UNIVERSITY OF GOTHENBURG

DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES

EXPLORING THE INTERACTIVE EFFECTS OF LIGHT INTENSITY AND PH ON CORAL OXYGEN PRODUCTION

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Abstract

The study aimed to explore the possible interaction between acidification and light intensity and the effects on corals' oxygen production. Interactions between temperature and pH have been thoroughly researched and proven to cause immense stress on the world's reefs. We hypothesize that increased CO_2 concentration from acidification, combined with higher light intensity, could benefit the photosynthetic zooxanthellae and lead to higher oxygen production. For this study, two species of tropical coral were used *(Montipora capricornis* and *Seriatopora caliendrum*). First, the corals were placed under five different light intensities (200, 400, 600, 800, and 1000 PAR) to determine the optimal light level (highest oxygen production) and harmful light intensity (lowest production). Afterward, different levels of acidification were tested; a pH of 7.6 (most acidic) pH 7.8, and 8.2. Results from a one-factor ANOVA showed that for *M. capricornis* oxygen production was at its highest at a light intensity of 600 PAR (mean oxygen production was 0.000697 ppm O_2 /area coral in mm^2), and 800 PAR was considered harmful (mean oxygen production was 0.000397 ppm O_2 / mm^2). For *S. caliendrum* optimal light intensity was 400 PAR (0.379 ppm O_2/gram) and lowest at 1000 PAR (0.0725 ppm O_2/gram). A two-factor ANOVA showed that pH and the interaction between pH and light intensity were significant. For *M. capricornis*, O_2 production was the highest in pH 8.2 in optimal light, and in harmful light oxygen production increased as acidification increased. For *S. caliendrum*, O_2 was overall highest under acidic conditions (pH 7.6). The results give support that there is an interaction between light intensity and pH.

Keywords: Ocean acidification, light intensity, photosynthesis

Sammanfattning

Studien syftade till att undersöka interaktionen mellan försurning och ljusintensitet samt deras effekter på korallernas syreproduktion. Tidigare forskning har noggrant undersökt interaktioner mellan temperatur och pH, vilka har visat sig orsaka betydande stress på korallrev runtom i världen. Vi antog att kombinationen av ökad CO_2-koncentration på grund av försurning och högre ljusintensitet kan gynna fotosyntetiska zooxanthellae och därigenom resultera i ökad syreproduktion. I studien användes två arter av tropiska koraller, *Montipora capricornis* och *Seriatopora caliendrum*. Korallerna placerades under fem olika ljusintensiteter (200, 400, 600, 800 och 1000 PAR) för att bestämma den optimala ljus nivån (högsta syreproduktion) och skadliga ljusintensitet (lägsta produktion). Därefter testades olika nivåer av försurning med pH-värden på 7,6 (surast), 7,8 och 8,2 (ungefär den normala pH-nivån i akvarier på Sjöfartsmuseet). Resultaten från en enfaktors ANOVA visade att för *M. capricornis* var syreproduktionen högst vid en ljusintensitet på 600 PAR (genomsnittlig syreproduktion var 0,000697 ppm O_2 / areakorall i mm^2) och 800 PAR ansågs skadlig (genomsnittlig syreproduktion var 0,000397 ppm O_2 / mm^2). För *S. caliendrum* var den optimala ljusintensiteten 400 PAR (0,379 ppm O_2/gram) och den lägsta vid 1000 PAR (0,0725 ppm O_2/gram). En tvåfaktors ANOVA visade att pH och interaktionen mellan pH och ljusintensitet var signifikanta. För *M. capricornis* var O_2-produktionen högst i normalt pH i optimalt ljus, och i skadligt ljus ökade syreproduktionen med ökad försurning. För *S. caliendrum* var syreproduktionen totalt sett högst under sura förhållanden (pH 7,6). Resultaten ger stöd för att det finns ett samspel mellan ljusintensitet och pH.

Nyckelord: Havsförsurning, ljusintensitet, fotosyntes

1. Introduction

1.1 Ocean acidification – a product of CO_2 emissions

Ocean acidification (OA) is a significant environmental issue affecting marine ecosystems worldwide. It occurs when carbon dioxide (CO_2) reacts with water (H_2O) to form carbonic acid (H_2CO_3), which subsequently dissociates into hydrogen ions (H^+) and bicarbonate ions (HCO_3^{-1}) (NOAA, 2020). The pH scale, a logarithmic measure of free H^+ ion concentration, indicates higher acidification levels with lower pH values (NOAA, 2020). Anthropogenic carbon dioxide emissions contribute to increased H+ ions in seawater, leading to ocean acidification (Kawahata, et al., 2019). This process poses a significant threat to coral calcification and the abundance of coral reefs (Hoegh-Guldberg et alt., 2007; Kleypas et al., 2009).

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^{-1}$$

The equation shows the chemical reactions when carbon dioxide CO_2 reacts with seawater H_2O (NOAA, 2020).

