentrations change the structure of Antarctic marine microbial communities. *Marine Ecology Progress Series*, 552:93–113.

Davis, B. E., Flynn, N. A., Miller, N. A., Nelson, F. A., Fangue, N. A., and Todgham, A. E. (2018). Antarctic emerald rockcod have the capacity to compensate for warming when uncoupled from CO_2-acidification. *Global Change Biology*, 24: e655-e670

Davis, B. E., Miller, N. A., Flynn, E. E., and Todgham, A. E. (2016). Juvenile Antarctic rockcod (*Trematomus bernacchii*) are physiologically robust to CO_2-acidified seawater. *Journal of Experimental Biology*, 219(8):1203–1213.

Deppeler, S., Petrou, K., Schulz, K. G., Westwood, K., Pearce, I., McKinlay, J., and Davidson, A. (2018). Ocean acidification of a coastal Antarctic marine microbial community reveals a critical threshold for CO_2 tolerance in phytoplankton productivity. *Biogeosciences*, 15(1):209.

Enzor, L. A., Hunter, E. M., and Place, S. P. (2017). The effects of elevated temperature and ocean acidification on the metabolic pathways of notothenioid fish. *Conservation Physiology*, 5.

Enzor, L. A., Zippay, M. L., and Place, S. P. (2013). High latitude fish in a high CO_2 world: Synergistic effects of elevated temperature and carbon dioxide on the metabolic rates of Antarctic notothenioids. *Comparative Biochemistry and Physiology, Part A*, 164(1):154–161.

Ericson, J. A., Ho, M. A., Miskelly, A., King, C. K., Virtue, P., Tilbrook, B., and Byrne, M. (2012). Combined effects of two ocean change stressors, warming and acidification, on fertilization and early development of the Antarctic echinoid *Sterechinus neumayeri*. *Polar Biology*, 35(7):1027–1034.

Ericson, J. A., Lamare, M. D., Morley, S. A., and Barker, M. F. (2010). The response of two ecologically important Antarctic invertebrates (*Sterechinus neumayeri* and *Parborlasia corrugatus*) to reduced seawater pH: effects on fertilisation and embryonic development. *Marine Biology*, 157(12):2689–2702.

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Gonzalez-Bernat, M. J., Lamare, M., and Barker, M. (2013). Effects of reduced seawater pH on fertilisation, embryogenesis and larval development in the Antarctic seastar *Odontaster validus*. *Polar Biology*, 36(2):235–247.

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Heiden, J P., Völkner, C., Jones, E. M., van de Poll, W., H., Buma, A. G. J., Meredith, M. P., de Baar, H. J. W., Bischof, K., Wolf-Gladrow, D., and Trimborn, S. (2019). Impact of ocean acidification and high solar radiation on productivity and species composition of a late summer phytoplankton community of the coastal Western Antarctic Peninsula. *Limnology and Oceanography*, 9999: 1-21.

Heiden, J. P., Thoms, S., Bischof, K., and Trimborn, S. (2018). Ocean acidification stimulates particulate organic carbon accumulation in two Antarctic diatom species under moderate and high nature solar radiation. *Jounral of Phycology*, 54: 505-517.

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Ho, M. A., Price, C., King, C. K., Virtue, P., and Byrne, M. (2013). Effects of ocean warming and acidification on fertilization in the Antarctic echinoid *Sterechinus neumayeri* across a range of sperm concentrations. *Marine Environmental Research*, 90:136–141.

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Hoshijima, U., Wong, J. M., and Hofmann, G. E. (2017). Additive effects of pCO_2 and temperature on respiration rates of the Antarctic pteropod *Limacina helicina antarctica*. *Conservation Physiology*, 5:1-14.

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Karelitz, S. E., Uthicke, S., Foo, S. A., Barker, M. F., Byrne, M., Pecorino, D., and Lamare, M. D. (2016). Ocean acidification has little effect on developmental thermal windows of echinoderms from Antarctica to the tropics. *Global Change Biology*, 23(2):657– 672.

Kawaguchi, S., Ishida, A., King, R., Raymond, B., Waller, N., Constable, A., Nicol, S., Wakita, M., and Ishimatsu, A. (2013). Risk maps for Antarctic krill under projected Southern Ocean acidification. *Nature Climate Change*, 3(9):843–847.

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Saba, G. K., Schofield, O., Torres, J. J., Ombres, E. H., and Steinberg, D. K. (2012). Increased feeding and nutrient excretion of adult Antarctic krill, *Euphausia superba*, exposed to enhanced carbon dioxide (CO_2). *PLoS ONE*, 7(12).

Schoenrock, K. M., Schram, J. B., Amsler, C. D., McClintock, J. B., Angus, R. A., and Vohra, Y. K. (2016). Climate change confers a potential advantage to fleshy Antarctic crustose macroalgae over calcified species. *Journal of Experimental Marine Biology and Ecology*, 474:58–66.

Schram, J. B., Schoenrock, K. M., McClintock, J. B., Amsler, C. D., and Angus, R. A. (2016a). Testing Antarctic resilience: the effects of elevated seawater temperature and decreased pH on two gastropod species. *ICES Journal of Marine Science*, 73(3): 739-752.

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Schram, J. B., Schoenrock, K. M., McClintock, J. B., Amsler, C. D., and Angus, R. A. (2016b). Seawater acidification more than warming presents a challenge for two Antarctic macroalgal-associated amphipods. *Marine Ecology Progress Series*, 554:81–97.

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Strobel, A., Bennecke, S., Leo, E., Mintenbeck, K., Pörtner, H. O., and Mark, F. C. (2012). Metabolic shifts in the Antarctic fish *Notothenia rossii* in response to rising temperature and pCO_2. *Frontiers in Zoology*, 9:28.

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Tortell, P. D., Payne, C. D., Li, Y., Trimborn, S., Rost, B., Smith, W. O., Riesselman, C., Dunbar, R. B., Sedwick, P., and DiTullio, G. R. (2008b). CO_2 sensitivity of Southern Ocean phytoplankton. *Geophysical Research Letters*, 35(4):1–5.

Tortell, P. D., Trimborn, S., Li, Y., Rost, B., and Payne, C. D. (2010). Inorganic carbon utilization by Ross Sea phytoplankton across natural and experimental CO_2 gradients. *Journal of Phycology*, 46(3):433– 443.

Trimborn, S., Brenneis, T., Sweet, E., and Rost, B. (2013). Sensitivity of Antarctic phytoplankton species to ocean acidification: growth, carbon acquisition, and species interaction. *Limnology and Oceanography*, 58(3):997–1007.

Trimborn, S., Thoms, S., Brenneis, T., Heiden, J. P., Beszteri, S., and Bischof, K. (2017). Two Southern Ocean diatoms are more sensitive to ocean acidification and changes in irradiance than the prymnesiophyte *Phaeocystis antarctica*. *Physiologia Plantarum*, 160(2): 155–170.

Westwood, K., Thomson, P., van den Enden, R., Ma- her, L., Wright, S., and Davidson, A. (2018). Ocean acidification impacts primary and bacterial production in Antarctic coastal waters during austral summer. *Journal of Experimental Marine Biology and Ecology*, 498:46–60.

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Young, J. N., Kranz, S. A., Goldman, J. A. L., Tortell, P. D., and Morel, F. M. M. (2015). Antarctic phytoplankton down-regulate their carbon-concentrating mechanisms under high CO_2 with no change in growth rates. *Marine Ecology Progress Series*, 532: 13–28.

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Zhu, Z., Qu, P., Gale, J., Fu, F., and Hutchins, D. A. (2017). Individual and interactive effects of warming and CO_2 on *Pseudo-nitzschia subcurvata* and *Phaeocystis antarctica*, two dominant phytoplankton from the Ross Sea, Antarctica. *Biogeosciences*,14:5281-5295.

