

Supplementary Material: Membrane lipid sensitivity to ocean warming and acidification poses a severe threat to Arctic pteropods

1 SUPPLEMENTARY TABLES AND FIGURES

Figures

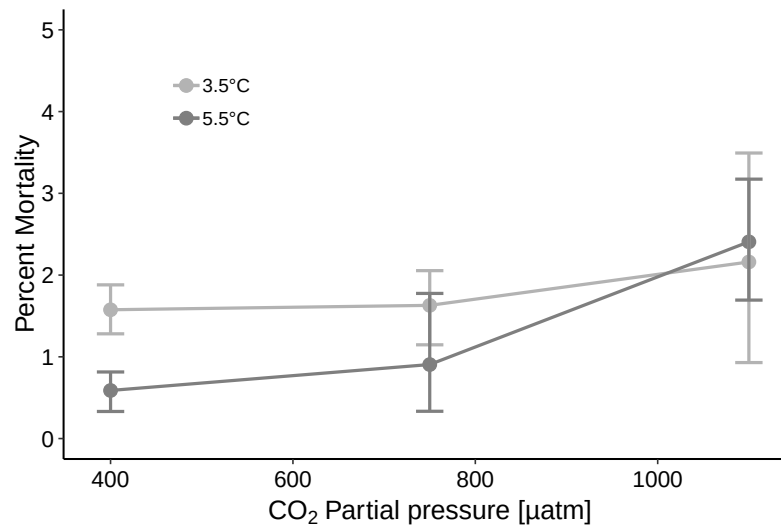


Figure S1. Mortality of pteropods as percentage of total recovered individuals at each treatment level at experiment termination. Error bars depict 95% confidence intervals.

SUPPLEMENTARY TABLES

Table S1. Mean carbonate system parameters calculated from samples taken from the prepared manipulated seawater at experiment start (22 August) and from samples of the incubation water at experiment end (29 August). The treatment column refers to target temperature [°C] and pCO₂ [μatm], of which the levels refer to present day (400 μatm, year 1990), year 2080 (750 μatm), and > year 2100 (1100 μatm) under the RCP 8.5 scenario (Rhein et al., 2013). The concentration of total CO₂ (C_T), and the saturation state of aragonite (Ω_{ar}) were derived from pH_T, total alkalinity (A_T), salinity (Sal) and temperature (T). Si is silicate. Numbers in parenthesis are Margins of Error.

Treatment		Sal	T (°C)		A _T (μmol kg ⁻¹)		pH _T		C _T (μmol kg ⁻¹)		pCO ₂ (μatm)		Ω _{ar}		Si (μmol kg ⁻¹)	
T	pCO ₂		start	end	start	end	start	end	start	end	start	end	start	end	start	end
3.5	400	32.4	3.8 (± 0.14)	3.9 (± 0.09)	2308 (± 3.33)	2321 (± 2.32)	8.082 (± 0.04)	8.038 (± 0.02)	2165 (± 14.50)	2195 (± 7.77)	364 (± 35.67)	409 (± 20.24)	1.66 (± 0.12)	1.51 (± 0.06)	1.94 (± 0.48)	2.44 (± 0.24)
3.5	750	32.5	3.9 (± 0.15)	3.6 (± 0.04)	2305 (± 5.89)	2312 (± 12.04)	7.918 (± 0.03)	7.850 (± 0.03)	2219 (± 9.46)	2242 (± 21.01)	550 (± 44.48)	651 (± 48.87)	1.18 (± 0.08)	1.06 (± 0.07)	2.30 (± 0.41)	2.16 (± 0.54)
3.5	1100	32.5	3.9 (± 0.22)	3.8 (± 0.09)	2304 (± 3.53)	2312 (± 8.18)	7.766 (± 0.03)	7.823 (± 0.05)	2264 (± 9.21)	2284 (± 23.07)	799 (± 64.10)	692 (± 105.73)	0.85 (± 0.06)	0.78 (± 0.09)	2.09 (± 0.38)	2.34 (± 0.27)
5.5	400	34.1	5.6 (± 0.20)	5.5 (± 0.04)	2309 (± 3.23)	2315 (± 6.42)	8.086 (± 0.06)	8.013 (± 0.01)	2142 (± 25.56)	2177 (± 11.02)	360 (± 59.39)	432 (± 33.53)	1.86 (± 0.23)	1.57 (± 0.11)	2.15 (± 0.61)	2.26 (± 0.29)
5.5	750	34.1	5.6 (± 0.19)	5.4 (± 0.00)	2307 (± 2.65)	2315 (± 1.18)	7.929 (± 0.04)	7.945 (± 0.01)	2200 (± 14.32)	2203 (± 1.60)	535 (± 55.52)	514 (± 8.22)	1.35 (± 0.12)	1.39 (± 0.02)	1.83 (± 0.58)	2.30 (± 0.47)
5.5	1100	34.1	5.7 (± 0.20)	5.4 (± 0.00)	2304 (± 2.53)	2315 (± 2.27)	7.773 (± 0.06)	7.894 (± 0.01)	2247 (± 16.63)	2220 (± 1.79)	789 (± 108.09)	585 (± 8.94)	0.97 (± 0.12)	1.25 (± 0.02)	1.83 (± 0.35)	2.39 (± 0.30)
Fjord																
23.08.	50 m	34.54	4.26		2284		8.203		2074		258		2.22		0.71	