The symbiotic relationship between corals and photosynthetic cells known as zooxanthellae is of vital importance (Cameron et al., 2022). Corals provide shelter and compounds for photosynthesis, while zooxanthellae convert CO_2 to glucose and oxygen, thereby elevating pH (Kuanui, et al., 2020). Diurnal fluctuations in pH naturally occur due to photosynthesis activity, with higher pH during the day and lower at night (Wijgerde et al., 2014). For instance, corals inhabiting the Indo-Pacific experience pH ranges of 8.7 pH during the day and 7.8 pH at night (Wijgerde et al., 2014).

Multiple studies have demonstrated the impact of light intensity and photon flux density on coral growth and photosynthesis (Kuanui, et al., 2020). While light variation can increase coral growth and photosynthetic efficiency, excessive light radiation has been shown to reduce photosystem II efficiency and potentially lead to coral bleaching (Kuanui, et al., 2020). Coral bleaching is the process when the host (coral) expels its symbiotic cells, most commonly because of thermal stress but also by high irradiance, as well as reduced light (Kuanui, et al., 2020).
Stony corals (Scleractinia) build their calcium carbonate ($CaCO_3$) skeleton through calcification (Wijgerde et al., 2014). Coral calcification occurs in the corals' calcifying fluid, which is influenced both by internal and external carbon chemistry (Cameron et al., 2022). According to Wijgerde et al, the calcification rate is dependent on the concentration of available carbonates CO_3^2. The concentration depletes when hydrogen ions react with the carbonate ions, impairing calcification (Wijgerde et al., 2014). However, more recent research has revealed that calcification primarily depends on bicarbonate ions (HCO_3^{-1}), obtained from seawater, or converted from mitochondrial CO_2 conversion (Roleda et al., 2012). Corals utilize respired CO_2, converted to HCO_3^{-1}, for both intra-and extracellular calcification processes (Roleda et al., 2012; Cameron et al., 2022). The key factor controlling gross calcification for corals appears to be the H^+ flux to the coral surface (Roleda et al., 2012). During OA conditions, calcification processes ($CaCO_3$ formation) are more energetically costly (Cameron et al., 2022). Photosymbionts are vital in mitigating the impacts of OA, by providing enough ATP to maintain calcification rates (Cameron et al., 2022). Ocean acidification primarily threatens coral dissolution rather than impaired calcification, as some corals can maintain their gross

calcification rates under acidic conditions (Roleda et al., 2012). Other responses triggered by low pH are impaired reproduction, impaired growth, and metabolic processes, as well as anomalies in skeleton morphology (Gonzalez et al., 2017). Studies predict that in the future with OA conditions, on the open ocean surface, the dissolution rate will overtake calcification, impacting reefs with a larger proportion of dead coral (Stark et al., 2019). Tropical scleractinian corals' calcification responses to OA are nuanced, some exhibiting reduced rates while others show threshold responses and others have no response at all (Cameron et al., 2022).

Moreover, seawater's oxygen saturation changes can influence calcification rates (Wijgerde et alt., 2014). Oxygen is essential for ATP synthesis, providing energy for calcification processes (Wijgerde et al., 2014). Light also plays a role in promoting coral growth and calcification, known as light-enhanced calcification, as zooxanthellae provide energy from photosynthesis, while simultaneously increasing pH and stimulating $CaCO_3$ deposition (Wijgerde et al., 2014). Studying corals' ability to produce oxygen in various light intensities may result in different calcification responses (Wijgerde et al., 2014).

A lowered pH has been shown to positively affect net oxygen production when combined with elevated temperature (Krueger, 2017). An increase in gross oxygen generation per unit of chlorophyll was an effect of lowered pH, independent of temperature (Krueger, 2017). It was shown that changes in symbiont photosynthesis directly led to an increase in oxygen flow on the colony surface, meaning an improvement in local water oxygenation during the day. This could benefit aerobic biological processes (Krueger, 2017).

The excessive concentration of CO_2 in the atmosphere has detrimental effects on aquatic environments (Bedwell-Ivers, et al., 2016). Changes in pH cause changes in biochemical reactions, and an imbalance in ocean chemistry (Bedwell-Ivers, et al., 2016). To fully understand how corals are affected by ocean acidification, knowledge about the effect of changes in Dissolved Inorganic carbon (DIC) and pH have on zooxanthellae photosynthesis and later coral calcification rates (Bedwell-Ivers, et al., 2016).

Climate models predict a global decline in pH corresponding to approximately 0.3 units and a decrease in oxygen saturation by approx. 5 percentage points (Wijgerde et al., 2014).

Coral reefs play a crucial role in marine biodiversity conservation and provide essential ecosystem services. They serve as coastal protection, fisheries, for building materials as well as attract tourism to the area (Hoegh-Guldberg, et al., 2007). Erosion of these habitats would mean a loss of ecological services and economic consequences (Krueger, 2017).

1.2 Aim

This study aimed to investigate how CO_2 modulates the light response in two coral species (*M. capricornis* and *S.caliendrum).* This could provide useful for further research in the future. We hypothesize that a combination of acidification and higher light intensity, which could be considered harmful under typical pH conditions, will benefit the photosynthetic zooxanthellae, and trigger higher oxygen production.