Papers not included in the meta-analysis and the reasoning behind omission

Boelen, P., van de Poll, W. H., van der Strate, H. J., Neven, I. A., Beardall, J., and Buma, A. G. J. (2011). Neither elevated nor reduced CO_2 affects the photophysiological performance of the marine Antarctic diatom *Chaetoceros brevis*. *Journal of Experimental Marine Biology and Ecology*, 406: 38-45
- Not included as there was no ambient CO_2 treatment, on elevated (790 ppmv) or reduced (190 ppmv) CO_2 treatments.

Benedetti, M., Lanzoni, I., Nardi, A., d'Errico, G., Di Carlo, M., Fattorini, D., Nigro, M., and Regoli, F. (2016). Oxidative responsiveness to multiple stressors in key Antarctic species, *Adamussium colbecki*: interactions between temperature, acidification and cadmium exposure. *Marine Environmental Research*, 121: 20-30.
- Not included as carbonate chemistry measurements required to convert pH (measured in the paper) to CO_2 (μatm) not provided in the paper and the corresponding author could not be contacted.

Beszteri, S., Thoms, S., Benes, V., Harms, L., and Trimborn, S. (2018). The response of three Southern Ocean phytoplankton species to ocean acidification and light availability: a transcriptomic study. *Protist*, 169: 958-975.
- Not included as this is a transcriptomic study and does not have usable measurements (mean and standard error) to input into meta-analytic statistical analyses.

Castrisios, K., Martin, A., Muller, M. N., Kennedy, F., McMinn, A., and Ryan, K. G. (2018). Response of Antarctic sea-ice algae to an experimental decrease in pH: a preliminary analysis from chlorophyll fluorescence imaging of melting ice. *Polar Research*, 37(1): 1438696.
- Not included as this was a sea-ice study with a high ambient CO_2 treatment (1651 μatm).

Cummings, V., Hwitt, J., Van Rooyen, A., Currie, K., Beard, S., Thrush, S., Norkko. J., Barr, N., Heath, P., Halliday, N. J., Sedcole, R., Gomez, A., McGraw, C., and Metcalf, V. (2011). Ocean acidification at high latitudes: potential effects of functioning of the Antarctic bivalve *Laternula elliptica*. *PLoS ONE*, 6(1):e16069.
- Not included as this is a genomic study and does not have usable measurements (mean and standard error) to input into meta-analytic statistical analyses.

Endo, H., Hattori, H., Mishima, T., Hashida, G., Sasaki, H., Nishioka, J., and Suzuki, K. (2017). Phytoplankton community responses to iron and CO_2 enrichment in different biogeochemical regions of the Southern Ocean. *Polar Biology*, 40: 2143-2159.
- Not included as there is no ambient iron with manipulated CO_2 treatment; there are only control, iron added and iron + CO_2 added treatments.

Enzor, L. A., and Place, S. P. (2014). Is warmer better? Decreased oxidative damage in notothenioid fish after long-term acclimation to multiple stressors. *The Journal of Experimental Biology*, 217:3301-3310.
- Not included as no biological measurements presented in the article were comparable to measurements in other fish studies.

Ericson, J. A., Hellessey, N., Kawaguchi, S., Nicol, S., Hoem, N., and Virtue, P. (2018). Adult Antarctic krill proves resilient in a simulated high CO_2 ocean. *Nature Communications*, 1(1):190.
- Not included as this is a long-term study (46 weeks) investigating the acclimative capacity of Antarctic krill to ocean acidification.

Hoppe, C. J. M., Hassler, C. S., Payne, C. D., Tortell, P. D., Rost, B., and Trimborn, S. (2013.) Iron limitation modulates ocean acidification effect on Southern Ocean phytoplankton communities. *PLoS ONE*, 8(11):e79890.
- Not included as this was a multistressor experiment investigating the effect of ocean acidification and iron availability. There was no ambient iron treatment only iron enriched and iron deplete where hydroxamate siderophore desferrioxamine was added to bind and reduce the bioavailability of iron.

Huth, T., and Place, S. (2016). RNA-seq reveals a diminished acclimation response to the combined effects of ocean acidification and elevated temperature in *Pagothenia borchgrevinki*. *Marine Genomics*, 28:87-97.
- Not included as this is a transcriptomic study and does not have usable measurements (mean and standard error) to input into meta-analytic statistical analyses.

Huth, T., and Place, S. (2016). Transcriptome wide analysis reveal a sustained cellular stress response in the gill tissue of *Trematomus bernacchii* after acclimation to multiple stressors. *BMC Genomics*, 17:127.
- Not included as this is a transcriptomic study and does not have usable measurements (mean and standard error) to input into meta-analytic statistical analyses.

Johnson, K. M., and Hofmann, G. E. (2017). Transciptomic response of the Antarctic pteropod *Limacina helicina antarctica* to ocean acidification. *BMC Genomics*, 18: 212.
- Not included as this is a transcriptomic study and does not have usable measurements (mean and standard error) to input into meta-analytic statistical analyses.

Kapsenberg, L., and Hofmann, G. E. (2014). Signals of resilience to ocean change: high thermal tolerance of early stage Antarctic sea urchins (*Sterechinus neumayeri*) reared under present-day and future pCO_2 and temperature. *Polar Biology*, 37: 967-950.
- Not included as there was no ambient temperature treatment. The effect of increased CO_2 over temperature gradients was investigated in this paper.

McMinn, A., Muller, M. N., Martin, A., Ugalde, S. C., Lee, S., Castrisios, K., and Ryan, K. G. (2017). Effect of CO_2 concentration on a late summer surface sea ice community. *Marine Biology*, 164: 87.
- Not included as this is a sea-ice study with a high ambient CO_2 treatment (1288 μatm).

McMinn, A., Muller, M. N., Martin, A., and Ryan, K. G. (2014). The response of Antarctic sea ice algae to changes in pH and CO_2. *PLoS ONE*, 9(1): e86984.
- Not included as this is a sea-ice study with a high ambient CO_2 treatment (1190 μatm).

Mutungi, G., and Johnston, I. A. (1988). Influence of pH and temperature on force development and shortening velocity in skinned muscle fibres from fish. *Fish Physiology and Biochemistry*, 5(4): 257-262.
- Not included as carbonate chemistry measurements required to convert pH (measured in the paper) to CO_2 (μatm) not provided in the paper and the corresponding author could not be contacted.

Schram, J. B., Amsler, M. O., Amsler, C. D., Schoenrock, K. M., McClintock, J. B., and Angus, R. A. (2016a). Antarctic crustacean grazer assemblages exhibit resistance following exposure to decreased pH. *Marine Biology*, 163(5).
- Not included as looking at crustacean grazer assemblage change and does not have usable measurements (mean and standard error) to input into meta-analytic statistical analyses.

Torstensson, M., Hedblom, M., Björk, M. M., Chierici, M., and Wulff, A. (2015). Long-term acclimation to elevated pCO_2 alters carbon metabolism and reduces growth in the Antarctic diatom *Nitzschia lecointei*. *Proceedings of the Royal Scoiety B: Biological Sciences*, 282: 20151513.
- Not included as this is a long-term study (147 days) investigating the acclimative capacity of Antarctic phytoplankton to ocean acidification.

Trimborn, S., Thoms, S., Petrou, K., Kranz, S. A., and Rost, B. (2014). Photophysiological responses of Southern Ocean phytoplankton to changes in CO_2 concentrations: short-term versus acclimation effects. *Journal of Experimental Marine Biology and Ecology*, 451: 44-54.
- Not included as this study measured response curves of low vs high CO_2 acclimated phytoplankton cultures and was therefore uncomparable to other studies included in the meta-analysis.

