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BIO 268 Marine Ecology

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**Effects of Ocean Acidification on Growth and**

**Photosynthetic Performance of Macroalgal Species *Ulva lactuca***

**ABSTRACT**

Rising anthropogenic CO2 input in our atmosphere has serious consequences for a variety of marine organisms. In this study, we examined the effects of ocean acidification on growth and photosynthetic performance of the ubiquitous macroalgal species *Ulva lactuca*. We hypothesized that lower pH seawater would overall benefit growth and photosynthetic performance of the alga. Our results revealed that in lower seawater pH (pH 7.6), *U. lactuca* experienced an increase in growth with a growth rate of 0.5 mg/7 days (s=0.0108). This is significantly higher than the growth rate in regular seawater pH (pH 8.1) where *U. lactuca* experienced a growth rate of -20.1 mg/7 days (s=0.0060) (T=3.18, p=0.045 in a one-tailed t-test). Achlorophyllous white tissue was also observed in *U. lactuca* under lower pH seawater conditions.

**INTRODUCTION**

The increasing amount of CO2 in the Earth’s atmosphere due to human activity is not only severely impacting terrestrial ecosystems but marine communities as well. Between 1759 and 1994, seawater pH decreased from about 8.25 pH to 8.14 pH, and is expected to decrease 0.3-0.4 units relative to current values by 2100 (Alexandre et al. 2012). This has serious consequences for numerous organisms living in these marine ecosystems (Jacobson 2005).

When atmospheric CO2 dissolves into the ocean and combines with water, it forms H2CO3− (carbonic acid) which then quickly dissociates to HCO3− (bicarbonate). Increasing acidity in seawater occurs when H+ concentrations increase with increased dissolved CO2:

CO2 + H2O = H2CO3

H2CO3 = H+ + HCO3−

HCO3− = H+ + CO32−

The excess H+ ions react with CO32− (carbonate) to form HCO3−, lowering the CO32− in the water column. The lack of available CO32−  in the oceans have harmful effects on calcifying organisms such as corals and snails which utilize carbonate for growth and development. Not surprisingly, most studies conducted on ocean acidification have focused on the effects of higher acidity on these calcifying animals. Few studies, however, have been done looking at the response of other organisms, such as non-calcifying macroalgae, to the decrease in seawater pH. Studies that have done so suggest that some algal species thrive in more acidic waters. In 2013, Olischläger et al. investigated *Ulva lactuca* performance under high CO2 levels in tidepools with limited water exchange. They found that when *U. lactuca* was exposed to more acidic waters, the alga experienced an increase in biomass and a slight enhancement in photosynthetic performance. Another study looking at the macroalga *Cystoseira compressa* found that the alga species exhibited an increase in carbon content and antioxidant activity, further suggesting that some macroalgae species benefit from higher CO2levels (Celis-Pla et al. 2015)*.* In contrast, the red alga *Palmaria palmata* showed a decrease in net primary production and respiration in response to more acidic waters (Nunes et al. 2015). These studies suggest that different species of non-calcifying macroalgae have different responses to ocean acidification.

To better understand the effects of ocean acidification on non-calcifying macroalgae, we have done the following study to observe the effects of heightened acidity on growth rates and photosynthetic performance of the ubiquitous macroalgal species *Ulva lactuca.* We hypothesize that the increase in CO2 concentrations in the water due to the lowering of pH will overall benefit *U. lactuca* due to its ability to more efficiently photosynthesize. Better understanding of the alga’s response to a more acidic environment will provide some insight into how *U. lactuca* may react to the effects of ocean acidification as the ocean’s pH continues to rise.

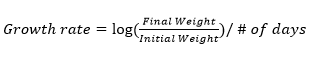
**MATERIALS AND METHODS**

To test the effects of increased ocean acidity on growth rates and photosynthetic performance of *Ulva lactuca*, we placed the alga in environments varying in pH levels and observed their growth in lab over the span of a week.