2. Method

2.1 Set up for the experiment.

Firstly, a wooden frame was constructed for the experiments. The setup consisted of the wooden frame (app. 1 meter x 1 meter), two industry-leading LED lights from Heliospectra, three white walls that were placed between the lamps to separate and contain the different light intensities, and a plastic tray as a sample holder (see **Figure 1**). A computer was stationed beside the frame to control the light intensity. The intensity was easily monitored with the program Heliospectra System Assistant version 1.3.0.

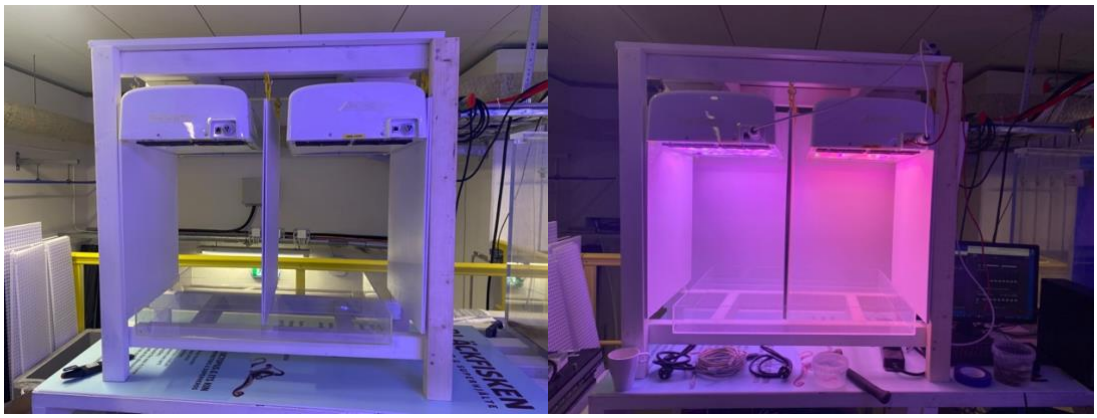

Figure 1. The setup for the experiment. On the left, the wooden frame was built and set up, on the right the finished setup with two Heliospectra lights.

2.2 Oxygen production in different light intensity (PAR)

The first part of the experiment consisted of measuring oxygen production in two species of coral (*Montipora capricornis* and *Seriatopora caliendrum*) in different light intensities, measured in PAR (photosynthetically active radiation, the unit is micromoles of photons per square meter per second, µmol quanta m^{-2} s^{-1}). The two coral species are native to the Red Sea and the Indo-Pacific region but grow differently. *Montipora capricornis* grows in flat colonies and inhabit the upper half of the reef (DeVantier, et al., 2008). *Seriatopora caliendrum* grows in a branched structure and inhabits shallow water on reef slopes at a depth of 25 meters (Hoeksema, et al., 2014). For a more extensive experimental design, two species were chosen to investigate the effects of CO_2 on corals' light responses. While the two species can be found in the same region, it was of interest to investigate if the species differentiated in their response to OA conditions. These species were relevant to previous studies done within the field of OA, done on tropical scleractinians. PAR, or photosynthetically active radiation, is the wavelength interval that is used by organisms to photosynthesize (Carruthers et al., 2001). These are wavelengths between 400 to 700 nm (Carruthers et al., 2001). The intensities tested were 200, 400, 600, 800, and 1000 PAR, to find the optimal light intensity and harmful light intensity, regarding O_2 production. A PAR meter was used to set the light to adequate intensity and provide an equal flow of photons over the samples. For each light intensity, the number of replicates was six for each species (n=6, in total 30 samples per species).
The wavelength and intensity were adjusted to set the correct PAR and color of light. For this experiment, white light was desired. This was done digitally by adjusting the different wavelengths to different ratios by connecting the lamps to a computer using Heliospectra System Assistant version 1.3.0.

The variable measured was oxygen produced per square millimeter of coral (ppm O_2/mm^2 coral, which stands for "parts per million") for *Montipora capricornis*, respectively oxygen produced per gram (ppm O_2 produced/g coral) for *Seriatopora caliendrum*. To calculate this, the *Montipora capricornis* fragments were photographed in front of graph paper, and later analyzed in ImageJ to calculate area. Fragments of *Seriatopora caliendrum* were weighed in grams using a scale.

The experiment started by measuring the oxygen concentration in the water before any treatment. The water used was newly mixed seawater, this gave a start value in oxygen concentration. As mentioned in the introduction, pH fluctuates diurnally. In this experiment, pH 8.2 was used as the "control" pH for the light-intensity experiment. pH values tend to naturally fluctuate during the day (Wijgerde et al., 2014), therefore there is no "typical" pH. The pH value used is an average of the usual pH in the aquariums at Sjöfartsmuseet during the day (during the morning pH levels tend to be lower, and reach an even pH level of approx. 8.2). Each container was labeled according to respective light intensity, and which replicate it was. A fragment of coral was placed in the middle of each container, with the photosynthesizing side facing upwards towards the light. The containers were submerged and closed with a lid underwater to avoid air bubbles in the samples. Each container was placed under the lights for an hour, placed within an interval of 5 minutes. After an hour, the concentration of oxygen was measured again. The change in O_2 concentration (ΔO_2) between start (O_{2start}) and finish (O_{2end}) was then used to calculate production per mm^2 alternatively per gram coral.