Table S2. Mean lipid class composition (% contribution on total lipids) and total lipids ($\mu\text{g individual}^{-1}$) of *Limacina helicina* at the different treatment combinations (temperature [$^{\circ}\text{C}$] / pCO_2 [μatm]) at experiment termination. WE = wax ester, TAG = triacylglycerol, ST = Sterols, FFA = free fatty acids, PE = phosphatidyl ethanolamine, PI = phosphatidyl inositol, PS = phosphatidyl serine, CL = cardiolipine, PC = phosphatidyl choline, PL = phospholipids (sum of PE, PI, PS, CL, PC), TL = total lipids. ME = Margins of Error.

Treatment	3.5/400 (n = 6)	3.5/750 (n = 6)	3.5/1100 (n = 6)	5.5/400 (n = 6)	5.5/750 (n = 6)	5.5/1100 (n = 6)
	Mean $\pm$ ME	Mean $\pm$ ME	Mean $\pm$ ME	Mean $\pm$ ME	Mean $\pm$ ME	Mean $\pm$ ME
Lipid Class						
WE	3.45 $\pm$ 1.33	1.85 $\pm$ 0.62	0.38 $\pm$ 0.61	—	0.88 $\pm$ 1.05	0.30 $\pm$ 0.78
TAG	13.88 $\pm$ 5.45	9.15 $\pm$ 5.16	17.70 $\pm$ 5.44	18.88 $\pm$ 9.66	16.26 $\pm$ 3.30	18.59 $\pm$ 4.13
ST	7.96 $\pm$ 0.53	7.72 $\pm$ 1.16	17.55 $\pm$ 5.94	16.64 $\pm$ 1.77	22.88 $\pm$ 2.31	18.76 $\pm$ 3.17
FFA	11.60 $\pm$ 2.82	14.87 $\pm$ 5.60	26.37 $\pm$ 7.99	29.09 $\pm$ 4.83	33.15 $\pm$ 2.78	36.30 $\pm$ 5.50
PE	19.37 $\pm$ 3.00	22.15 $\pm$ 3.02	15.51 $\pm$ 3.49	12.66 $\pm$ 2.94	11.40 $\pm$ 1.51	9.31 $\pm$ 2.80
PI	7.11 $\pm$ 1.13	6.75 $\pm$ 0.85	6.12 $\pm$ 2.13	3.85 $\pm$ 4.48	—	—
PS	5.14 $\pm$ 0.56	4.81 $\pm$ 0.35	5.44 $\pm$ 4.49	7.80 $\pm$ 1.10	1.87 $\pm$ 3.04	7.06 $\pm$ 1.60
CL	3.54 $\pm$ 0.24	4.07 $\pm$ 1.99	2.80 $\pm$ 2.94	1.81 $\pm$ 0.39	3.55 $\pm$ 2.50	1.56 $\pm$ 0.33
PC	27.97 $\pm$ 1.45	28.64 $\pm$ 2.46	8.13 $\pm$ 1.70	9.26 $\pm$ 1.25	10.01 $\pm$ 2.01	8.12 $\pm$ 2.45
$\sum\text{PL}$	63.12 $\pm$ 4.08	66.41 $\pm$ 7.07	38.00 $\pm$ 5.83	35.38 $\pm$ 8.71	26.83 $\pm$ 3.01	26.05 $\pm$ 6.21
Total Lipid						
TL	0.19 $\pm$ 0.04	0.20 $\pm$ 0.04	0.09 $\pm$ 0.03	0.10 $\pm$ 0.03	0.06 $\pm$ 0.02	0.08 $\pm$ 0.03

Table S3. Mean contribution of fatty acids, fatty alcohols, and fatty acid classes (% contribution on the total lipid amount) of *Limacina helicina* in the different treatment combinations (temperature [°C] / pCO₂ [μatm]) at experiment termination. SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, ME = Margins of Error.

