**Supplementary data for**

**Ocean warming enhances the competitive advantage of *Ulva prolifera* over a golden tide alga, *Sargassum horneri* under eutrophication**

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**Table S1.** Homogeneity of variance test (Levene test) of physiological traits in *Ulva prolifera* and *Sargassum horneri*. The physiological parameters include the relative growth rate (RGR), the pigment content of chlorophyll *a* (Chl *a*), carotenoid (Car), net photosynthetic rate (NPR), dark respiration (DR), soluble protein (SP), and superoxide dismutase activity (SOD). F means the value of Levene statistic, df means degree of freedom, and Sig. means *p*-value. If *p*-value > 0.05, it indicates that the variance is homogeneous.

|  |  |  |
| --- | --- | --- |
| Levene test | *U. prolifera* | *S. horneri* |
| Growth | Chl a | Car | NPR | DR | SP | SOD | Growth | Chl a | Car | NPR | DR | SP | SOD |
| F | 1.962 | 0.658 | 0.901 | 0.730 | 1.506 | 0.166 | 1.210 | 1.587 | 0.646 | 0.664 | 1.178 | 1.898 | 0.357 | 1.747 |
| df | 17 | 17 | 17 | 17 | 17 | 11 | 11 | 17 | 17 | 17 | 17 | 17 | 11 | 11 |
| Sig. | 0.075 | 0.821 | 0.578 | 0.753 | 0.148 | 0.998 | 0.332 | 0.120 | 0.831 | 0.815 | 0.329 | 0.052 | 0.961 | 0.122 |

**Table S2.** Homogeneity of variance test (Shapiro-Wilk test) of physiological traits in *Ulva prolifera* and *Sargassum horneri*. The physiological parameters include the relative growth rate (RGR), the pigment content of chlorophyll *a* (Chl *a*), carotenoid (Car), net photosynthetic rate (NPR), dark respiration (DR), soluble protein (SP), and superoxide dismutase activity (SOD). F means the value of Shapiro-Wilk statistic, df means degree of freedom, and Sig. means *p*-value. If *p*-value > 0.05, it indicates that the data conform to normal distribution.

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| --- | --- | --- | --- |
| Temp(℃) | Shapiro-Wilk test | *U. prolifera* | *S. horneri* |
| Growth | Chl a | Car | NPR | DR | SP | SOD | Growth | Chl a | Car | NPR | DR | SP | SOD |
| 5 | F | 0.845 | 0.858 | 0.938 | 0.884 | 0.898 | 0.975 | 0.918 | 0.819 | 0.954 | 0.872 | 0.899 | 0.886 | 0.861 | 0.953 |
| df | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Sig. | 0.143 | 0.182 | 0.645 | 0.290 | 0.363 | 0.922 | 0.491 | 0.087 | 0.770 | 0.236 | 0.366 | 0.299 | 0.194 | 0.762 |
| 10 | F | 0.949 | 0.952 | 0.933 | 0.873 | 0.937 | 0.883 | 0.905 | 0.895 | 0.923 | 0.984 | 0.906 | 0.941 | 0.972 | 0.822 |
| df | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Sig. | 0.734 | 0.759 | 0.604 | 0.239 | 0.633 | 0.284 | 0.401 | 0.344 | 0.525 | 0.971 | 0.408 | 0.664 | 0.908 | 0.092 |
| 15 | F | 0.964 | 0.897 | 0.918 | 0.905 | 0.930 | 0.962 | 0.878 | 0.877 | 0.918 | 0.947 | 0.814 | 0.842 | 0.866 | 0.904 |
| df | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| Sig. | 0.833 | 0.145 | 0.268 | 0.186 | 0.385 | 0.834 | 0.261 | 0.080 | 0.270 | 0.600 | 0.013 | 0.029 | 0.209 | 0.398 |
| 20 | F | 0.950 | 0.897 | 0.931 | 0.940 | 0.837 | 0.948 | 0.914 | 0.927 | 0.923 | 0.941 | 0.845 | 0.868 | 0.923 | 0.903 |
| df | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| Sig. | 0.632 | 0.144 | 0.391 | 0.492 | 0.025 | 0.721 | 0.463 | 0.353 | 0.311 | 0.518 | 0.032 | 0.061 | 0.527 | 0.394 |
| 25 | F | 0.966 | 0.857 | 0.973 | 0.863 | 0.792 | 0.914 | 0.810 | 0.895 | 0.873 | 0.955 | 0.867 | 0.762 | 0.904 | 0.971 |
| df | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| Sig. | 0.864 | 0.045 | 0.937 | 0.053 | 0.008 | 0.461 | 0.072 | 0.136 | 0.071 | 0.709 | 0.059 | 0.004 | 0.400 | 0.901 |
| 30 | F | 0.879 | 0.843 | 0.934 | 0.815 | 0.800 | 0.833 | 0.934 | 0.786 | 0.874 | 0.948 | 0.913 | 0.958 | 0.966 | 0.974 |
| df | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Sig. | 0.265 | 0.139 | 0.615 | 0.080 | 0.058 | 0.115 | 0.612 | 0.044 | 0.241 | 0.723 | 0.459 | 0.804 | 0.861 | 0.916 |

**Table S3.** Three-way analysis of variance for the effects of temperatures (T), nutrient conditions (N), and coculture (Co) on relative growth rate (RGR) of *Ulva prolifera* and *Sargassum horneri.* The × means the interactive effect, df means degree of freedom, F means the value of F statistic, and Sig. means *p*-value.

