

## Supplementary Materials

### Coral calcification in a warming ocean and the interactive effects of temperature and light

#### Supplementary Materials

Fig. S1. Treatment effects (temperature and light) on coral response variables.

Fig. S2. Timeseries of coral calcifying fluid carbonate chemistry parameters.

Table S1. Statistical results for the effect of treatment, time, temperature, and light on  $F_v/F_m$ .

Table S2. Statistical results for the effect of time, temperature, and light on net photosynthesis ( $P_{net}$ ) and dark respiration rates ( $R_{net}$ ).

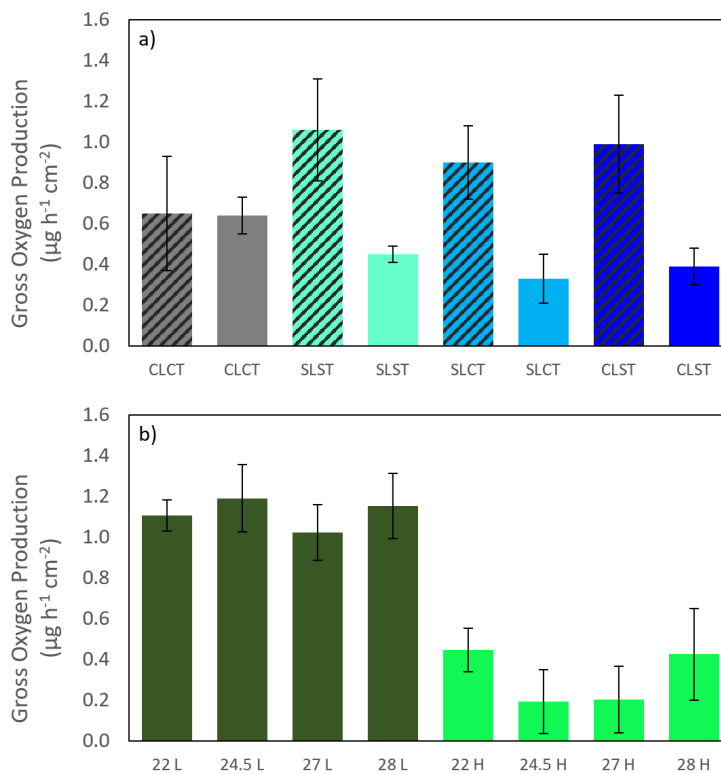
Table S3. Statistical results for the effect of time, temperature, and light on coral calcifying fluid carbonate chemistry

Table S4. Statistical results for the effect of temperature, light, and time on calcification rates.

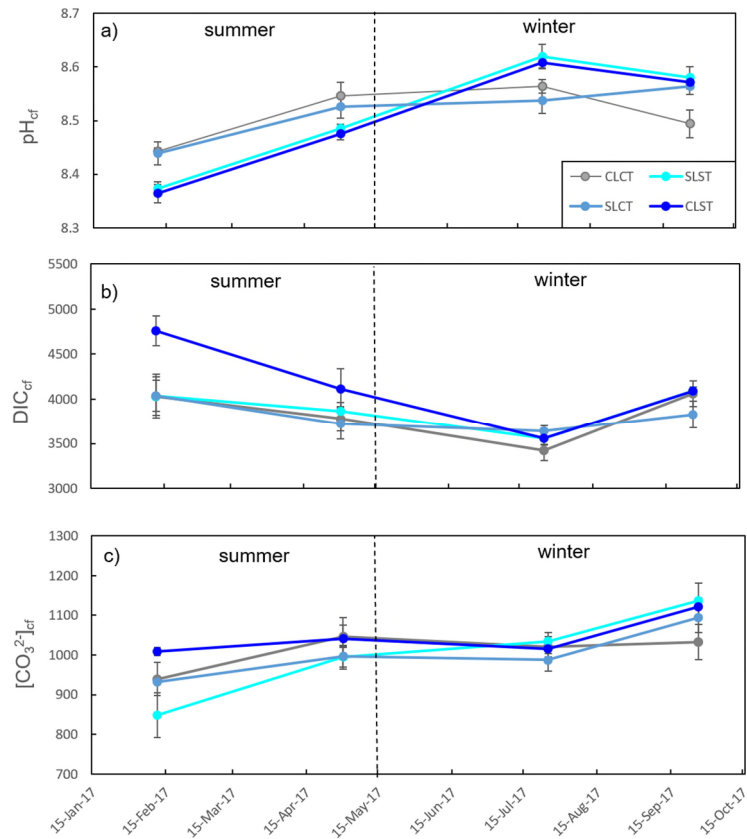
Table S5. Summary of the published coral  $pH_{cf}$ -temperature relationships from linear regression (in the form  $pH_{cf} = m \times T(^{\circ}C) + b$ ).