2.3 Test oxygen production in optimal and harmful light and different pH

The method is similar to the second part, except pH was a factor added this time. Three different pH treatments were used on the two corals, *Montipora capricornis* (light intensities: 600 PAR for optimal light and 800 PAR for harmful) and *Seriatopora caliendrum* (light intensities: 400 PAR for optimal light intensity, and 1000 PAR for harmful). The pH used were 7.60, 7.80, and 8.20. Each species of coral presented different oxygen production in different light intensities (see **Figure 2 and Figure 3**).
The method of adding carbon dioxide (CO_2) was used to acidify the water. Bubbling the water with gas is a quick and efficient way to manipulate the pH (Gattuso, et al., 2010). Using a CO_2 gas tank/tube, CO_2 was added by bubbling into seawater. While it was bubbling, a pH meter was placed to continuously measure the acidity. An oxygen (O_2) gas pump was also used, to regulate the pH if it was too acidic. This method was used to acidify water to pH 7,60 and pH 7,80. Before placing the containers under the lights, O_2 was measured as a start value. The containers were placed under the lights for an hour, in an interval of 5 minutes. After an hour, oxygen levels were measured in each container using an oxygen meter (units: ppm, "parts per million").

2.4 Statistical Analyses

A one-factor ANOVA was performed to determine the effect of different light intensities on the corals' oxygen production. Additionally, Cochran's and Levene's tests were conducted to assess the homogeneity of variances. In the case of heterogeneous variances, the data were transformed by taking the square root of the mean. The transformed data were then subjected to a one-factor ANOVA again. Furthermore, an SNK test ("Student-Newman-Keuls") was initially performed, but it did not yield accurate results as it showed no significance between

the groups. Therefore, a Paired t-test was used to compare each group separately. Subsequently, a two-factor ANOVA was conducted to investigate the combined effects of light intensity and pH on corals' oxygen production and assess the presence of an interaction. Finally, a Tukey HSD (Honestly significant difference) test was employed as a post hoc test to determine which groups exhibited significant differences. The results were graphically represented in various graphs (**Figure 2-5**).

3. Results

3.1 Oxygen production in different light intensities

3.1.1 Montipora capricornis

A one-factor ANOVA tested for significance between the light intensities and gave a significant p-value of 0.0021). A posthoc test, including Student-Newman-Keuls (SNK) test and Paired t-test, showed between which groups there was a significant ($p<0.05$) difference, shown in **Figure 2.** There was a significant difference between the light intensities 200 and 400 PAR, 200 and 600, 400 and 800, 600 and 800, 400 and 1000, 600 and 1000, and 800 and 1000. As shown in **Figure 2** the oxygen production was at its highest under a light intensity of 600 PAR. **Figure 2** shows a steady increase in oxygen production in the light intensity range of 200 and 600 PAR and a decrease in oxygen production at 800 PAR.

