## Ocean warming and high light availability rather support productivity of green than brown and red macroalgae from the Mediterranean Sea

Leonie Hesse\*1, 4,5Merlin Weiss, Selma D. Mezger1, Yusuf C. El-Khaled1,2, Alexandra Kler Lago1, Mischa Schwarzmeier3, Christian Wild1

1University of Bremen, Faculty of Biology and Chemistry, Department of Marine Ecology, Leobener Str. 6, 28359 Bremen, Germany

2Red Sea Research Center (RSRC), Division of Biological and Environmental Science and Engineering (BESE), King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

3Institut für Marine Biologie (ifMB), Karlsruhe, Germany

4ETH Zurich, Institute of Terrestrial Ecosystems, Department of Environmental Systems Science, Universitätstrasse 16, 8092 Zurich, Switzerland

5ETH Zurich, Institute of Biogeochemistry and Pollutant Dynamics, Department of Environmental Systems Science, Universitätstrasse 16, 8092 Zurich, Switzerland

*\*E-mail of the corresponding author:* [*leohesse@uni-bremen.de*](mailto:leohesse@uni-bremen.de)

## Abstract

In the Mediterranean Sea, three macroalgae with different pigmentation currently overgrow rocky substrates or seagrass meadows: the red alga Phyllophora crispa, the brown alga Cystoseira sp. and the green alga Flabellia petiolata. The extent to which these algal species respond to changing water temperatures and light intensities, is poorly understood, although related knowledge is key for understanding their current and future invasion success. Accordingly, we asked how different water temperatures and light availabilities influence photosynthesis (P) and respiration (R) of the macroalgae. We collected samples of all three algae from water depths of 20 m at Giglio Island, Italy, and measured their oxygen fluxes at water temperatures of 21, 26, and 30 °C and light availabilities of 180, 320, and 760 µmol s-1 m-1 using a fully crossed design. Our results show that high water temperatures led to higher respiration and reduced P:R ratios of all three species. High light intensity decreased photosynthesis and lowered the P:R ratio of Cystoseira sp. and F. petiolata, but had no significant effect on P. crispa. Under combined temperature and light, the P:R ratio declined for *Cystoseira* sp. and *P. crispa*, with *Cystoseira* sp. experiencing the largest decrease to 0.4. F. petiolata displayed stable or even enhanced photosynthesis rates under combined conditions*.* The combined effects of temperature and light exhibit a synergistic impact on ***Phyllophora crispa*** and ***Cystoseira sp.***, as a more **significant** decline in oxygen production compared toYYY occurred. Findings suggest that under ocean warming scenarios and varying light availabilities, ***F. petiolata*** may become a dominant macroalga,. This could have major implications for habitat complexity and biodiversity since the green alga compared to brown and red algae does not provide stable, three-dimensional, and long-lived habitats for associated organisms.

Keywords: macroalgae, algal stress responses, oxygen flux, climate change resilience

## Introduction

Algae are fundamental primary producers in marine ecosystems, driving biogeochemical cycles and supporting trophic networks through oxygen production and carbon sequestration (Litchman et al., 2015). Furthermore, Macroalgae function as ecosystem engineers in marine environments by creating and modifying habitats, thereby influencing the distribution and abundance of various marine organisms. Mediterranean Species like *Phyllophora crispa*, a red algae, form dense underwater mats up to 15 cm thick on rocky substrates from 20 m depth with its firm, cartilaginous texture with flattened, dichotomously branching fronds (Schmidt et al., 2021). Furthermore it modifies environmental conditions by reducing water movement and light penetration, creating microhabitats that support diverse invertebrates, and thereby enhancing benthic biodiversity (Schmidt et al., 2021). Green macroalgae like *Flabellia petiolata* which features a fan-shaped thallus reaching 10 cm in height, inhabits hard substrates from a few meters deep. In warmer waters, it tolerates well-lit areas, often hosting epiphytes such as calcareous algae and tube-dwelling worms (Díaz et al., 2019). It plays a key role in the phytocoenoses of the endemic and endangered seagrass Posidonia oceanica, contributing to habitat stability (Penna et al., 2015), (Gnavi et al., 2017). Brown algae such as Cystoseira spp., inhabit depths up to 50 m, anchoring to rocky substrates via a robust holdfast with lateral branches (Mancuso et al., 2024). As foundational species, Cystoseira spp. forms marine forests that enhance biodiversity and ecosystem productivity by providing habitat for invertebrates, fish, and other algae (Verdura et al., 2023).