Table S6. Summary of the published relationships between coral  $pH_{cf}$  and  $DIC_{cf}$  from linear regression in the form of  $pH_{cf} = m \times DIC_{cf/sw} + b$ .

## Supplementary Figures



**Figure S1. Treatment effects (temperature and light) on coral response variables.** Changes in (a, b) gross photosynthesis for the coral *Acropora nasuta*. On the top is experiment 1 during summer (stripes) and winter (no stripes) for the three treatments with seasonally variable temperature and/or light, and the control treatment (grey). On the right is experiment 2 showing each of the eight temperature and light treatments at the end of the experiment. Values shown are mean  $\pm$  SE. Treatment conditions for experiment 1 are the following: constant light and constant temperature (CLCT), seasonal light and constant temperature (SLCT), constant light and seasonal temperature (CLST), and seasonal light and seasonal temperature; (SLST). Treatment conditions for experiment 2 consist of high (28H, 27H, 24.5H, and 22H) and low (28L, 27L, 24.5L, 22L) light diurnal PAR cycles at each of the four temperatures (28°C, 27°C, 24.5°C, and 22°C). See Table 1 for summary of the treatment conditions.



**Figure S2. Timeseries of coral calcifying fluid carbonate chemistry parameters.** (a) pH<sub>cf</sub>, (b) DIC<sub>cf</sub>, and (c) [CO<sub>3</sub><sup>2-</sup>]<sub>cf</sub> for *A. nasuta* during Experiment 1. Values shown are mean ± SE. Treatment conditions for experiment 1 are the following: constant light and constant temperature (CLCT), seasonal light and constant temperature (SLCT), constant light and seasonal temperature (CLST), and seasonal light and seasonal temperature; (SLST).

**Table S1. Effects of temperature, light and time on photo-physiology.** Statistical results for the effect of treatment, time, temperature, and light on photo-physiology ( $F_v/F_m$ ). Bold values are significant ( $p < 0.05$ ).

	Effect	<i>df</i>	F statistic	<i>p</i> value	AICc	
Exp. 1 (7 time points)	Treatment	1,26	3.997	<b><i>p</i> &lt; 0.001</b>	n/a	
	Temp	1, 212	1.552	0.214	-833.95	
	Light	1, 212	4.288	<b>0.040</b>	-836.52	
	Time (season)	1, 212	5.836	<b>0.017</b>	-837.11	
	Temp: Light	1, 210	24.145	<b><i>p</i> &lt; 0.001</b>	-856.80	
	Temp: Time	1, 210	1.933	0.166	-841.45	
	Light: Time	1, 210	18.931	<b><i>p</i> &lt; 0.001</b>	-859.65	
	Temp: Light: Time	1, 206	3.919	<b>0.049</b>	-871.27	
	Exp. 2 (14 time points)	Treatment	1, 47	8.08	<b><i>p</i> &lt; 0.001</b>	n/a
		Temp	1, 622	0.664	0.415	-2401.40
Light		1, 622	182.100	<b><i>p</i> &lt; 0.001</b>	-2644.80	
Time (no. days)		1, 622	127.070	<b><i>p</i> &lt; 0.001</b>	-2463.90	
Temp: Light		1, 620	2.615	0.106	-2650.50	
Temp: Time		1, 620	88.400	<b><i>p</i> &lt; 0.001</b>	-2508.00	
Light: Time		1, 620	86.309	<b><i>p</i> &lt; 0.001</b>	-2810.50	
Temp: Light: Time		1, 616	21.306	<b><i>p</i> &lt; 0.001</b>	-2912.90	

**Table S2: Effects of temperature, light and time on coral metabolic rates.** Statistical results for the effect of time, temperature, and light on net photosynthesis ( $P_{\text{net}}$ ), gross photosynthesis ( $P_{\text{gross}}$ ) and dark respiration rates ( $R_{\text{net}}$ ). Bold values are significant ( $p < 0.05$ ).