We used 8.0 pH and 7.6 pH seawater as our control and experimental environments, respectively, with three repetitions per pH environment. We used 150 mL beakers filled with seawater (135 mL) and chemical buffer *Tris* (0.1M, 15 mL) per repetition. Hydrochloric acid was used to increase acidity of the experimental setup to 7.6 pH. *U. lactuca* was dried using a salad spinner and blotted using a paper towel before weighing, and 1.2 g FW of the alga was placed in each beaker. The six containers were well-aerated and kept in growth chambers for a week under 12 hours light and dark intervals at room temperature (24**°**C).

Algal weight measurements were taken at the beginning and end of the experiment using the same lettuce spinner and blotting method. We checked pH levels everyday at 11:00 a.m., making necessary adjustments to the pH using hydrochloric acid every other day.

At the end of our experiment, we determined the mean algal weight from the two different pH environments. The following formula was used to find growth rates:



A t-test was applied to determine if the two growth rates were significantly different using Microsoft Excel.

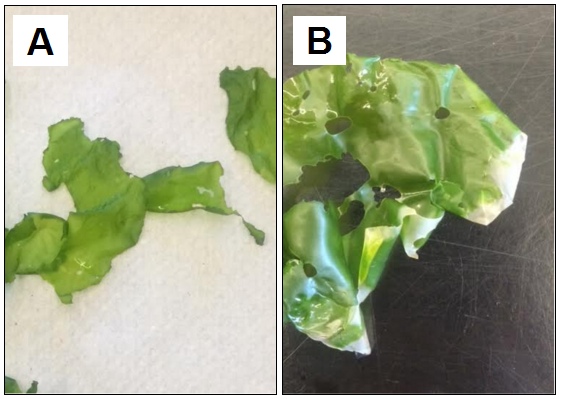
**RESULTS**

The results from our data showed that *Ulva lactuca* experienced a growth rate of -20.1 mg/7 days (s=0.006) under natural 8.1 pH conditions, while *U. lactuca* experienced a significantly higher growth rate of 0.5 mg/7 days (s=0.0108) under the more acidic 7.6 pH conditions (T=3.18, p=0.045 in a one-tailed t-test) (Table 1). The negative value of the experimental growth rate may be attributed to measuring error.

Achlorophyllous white tissue was observed along the outer edges of the alga in the experimental setup. No such tissue was observed in the alga from our control setup (Figure 1).

**Table 1.** The effects of increased pH levels on growth rate of *Ulva lactuca.*

|  |  |  |
| --- | --- | --- |
| pH Group | Mean Growth Rate (g/7 days) |  |
| Control (8.1 pH) | -0.0201 (s=0.0060) |  |
| Experimental (7.6 pH) | 0.0005 (s=0.0108) |  |



**Figure 1.** *Ulva lactuca* after 7 days under 8.1 pH control conditions (A) and in 7.6 pH experimental conditions (B). White, achlorophyllous tissue was observed along the alga’s fringe in the experimental group (B).

**DISCUSSION**

We hypothesized that *Ulva lactuca* would benefit from lower pH waters due to the increase in dissolved CO2, as it takes advantage of this resource for photosynthesis. Our results supported these predictions as a higher growth rate was observed in *U. lactuca* under more acidic conditions; however, achlorophyllous tissue was also observed in these alga, indicating that more acidic waters may also have negative effects on the development of *U. lactuca.*

**Growth rate of *Ulva lactuca***

Our study showed that when placed under more acidic seawater conditions with higher CO2, *Ulva lactuca* experienced an increase in growth. As CO2 is a limiting bottom-up control in most aquatic photosynthetic organisms, the increase in its availability most likely allowed *U. lactuca* to take advantage of the available CO2, thus enhancing its photosynthetic performance and resulting in increased growth and productivity. Our findings agree with a study by Celis-Pla et al. (2015) which found that the non-calcifying algal species *Cystoseira compressa* grows faster under lower pH conditions due to its ability to capitalize on increased concentrations of carbon. Similarly, Nunes et al. in 2015 observed an increase in growth in the kelp *Saccharina latissima* under high CO2 environments, and attributed this growth to the increase of photosynthetic rates under higher acidic conditions.