Recent observations indicate that certain macroalgal species are proliferating excessively, leading to the overgrowth of seagrass meadows and hard-bottom communities (El-Khaled et al., 2023). Many aspects influence the composition of marine ecosystem communities in the Mediterranean Sea and the role of macroalgae. In the context of climate change, the photosynthetic performance of algae is strongly influenced by factors such as temperature and light availability, which regulate their energy acquisition, respiration, and overall metabolic balance (Raven & Beardall, 2016). Rising sea temperatures, particularly during marine heatwaves, have led to mass mortality events among sensitive macroalgal species, resulting in reduced biomass and altered community structures (Verdura et al., 2019). Elevated temperatures can lead to oxidative stress, resulting in damage to the photosynthetic apparatus and reduced photosynthetic rates. Conversely, low temperatures can limit enzymatic activities involved in photosynthesis, also diminishing net photosynthesis (Maltsev et al., 2021). While adequate light is essential for photosynthetic processes, excessive light can cause photoinhibition, leading to a decline in photosynthetic efficiency. Algae have developed mechanisms such as the xanthophyll cycle to dissipate excess light energy and mitigate photodamage. However, under prolonged high light exposure, these protective mechanisms may be insufficient, resulting in decreased net photosynthesis (Maltsev et al., 2021).

In the Mediterranean Sea, macroalgal communities are particularly vulnerable to temperature stress, as regional warming trends exceed global averages, with summer surface temperatures increasing by 1.15 °C over the last three decades (Marbà et al., 2015). Fewer studies have addressed the effects of light and temperature stress on Mediterranean algae under controlled experimental conditions. Therefore, it is crucial to investigate whether different macroalgal species exhibit varying resilience thresholds to combined stressors, as this could significantly shape competitive dynamics and impact ecosystem stability in a warming Mediterranean Sea.

Here, we investigate the effects of temperature and light on the photosynthetic performance and metabolic balance of macroalgae. Specifically, we examine how the productivity of different macroalgal species responds to fluctuations in water temperature and light availability, both independently and in combination. Finally, we seek to determine whether macroalgal species differ in their resilience to variations in temperature and light, identifying which species are best adapted to these fluctuations and which are likely to perform optimally under projected environmental changes. We hypothesize that temperature and light intensity significantly affect net photosynthesis in marine macroalgae. Higher temperatures should reduce photosynthesis, with species-specific variations in response. Additionally, we expect a significant interaction between temperature and light, where their combined effects exceed their individual impacts. To test these hypotheses, we conducted a controlled laboratory experiment exposing three Mediterranean macroalgae species to a factorial combination of three temperature levels (21°C, 26°C, 30°C) and three light intensities (180 µmol s-1 m-1, 320 µmol s-1 m-1, 760 µmol s-1 m-1). Photosynthetic responses were measured by analyzing net photosynthesis, gross photosynthesis, and respiration rates across treatments. Our findings provide insights into the potential impacts of climate change on macroalgal productivity. This may allow for predictions regarding future shifts in species dominance and their implications for ecosystem structure, including habitat composition and stability.

## Material & Methods

## Data collection and preparation

XXX text on field and lab work needed

[...]