		Effect	df	F statistic	p value	AICc	
$P_{\text{gross}}$	Exp. 1 (2 time points)	Temp	1, 54	12.597	<b>p &lt; 0.001</b>	44.94	
		Light	1, 54	8.471	<b>0.005</b>	48.32	
		Time	1, 54	11.211	<b>p &lt; 0.001</b>	45.99	
		Interactions:					
		Temp: Light	1, 52	1.544	0.220	44.19	
		Temp: Time	1, 52	0.985	0.320	43.34	
		Light: Time	1, 52	5.009	<b>0.030</b>	45.81	
		Temp: Light: Time	1, 48	0.065	0.800	48.75	
	Exp. 2 (1 time point)	Temp	1, 46	0.046	0.831	80.65	
		Light	1, 46	60.590	<b>p &lt; 0.001</b>	41.63	
Temp: Light		1, 44	0.022	0.883	46.17		
$P_{\text{net}}$	Exp. 1 (2 time points)	Temp	1, 56	36.193	<b>p &lt; 0.001</b>	53.52	
		Light	1, 56	8.681	<b>0.005</b>	71.04	
		Time	1, 56	12.046	<b>p &lt; 0.001</b>	68.19	
		Interactions:					
		Temp: Light	1, 54	2.127	0.151	52.92	
		Temp: Time	1, 54	0.592	0.446	53.02	
		Light: Time	1, 54	7.2682	<b>0.009</b>	68.23	
		Temp: Light: Time	1, 50	0.207	0.651	59.27	
	Exp. 2 (1 time point)	Temp	1, 46	2.526	0.119	68.38	
		Light	1, 46	28.211	<b>p &lt; 0.001</b>	52.36	
Temp: Light		1, 44	0.125	0.725	52.99		
$R_{\text{net}}$	Exp. 1 (2 time points)	Temp	1, 54	46.983	<b>p &lt; 0.001</b>	-62.24	
		Light	1, 54	1.699	<b>0.198</b>	-31.40	
		Time	1, 54	2.751	0.103	-32.39	
		Interactions:					
		Temp: Light	1, 52	0.040	0.843	-58.32	
		Temp: Time	1, 52	0.713	0.403	-57.86	
		Light: Time	1, 52	2.788	0.101	-28.56	
		Temp: Light: Time	1, 48	1.270	0.265	-49.71	
	Exp. 2 (1 time point)	Temp	1, 46	5.316	<b>0.026</b>	-7.72	
		Light	1, 46	38.383	<b>p &lt; 0.001</b>	-15.18	
Temp: Light		1, 44	0.282	0.598	-23.40		

**Table S3: Effects of temperature, light and time on coral calcifying fluid carbonate chemistry.** Statistical results for the effect of time, temperature, and light on coral calcifying fluid carbonate chemistry (DIC<sub>cf</sub>, pH<sub>cf</sub>, and [CO<sub>3</sub><sup>2-</sup>]<sub>cf</sub>). Bold values are significant ( $p < 0.05$ ).

		Effect	<i>df</i> 1, <i>df</i> 2	F statistic	<i>p</i> value	AICc
pH <sub>cf</sub>	Exp. 1 (4 time points)	Temp	1, 61	88.53	<b><math>p &lt; 0.001</math></b>	-188.34
		Light	1, 61	10.007	<b>0.002</b>	-142.33
		Time	1, 61	65.092	<b><math>p &lt; 0.001</math></b>	-177.75
		Interactions:				
		Temp: Light	1, 59	0.319	0.574	-193.40
		Temp: Time	1, 59	18.496	<b><math>p &lt; 0.001</math></b>	-212.78
		Light: Time	1, 59	0.003	0.958	-181.17
		Temp: Light: Time	1, 55	1.266	0.266	-211.89
	Exp. 2 (1 time point)	Temp	1, 46	4.192	<b>0.046</b>	-123.71
		Light	1, 46	27.363	<b><math>p &lt; 0.001</math></b>	-141.35
Temp: Light		1, 44	0.412	0.524	-141.90	
DIC <sub>cf</sub>	Exp. 1 (4 time points)	Temp	1, 61	9.394	<b>0.003</b>	931.71
		Light	1, 61	7.262	<b>0.009</b>	932.41
		Time	1, 61	5.515	<b>0.022</b>	933.53
		Interactions:				
		Temp: Light	1, 59	1.440	0.235	930.07
		Temp: Time	1, 59	28.784	<b><math>p &lt; 0.001</math></b>	912.19
		Light: Time	1, 59	2.421	0.125	930.59
		Temp: Light: Time	1, 55	5.790	<b>0.019</b>	912.74
	Exp. 2 (1 time point)	Temp	1, 46	0.258	0.614	728.12
		Light	1, 46	44.909	<b><math>p &lt; 0.001</math></b>	697.13
Temp: Light		1, 44	0.390	0.536	700.14	
[CO <sub>3</sub> <sup>2-</sup> ] <sub>cf</sub>	Exp. 1 (4 time points)	Temp	1, 62	17.294	<b><math>p &lt; 0.001</math></b>	747.21
		Light	1, 62	1.512	0.223	761.02
		Time	1, 62	37.126	<b><math>p &lt; 0.001</math></b>	733.64
		Interactions:				
		Temp: Light	1, 60	11.454	<b><math>p &lt; 0.001</math></b>	740.74
		Temp: Time	1, 60	0.939	0.3365	736.47
		Light: Time	1, 60	11.513	<b><math>p &lt; 0.001</math></b>	727.37
		Temp: Light: Time	1, 56	4.973	<b>0.030</b>	728.51
	Exp. 2 (1 time point)	Temp	1, 46	11.997	<b><math>p &lt; 0.001</math></b>	497.40
		Light	1, 46	6.172	<b>0.017</b>	502.78
Temp: Light		1, 44	0.051	0.823	496.41	