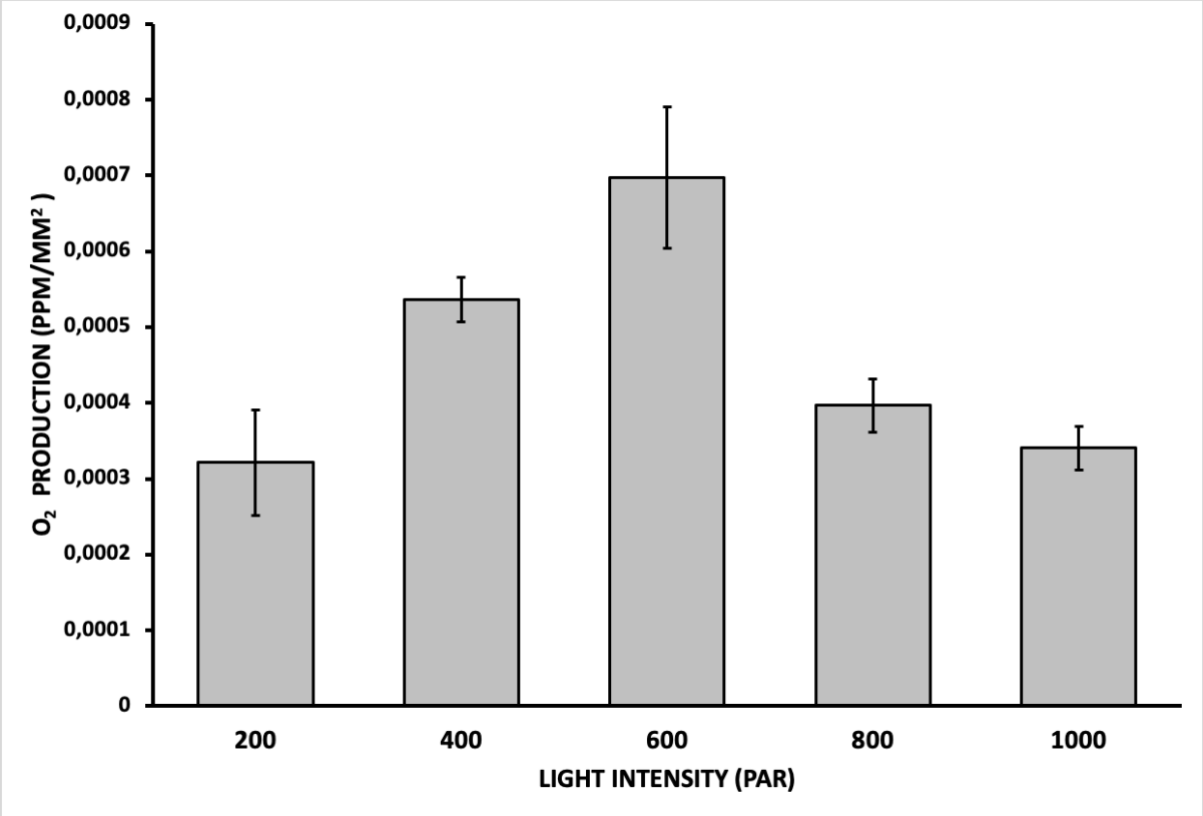

Figure 2. Oxygen production in coral *Montipora capricornis* under different light intensities (PAR). The graph shows the mean oxygen production at each light intensity. Error bars are +/- SE, n=6.

3.1.2 Seriatopora caliendrum

Cochran's test was conducted to assess the homogeneity of variances, which indicated heterogeneous variances (>$C_{critical}$). Therefore, the data were transformed by taking the square root of the values, which resulted in homogeneous variances, in both Cochran and Levene's tests. The one-factor ANOVA gave a strong statistical significance (p-value = 0.000847).
The tests showed statistical significance between light intensities 400 and 1000 PAR, 800 and 1000, and 400 and 600 PAR (see **Figure 3).**

An outlier replicate with significantly higher oxygen production was found in light intensity 800 PAR, which may have influenced the overall result. One replicate from each light intensity was selected to get an equal number of replicates (n=5). **Figure 3** shows that the max in oxygen production was n light intensity 400 PAR and the lowest oxygen production at 1000 PAR.

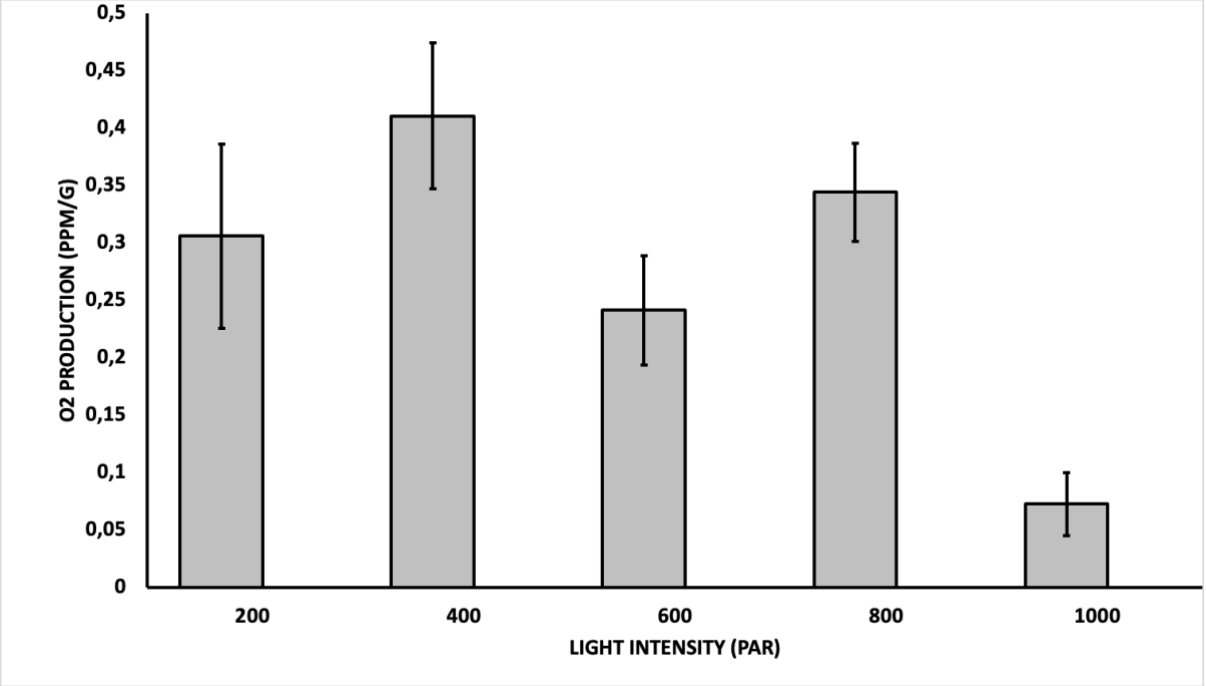

Figure 3. Oxygen production in *Seriatopora caliendrum* under different light intensities (PAR). The graph shows the mean oxygen production at each light intensity. n=5 Error bars are +/- SE.