We measured the net photosynthesis (Pn) and oxygen consumption (i.e., respiration, R) in algae across 161 samples, which included 54 *Cystoseira spp.* (brown) and *Phyllophora crispa* (red) algae, and 53 for *Flabellia petiolata* (green) algae. Our setup included 18 *Cystoseira spp.* and *Phyllophora crispa* samples and 17 *Flabellia petiolata* samples per experimental condition.

We then calculated the photosynthesis-to-respiration (P:R) ratio to assess the metabolic balance between autotrophic carbon fixation and respiratory carbon loss. Since the P:R ratio requires an estimate of gross photosynthesis (Pg), we first derived Pg as the sum of net photosynthesis (Pn) and the absolute value of respiration (R). The P:R ratio was then computed by dividing the gross photosynthesis by the absolute value respiration (R) values, as respiration (R) was treated as a negative flux.

# Statistical analysis

We modelled net photosynthesis and the P:R ratio in response to experimental conditions. All statistical analyses were conducted in R (v. 4.4.1). Prior to analysis, we assessed data normality, linearity, homogeneity, and outliers following Zuur et al. (2010). As both response variables – net photosynthesis and the P:R ratio – exhibited non-linearity with temperature and light, we treated these predictors as categorical factors with three levels: control (21°C), warm (26°C), and hot (30°C) for temperature, and control (180 µmol s-1 m-1), medium (320 µmol s-1 m-1), and high (760 µmol s-1 m-1) for light intensity.

To test the effects of temperature and light stress on net photosynthesis across species, we first fitted a series of linear mixed-effects models using lme4 (Bates et al., 2015). The initial model included a full-factorial structure with temperature, light intensity, species identity, and all possible two-way and three-way interactions as fixed effects. The species was initially included as a random effect to account for species-specific variation in responses to environmental conditions. Both random intercept and random slope structures were tested to account for baseline variability in net photosynthesis and differential species-specific responses. However, nested model comparisons using likelihood ratio tests (ANOVA) indicated that random slopes did not significantly improve model fit, and their inclusion risked overparameterization. Additionally, species-specific intercepts showed minimal variation (<0.001), leading us to discard the random effect entirely and opt for a General Linear Model (GLM) to avoid convergence issues and numerical instability.

Model fit and performance were assessed using likelihood ratio tests and the Akaike Information Criterion (AIC). To ensure model parsimony, non-significant higher-order interactions were sequentially removed using backward stepwise selection, with model comparisons based on F-tests. However, reduced models performed significantly worse than the full-factorial model, and we therefore retained all fixed effects and interaction terms. Model validation was performed via residual diagnostics, confirming no violations of homoscedasticity or multicollinearity. The final model showed strong explanatory power (Adj. R² = 0.603), accounting for 66.8% of the variance in net photosynthesis (Table 1). Post-hoc pairwise comparisons of significant terms were done using emmeans (Lenth, 2017), with Tukey’s Honest Significant Difference (HSD) tests to control for multiple comparisons (Fig. 2, Table 2).

To assess the balance between photosynthetic oxygen production and respiratory oxygen consumption, and to identify conditions under which metabolic imbalance occurs, we modelled the photosynthesis-to-respiration (P:R) ratio following the same approach used for net photosynthesis. The most parsimonious model was a GLM with a Gamma distribution and log-link function, given the right-skewed distribution of P:R ratios and their strictly positive values. Temperature, light intensity, and species identity, along with their full-factorial interactions, were included as fixed effects.

