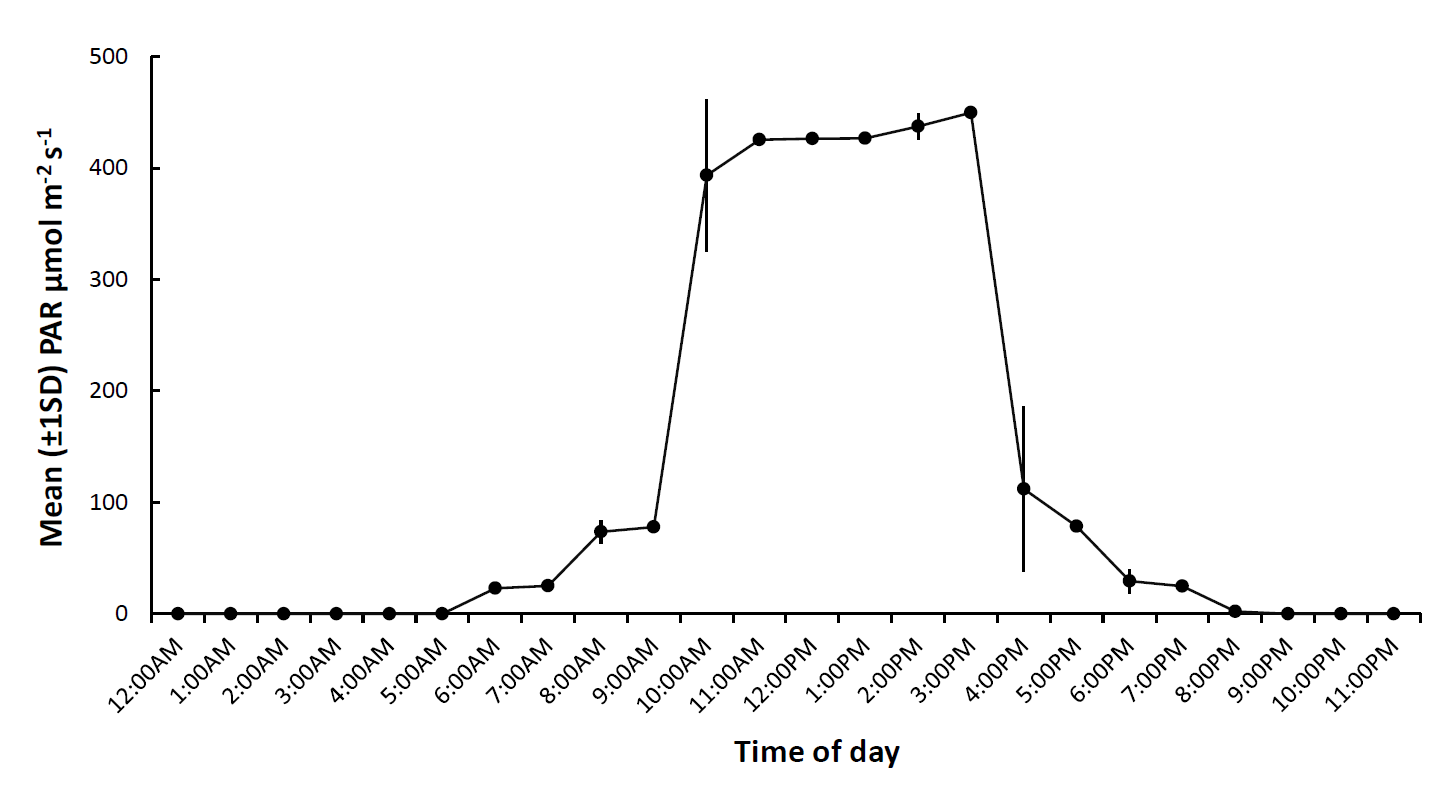
Supplementary Material