3.2 pH treatments

A two-factor ANOVA was conducted to examine light intensity and pH's interactive effects on oxygen production.

3.2.1 Montipora capricornis

The light intensities chosen for the second experiment were 600 PAR as optimal lighting, and 800 PAR as harmful lighting. Data from the two light intensities as well as the three different pH treatments are presented in **Figure 4**.

The two-factor ANOVA showed statistical significance on pH (p=0.0190) and the interaction between light intensity and pH (p=0.00663). No statistical significance was shown for light intensity (p=0.5318). A Tukey HSD test revealed a significant difference in oxygen production

observed between light intensities 600 PAR with pH 7.6 and 7.8 and between pH 7.8 and 8.2 under light intensity 800 PAR. However, no significant difference was found between pH 7.6 and 8.2 under light intensity 600 PAR (shown in **Figure 4**).

For light intensity 800 PAR, there was a significant difference in productivity between all pH treatments. It was also shown to be a significant difference between different light intensities and pH (600 PAR pH 7.6 and 800 PAR pH 8.2; 600 PAR pH 7.8 and 800 PAR pH 7.6). The results suggest that pH significantly affects oxygen production in *Montipora capricornis* and the interaction of pH and light intensity. The results are presented in **Figure 4**.

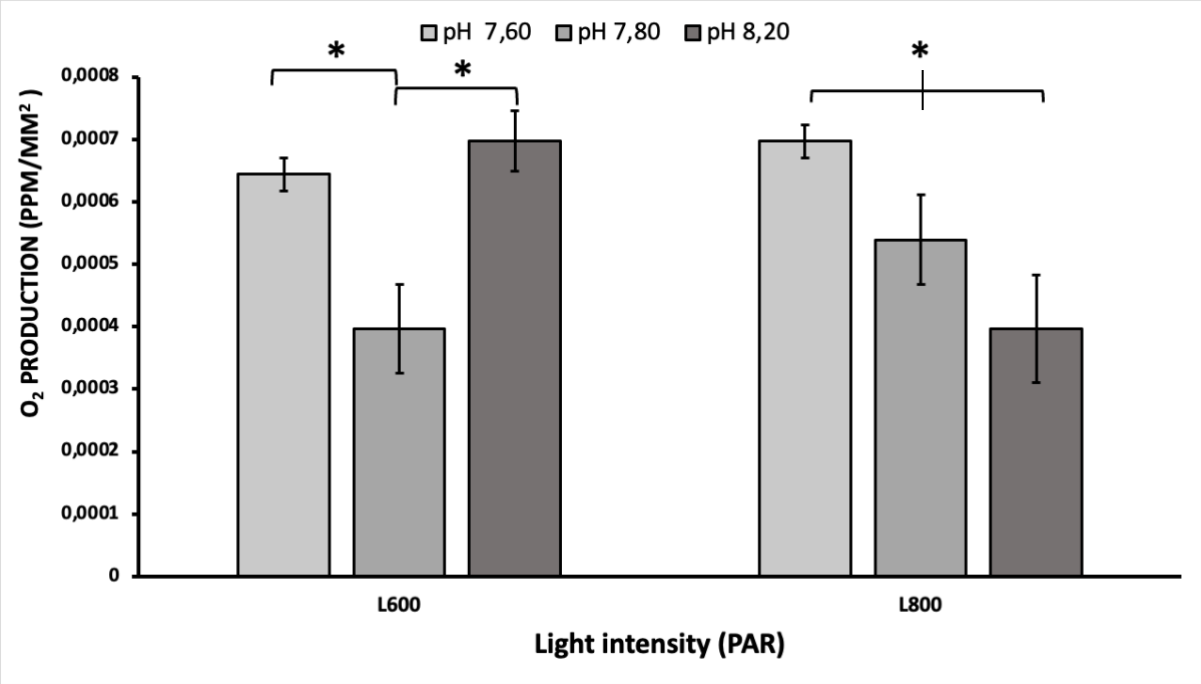

Figure 4. Oxygen production in coral *M. capricornis* under different light intensities (PAR) and acidity levels (pH). The graph shows the mean oxygen production at each light intensity. Significance bars present statistical significance. Error bars= +/- SE, n=6.

3.2.2 Seriatopora caliendrum

The light intensities chosen for the second experiment were 400 PAR as optimal lighting, and 1000 PAR as harmful lighting. The two-factor ANOVA showed statistical significance on pH ($p=0.000364$) and the interaction between light intensity and pH ($p=0.0130$). No statistical significance was shown for light intensity ($p=0.2401$).