Model validation followed the same procedure as for net photosynthesis. While residual diagnostics indicated some deviations from the assumed Gamma distribution at higher P:R values, overall model estimates remained robust. Due to concerns regarding normality, we report estimated P:R ratios but refrain from interpreting p-values for statistical significance. Species- and condition-specific variation in P:R ratios was visualized using a heatmap (Fig. 3) with thresholds representing metabolic imbalance (red, P:R < 1), moderate autotrophy (orange-yellow, 1 ≤ P:R < 3), stable metabolic conditions (green, 3 ≤ P:R <5 ), and strong autotrophy with high photosynthetic efficiency (blue, P:R > 5)

## Results

*Species-Specific Differences in net Photosynthetic Performance*

At baseline conditions (21°C, 180 µmol s-1 m-1), *Cystoseira spp.* (0.0072 ± 0.0008 µmol O₂ cm⁻² h⁻¹) and *Phyllophora crispa* (0.0071 ± 0.0006 µmol O₂ cm⁻² h⁻¹) exhibited significantly higher photosynthetic activity compared to *Flabellia petiolata* (0.004 ± 0.0005 µmol O₂ cm⁻² h⁻¹; p < 0.001; Fig. 2, Table 2). However, no significant difference was detected between *Cystoseira spp.* and *Phyllophora crispa* under control conditions (p = 0.994, Table 2).

*Effects of Temperature and Light on Net Photosynthesis*

Both temperature and light significantly influenced net photosynthesis, with species-specific responses (p < 0.001, Table 1). Increasing light intensity had a strong negative effect, with the net photosynthesis being significantly lower under high-light conditions compared to control and medium-light levels (p < 0.001, Table 1). Temperature effects were more variable: warming (26°C) led to a significant reduction in net photosynthesis (p = 0.002, Table 1), while exposure to 30°C did not induce a statistically significant reduction relative to control conditions (p = 0.540, Table 1). However, the significant Species × Temperature × Light interaction (p < 0.001, Table 1) suggests species-specific responses to interactive temperature and light stress.

*Cystoseira spp.* was the most negatively affected species, exhibiting a substantial reduction in photosynthetic rates under increased temperature and light stress (Table 1, Fig. 2). Under high-light conditions, net photosynthesis declined significantly at both warm (26°C) and hot (30°C) temperatures (p < 0.001, Table 1). Notably, under hot (30°C) and control light conditions, *Cystoseira spp.* maintained significantly higher net photosynthesis than *Flabellia petiolata* (p = 0.049, Table 2), though it did not significantly differ from *Phyllophora crispa* (p = 0.946, Table 2). However, under hot (30°C) and high-light exposure, photosynthesis was nearly halted (p < 0.001, Table 1).

*Phyllophora crispa* exhibited a relatively stable photosynthetic performance across treatments (Table 1, Fig. 2). Unlike *Cystoseira spp.*, *Phyllophora crispa* did not show a significant decline under high-light conditions (p = 0.103, Table 2), suggesting greater tolerance to irradiance stress. *Phyllophora crispa’s* photosynthetic rate increased slightly under high-light and warm temperatures compared to control conditions (p = 0.028, Table 2), indicating a potential compensatory response to moderate warming.

*Flabellia petiolata* exhibited the highest resilience to environmental fluctuations (Fig. 2). Optimal photosynthetic performance occurred under medium-light conditions across all temperatures (Table 1). However, a significant reduction in net photosynthesis was observed under high-light conditions at warm (26°C) and hot (30°C) temperatures (p < 0.001, Table 1). *Flabellia petiolata* maintained significantly higher net photosynthesis than *Cystoseira spp.* under multiple conditions, particularly under hot (30°C) and high-light conditions (p < 0.001, Table 2). *Flabellia petiolata* may thus possesses a relatively high degree of physiological plasticity in response to warming.

A diagram of different types of light

AI-generated content may be incorrect.

Figure 1: Observed responses of net photosynthesis to temperature and stress across three algal species. (Top Left) The main effect of temperature on net photosynthesis for each species. (Top Right) The main effect of light intensity on net photosynthesis. (Bottom) Interaction effects between temperature and light intensity, with separate panels for each light treatment. Individual points represent observed data, and smoothed lines indicate species-specific loess trends.

A chart of different colored squares

AI-generated content may be incorrect.

Figure 2: Model-based estimated marginal means of net photosynthesis in algae species across environmental conditions. The panel x axis resembles temperature conditions, the panel y axis light conditions. Bars show estimated net photosynthesis per algae species with error bars representing 95% confidence intervals.