Yang, G., King, R. A., and Kawaguchi, S. (2018). Behavioural responses of Antarctic krill (*Euphausia superba*) to CO_2-induced ocean acidification: would krill really notice? *Polar Biology*, 41: 727-732.
- Not included as there are no usable measurement (mean and standard error) to input into meta-analytic statistical analyses.

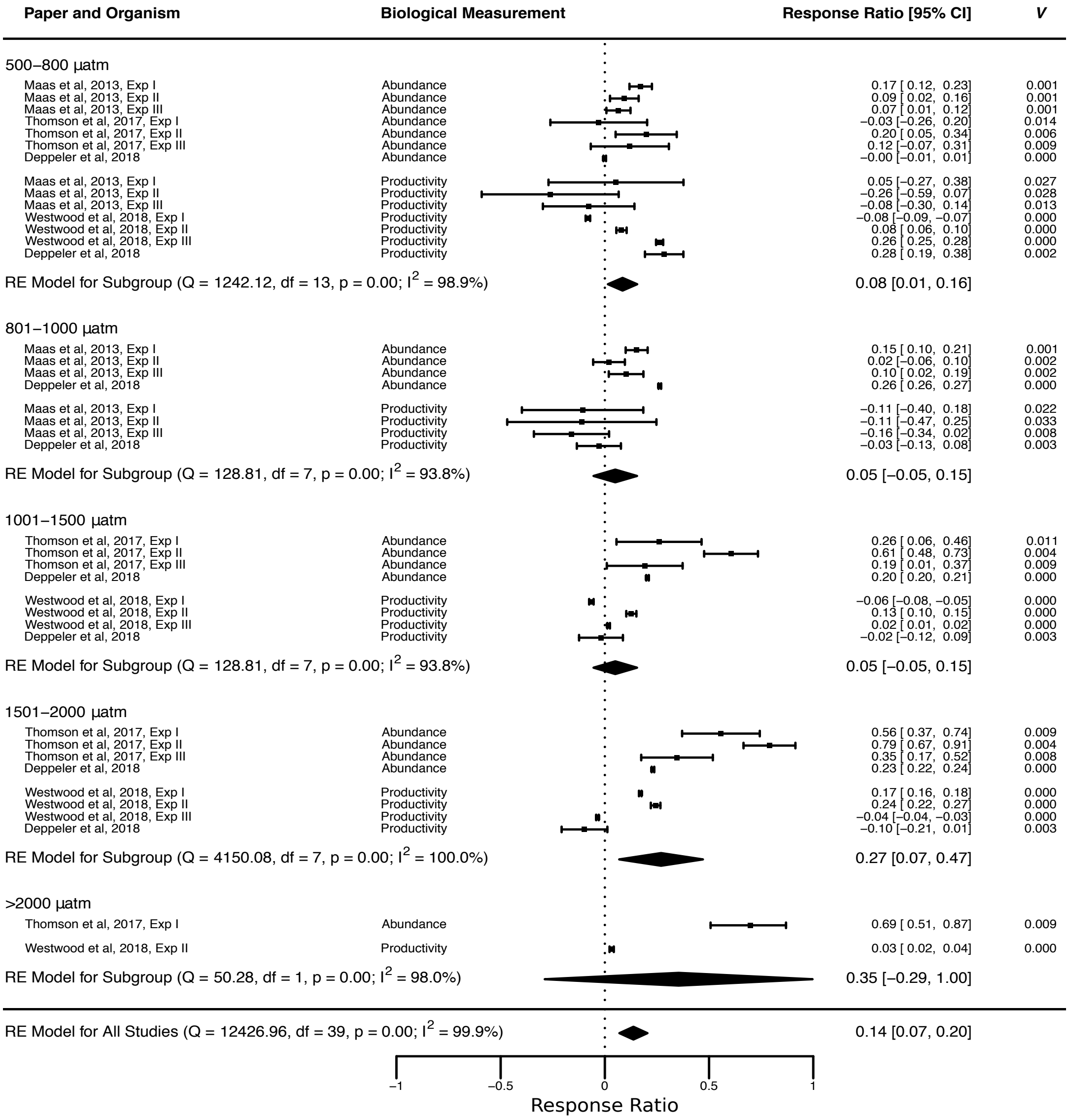

Figure S1: Forest plots of all bacterial response ratios and variance included in the meta-analysis. The data is separated by CO_2 treatment at which the response was measured and information is provided on the study paper, experiment and biological measurement from which the response ratio is calculated. At the end of each CO_2 bracket summary statistics from weighted, random effects are provided including the Q statistic, degrees of freedom, p-value, I^2, mean response ratio and 95% confidence interval.

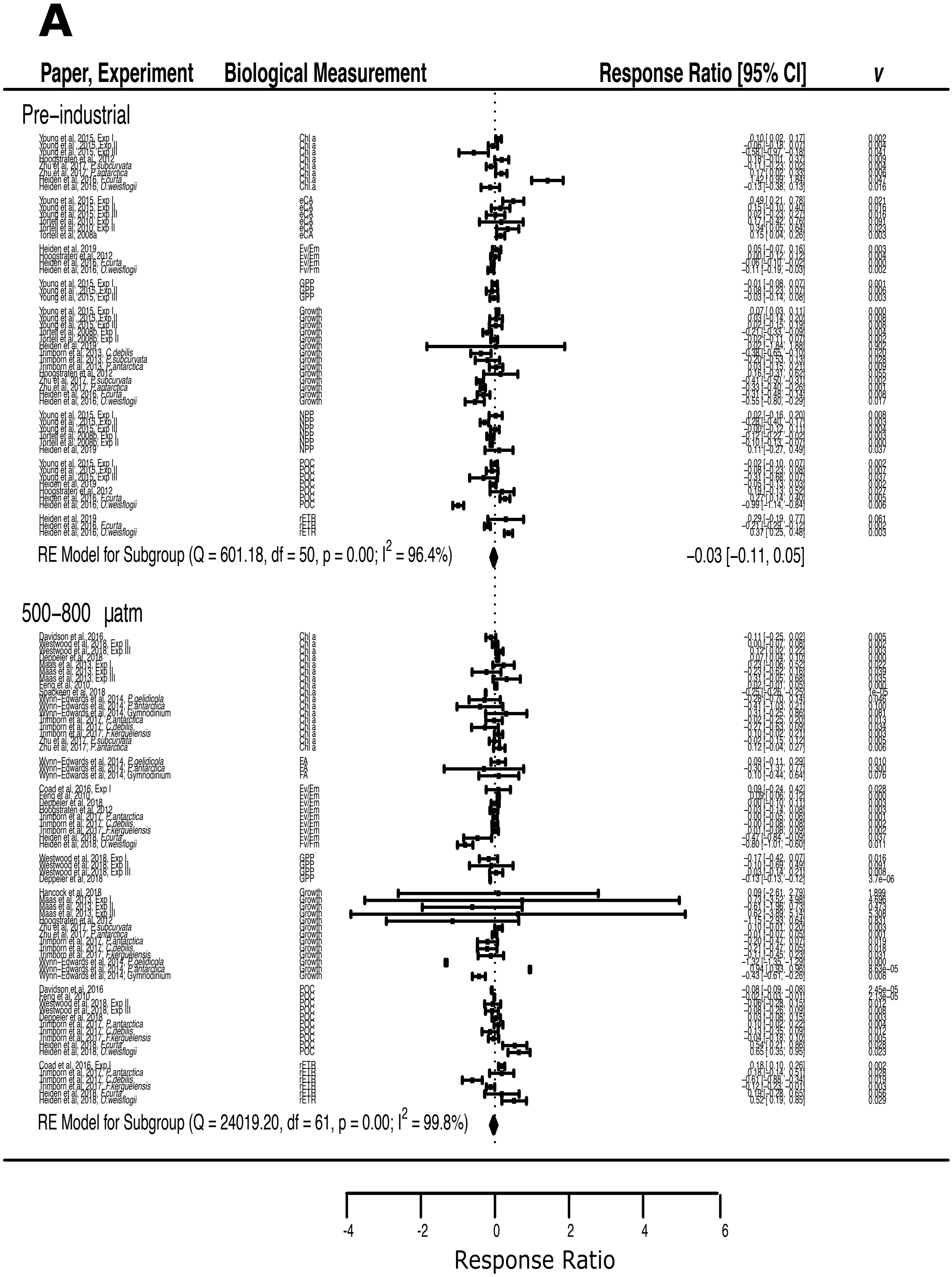

Figure S2: Forest plot of all phytoplankton response ratios, 95% confidence intervals and variance (v) included in the meta-analysis.