Results from a Tukey HSD test indicated significant differences in productivity among all pH treatments under light intensity 400 PAR. For light intensity 1000 PAR, a significant difference was observed only between pH 7.6 and 8.2. Additionally, light intensity was only significant in one comparison (pH 7.8 for 400 and 1000 PAR). An interaction between factors pH and light intensity is showcased in multiple comparisons, giving statistical significance. The results are presented in **Figure 5**.

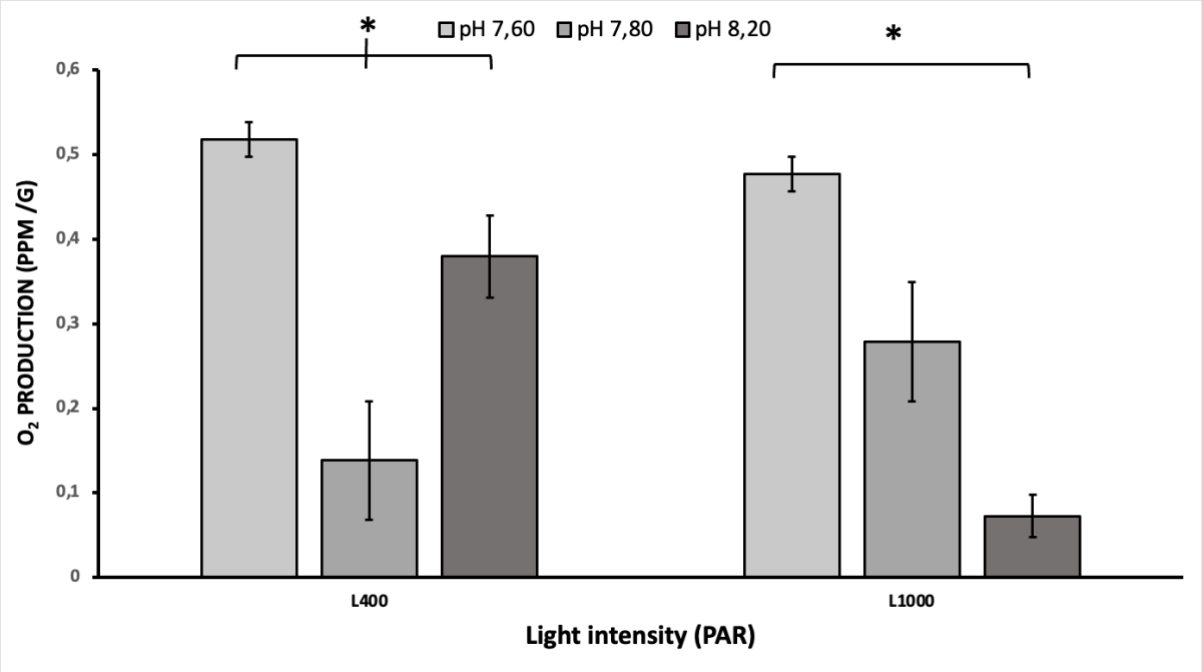

Figure 5. Oxygen production in coral *S. caliendrum* under different light intensities (PAR) and acidity levels (pH). The graph shows the mean oxygen production at each light intensity. Significance bars present statistical significance. Error bars= +/- SE, n=6.

4. Discussion

The findings from our study indicate that light intensity plays a crucial role in oxygen production for *M. capricornis* and *S. caliendrum*. For *M. capricornis*, we observed that oxygen production was highest at a light intensity of 600 PAR. However, this data point also had the largest variance, suggesting a potential spread of data points and uncertainty in representing the true population mean (Biology for Life, 2009). Despite the large variance, the productivity at 600 PAR was the highest among all light intensities (0.000697 ppm O_2/mm^2).

When examining the perceived harmful light intensities for *M. capricornis*, we considered light intensities of 200, 800, and 1000 PAR. We found a significant difference between the light intensities of 800 and 1000 PAR, indicating that higher light intensities negatively impacted oxygen production (p=0.00648). However, there was no significant difference between the 200 and 800 PAR light intensities. An explanation could be that 200 PAR is considered too low to reach maximum oxygen production, while a light intensity of 800 PAR was considered too high light exposure, causing a decrease in production. Oxygen production was similar under both light intensities, but oxygen production was negatively affected at higher intensities. Considering these findings, we selected 800 PAR as the relevant level of harmful lighting for subsequent analysis.

Moving on to *S. caliendrum*, the light intensity levels were determined by eliminating outliers. In 800 PAR, one replicate had an oxygen production that was unexpectedly high and was therefore selected out. For the other light intensities, one replicate was randomly excluded.
The data were plotted in **Figure 3**, where 400 PAR had significantly higher oxygen production compared to the other light intensities, and 1000 PAR remained the lowest in oxygen production.

In terms of pH, our analysis focused on examining the effects of different pH levels on oxygen production. For *M. capricornis*, we found no significant difference in oxygen production between acidic conditions (pH 7.6) and pH 8.2 at a light intensity of 600 PAR. However, there was a significant difference between pH 7.6 and pH 7.8, as well as between pH 7.8 and pH 8.2. This suggests that a pH level of 7.8 may have influenced oxygen production differently compared to the other pH levels. This pH level might represent a critical threshold, triggering specific adaptive responses in corals. Further investigation is required to understand the underlying mechanisms responsible for this difference. This could be especially interesting to investigate, considering that the carbon emissions scenario predicts that pH will range between 7.8 to 8.0 by the end of the century (Gonzalez-Pech et al., 2017). Our results are not entirely intuitive and are hard to interpret.