Table 1: Parameter estimates from the top model testing the effects of temperature, light, species, and their interactions on net photosynthesis (µmol O₂ cm⁻² h⁻¹). Significant effects (p < 0.05) are highlighted in bold. Interaction terms represent the combined effects of multiple predictors, indicating deviations from additive effects.

| Parameter | Estimate | SE | T Ratio | p-value |
| --- | --- | --- | --- | --- |
| (Intercept) | 0.007 | 0.001 | 11.983 | 0.000 |
| **Temperature 26°C** | **-0.003** | **0.001** | **-3.198** | **0.002** |
| Temperature 30°C | -0.001 | 0.001 | -0.614 | 0.540 |
| Light medium | -0.001 | 0.001 | -1.533 | 0.128 |
| **Light high** | **-0.004** | **0.001** | **-5.183** | **0.000** |
| **Species Flabellia** | **-0.003** | **0.001** | **-3.694** | **0.000** |
| Species Phyllophora | -0.000 | 0.001 | -0.104 | 0.917 |
| **Temperature 26°C : Light medium** | **0.004** | **0.001** | **3.112** | **0.002** |
| Temperature 30°C : Light medium | 0.002 | 0.001 | 1.474 | 0.143 |
| Temperature 26°C: Light high | 0.000 | 0.001 | 0.300 | 0.764 |
| Temperature 30°C : Light high | -0.001 | 0.001 | -1.117 | 0.266 |
| **Temperature 26°C: Species Flabellia** | **0.003** | **0.001** | **2.290** | **0.024** |
| Temperature 30°C : Species Flabellia | 0.001 | 0.001 | 1.033 | 0.303 |
| Temperature 26°C : Species Phyllophora | -0.000 | 0.001 | -0.266 | 0.791 |
| Temperature 30°C : Species Phyllophora | -0.000 | 0.001 | -0.152 | 0.879 |
| Light medium : Species Flabellia | 0.000 | 0.001 | 0.203 | 0.839 |
| **Light high : Species Flabellia** | **0.004** | **0.001** | **2.959** | **0.004** |
| Light medium : Species Phyllophora | 0.000 | 0.001 | 0.067 | 0.946 |
| Light high : Species Phyllophora | 0.002 | 0.001 | 1.909 | 0.058 |
| Temperature 26°C : Light medium : Species Flabellia | -0.000 | 0.002 | -0.206 | 0.837 |
| Temperature 30°C : Light medium : Species Flabellia | 0.002 | 0.002 | 1.009 | 0.315 |
| Temperature 26°C : Light high : Species Flabellia | 0.003 | 0.002 | 1.456 | 0.148 |
| **Temperature 30°C : Light high : Species Flabellia** | **0.004** | **0.002** | **2.264** | **0.025** |
| Temperature 26°C : Light medium : Species Phyllophora | -0.001 | 0.002 | -0.789 | 0.432 |
| Temperature 30°C : Light medium : Species Phyllophora | -0.001 | 0.002 | -0.398 | 0.691 |
| **Temperature 26°C : Light high : Species Phyllophora** | **0.004** | **0.002** | **2.513** | **0.013** |
| **Temperature 30°C : Light high : Species Phyllophora** | **0.005** | **0.002** | **2.810** | **0.006** |

Table 2: Pairwise comparisons of species under varying temperature and light conditions, estimated using marginal means from the final model. Tukey-adjusted p-values are reported to account for multiple comparisons.