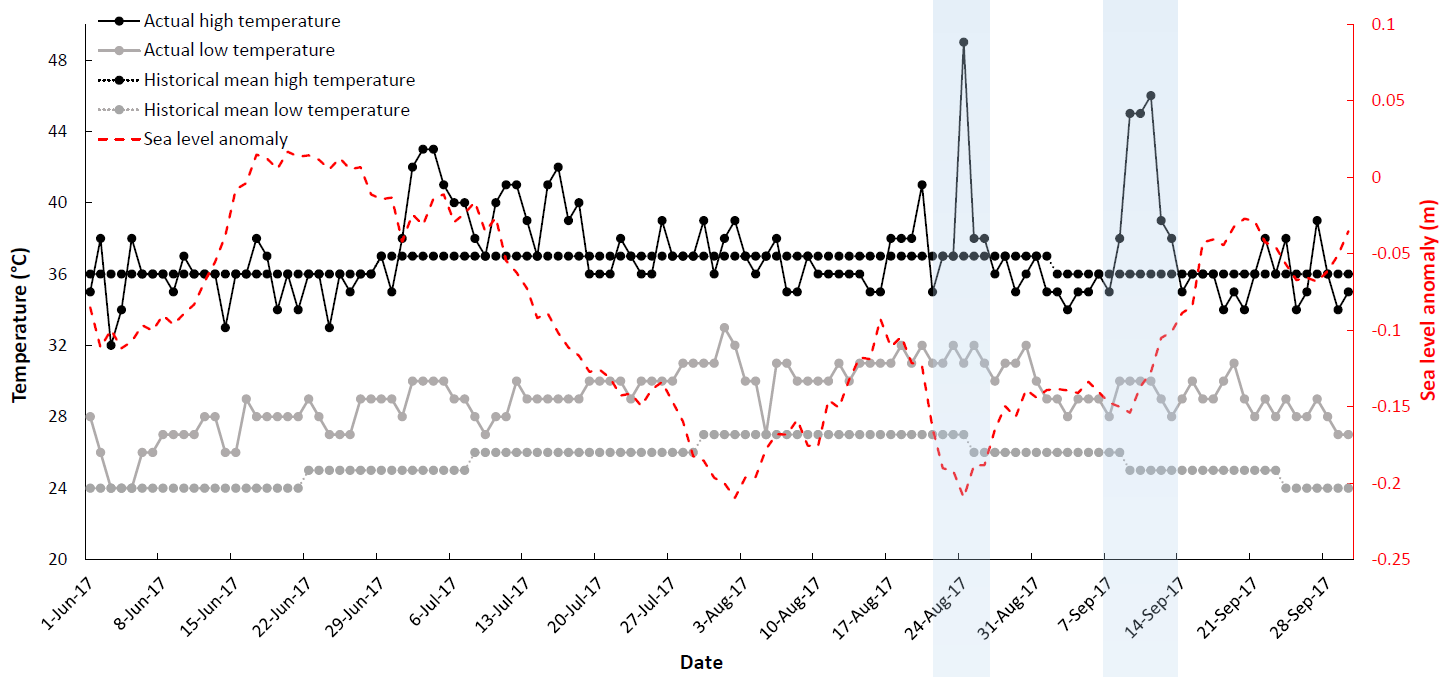
(a)

(b)