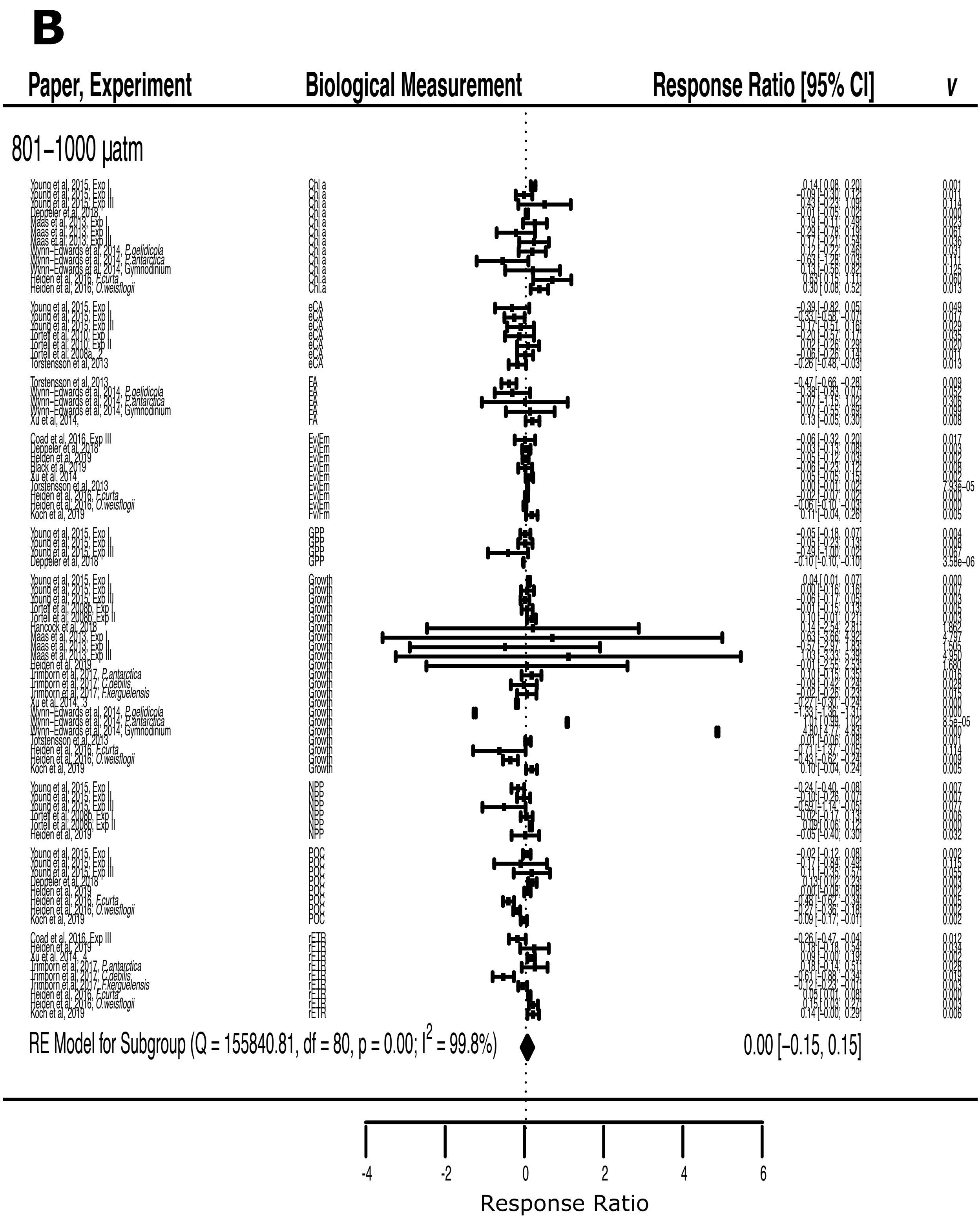

Figure S2: Forest plot of all phytoplankton response ratios, 95% confidence intervals and variance (v) included in the meta-analysis.