| Contrast | Temperature | Light | Estimate | SE | DF | T Ratio | p-value |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ***Cystoseira - Flabellia*** | **21°C** | **control** | **0.003** | 0.001 | 134 | 3.694 | **0.001** |
| *Cystoseira - Phyllophora* | 21°C | control | 0.000 | 0.001 | 134 | 0.104 | 0.994 |
| ***Flabellia - Phyllophora*** | **21°C** | **control** | **-0.003** | 0.001 | 134 | -3.595 | **0.001** |
| *Cystoseira - Flabellia* | 26°C | control | 0.000 | 0.001 | 134 | 0.555 | 0.844 |
| *Cystoseira - Phyllophora* | 26°C | control | 0.000 | 0.001 | 134 | 0.480 | 0.881 |
| *Flabellia - Phyllophora* | 26°C | control | -0.000 | 0.001 | 134 | -0.076 | 0.997 |
| ***Cystoseira - Flabellia*** | **30°C** | **control** | **0.002** | 0.001 | 134 | 2.376 | **0.049** |
| *Cystoseira - Phyllophora* | 30°C | control | 0.000 | 0.001 | 134 | 0.319 | 0.946 |
| *Flabellia - Phyllophora* | 30°C | control | -0.002 | 0.001 | 134 | -2.057 | 0.103 |
| ***Cystoseira - Flabellia*** | **21°C** | **medium** | **0.003** | 0.001 | 134 | 3.579 | **0.001** |
| *Cystoseira - Phyllophora* | 21°C | medium | 0.000 | 0.001 | 134 | 0.009 | 1.000 |
| ***Flabellia - Phyllophora*** | **21°C** | **medium** | **-0.003** | 0.001 | 134 | -3.570 | **0.001** |
| *Cystoseira - Flabellia* | 26°C | medium | 0.001 | 0.001 | 134 | 0.677 | 0.777 |
| *Cystoseira - Phyllophora* | 26°C | medium | 0.002 | 0.001 | 134 | 1.962 | 0.126 |
| *Flabellia - Phyllophora* | 26°C | medium | 0.001 | 0.001 | 134 | 1.284 | 0.406 |
| *Cystoseira - Flabellia* | 30°C | medium | 0.000 | 0.001 | 134 | 0.038 | 0.999 |
| *Cystoseira - Phyllophora* | 30°C | medium | 0.001 | 0.001 | 134 | 1.020 | 0.566 |
| *Flabellia - Phyllophora* | 30°C | medium | 0.001 | 0.001 | 134 | 0.982 | 0.590 |
| *Cystoseira - Flabellia* | 21°C | high | -0.000 | 0.001 | 134 | -0.414 | 0.910 |
| ***Cystoseira - Phyllophora*** | **21°C** | **high** | **-0.002** | 0.001 | 134 | -2.596 | **0.028** |
| *Flabellia - Phyllophora* | 21°C | high | -0.002 | 0.001 | 134 | -2.182 | 0.078 |
| ***Cystoseira - Flabellia*** | **26°C** | **high** | **-0.006** | 0.001 | 134 | -6.681 | **0.000** |
| ***Cystoseira - Phyllophora*** | **26°C** | **high** | **-0.006** | 0.001 | 134 | -7.246 | **0.000** |
| *Flabellia - Phyllophora* | 26°C | high | -0.000 | 0.001 | 134 | -0.565 | 0.839 |
| ***Cystoseira - Flabellia*** | **30°C** | **high** | **-0.006** | 0.001 | 134 | -6.497 | **0.000** |
| ***Cystoseira - Phyllophora*** | **30°C** | **high** | **-0.007** | 0.001 | 134 | -8.001 | **0.000** |
| *Flabellia - Phyllophora* | 30°C | high | -0.001 | 0.001 | 134 | -1.504 | 0.292 |

*Effects of Temperature and Light on the Photosynthesis-to-Respiration Ratio (P:R)*

The P:R ratio, representing metabolic balance, varied strongly across species and environmental conditions (Fig. 3). Under baseline conditions (21°C, control light at 180 µmol photons µmol O₂ cm⁻² h⁻¹), *Flabellia petiolata* had the highest metabolic efficiency (P:R = 7.08 ± 0.73), followed by *Cystoseira spp*. (P:R = 3.64 ± 0.34) and *Phyllophora crispa* (P:R = 3.32 ± 0.31).