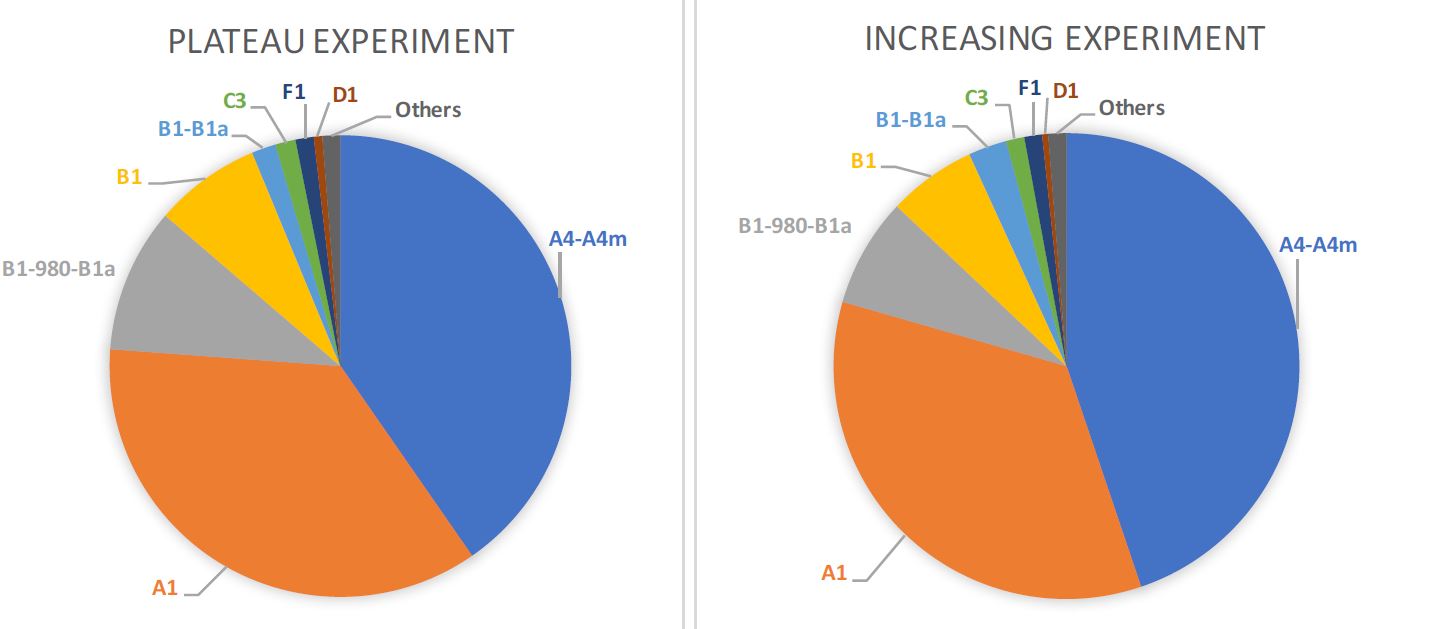
**Figure S1** (a) Non-bleached (typical) *Cassiopea* sp. observed prior to bleaching event and, (b) representative example of bleached *Cassiopea* sp. population observed 12th September, 2017 in a shallow, semi-enclosed lagoon ecosystem (0.2-1m depth, 22.39°N, 39.13°E) in the central Red Sea.

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**Figure S2** Mean (±1SD) Photosynthetic Active Radiation (PAR) regime over a 24h cycle across all five experimental treatments during the experiment.

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**Figure S3** Actual and historical (mean) atmospheric maximum temperature data for Thuwal, Saudi Arabia for 1st June – 28th September, 2017 (obtained from AccuWeather©). Near-real-time (NRT) sea level anomaly data for the same period and location were generated using *E.U Copernicus Marine Service Information* (<http://marine.copernicus.eu/>). Orange arrow indicates when *Cassiopea* sp. medusae bleaching was observed and blue (shaded) panels represent extreme temperature anomalies preceding the bleaching event.



**(a)**

**(b)**

**Figure S4** Typical,mean percent (%) composition ofSymbiodiniaceae ITS2 types within holobionts in (a) the ‘Plateau’ experiment (Part II: control, SPlat, OPlat, *n*=33) and (b) the ‘Increasing’ experiment (Part III: control, SIncr, OIncr, *n*= 31) sampled at Day 1, Day 13, and post-bleaching, identified using SymPortal [see, 1].

**Table S1** Sizes of medusae (mm) allocated to each treatment in Experiment Part I and II, including mean medusae size and ± 1SE (standard error) for each treatment. A one-way ANOVA (dependent variable = size (mm), factor = treatment (five levels: control, SPlat, OPlat, SIncr, OIncr) revealed no significant difference between medusae sizes among the five treatments (*P* = 0.776, *F*= 0.444, Df = 4) in this study.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Replicate medusae | Control | Stable Plateau (SPlat) | Oscillating Plateau (OPlat) | Stable Increasing (SIncr) | Oscillating Increasing (OIncr) |
| 1 | 61 | 72 | 61 | 94 | 81 |
| 2 | 68 | 87 | 72 | 78 | 62 |
| 3 | 88 | 89 | 85 | 78 | 68 |
| 4 | 73 | 78 | 64 | 88 | 82 |
| 5 | 75 | 50 | 73 | 80 | 82 |
| 6 | 65 | 95 | 72 | 69 | 68 |
| 7 | 85 | 62 | 79 | 48 | 76 |
| 8 | 43 | 42 | 82 | 84 | 59 |
| 9 | 71 | 89 | 75 | 68 | 77 |
| 10 | 81 | 86 | 51 | 50 | 77 |
| 11 | 66 | 91 | 59 | 81 | 80 |
| Mean ± 1SE | 70.54 ± 3.76 | 70.27 ± 3.14 | 76.45 ± 5.38 | 74.36 ± 4.39 | 73.81 ± 2.47 |
|  |  |  |  |  |  |