**Table S4: Effects of temperature, light and time on coral calcification rates.** Statistical results for the effect of temperature, light, and time on calcification rates. Bold values are significant ( $p < 0.05$ ).

	Effect	<i>df</i>	F statistic		<i>p</i> value	AICc
Exp. 1 (9 time points)	Temp	1, 238	20.658		<b><math>p &lt; 0.001</math></b>	350.07
	Light	1, 238	44.636		<b><math>p &lt; 0.001</math></b>	333.49
	Time	1, 238	55.924		<b><math>p &lt; 0.001</math></b>	324.16
	Interactions:					
	Temp: Light	1, 236	1.220		0.270	324.67
	Temp: Time	1, 236	55.145		<b><math>p &lt; 0.001</math></b>	309.89
	Light: Time	1, 236	5.875		<b>0.0161</b>	311.05
	Temp: Light: Time	1, 232	4.782		<b>0.030</b>	304.38
Exp. 2 (4 time points)	Temp	1, 190	0.121		0.728	-2401.40
	Light	1, 190	73.806		<b><math>p &lt; 0.001</math></b>	-2644.80
	Time	1, 190	42.466		<b><math>p &lt; 0.001</math></b>	-2463.90
	Interactions:					
	Temp: Light	1, 188	1.503		0.221	-2650.50
	Temp: Time	1, 188	39.674		<b><math>p &lt; 0.001</math></b>	-2508.00
	Light: Time	1, 188	1.283		0.259	-2810.50
	Temp: Light: Time	1, 184	3.482		0.064	-2912.90

**Table S5. Relationships between temperature and coral calcifying fluid pH.** Summary of the published relationships between temperature (T °C) and pH<sub>cf</sub> from linear regression (in the form pH<sub>cf</sub> = m × T(°C) + b) for various coral taxa and locations. Note that for Guo et al., (2019), the relationship presented is for ΔpH<sub>cf</sub> (i.e. pH<sub>cf</sub> elevation above seawater pH).

Location	Coral species and colony ID	T (°C)	m	b	r <sup>2</sup>	Reference
Aquaria study	<i>Acropora nasuta</i>	22-27	-0.05	9.70	0.64	This study (experiment 1)
Aquaria study	<i>Acropora nasuta</i>	22-28	-0.01	8.68	0.14	This study (experiment 2)
Aquaria study	<i>Stylophora pistillata</i>	28 and 31	n/a	n/a	n/a	(Guillermic et al. 2021)
Aquaria study	<i>Pocillopora damicornis</i>	28 and 31	n/a	n/a	n/a	(Guillermic et al. 2021)
Numerical modelling*	<i>Porites</i>	20-30	-0.04	n/a	n/a	(Guo 2019)
Numerical modelling*	<i>Desmophyllum dianthus</i>	5-15	-0.015	n/a	n/a	(Guo 2019)
Davies Reef, Great Barrier Reef, Australia	<i>Porites</i> (D-2)	22-29	-0.02	9.00	0.85	(McCulloch et al. 2018)
Davies Reef, Great Barrier Reef, Australia	<i>Porites</i> (D-3)	22-29	-0.03	9.30	0.93	(McCulloch et al. 2018)
Lizard Island, Great Barrier Reef, Australia (1994-2013)	<i>Porites australiensis</i> (LIZ13_1)	22-29	-0.030	9.173	0.94	(D'Olivo et al. 2019)
Shell Island, South Kimberley, Western Australia	<i>Acropora aspera</i>	26-31	-0.014	8.81	n/a	(Schoepf et al. 2021)
Coral Bay, Western Australia	<i>Acropora muricata</i>	22-28	-0.02	8.81	0.27	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Pocillopora damicornis</i>	22-28	-0.01	8.67	0.28	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Acropora nasuta</i>	22-28	-0.02	8.85	0.24	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Acropora pulchra</i>	22-28	-0.01	8.54	0.38	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Stylophora pistillata</i>	22-28	-0.02	8.82	0.68	(Ross et al. 2019)
Rottnest Island, Western Australia	<i>Acropora yongei</i>	18-24	-0.04	9.23	0.59	(Ross et al. 2017)
Rottnest Island, Western Australia	<i>Pocillopora damicornis</i>	18-24	-0.04	9.36	0.73	(Ross et al. 2017)
Bremer Bay, Western Australia	<i>Turbinaria reniformis</i>	16-22	-0.03	9.02	0.49	(Ross et al. 2018)