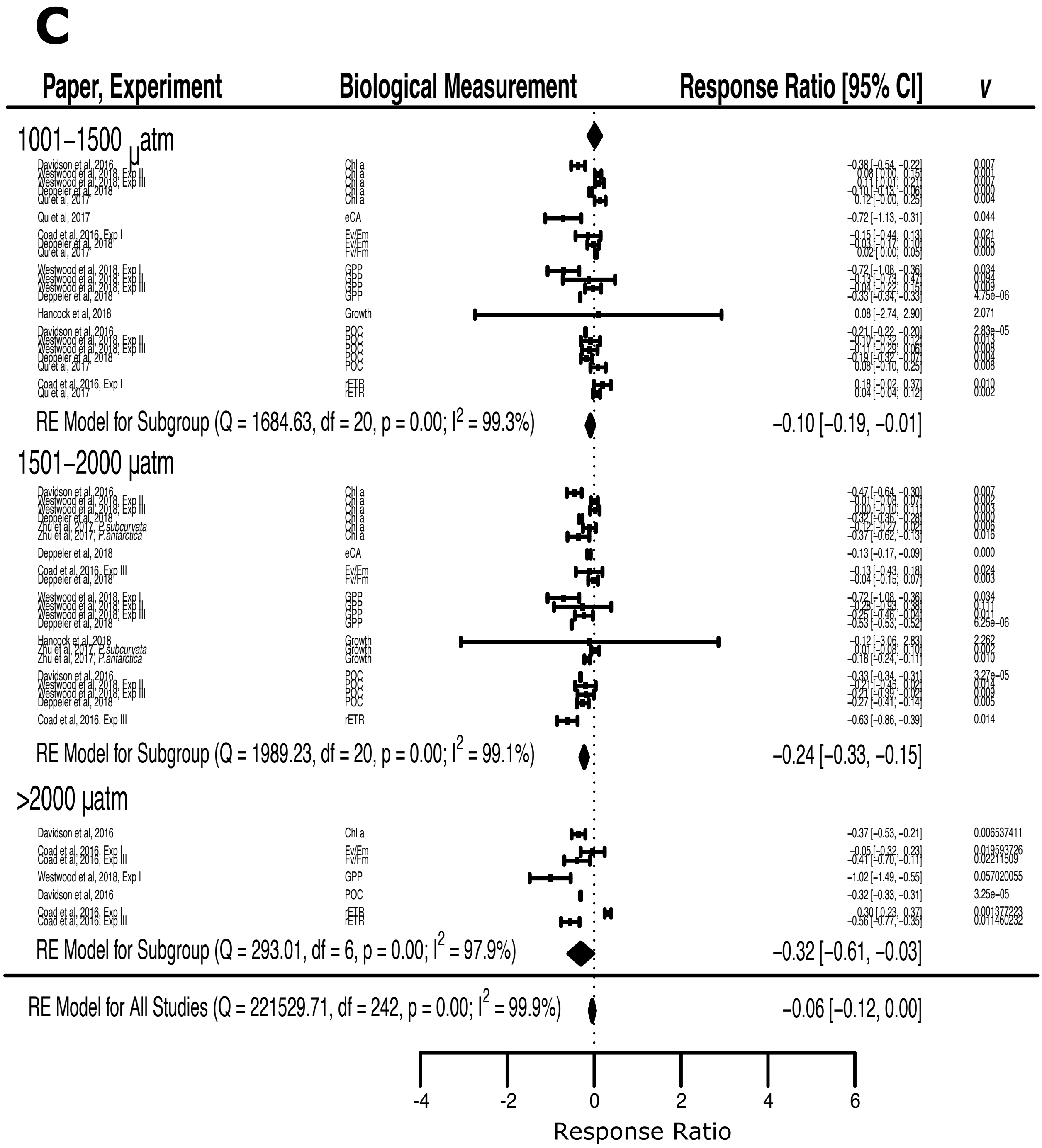

Figure S2: Forest plot of all phytoplankton response ratios, 95% confidence intervals and variance (v) included in the meta-analysis (A: pre-industrial and 500-800 μatm, B: 801-1000 μatm, C: 1001-1500, 1501-2000 and >2000 μatm). The data is separated by CO_2 level at which the response was measured and information is provided on the study paper and biological response from which the response ratio is calculated. At the end of each CO_2 level summary statistics from weighted random effects models are provided including the Q statistic, degrees of freedom, p-value, I^2, mean response ratio and 95% confidence interval. Summary statistics are also provided at the bottom of the figure for all phytoplankton response ratios with all CO_2 levels together.

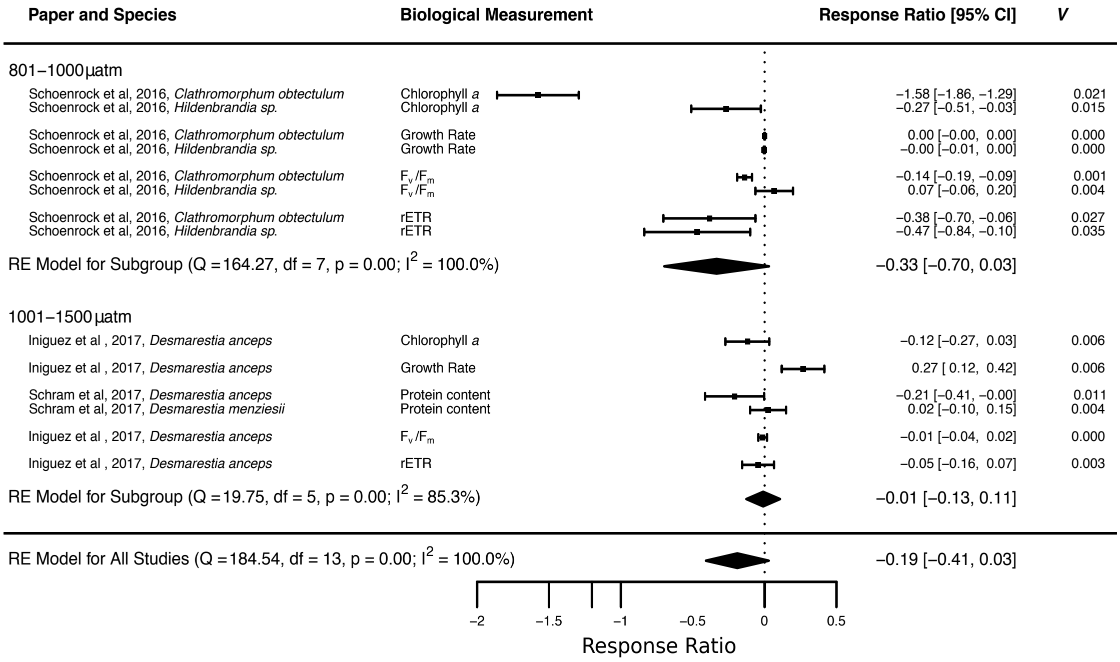

Figure S3: Forest plots of all macroalgal response ratios and variance included in the meta-analysis. The data is separated by CO_2 treatment at which the response was measured and information is provided on the study paper, species and biological measurement from which the response ratio is calculated. At the end of each CO_2 bracket summary statistics from weighted, random effects are provided including the Q statistic, degrees of freedom, p-value, I^2, mean response ratio and 95% confidence interval.

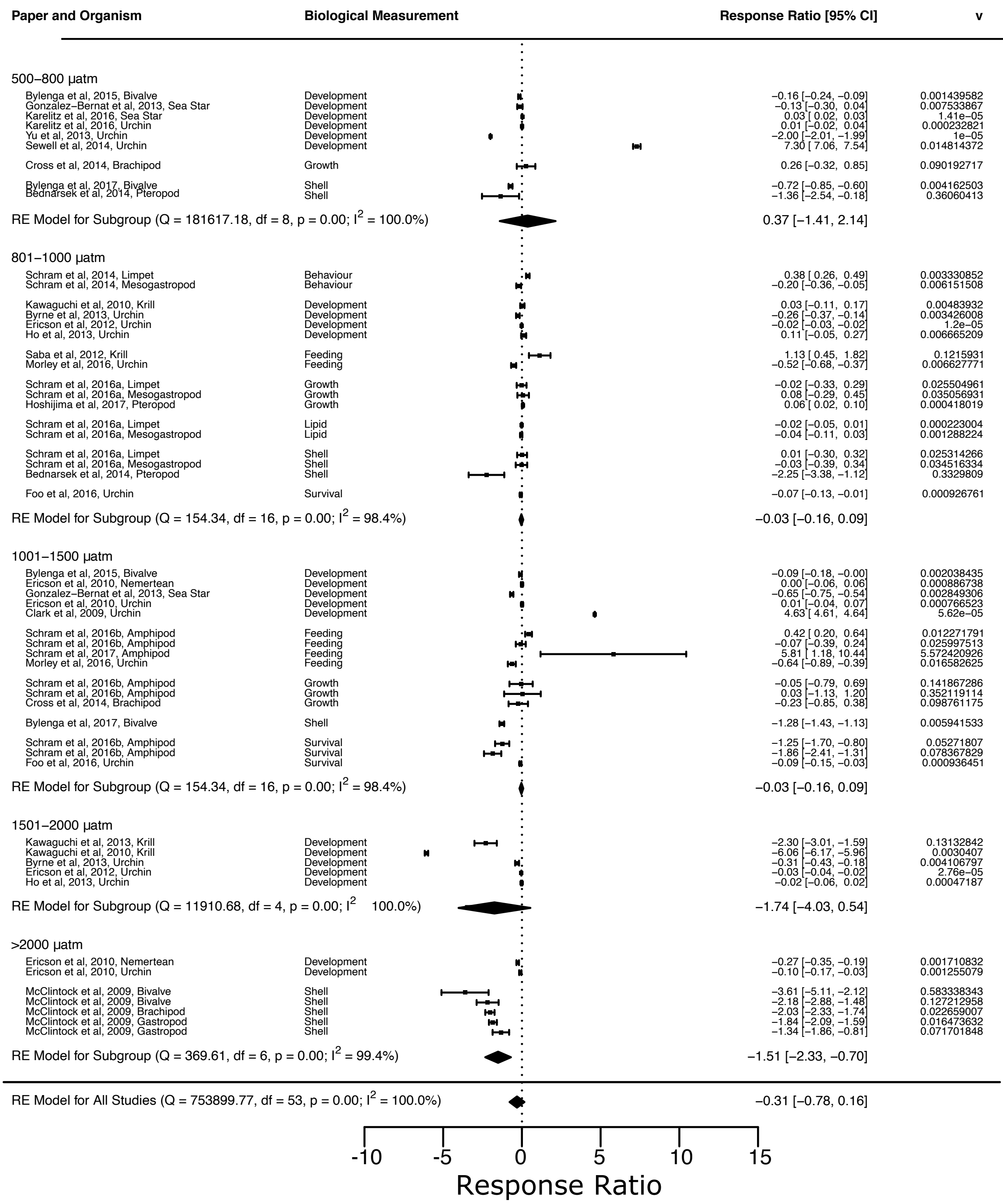

Figure S4: Forest plots of all invertebrate response ratios and variance included in the meta-analysis. The data is separated by CO_2 treatment at which the response was measured and information is provided on the study paper, organism and biological measurement from which the response ratio is calculated. At the end of each CO_2 bracket summary statistics from weighted, random effects are provided including the Q statistic, degrees of freedom, p-value, I^2, mean response ratio and 95% confidence interval.