*Metabolic balance under warming*

At warm temperatures (26°C) under control light, the P:R ratio decreased across all species. *Cystoseira spp.* and *Phyllophora crispa* exhibited the most pronounced reductions (P:R = 2.05 ± 0.19 and P:R = 1.90 ± 0.18, respectively), while *Flabellia petiolata* maintained a higher P:R ratio (3.48 ± 0.33). At 30°C, *Cystoseira spp.* showed a partial recovery (P:R = 3.15 ± 0.30), whereas *Phyllophora crispa* and *Flabellia petiolata* maintained lower but similar values (P:R = 2.94 ± 0.28 and P:R = 2.97 ± 0.28, respectively).

*Light-dependent effects on metabolic balance*

Light conditions also had a strong influence on P:R ratios, but with species-specific responses (Fig. 3). Under high-light stress at warm temperatures (26°C), *Cystoseira spp*. showed a critical decline in metabolic balance (P:R = 1.12 ± 0.11), nearing the threshold of metabolic collapse (P:R < 1 ). In contrast*, Flabellia petiolata* (P:R = 4.78 ± 0.45) and *Phyllophora crispa* (P:R = 2.90 ± 0.27) maintained relatively higher metabolic efficiency. At the highest level of stress (30°C, high light), *Cystoseira spp.* remained near metabolic breakdown (P:R = 1.32 ± 0.13), while *Flabellia petiolata* (P:R = 3.76 ± 0.35) and *Phyllophora crispa* (P:R = 3.66 ± 0.35) maintained positive net autotrophy, albeit at reduced efficiency (Fig. 3).

*Interactive Effects of Temperature and Light on Photosynthetic Resilience*

The significant interaction between temperature and light suggests that their combined effects were greater than the sum of their individual influences (Table 1, Fig. 1). For example, while warming alone led to decreased photosynthesis in *Cystoseira spp*., this effect was exacerbated under high-light conditions (p = 0.002, Table 1). In contrast, *Phyllophora crispa* exhibited a photosynthetic increase under warm temperatures and high light (p = 0.028, Table 2), hinting at a divergent adaptive strategy compared to *Cystoseira spp.*

Similarly, the P:R ratio analysis further supports this pattern, highlighting *Cystoseira spp*. as the most vulnerable species under combined stressors, while *Flabellia petiolata* maintained the highest metabolic resilience (Fig. 3). These results suggest that species-specific differences in photosynthetic efficiency and metabolic balance determine macroalgal resilience under fluctuating temperature and light regimes.