Interestingly, when comparing the oxygen production at 600 PAR and pH 7.6 with that at 800 PAR and pH 8.2 for *M. capricornis*, we found similar levels of production with no statistical significance. The absence of a significant difference between the extreme conditions of optimal light and pH 8.2 versus harmful light and acidic conditions challenges conventional assumptions, highlighting the complex interplay between light intensity and pH.

The influx of CO_2 in acidic conditions, combined with stronger light intensity, is shown to enhance coral oxygen production (Krueger et al., 2017). In the case of 800 PAR, there was a significant difference in oxygen production across all acidification levels, indicating the complex interplay between light intensity and pH (see **Figure 4**).

For *S. caliendrum*, we observed the lowest oxygen production at a light intensity of 1000 PAR and pH 8.2, followed by 400 PAR and pH 7.8. Surprisingly, the highest oxygen production was observed at 400 PAR and pH 7.6, which deviated from our initial expectations. Additionally, there was minimal difference in oxygen production in acidic conditions (pH 7.6) between the two light intensities. Notably, pH 8.2 resulted in significantly higher production in the optimal light intensity (see **Figure 5**).

In our experiment, it could be argued that only the photosynthetic zooxanthellae's well-being is being measured, rather than the well-being of the holobiont. By looking at oxygen production, it does not directly tell us about coral calcification or coral health. For this study, we wanted to use oxygen production as a proxy to measure coral growth.
Previous studies at Sjöfartsmuseet have shown that short-term oxygen production experiments are a good proxy for coral growth (i.e., calcification) under different light intensities (pers. comm Björn Källström).
An increase in available CO_2 and more light exposure makes photosynthesis more effective (McNicholl et al., 2019). Photosynthetic activity and proton pumps increase the pH in the surrounding water, helping to maintain the availability of carbonate ions for calcification (McNicholl et al., 2019). The same study also suggests that the mechanism of sustaining calcification under ocean acidification would be more effective in tropical environments, where there is high light intensity and warm temperatures (McNicholl et al., 2019). In addition to studying shallow-water corals, it is also important to investigate the impacts on deep-sea corals, which lack photosymbionts and rely on heterotrophic feeding for calcification (Cameron et al., 2022).

Certain limitations were done to the gravity of the thesis. Short-term trials were performed, which only measure oxygen production and not calcification rates. This can lead to

inconsistencies in results (Cornwall et al., 2015). For better results of actual coral calcification rates, it is more appropriate to examine the calcifying fluid in corals and its properties in different pH treatments (Cameron et al., 2022). The most appropriate and relevant method to study the responses of calcification and coral growth responses to higher acidification would be to adjust to long-term experiments and measure coral growth for an extended period. Due to time constrictions, this was not possible for this thesis. Other solutions could be to standardize CO_2 levels as well as extend the experiments' duration to better capture long-term effects (Cornwall et al., 2015). Future research could employ Free Ocean Carbon Enrichment (FOCE) technology, as conducted by Kline et al., to investigate the calcification and dissolution processes of corals "in situ" over an extended period (Stark et al., 2019).

5. Conclusion

In conclusion, our study explored the role of light intensity and pH on oxygen production in the corals *M. capricornis* and *S. caliendrum*. The findings revealed that light intensity significantly influenced oxygen production in both species. For *M. capricornis*, the highest productivity was observed at a light intensity of 600 PAR. The harmful light intensity for *M. capricornis* was determined to be 800, with higher intensities negatively impacting oxygen production. In the case of *S. caliendrum* the highest oxygen production occurred at 400 PAR, and the harmful was at 1000 PAR. The analysis of pH effects revealed significant differences in oxygen production at different pH levels for *M. capricornis*, with pH 7.8 exhibiting unique effects. However, no significant difference in oxygen production was found when comparing extreme conditions, optimal light, and pH 8.2 versus harmful light and acidic conditions. The interplay between light intensity and pH was complex, and further investigation is required to understand the underlying mechanisms. Similar complexities were observed in *S. caliendrum*, where the lowest oxygen production occurred at 1000 PAR and pH 8.2, while the highest production was observed at 400 PAR and pH 7.6. The limitations of the study included the focus on photosynthetic zooxanthellae without directly assessing coral calcification or overall health. Short-term trials and the need for standardizing CO_2 levels were identified as areas for improvement. Extending the duration of experiments would also help capture long-term effects and provide a more comprehensive understanding of coral responses.

6. Acknowledgment

I want to kindly thank Björn Källström for being my supervisor and always offering help and support when needed. I also want to thank our fellow student Johanna, who supported me throughout this process, and the rest of the staff at Sjöfartsmuseet for providing such a fun work environment.

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