**Table S2** Summary of results for three repeated LMMs comparing bell contractions (min-1), medusae size (% change), and maximum photochemical efficiency (Fv/Fm) between treatments in the ‘Plateau’ experiment (Part II: control, SPlat, OPlat) during the first 14 days of exposure (Days 1-14). Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable |  |  | Bell contractions (min-1) | Medusae size (% change) | Maximum photochemical efficiency (Fv/Fm) |
| Transformation |  |  | Ln | Ln(*x* + *a\** +1) | None |
| Repeated covariance type |  |  | AR(1) | AR(1) | CS |
| Information Criterion |  |  | BIC= 114.959 AIC= 109.540 | BIC= 14.741 AIC= 9.322 | BIC= -287.275 AIC= -292.694 |
| Source of variation | **Df** | **Denominator Df** | ***P*** | ***P*** | ***P*** |
| Treatment | 2 | 32.748 | **0.004** *F=6.409* | **<0.001** *F=24.498* | **<0.001** *F=49.257* |
| Exposure time | 5 | 79.254 | **0.009** *F=3.350* | **<0.001** *F=23.462* | **<0.001** *F=26.718* |
| Treatment × Exposure time | 10 | 79.254 | **0.001** *F=3.404* | **<0.001** *F=23.202* | **<0.001** *F=13.500* |

\**a=*min value of the dependent variable.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable |  |  | Bell contractions (min-1) | Medusae size (% change) | Maximum photochemical efficiency (Fv/Fm) |
| Transformation |  |  | None | None | None |
| Information Criterion |  |  | BIC= 44.850 AIC= 45.058 | BIC= 37.063 AIC= 37.271 | BIC= -15.709 AIC= -15.500 |
| Source of variation | **Df** | **Denominator Df** | ***P*** | ***P*** | ***P*** |
| Treatment | 1 | 5 | 0.306 *F=1.254* | **0.017** *F=10.594* | **0.001** *F=41.092* |

**Table S3** Summary of results for three LMMs comparing bell contractions (min-1), medusae size (% change), and maximum photochemical efficiency (Fv/Fm) between treatments in the ‘Plateau’ experiment (Part II: Control and OPlat) that remained after 16 days of exposure. Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

**Table S4** Summary of results for five two-way LMMs comparing Symbiodiniaceaecell density (µg-1 total protein) and total chlorophyllcontent cell-1 (pg) between treatments in the ‘Plateau’ experiment (Part II: control, SPlat, OPlat) after 1 and 13 days of exposure. Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable |  |  | *Symbiodiniaceae* celldensity  (µg-1 total protein) | Total Chlcontent  (pg cell-1) |
| Transformation |  |  | None | Ln |
| Information Criterion |  |  | BIC= 47.177 AIC= 46.469 | BIC= 10.296 AIC= 9.588 |
| Source of variation | **Df** | **Denominator Df** | ***P*** | ***P*** |
| Treatment | 2 | 15 | 0.646 *F=0.449* | 0.222 *F=1.668* |
| Exposure time | 1 | 15 | 0.843 *F=0.041* | 0.231 *F=1.556* |
| Treatment × Exposure time | 2 | 15 | 0.810 *F=0.214* | 0.719 *F=0.338* |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable |  |  | *Symbiodiniaceae* celldensity  (µg-1 total protein) | Total Chlcontent  (pg cell-1) | |
| Transformation |  |  | Ln(*x* + 1) | | Ln( *x*+ 1) | |
| Information Criterion |  |  | BIC= 12.115 AIC= 11.917 | | BIC= 17.422 AIC= 17.225 | |
| Source of variation | **Df** | **Denominator Df** | ***P*** | | ***P*** | |
| Treatment | 2 | 9 | **0.001** *F=14.634* | | 0.068 *F=3.682* | |

**Table S5** Summary of results for five LMMs comparing Symbiodiniaceaecell density (µg-1 total protein) and total chlorophyll content cell-1 (pg) between treatments in the ‘Plateau’ experiment (Part II: control, SPlat, OPlat), post-bleaching. Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

\**a=*min value of the dependent variable.