Treatment	3.5/400 (n = 5) Mean ± ME	3.5/750 (n = 5) Mean ± ME	3.5/1100 (n = 6) Mean ± ME	5.5/400 (n = 4) Mean ± ME	5.5/750 (n = 6) Mean ± ME	5.5/1100 (n = 4) Mean ± ME
Fatty Acid						
14:0	3.43 ± 0.69	3.30 ± 0.62	2.14 ± 0.91	2.23 ± 0.67	3.59 ± 0.63	4.26 ± 0.86
15:0	0.95 ± 0.08	0.18 ± 0.49	0.37 ± 0.45	0.44 ± 0.81	1.15 ± 0.08	1.08 ± 0.72
i-15:0	0.00 ± 0.00	0.00 ± 0.00	0.25 ± 0.30	0.33 ± 0.35	0.50 ± 0.41	0.24 ± 0.77
a-15:0	0.64 ± 0.55	0.41 ± 0.48	0.20 ± 0.32	0.28 ± 0.53	0.12 ± 0.30	0.57 ± 0.75
16:0	16.97 ± 0.51	17.19 ± 1.58	15.13 ± 1.86	16.16 ± 2.19	17.79 ± 1.02	19.91 ± 2.44
16:1(n-5)	0.35 ± 0.71	0.81 ± 1.06	0.77 ± 0.44	0.83 ± 1.12	0.70 ± 0.97	0.76 ± 1.46
16:1(n-7)	4.15 ± 2.71	2.81 ± 1.21	2.42 ± 0.27	2.37 ± 0.31	2.97 ± 0.89	2.64 ± 0.76
16:1(n-9)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.14 ± 0.46	0.18 ± 0.47	0.00 ± 0.00
16:2(n-4)	0.61 ± 0.44	0.54 ± 0.66	1.00 ± 0.48	1.08 ± 0.90	1.41 ± 0.56	0.58 ± 0.62
16:3(n-4)	0.26 ± 0.45	0.35 ± 0.40	0.31 ± 0.36	0.35 ± 0.65	0.60 ± 0.49	0.40 ± 0.44
16:4(n-1)	0.00 ± 0.00	0.18 ± 0.30	0.33 ± 0.28	0.37 ± 0.39	0.09 ± 0.24	0.33 ± 0.35
17:0	0.24 ± 0.42	0.49 ± 0.56	0.72 ± 0.68	0.72 ± 0.16	0.58 ± 0.76	0.99 ± 0.14
i-17:0	0.87 ± 0.99	1.10 ± 0.79	0.73 ± 0.86	0.32 ± 1.00	0.58 ± 0.94	1.86 ± 1.53
a-17:0	0.81 ± 0.92	0.70 ± 0.65	0.65 ± 0.74	0.36 ± 1.16	0.25 ± 0.63	1.84 ± 0.30
17:1(n-8)	0.18 ± 0.31	0.00 ± 0.00	0.31 ± 0.36	0.31 ± 0.57	0.18 ± 0.30	0.00 ± 0.00
18:0	10.30 ± 3.07	11.69 ± 7.06	7.76 ± 5.80	8.96 ± 5.28	6.61 ± 0.75	6.49 ± 2.66
18:1(n-7)	1.69 ± 0.43	1.63 ± 0.21	1.63 ± 0.21	1.80 ± 0.49	1.65 ± 0.87	1.90 ± 0.31
18:1(n-5)	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.82	0.00 ± 0.00	0.34 ± 0.88	0.00 ± 0.00
18:1(n-9)	2.46 ± 0.58	2.39 ± 0.73	1.53 ± 0.84	2.51 ± 0.68	2.72 ± 0.87	2.41 ± 0.37
18:2(n-6)	1.71 ± 0.74	2.37 ± 0.92	2.17 ± 0.65	2.53 ± 0.91	1.67 ± 0.49	1.38 ± 0.19
18:3(n-3)	0.70 ± 0.50	0.80 ± 0.58	0.67 ± 0.56	0.95 ± 0.31	0.62 ± 0.51	0.93 ± 0.21
18:3(n-6)	0.15 ± 0.41	0.00 ± 0.00	0.18 ± 0.45	0.00 ± 0.00	0.40 ± 0.47	0.17 ± 0.53
18:4(n-3)	2.63 ± 0.69	2.89 ± 0.81	3.16 ± 0.58	3.02 ± 1.34	2.74 ± 0.45	2.86 ± 0.62
20:0	0.49 ± 0.37	0.30 ± 0.85	0.52 ± 0.73	0.57 ± 0.60	0.36 ± 0.43	0.44 ± 0.49