Several studies examining the effects of ocean acidification on non-calcifying macroalgae have found that some macroalgae species, including *U. lactuca*, are able to utilize both CO2 and HCO3− through a process known as carbon concentrating mechanisms (CCMs) (Nunes et al. 2015). The role of CCMs is to convert HCO3− into CO2, thereby increasing densities of the latter for Rubisco, an enzyme primarily responsible for carbon fixation. However, Rubisco is a relatively inefficient enzyme, and at atmospheric levels of CO2, Rubisco functions at only 25% of its catalytic capacity. Moreover, the diffusion rate of atmospheric CO2 into the ocean is 10,000 times slower than the diffusion rate of CO2 in the atmosphere. As a result, certain macroalgae species, such as *U. lactuca*, have adapted to these CO2-limiting environments by developing CCMs that convert HCO3− into CO2 (Moroney and Ynalvez, 2007).

The use of CCMs to utilize HCO3−, however, is more energetically taxing than utilizing only CO2. High concentrations of CO2 are therefore beneficial to the algal species as less energy is needed for carbon fixation, allocating energy otherwise spent on CCM to increase tissue growth instead. More alkaline waters hold carbon mostly in the form of HCO3−, while more acidic waters hold it in the form of CO2. By decreasing water pH, and thus increasing CO2 concentrations, the process of carbon fixation in *U. lactuca* becomes more efficient (Nunes et al. 2015).

Future studies exploring the effects of ocean acidification on the growth of *U. lactuca* may want to include a larger sample size and a longer experimental time. This allows a more accurate comparison in growth rates in natural versus more acidic waters.

**Achlorophyllous tissue**

White, achlorophyllous tissue was observed along the edges of *U. lactuca* under more acidic 7.6 pH conditions. This lack of chlorophyll in these tissues imply that while lower pH conditions appear to benefit the species in terms of growth, the lack of observed pigmentation in the tissues suggests that *U. lactuca* was also stressed under lower pH conditions.

A possible explanation for this is that acidity may have had an impact in nutrient availability and absorption in this algal species. For example, enzymes such as phosphatases are sensitive to pH, and different pH levels likely affects the transport rate of ionic nutrients like phosphate and nitrate. These nutrients are dependent on pH due to its reliance on H+ transport in the alga’s cell membranes (Brezonik 1994). Such possible hurdles in transport mechanisms for nutrient uptake in *U. lactuca* may have resulted in malnourishment, leading to the formation of achlorophyllous tissue.

It is difficult to determine the actual cause for the achlorophyllous tissue observed due to the limitations in our experiment. An interesting future study could further investigate how nutrient uptake differs in *U. lactuca* under these different pH conditions using specialized tools and machinery to measure chlorophyll densities, nutrient availability, and nutrient uptake, among others. Doing so may give a more accurate explanation as to why this is observed.

As ocean acidification continues to increase the amount inorganic carbon made available to the oceans, higher CO2 levels could enhance the opportunistic macroalga *U. lactuca*’s photosynthetic rates, encouraging algal growth, and potentially contributing to excessive macroalgal blooms in the future. The prevalence of these macroalgal blooms will have serious social, economic, and ecological consequences. Dense canopies of macroalgal blooms interfere with a variety of human activities such as tourism, fishing, and mariculture. Rotting mats of macroalgae are toxic and pose a serious health risk to humans and other organisms (Lyons et al. 2014). Studies examining the allelopathic properties of green tide seaweeds have shown that extracts from *U. lactuca* can inhibit larval development in several marine species, such as the Pacific oyster *Crassostrea gigas* and the green crab *Carcinus maenas* (Nelson et al. 2008).

Macroalgal blooms also have the potential to alter community structure as dense canopies of *U. lactuca* create mats of algae that may float in the water column if detached, blocking sunlight necessary for development in other photosynthetic organisms. Mats of macroalgae that settle onto the seafloor induce anoxia/hypoxia and release hydrogen sulfide chemicals that are harmful to certain organisms (Gamenick et al. 1996). Warming of our oceans due to climate change will further worsen the effects of seasonal hypoxia on many marine animals. Furthermore, *U. lactuca* is a strong competitor for space and resources, and the competitive effects of *U. lactuca* blooms on the decline of seagrass beds and other non-blooming macroalgae has been well documented (Qiuying Han 2014).

Because of all the negative ecological stresses attributed to the increase in growth and productivity of *U. lactuca,* studies like these which explore how ocean acidification impacts their performance is vital in solving problems caused by the overabundance of this algal species.

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