**Table S6** Summary of results for three repeated LMMs comparing bell contractions (min-1), medusae size (% change), and maximum photochemical efficiency (Fv/Fm) between treatments in the ‘Increasing’ experiment (Part III: control, SIncr, OIncr) during the first 14 days of exposure (Days 1-14). Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable |  |  | Bell contractions (min-1) | Medusae size (% change) | Maximum photochemical efficiency (Fv/Fm) |
| Transformation |  |  | Ln | Ln(*x* + *a\** +1) | Ln(*x* + 1) |
| Repeated covariance type |  |  | AR(1) | AR(1) | AR(1) |
| Information Criterion |  |  | BIC=120.522 AIC= 115.103 | BIC= 81.682 AIC= 76.263 | BIC= -367.961 AIC= -373.380 |
| Source of variation | **Df** | **Denominator Df** | ***P*** | ***P*** | ***P*** |
| Treatment | 2 | 30.322 | 0.105 *F=2.429* | **0.016** *F=4.973* | **<0.001** *F=26.221* |
| Exposure time | 5 | 78.463 | **<0.001** *F=8.411* | **0.002** *F=4.355* | **<0.001** *F=17.336* |
| Treatment × Exposure time | 10 | 78.463 | **0.020** *F=2.307* | **<0.001** *F=4.956* | **<0.001** *F=11.668* |

\**a=*min value of the dependent variable.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable |  |  | Bell contractions (min-1) | Medusae size (% change) | Maximum photochemical efficiency (Fv/Fm) |
| Transformation |  |  | None | None | Ln (*x* +1) |
| Information Criterion |  |  | BIC= 36.612 AIC= 37.003 | BIC= 40.508 AIC= 40.898 | BIC= -18.773 AIC= -18.383 |
| Source of variation | **Df** | **Denominator Df** | ***P*** | ***P*** | ***P*** |
| Treatment | 2 | 8 | **0.010** *F=15.973* | **0.049** *F=6.732* | **<0.001** *F=294.056* |

**Table S7** Summary of results for three LMMs comparing bell contractions (min-1), medusae size (% change), and maximum photochemical efficiency (Fv/Fm) between treatments in the ‘Increasing’ experiment (Part III: control and OIncr) that remained after 16 days of exposure. Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

**Table S8** Summary of results for five two-way LMMs comparing Symbiodiniaceaecell density (µg-1 total protein) and total chlorophyll content cell-1 (pg) between treatments in the ‘Increasing’ experiment (Part III: control, SIncr, OIncr) after 1 and 13 days of exposure. Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable |  |  | *Symbiodiniaceae* celldensity  (µg-1 total protein) | Total Chlcontent  (pg cell-1) |
| Transformation |  |  | None | Ln |
| Information Criterion |  |  | BIC= 39.559 AIC= 38.851 | BIC= 16.368 AIC= 15.660 |
| Source of variation | **Df** | **Denominator Df** | ***P*** | ***P*** |
| Treatment | 2 | 15 | 0.251 *F=1.517* | 0.731 *F=0.320* |
| Exposure time | 1 | 15 | 0.961 *F=0.002* | 0.702 *F=0.152* |
| Treatment × Exposure time | 2 | 15 | 0.638 *F=0.463* | 0.393 *F=0.995* |

**Table S9** Summary of results for five LMMs comparing Symbiodiniaceaecell density (µg-1 total protein) and total chlorophyll content cell-1 (pg) between treatments in the ‘Increasing’ experiment (Part III: control, SIncr, OIncr), post-bleaching. Df= degrees of freedom. AIC =Akaike information criterion, BIC = Bayesian information criterion. *P* values in bold are statistically significant (*P*<0.05).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable |  |  | *Symbiodiniaceae* celldensity  (µg-1 total protein) | Total Chlcontent  (pg cell-1) |
| Transformation |  |  | Ln(*x* + 1) | Ln(*x* + 1) |
| Information Criterion |  |  | BIC= 9.797 AIC= 9.851 | BIC= 6.942 AIC= 6.978 |
| Source of variation | **Df** | **Denominator Df** | ***P*** | ***P*** |
| Treatment | 2 | 7 | **0.007** *F=10.905* | 0.152 *F=2.500* |

\**a=*min value of the dependent variable.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable |  | % composition of  *Symbiodiniaceae* ITS2 types in Plateau exp. (Day 1 & 13) | % composition of  *Symbiodiniaceae* ITS2 types in Plateau exp. (post-bleaching) |
| Transformation |  | None | None |
| Number of permutations |  | 999 | 999 |
| Source of variation | **Df** | ***P* (Perm)** | ***P* (Perm)** |
| Treatment | 2 | 0.460 *F=0.98055* | 0.168 *F=1.5178* |
| Exposure time | 1 | 0.937  *F=0.21141* | **-** |
| Treatment × Exposure time | 2 | 0.700  *F=0.70574* | **-** |