20:1(n-11)	1.39 ± 1.14	1.10 ± 1.57	2.27 ± 1.45	1.70 ± 0.19	2.26 ± 0.55	2.22 ± 0.40
20:1(n-9)	5.33 ± 0.68	4.52 ± 1.27	4.39 ± 2.01	5.23 ± 0.37	5.87 ± 0.37	5.52 ± 0.30
20:1(n-7)	2.07 ± 3.21	1.36 ± 2.64	0.40 ± 0.33	0.44 ± 0.47	0.67 ± 0.05	0.35 ± 0.64
20:2(n-6)	1.17 ± 0.82	1.48 ± 0.19	1.55 ± 0.12	0.80 ± 1.48	1.44 ± 0.78	1.14 ± 1.21
20:3(n-3)	0.15 ± 0.40	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.09 ± 0.24	0.00 ± 0.00
20:4(n-6)	0.53 ± 0.38	0.42 ± 0.48	0.62 ± 0.37	0.81 ± 0.11	0.67 ± 0.35	0.70 ± 0.19
20:4(n-3)	0.59 ± 0.64	0.51 ± 0.36	0.46 ± 0.38	0.46 ± 0.49	0.65 ± 0.05	0.51 ± 0.55
20:5(n-3)	20.28 ± 3.14	21.50 ± 3.72	25.32 ± 2.24	23.36 ± 4.60	21.79 ± 1.57	19.81 ± 2.04
22:1(n-11)	1.35 ± 2.02	0.26 ± 0.73	0.00 ± 0.00	0.00 ± 0.00	0.27 ± 0.70	0.11 ± 0.34
22:1(n-9)	0.41 ± 0.71	0.11 ± 0.31	0.00 ± 0.00	0.00 ± 0.00	0.12 ± 0.31	0.00 ± 0.00
22:5(n-3)	0.54 ± 0.39	0.40 ± 0.46	0.49 ± 0.40	0.70 ± 0.17	0.37 ± 0.42	0.44 ± 0.47
22:6(n-3)	16.60 ± 2.85	18.19 ± 2.83	21.02 ± 1.90	19.84 ± 3.86	18.00 ± 1.73	17.16 ± 1.84
Fatty Alcohol						
14:0	48.81 ± 38.24	22.79 ± 19.99	44.14 ± 18.03	46.60 ± 57.00	51.34 ± 9.74	68.35 ± 33.58
16:0	14.20 ± 16.81	17.54 ± 15.79	30.41 ± 13.39	18.94 ± 21.09	32.86 ± 18.32	31.65 ± 33.58
16:1(n-7)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	9.97 ± 31.69	0.00 ± 0.00	0.00 ± 0.00
18:1(n-9)	20.70 ± 26.15	44.76 ± 46.90	13.09 ± 15.86	17.48 ± 32.87	15.80 ± 27.29	0.00 ± 0.00
18:1(n-7)	0.00 ± 0.00	6.57 ± 16.34	12.36 ± 14.97	7.02 ± 22.33	0.00 ± 0.00	0.00 ± 0.00
20:1(n-9)	6.04 ± 16.80	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
22:1(n-11)	10.25 ± 17.45	8.34 ± 12.47	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
22:1(n-9)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Fatty Acid Class						
SFA	34.70 ± 3.83	35.36 ± 9.79	28.48 ± 6.98	30.38 ± 9.60	31.52 ± 2.79	37.69 ± 6.05
MUFA	19.38 ± 9.17	15.01 ± 4.08	14.23 ± 1.47	15.33 ± 1.29	17.95 ± 3.85	15.91 ± 2.13
PUFA	45.92 ± 6.45	49.63 ± 6.88	57.30 ± 5.78	54.28 ± 8.92	50.54 ± 4.47	46.40 ± 4.76

REFERENCES

Rhein, M., Rintoul, R., Aoki, S., Campos, E., Chambers, D., Feely, R., et al. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA), chap. Observations: Ocean. 255–297