**Table S6. Relationships between temperature and coral calcifying fluid dissolved inorganic carbon.** Summary of the published relationships between coral  $\text{pH}_{\text{cf}}$  and  $\text{DIC}_{\text{cf}}$  from linear regression in the form of  $\text{pH}_{\text{cf}} = m \times \text{DIC}_{\text{cf}}/\text{DIC}_{\text{sw}} + b$ . Note that for Cornwall et al., (2018), the relationship presented is for  $\text{DIC}_{\text{cf}}$  instead of  $\text{DIC}_{\text{cf}}/\text{DIC}_{\text{sw}}$ .

Location of study or coral collection	Coral species and colony ID	T (°C)	m	b	r <sup>2</sup>	Reference
Aquaria study (Coral Bay, Western Australia)	<i>Acropora nasuta</i>	22-27	-0.36	9.23	0.54	This study (experiment 1)
Aquaria study (Coral Bay, Western Australia)	<i>Acropora nasuta</i>	22-28	-0.23	8.93	0.69	This study (experiment 2)
Aquaria study (Kimberley region, Western Australia)	<i>Goniopora</i>	36.2	-0.002	9.07	0.55	(Cornwall et al. 2018)
Aquaria study (Rottnest Island, Western Australia)	<i>Acropora yongei</i>	22	-0.35	9.11	0.41	(Comeau et al. 2017)
Aquaria study (Rottnest Island, Western Australia)	<i>Pocillopora damicornis</i>	22	-0.40	9.09	0.29	(Comeau et al. 2017)
Aquaria study (Rottnest Island, Western Australia)	<i>Acropora yongei</i>	20	-0.057	8.45	0.17	(Comeau et al. 2018)
Aquaria study (Rottnest Island, Western Australia)	<i>Pocillopora damicornis</i>	20	-0.048	8.44	0.29	(Comeau et al. 2018)
Aquaria study (Rottnest Island, Western Australia)	<i>Acropora yongei</i>	20.5	-0.043	8.55	0.08	Comeau et al. 2019
Aquaria study (Rottnest Island, Western Australia)	<i>Plesiastrea</i>	20.5	-0.349	9.10	0.19	Comeau et al. 2019
Aquaria study (Rottnest Island, Western Australia)	<i>Acropora yongei</i>	22	-0.35	9.11	0.41	(Comeau et al. 2017)
Davies Reef, Great Barrier Reef, Australia	<i>Porites</i> (D-2)	22-29	-0.19	9.00	0.90	McCulloch et al., (2017)
Davies Reef, Great Barrier Reef, Australia	<i>Porites</i> (D-3)	22-29	-0.24	9.00	0.94	McCulloch et al., (2017)
Coral Bay, Western Australia	<i>Porites</i>	22-28	-0.30	9.20	0.93	McCulloch et al., (2017)
Coral Bay, Western Australia	<i>Porites</i>	22-28	-0.32	9.10	0.88	McCulloch et al., (2017)
Coral Bay, Western Australia	<i>Acropora muricata</i>	22-28	-0.33	9.00	0.78	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Pocillopora damicornis</i>	22-28	-0.28	8.86	0.88	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Acropora nasuta</i>	22-28	-0.23	8.81	0.33	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Acropora pulchra</i>	22-28	0.04	8.3	0.09	(Ross et al. 2019)
Coral Bay, Western Australia	<i>Stylophora pistillata</i>	22-28	0.15	8.02	0.16	(Ross et al. 2019)
Rottnest Island, Western Australia	<i>Acropora yongei</i>	18-24	-0.38	9.27	0.56	(Ross et al. 2017)
Rottnest Island, Western Australia	<i>Pocillopora damicornis</i>	18-24	-0.43	9.20	0.49	(Ross et al. 2017)
Bremer Bay, Western Australia	<i>Turbinaria reniformis</i>	16-21	-0.27	9.04	0.46	(Ross et al. 2018)

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