**Table S10** Summary of results for two separate PERMANOVA analyses used to analyse percent (%) composition of Symbiodiniaceae ITS2 types within holobionts between treatments in the ‘Plateau’ experiment (Part II: control, SPlat, OPlat). The % composition of Symbiodiniaceae genetic types at Day 1 & Day 13 were first analysed using two-way (PERMANOVA) and second, a one-way PERMANOVA multivariate analysis was used to compare % composition of Symbiodiniaceae ITS2 types within holobionts among treatments post-bleaching.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable |  | % composition of  *Symbiodiniaceae* ITS2 types in Increasing exp. (Day 1 & 13) | % composition of  *Symbiodiniaceae* ITS2 types in Increasing exp. (post-bleaching) |
| Transformation |  | None | None |
| Number of permutations |  | 999 | 999 |
| Source of variation | **Df** | ***P* (Perm)** | ***P* (Perm)** |
| Treatment | 2 | 0.736 *F=0.72536* | 0.335 *F=0.232* |
| Exposure time | 1 | 0.473  *F=0.95417* | **-** |
| Treatment × Exposure time | 2 | 0.404  *F=1.0595* | **-** |

**Table S11** Summary of results for two separate PERMANOVA analyses used to analyse percent (%) composition of Symbiodiniaceae ITS2 types within holobionts between treatments in the ‘Increasing’ experiment (Part II: control, SIncr, OIncr). First, the % composition of Symbiodiniaceae genetic types at Day 1 & Day 13 were first analysed using two-way (PERMANOVA) and second, a one-way PERMANOVA multivariate analysis was used to compare % composition of Symbiodiniaceae ITS2 types within holobionts among treatments post-bleaching.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Days of exposure | Control | Constant Increasing (CIncr) | Oscillating Increasing (OIncr) | Constant Plateau  (CPlat) | Oscillating Plateau  (OPlat) |
| 1 | 28.116 | 28.204 | 28.131 | 28.055 | 28.263 |
| 2 | 28.072 | 28.967 | 28.548 | 29.049 | 28.99 |
| 3 | 28.268 | 29.844 | 29.214 | 30.009 | 29.145 |
| 4 | 28.267 | 30.8975 | 29.632 | 31.050 | 30.381 |
| 5 | 28.258 | 32.0256 | 30.489 | 32.163 | 30.678 |
| 6 | 28.294 | 33.129 | 31.463 | 33.071 | 30.897 |
| 7 | 28.229 | 34.026 | 32.584 | 34.137 | 31.037 |
| 8 | 28.048 | 34.801 | 33.426 | 35.123 | 33.433 |
| 9 | 28.199 | 35.109 | 33.328 | 35.084 | 33.324 |
| 10 | 28.054 | 35.262 | 33.054 | 35.150 | 33.143 |
| 11 | 28.361 | 35.198 | 33.116 | 35.080 | 33.0505 |
| 12 | 28.291 | 35.183 | 33.250 | 35.434 | 33.589 |
| 13 | 28.266 | 37.074 | 34.890 | 37.098 | 34.559 |
| 14 | 28.248 | **38.846** | 37.212 | **37.0223** | 34.889 |
| 15 | 28.314 |  | 39.290 |  | 35.213 |
| 16 | 28.088 |  | **40.548** |  | **35.716** |

**Table S11** Mean daily temperature (°C) conditions for each of the five treatments throughout the experiment. Temperature values in bold represent mean daily temperature conditions under which medusae bleaching in their respective treatments.

**Reference List**

[1] Hume B.C. C., S.E.G., Ziegler M., Warrington H. J. M., Burt J. A., LaJeunesse T. C., Wiedenmann J. & Voolstra C. R. 2018 SymPortal: a novel analytical framework and platform for coral algal symbiont next-generation sequencing ITS2 profiling. *(Submitted)*.

[2] Maynard, J.A., Turner, P.J., Anthony, K., Baird, A.H., Berkelmans, R., Eakin, C.M., Johnson, J., Marshall, P.A., Packer, G.R. & Rea, A. 2008 ReefTemp: An interactive monitoring system for coral bleaching using high‐resolution SST and improved stress predictors. *Geophysical Research Letters* **35**.