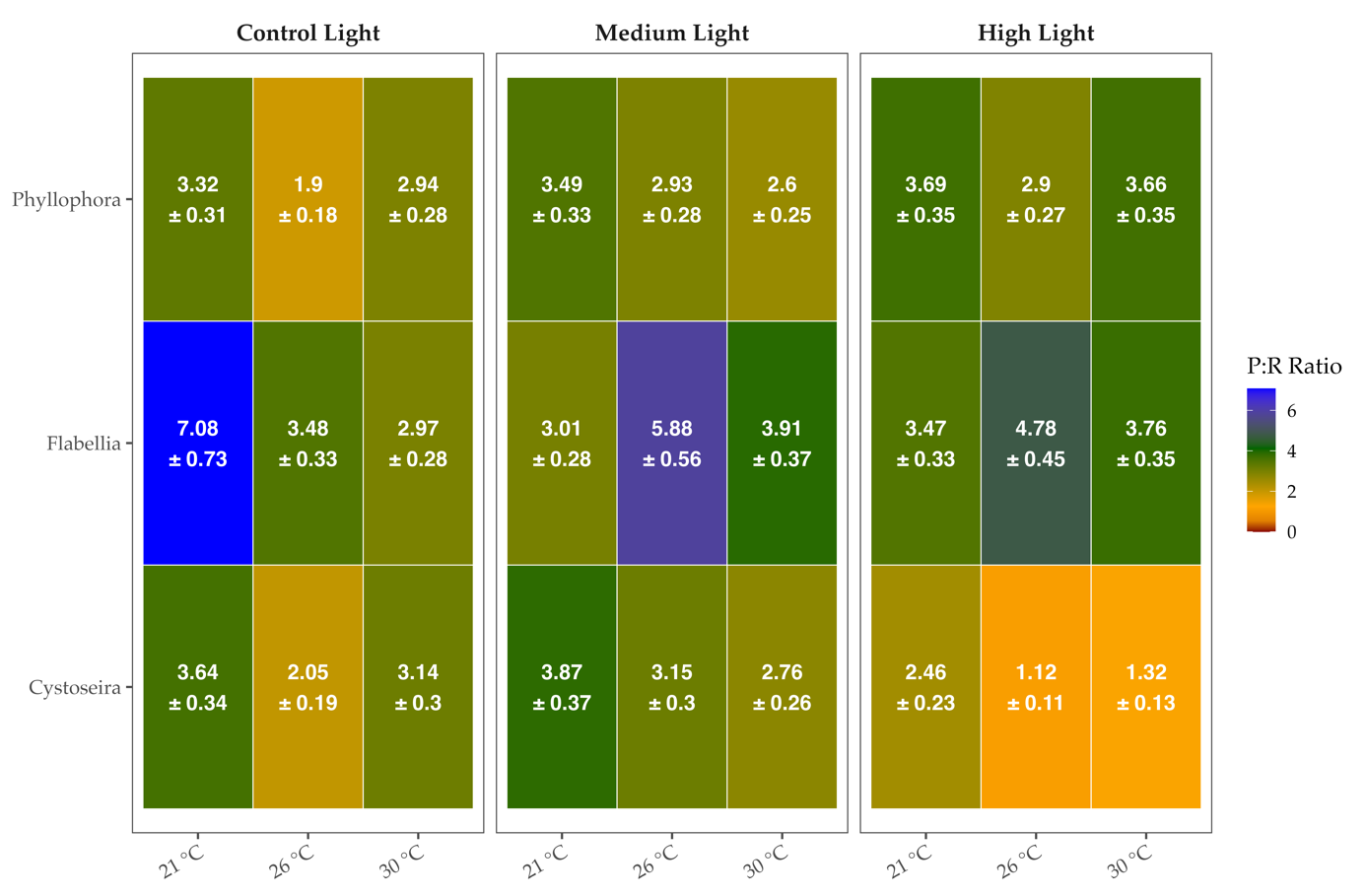


Figure 3 Heatmap depicting the estimated marginal means of the P:R ratio for three algal species under different and light conditions. Colours represent metabolic imbalance (red, P:R < 1), moderate autotrophy (orange-yellow, 1 ≤ P:R < 3), stable metabolic conditions (green, 3 ≤ P:R < 5), and strong autotrophy with high photosynthetic efficiency (blue, P:R >5). The text indicates the estimated mean P:R ration ± standard error.

## Discussion

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Data and Code availability

The data is available [...] and R code used to recreate the analysis can be found on the designated [GitHub repository](https://github.com/MerlinWe/algae_photosynthesis/blob/main/code/algae_analysis.R).

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## Appendix

Ein Bild, das Text, Diagramm, Screenshot, Plan enthält.

KI-generierte Inhalte können fehlerhaft sein.

Figure S1: Net and gross photosynthesis and respiration rates of three algal species (Cystoseira sp., P.crispa, and U.petiolata) under three temperature conditions (21 °C, 26 °C, 30 °C) and varying light intensities (control, medium, high). Bars represent oxygen flux (μmol O₂ cm⁻² h⁻¹) with standard deviations. The small numbers above the bars indicate the P:R ratio. Significant differences in the measured parameters are highlighted in red color