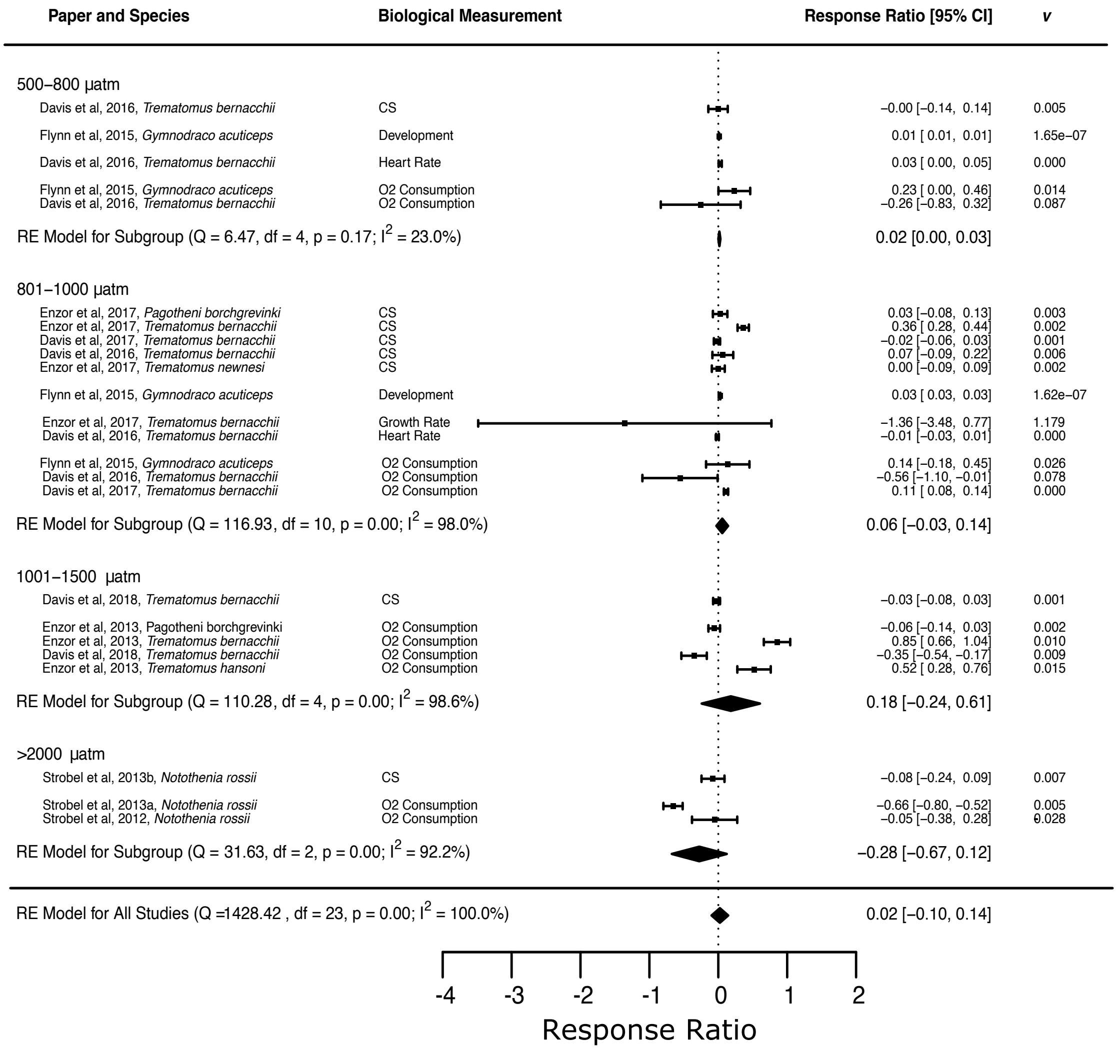

Figure S5: Forest plots of all fish response ratios and variance included in the meta-analysis. The data is separated by CO_2 treatment at which the response was measured and information is provided on the study paper, species and biological measurement from which the response ratio is calculated. At the end of each CO_2 bracket summary statistics from weighted, random effects are provided including the Q statistic, degrees of freedom, p-value, I^2, mean response ratio and 95% confidence interval.

Table S2: Q test and random effects model results for bacteria.

	Q-Test Results			Model Results
	df	Q	p	
per CO_2 Level				
All levels	39	12427.0	<0.0001	Positive
500-800 μatm	13	1242.1	<0.0001	Positive
801-1000 μatm	7	128.8	<0.0001	Positive
1001-1500 μatm	7	2696.9	<0.0001	Positive
1501-2000 μatm	7	4150.1	<0.0001	Positive
>2000 μatm	7	50.3	<0.0001	Positive
per Biological Measurement				
Abundance	19	4505.4	<0.0001	Positive
Productivity	19	4201.6	<0.0001	No effect
per CO_2 Level and Biological Measurement				
Abundance				
500-800 μatm	6	58.6	<0.0001	Positive
801-1000 μatm	3	69.5	<0.0001	Positive
1001-1500 μatm	3	37.2	<0.0001	Positive
1501-2000 μatm	3	90.6	<0.0001	Positive
>2000 μatm	1 study	N/A		Positive
Productivity				
500-800 μatm	6	1163.5	<0.0001	No effect
801-1000 μatm	3	1.7	**0.647**	Negative
1001-1500 μatm	3	275.0	<0.0001	No effect
1501-2000 μatm	3	2334.5	<0.0001	Positive
>2000 μatm	1 study	N/A		Positive

Table S3: Q test and random effects model results for phytoplankton. CO_2 levels are in μatm, Pos = positive effect, Neg = negative effect, and NE = no effect.