|  |  |  |
| --- | --- | --- |
| Trait | RGR of *Ulva prolifera* | RGR of *Sargassum horneri* |
| df | F | Sig. | df | F | Sig. |
| Temperature | 2 | 8.1 | 0.002 | 2 | 4.1 | 0.029 |
| Nutrient | 1 | 50.8 | <0.001 | 1 | 68.0 | <0.001 |
| Coculture | 1 | 50.7 | <0.001 | 1 | 55.8 | <0.001 |
| T × N | 2 | 0.5 | 0.590 | 2 | 16.6 | <0.001 |
| T × Co | 2 | 2.9 | 0.073 | 2 | 23.1 | <0.001 |
| N × Co | 1 | 0.6 | 0.465 | 1 | 4.2 | 0.050 |
| T × N × Co | 2 | 1.6 | 0.227 | 2 | 7.2 | 0.004 |

**Table S4.** Three-way analysis of variance for the effects of temperature, CO2 and coculture on chlorophyll *a* (Chl *a*) of *Ulva prolifera* and *Sargassum horneri.* The × means the interactive effect, df means degree of freedom, F means the value of F statistic, and Sig. means *p*-value.

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| --- | --- | --- |
| Trait | Chl *a* of *Ulva prolifera* | Chl *a* of *Sargassum horneri* |
| df | F | Sig. | df | F | Sig. |
| Temperature | 2 | 27.6 | <0.001 | 2 | 23.6 | <0.001 |
| Nutrient | 1 | 216.5 | <0.001 | 1 | 34.6 | <0.001 |
| Coculture | 1 | 4.3 | 0.048 | 1 | 132.6 | <0.001 |
| T × N | 2 | 5.6 | 0.010 | 2 | 0.8 | 0.453 |
| T × Co | 2 | 0.4 | 0.674 | 2 | 3.2 | 0.057 |
| N × Co | 1 | 0.1 | 0.793 | 1 | 3.0 | 0.094 |
| T × N × Co | 2 | 2.0 | 0.151 | 2 | 1.8 | 0.194 |

**Table S5.** Three-way analysis of variance for the effects of temperature, CO2 and coculture on carotenoid (Car) of *Ulva prolifera* and *Sargassum horneri.* The × means the interactive effect, df means degree of freedom, F means the value of F statistic, and Sig. means *p*-value.

|  |  |  |
| --- | --- | --- |
| Trait | Car of *Ulva prolifera* | Car of *Sargassum horneri* |
| df | F | Sig. | df | F | Sig. |
| Temperature | 2 | 17.7 | <0.001 | 2 | 15.5 | <0.001 |
| Nutrient | 1 | 22.8 | <0.001 | 1 | 4.2 | 0.052 |
| Coculture | 1 | 9.7 | 0.005 | 1 | 9.1 | 0.006 |
| T × N | 2 | 4.1 | 0.029 | 2 | 3.9 | 0.035 |
| T × Co | 2 | 4.8 | 0.018 | 2 | 20.1 | <0.001 |
| N × Co | 1 | 2.2 | 0.153 | 1 | 3.6 | 0.070 |
| T × N × Co | 2 | 0.5 | 0.591 | 2 | 1.7 | 0.208 |

**Table S6.** Three-way analysis of variance for the effects of temperature, CO2 and coculture on net photosynthetic rate (NPR) of *Ulva prolifera* and *Sargassum horneri.* The × means the interactive effect, df means degree of freedom, F means the value of F statistic, and Sig. means *p*-value.

|  |  |  |
| --- | --- | --- |
| Trait | NPR of *Ulva prolifera* | NPR of *Sargassum horneri* |
| df | F | Sig. | df | F | Sig. |
| Temperature | 2 | 0.5 | <0.001 | 2 | 59.0 | <0.001 |
| Nutrient | 1 | 467.1 | <0.001 | 1 | 42.3 | <0.001 |
| Coculture | 1 | 61.7 | <0.001 | 1 | 1287.8 | <0.001 |
| T × N | 2 | 8.3 | 0.002 | 2 | 2.4 | 0.117 |
| T × Co | 2 | 4.8 | 0.018 | 2 | 0.4 | 0.705 |
| N × Co | 1 | 11.2 | 0.003 | 1 | 1.4 | 0.253 |
| T × N × Co | 2 | 0.1 | 0.917 | 2 | 1.2 | 0.305 |

**Table S7.** Three-way analysis of variance for the effects of temperature, CO2 and coculture on dark respiration (DR) of *Ulva prolifera* and *Sargassum horneri.* The × means the interactive effect, df means degree of freedom, F means the value of F statistic, and Sig. means *p*-value.

|  |  |  |
| --- | --- | --- |
| Trait | DR of *Ulva prolifera* | DR of *Sargassum horneri* |
| df | F | Sig. | df | F | Sig. |
| Temperature | 2 | 10.3 | 0.001 | 2 | 36.9 | <0.001 |
| Nutrient | 1 | 188.1 | <0.001 | 1 | 10.3 | 0.004 |
| Coculture | 1 | 336.2 | <0.001 | 1 | 807.1 | <0.001 |
| T × N | 2 | 11.0 | <0.001 | 2 | 1.7 | 0.196 |
| T × Co | 2 | 2.2 | 0.131 | 2 | 9.9 | 0.001 |
| N × Co | 1 | 124.7 | <0.001 | 1 | 0.2 | 0.657 |
| T × N × Co | 2 | 13.2 | <0.001 | 2 | 0.3 | 0.742 |