	Q-Test Results			Model Results		Q-Test Results			Model Results		Q-Test Results			Model Results
	df	Q	p			df	Q	p			df	Q	p	
per CO_2 Level					*per CO_2 Level (Single Species Studies Only)*					*per CO_2 Level (Community Level Studies Only)*				
All levels	242	1529.7	<0.0001	Neg	All levels	102	161284.2	<0.0001	NE	All levels	139	1201.1	<0.0001	Neg
Pre-industrial	50	601.2	<0.0001	NE	Pre-industrial	20	531.1	<0.0001	NE	Pre-industrial	29	38.2	<0.0001	NE
500-800	60	21850.6	<0.0001	NE	500-800	35	19367.7	<0.0001	NE	500-800	24	994.9	<0.0001	NE
801-1000	80	155840.8	<0.0001	NE	801-1000	36	135163.8	<0.0001	NE	801-1000	43	374.1	<0.0001	Neg
1001-1500	20	1684.6	<0.0001	Neg	1001-1500	4	15.3	0.0042	NE	1001-1500	15	840.8	<0.0001	Neg
1501-2000	20	1989.2	<0.0001	Neg	1501-2000	3	15.5	0.0014	Neg	1501-2000	16	1749.1	<0.0001	Neg
>2000	6	293.0	<0.0001	Neg	>2000	0 studies		N/A		>2000	6	293.0	<0.0001	Neg
per Biological Measurement					*per Biological Measurement(Single Species Studies Only)*					*per Biological Measurement(Community Level Studies Only)*				
Chlorophyll *a*	48	1610.2	<0.0001	NE	Chlorophyll *a*	20	94.8	<0.0001	NE	Chlorophyll *a*	27	1385.9	<0.0001	NE
Growth	51	152844.1	<0.0001	NE	Growth	29	14727.9	<0.0001	NE	Growth	21	28.1	**0.1380**	NE
GPP	19	23994.4	<0.0001	Neg	GPP	0 studies		N/A		GPP	19	23994.4	<0.0001	Neg
NPP	11	112.8	<0.0001	Neg	NPP	0 studies		N/A		NPP	11	112.9	<0.0001	Neg
F_v/F_m	28	148.7	<0.0001	Neg	F_v/F_m	14	97.1	<0.0001	NE	F_v/F_m	13	35.1	0.0008	NE
rETR	22	277.4	<0.0001	NE	rETR	14	143.9	<0.0001	NE	rETR	7	117.1	<0.0001	NE
POC	34	3290.4	<0.0001	Neg	POC	11	267.5	<0.0001	NE	POC	22	3019.9	<0.0001	Neg
Fatty Acids	7	26.7	0.0004	NE	Fatty Acidst	7	26.7	0.004	NE	Fatty Acids	0 studies		N/A	
eCA	14	70.2	<0.0001	NE	eCA	1	3.8	**0.0517**	Neg	eCA	12	58.8	<0.0001	Neg

Table S.3 continued.

per CO_2 Level and Biological Measurement	Q-Test Results: df	Q	p	Model Results
<u>Chlorophyll *a*</u>				
Pre-industrial	7	65.2	<0.0001	NE
500-800	15	29.8	0.0125	Pos
801-1000	11	42.2	<0.0001	NE
1001-1500	4	51.0	<0.0001	NE
1501-2000	5	81.6	<0.0001	Neg
>2000	1 study		N/A	Neg
<u>Growth</u>				
Pre-industrial	13	90.5	<0.0001	Neg
500-800	12	19061.2	<0.0001	Neg
801-1000	20	123630.7	<0.0001	NE
1001-1500	1 study		N/A	NE
1501-2000	2	11.5	0.0032	NE
>2000	0 studies		N/A	
<u>GPP</u>				
Pre-industrial	2	0.7	**0.7016**	NE
500-800	3	3.4	**0.3374**	Neg
801-1000	3	3.1	**0.3797**	Neg
1001-1500	3	14.7	0.0021	Neg
1501-2000	3	8.5	0.0361	Neg
>2000	1 study		N/A	Neg

per CO_2 Level and Biological Measurement (Single Species Studies Only)	Q-Test Results: df	Q	p	Model Results
<u>Chlorophyll *a*</u>				
Pre-industrial	4	50.9	<0.0001	NE
500-800	7	10.7	**0.1511**	NE
801-1000	4	10.1	**0.0382**	NE
1001-1500	1 study		N/A	Pos
1501-2000	1	2.9	**0.0909**	Neg
>2000	0 studies		N/A	
<u>Growth</u>				
Pre-industrial	7	25.2	0.0007	Neg
500-800	8	19059.7	<0.0001	NE
801-1000	10	1189006.2	<0.0001	NE
1001-1500	0 studies		N/A	
1501-2000	1	11.5	0.0007	NE
>2000	0 studies		N/A	

per CO_2 Level and Biological Measurement (Community Level Studies Only)	Q-Test Results: df	Q	p	Model Results
<u>Chlorophyll *a*</u>				
Pre-industrial	2	13.7	0.0011	NE
500-800	7	19.0	0.0081	Pos
801-1000	6	26.0	0.0002	Pos
1001-1500	3	43.1	<0.0001	NE
1501-2000	3	78.2	<0.0001	Neg
>2000	1 study		N/A	Neg
<u>Growth</u>				
Pre-industrial	5	21.6	0.0006	NE
500-800	3	0.7	**0.8792**	NE
801-1000	9	5.4	**0.7966**	NE
1001-1500	1 study		N/A	NE
1501-2000	1 study		N/A	NE
>2000	0 studies		N/A	
<u>GPP</u>				
Pre-industrial	2	0.7	**0.7016**	NE
500-800	3	3.4	**0.3374**	Neg
801-1000	3	3.1	**0.3797**	Neg
1001-1500	3	14.7	0.0021	Neg
1501-2000	3	8.5	0.0361	Neg
>2000	1 study		N/A	Neg

Table S.3 continued.

per CO_2 Level and Biological Measurement	df	Q	p	Model Results
NPP				
Pre-industrial	5	15.9	**0.0072**	Neg
500-800	5	26.6	<0.0001	Neg
801-1000	0 studies		N/A	
1001-1500	0 studies		N/A	
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	
F_v/F_m				
Pre-industrial	3	5.8	**0.1231**	NE
500-800	8	86.4	<0.0001	NE
801-1000	8	16.3	0.0383	NE
1001-1500	2	2.2	**0.336**	NE
1501-2000	1	0.3	**0.5769**	NE
>2000	1	3.1	**0.0807**	Neg
rETR				
Pre-industrial	0 studies		N/A	
500-800	5	49.8	<0.0001	NE
801-1000	8	45.7	<0.0001	NE
1001-1500	1	1.6	**0.2069**	NE
1501-2000	1 study		N/A	Neg
>2000	1	57.5	<0.0001	NE

per CO_2 Level and Biological Measurement (Single Species Studies Only)	df	Q	p	Model Results
F_v/F_m				
Pre-industrial	2	2.4	**0.2998**	Neg
500-800	5	60.8	<0.0001	NE
801-1000	4	14.7	0.0053	NE
1001-1500	1 study		N/A	Pos
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	
rETR				
Pre-industrial	0 studies		N/A	
500-800	4	31.6	<0.0001	NE
801-1000	6	37.6	<0.0001	NE
1001-1500	1 study		N/A	NE
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	

per CO_2 Level and Biological Measurement (Community Level Studies Only)	df	Q	p	Model Results
NPP				
Pre-industrial	5	15.9	**0.0072**	Neg
500-800	5	26.6	<0.0001	Neg
801-1000	0 studies		N/A	
1001-1500	0 studies		N/A	
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	
F_v/F_m				
Pre-industrial	1 study		N/A	NE
500-800	2	2.2	**0.3307**	Pos
801-1000	3	0.1	**0.9872**	NE
1001-1500	1	0.6	**0.4573**	NE
1501-2000	1	0.3	**0.5769**	NE
>2000	1	3.1	**0.0807**	Neg
rETR				
Pre-industrial	0 studies		N/A	
500-800	1 study		N/A	Pos
801-1000	1	4.1	0.0418	Neg
1001-1500	1 study		N/A	Pos
1501-2000	1 study		N/A	Neg
>2000	1	57.4	<0.0001	NE

Table S.3 continued.

per CO_2 Level and Biological Measurement	df	Q	p	Model Results
POC				
Pre-industrial	6	179.6	<0.0001	NE
500-800	9	144.7	<0.0001	NE
801-1000	7	68.8	<0.0001	NE
1001-1500	4	12.6	0.0132	Neg
1501-2000	3	3.0	**0.3976**	Neg
>2000	1 study		N/A	Neg
eCA				
Pre-industrial	5	7.8	**0.1703**	Pos
500-800	0 studies		N/A	
801-1000	6	5.9	**0.4318**	Neg
1001-1500	1 study		N/A	Neg
1501-2000	1 study		N/A	Neg
>2000	0 studies		N/A	
Fatty Acids				
Pre-industrial	0 studies		N/A	
500-800	2	0.5	**0.7806**	NE
801-1000	4	21.9	0.0002	Neg
1001-1500	0 studies		N/A	
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	

per CO_2 Level and Biological Measurement (Single Species Studies Only)	df	Q	p	Model Results
POC				
Pre-industrial	2	162.9	<0.0001	NE
500-800	4	27.9	<0.0001	NE
801-1000	0 studies		N/A	
1001-1500	1 study		N/A	NE
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	
eCA				
Pre-industrial	0 studies		N/A	
500-800	0 studies		N/A	
801-1000	1 study		N/A	Neg
1001-1500	1 study		N/A	Neg
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	
Fatty Acids				
Pre-industrial	0 studies		N/A	
500-800	2	0.5	**0.7806**	NE
801-1000	4	21.9	0.0002	Neg
1001-1500	0 studies		N/A	
1501-2000	0 studies		N/A	
>2000	0 studies		N/A	

per CO_2 Level and Biological Measurement (Community Level Studies Only)	df	Q	p	Model Results
POC				
Pre-industrial	3	2.4	**0.4892**	Neg
500-800	4	105.3	<0.0001	Neg
801-1000	4	4.9	**0.3009**	NE
1001-1500	3	2.2	**0.5200**	Neg
1501-2000	3	3.0	**0.3976**	Neg
>2000	1 study		N/A	Neg
eCA				
Pre-industrial	5	7.8	**0.1703**	Pos
500-800	0 studies		N/A	
801-1000	5	5.3	**0.3853**	Neg
1001-1500	0 studies		N/A	
1501-2000	1 study		N/A	Neg
>2000	0 studies		N/A	

Table S4: Q test and random effects model results for macroalgae.

	Q-Test Results			Model Results
	df	Q	p	
per CO_2 Level				
All levels	13	184.5	<0.0001	Negative
801-1000 μatm	7	164.3	<0.0001	Negative
1001-1500muatm	5	19.7	0.0014	No effect
per Biological Measurement				
Chlorophyll *a* concentration	2	80.0	<0.0001	Negative
Growth Rate	2	13.5	0.0012	No effect
Protein content	1	3.6	**0.0578**	No effect
rETR	2	7.7	0.0208	Negative
F_v/F_m	2	19.6	<0.0001	No effect
per CO_2 Level and Biological Measurement				
Chlorophyll *a* concentration				
801-1000 μatm	1	47.3	<0.0001	No effect
1001-1500 μatm	1 study	N/A		No effect
Growth Rate				
801-1000 μatm	1	1.0	**0.3232**	No effect
1001-1500 μatm	1 study	N/A		Positive
Protein Content				
801-1000 μatm	0 studies	N/A		
1001-1500 μatm	11	3.6	**0.0578**	No effect
rETR				
801-1000 μatm	1	0.1	**0.7347**	Negative
1001-1500 μatm	1 study	N/A		No effect
F_v/F_m				
801-1000 μatm	1	8.2	0.0041	No effect
1001-1500 μatm	1 study	N/A		No effect
per Species				
Clathromorphum obtectulum	3	151.7	<0.0001	Negative
(only studied at 801-1000 μatm)				
Desmarestia anceps	4	19.4	0.0006	No effect
(only studied at 1001-1500 μatm)				
Desmarestia menziesii	1 study	N/A		No effect
(only studied at 1001-1500 μatm)				
Hildenbrandia sp.	3	11.9	0.0079	Negative
(only studied at 801-1000 μatm)				

Table S5: Q test and random effects model results for invertebrates.

	Q-Test Results			Model Results
	df	Q	p	
per CO_2 Level				
All levels	55	754524.3	<0.0001	Negative
500-800 μatm	8	181617.2	<0.0001	No effect
801-1000 μatm	18	218.3	<0.0001	No effect
1001-1500 μatm	15	509.5	<0.0001	Negative
1501-2000 μatm	4	11910.7	<0.0001	Negative
>2000 μatm	6	369.6	<0.0001	Negative
per Biological Measurement				
Development	21	751805.0	<0.0001	No effect
Behaviour	1	35.4	<0.0001	No effect
Feeding	5	80.6	<0.0001	No effect
Growth Rate	6	1.6	**0.9496**	Positive
Lipid and Protein Content	1	0.4	**0.5191**	No effect
Shell State	10	216.8	<0.0001	Negative
Survival	3	65.8	<0.0001	Negative
per CO_2 Level and Biological Measurement				
Development				
500-800 μatm	5	181557.2	<0.0001	No effect
801-1000 μatm	3	19.1	0.0003	No effect
1001-1500 μatm	4	137.2	<0.0001	Negative
1501-2000 μatm	4	11910.7	<0.0001	Negative
>2000 μatm	1	9.2	0.0024	Negative
Behaviour				
500-800 μatm	0 studies	N/A		
801-1000 μatm	1	35.4	<0.0001	No effect
1001-1500 μatm	0 studies	N/A		
1501-2000 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		
Feeding				
500-800 μatm	0 studies	N/A		
801-1000 μatm	1	21.4	<0.0001	No effect
1001-1500 μatm	3	45.3	<0.0001	No effect
1501-2000 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		

Table S.5 continued.

	Q-Test Results			Model Results
	df	Q	p	
per CO_2 Level and Biological Measurement continued				
Growth Rate				
500-800 μatm	1 study	N/A		No effect
801-1000 μatm	2	0.2	**0.8853**	No effect
1001-1500 μatm	2	0.2	**0.8945**	No effect
1501-2000 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		
Lipid and Protein Content				
500-800 μatm	0 studies	N/A		
801-1000 μatm	1	0.4	**0.5191**	Negative
1001-1500 μatm	0 studies	N/A		
1501-2000 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		
Shell State				
500-800 μatm	1	1.1	**0.2923**	Negative
801-1000 μatm	2	14.5	0.0007	No effect
1001-1500 μatm	1 study		N/A	Negative
1501-2000 μatm	0 studies	N/A		
>2000 μatm	4	11.035	0.0262	Negative
Survival				
500-800 μatm	0 studies	N/A		
801-1000 μatm	1 study	N/A		Negative
1001-1500 μatm	2	63.5	<0.0001	Negative
1501-2000 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		

Table S6: Q test and random effects model results for fish.

	Q-Test Results			Model Results
	df	Q	p	
per CO_2 Level				
All levels	23	1428.2	<0.0001	No effect
500-800 μatm	4	6.4	**0.1701**	Positive
801-1000 μatm	10	116.6	<0.0001	No effect
1001-1500 μatm	4	110.2	<0.0001	No effect
>2000 μatm	2	31.6	<0.0001	Negative
per Biological Measurement				
Development	1	1102.2	<0.0001	Positive
CS	7	73.9	<0.0001	No effect
Growth Rate	1 study	N/A		Negative
Heart Rate	1	6.4	0.0115	No effect
Oxygen Consumption	8	221.5	<0.0001	No effect
per CO_2 Level and Biological Measurement				
Development				
500-800 μatm	1 study	N/A		Positive
801-1000 μatm	1 study	N/A		Positive
1001-1500 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		
Citrate synthase enzyme activity (CS)				
500-800 μatm	1 study	N/A		No effect
801-1000 μatm	4	65.3	<0.0001	No effect
1001-1500 μatm	1 study	N/A		No effect
>2000 μatm	0 studies	N/A		
Growth Rate				
500-800 μatm	0 studies	N/A		
801-1000 μatm	1 study	N/A		Negative
1001-1500 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		
Heart Rate				
500-800 μatm	1 study	N/A		Positive
801-1000 μatm	1 study	N/A		No effect
1001-1500 μatm	0 studies	N/A		
>2000 μatm	0 studies	N/A		
Oxygen Consumption				
500-800 μatm	0 studies	N/A		
801-1000 μatm	2	4.0	**0.1341**	Positive
1001-1500 μatm	3	106.0	<0.0001	No effect
>2000 μatm	1	11.0	0.0009	Negative