J. Dawn. Res., Vol. 3, 2021
www.dawningresearch.org

Journal of Dawning Research

The Effectiveness of Laminaria Digitata on Mitigating Ocean Acidification Through pH Analysis

Research Article

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Abstract: In recent years CO_2 levels have been rising worldwide, causing increased acidification of ocean water. Currently the average oceanic pH is 8, and while it is known that ocean water is naturally slightly alkaline, CO_2 emissions continue to rise and the ocean continues to absorb these emissions. This leads to a decrease in oceanic pH as it continues to become more acidic. The pH levels of the ocean have already fallen by 0.1 in the last 200 years. A 0.1 decrease may not seem drastic but consider the fact that the human body has a natural pH of around 7.4, and if it drops to 7.2 (just a 0.2 decrease) it may lead to death. A seemingly insignificant difference in pH level can have drastic effects on the human body, thus, the same can be considered when it comes to the ocean. Ocean acidification has already impacted many different forms of marine life and will continue to do so if no method is found to prevent the further acidification of ocean water. In the following experiment, Laminaria (kelp) was tested for capabilities of neutralizing the pH of ocean water. To combat the current ocean acidification conflict, recently, macroalgaes have been in the spotlight for its capabilities of absorbing CO_2 from ocean water with remarkable results. Laminarias have proven to be particularly effective at absorbing CO_2 and restoring pH levels of ocean waters, justifying its use in this experiment. Through pH analysis, the effectiveness of the Laminaria was measured over a 21 day time frame, and data was collected.

Keywords: Laminaria • Ocean Acidification • Marine Life • pH • Environmental Science

1. Introduction

As the ocean becomes more acidic, water becomes more corrosive and detrimental to marine life. According to a National Geographic article, in the 1700's (during the time of the Industrial Revolution), the pH of the ocean was approximately 8.1 which is considered somewhat alkaline. However, since the Industrial Revolution, the Ocean's pH dropped by about 0.1 which is a significantly large decrease. This is actually 28 percent more acidic. According to an article published Alejandra Borunda [1] , by the year 2100, the ocean's pH could drop to under 7.8, which would be devastating. This type of drastic pH drop can lead to extinction of marine species as

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well as an increased break in the food chain. To combat this, recently, macroalgaes (seaweeds) have been in the spotlight for being able to absorb CO_2 from ocean water in remarkable measures. According to Hirsh et al. [2], "When kelp photosynthesizes, CO_2 is removed from seawater (reducing acidity), and oxygen is produced." While many different factors affect the efficiency of CO_2 absorption by these macroalgaes, it is important to understand the effectiveness that seaweed colonies can have within a shorter amount of time. If this is considered as a long term solution it is important to comprehend that massive amounts of seaweed must be grown yearly to fulfill global needs.

According to an article published by Mathieu Mongin et al., the rising amount of CO_2 in the atmosphere is lowering pH in waters by about 0.01 every decade [3]. When taking this into account, the researchers created an objective geared towards determining the most sufficient location for a seaweed farm as well as its plant density, for the purposes of mitigating global ocean acidification. This research paper speaks of different reasons on why the reefs cannot be located in certain areas and different Independent Variables that can affect seaweed capabilities. Mathieu Mongin et al., states "…the seaweed farm needs to be located in areas where the water originating from the farm flows onto, and resides on, the reef for a reasonable duration. Additionally, the farm cannot be located on the reef itself, due to damage to the reef and reduced light availability for coral growth. The farm also needed to be located in an area deep enough so that the seaweed is always submerged." All of these factors that are mentioned are crucial in determining the efficiency of the seaweed, due to the fact that seaweed usage for mitigating ocean acidification should be optimized to the fullest. This relates to the experiment that is planned to be conducted, for the reason that it is important to know what factors will lead to a more efficient running model of Laminaria usage.

A 2011 study analyzed CO_2 absorption of seaweed and shellfish in China [4]. The researchers studied several types of seaweed and shellfish to see how much carbon dioxide they were able to absorb from ocean water, and compare the different species. According to Tang et al., "Seaweeds can transform DIC (Dissolved Inorganic Carbon) into organic carbon by photosynthesis, which can decrease the pCO_2 in seawater. Dissolved nutrients such as nitrate and phosphate can be taken up during photosynthesis to raise the alkalinity of surface water, which will further reduce seawater pCO_2, and therefore improve the rate at which atmospheric CO_2 diffuses into the seawater.", [4]. This is helpful to this experiment since it confirms that seaweed has the ability to absorb carbon dioxide from ocean water, and more specifically that Laminaria was most effective in absorbing carbon. It was claimed that "…the content of carbon in Laminaria is 31.2%, higher than in some other seaweed species.", [4]. This is important when regarding Laminaria usage because Laminaria can take in more CO_2 (specifically 31.2% more) than other macroalgaes.

A specific article by National Geographic, Seaweed 'forests' can help fight climate change, claimed "Seaweed also ameliorates acidification, deoxygenation, and other marine impacts of global warming…", [5]. This is a crucial point to take into account since seaweed is able to absorb CO_2, this indicates Seaweed Forests can actually utilize the CO_2 that they absorb and use it to help the surrounding marine ecosystem. Thus, there are two enormous advantages. Halley Froehlich, a scientist at the University of California, Santa Barbara, is the lead author of this new 2019 study [6] is remarkably the first study to quantify and accurately propose large scale seaweed farming as an offset and counteracting technique to carbon emissions. Her and her researchers found that "…raising macroalgae in just 0.001 percent of seaweed-growing waters worldwide and then burying it at sea could offset the entire carbon emissions of the rapidly growing global aquaculture industry, which supplies half of the world's seafood. Altogether, 18.5 million square miles of the ocean is suitable for seaweed cultivation…", [6]. Furthermore, using the average seaweed production and estimations, researchers compared three net-neutral seaweed carbon-offsetting scenarios (1) global finfish and crustacean aquaculture, (2) direct global agricultural emissions, and (3) California agricultural emissions. The researchers stated that eutrophication (excessive nutrients), hypoxia (inadequate oxygen levels), and ocean acidification are three dominant stressors to coastal systems that could be reduced through seaweed production. They went on to say that all three disturbances appear to be increasing in extent, duration, and magnitude globally. They found that placing seaweed in highly nutrified waters could potentially improve water quality by absorbing CO_2. This is relevant to the proposed experiment because it highlights the importance of providing seaweeds with a nutrient-rich environment in order for them to grow properly and absorbs CO_2 effectively.

A 2019 study, *Role of Seaweeds in Neutralizing The Impact of Seawater Acidification- A Laboratory Study With Beached Shells of Certain Bivalves And Spines of A Sea Urchin,* found that "Live thallus of green seaweed Chaetomorpha Antennina did reduce the magnitude of dissolution rates of all the shells and spines considerably as well as the change in pH of ambient seawater due to the addition of CO_2.", [7]. Not only did seaweed help reduce the change in pH levels, it also reduced the rate at which shells/spines of marine organisms dissolved. The shells/spines of marine organisms are sensitive to CO_2 and pH changes, and will start to dissolve if ocean water becomes too acidic, leading to injury or death of those organisms. This study highlights yet another importance of the proposed experiment. It also supports the hypothesis of this experiment by pointing to relevant results.

1.1. Examples of The Effects of Ocean Acidification

In Figure 1, the effects of ocean acidification are seen to be drastic when comparing unaffected coral to affected coral. The effects of ocean acidification can also be seen in Figure 2, dissolving a calcifer shell over time. It is noticeable how a minuscule pH drop has contributed to the apparent break down of the calcifer shell. Based on a research completed by Mekkes et. al [8], "Depth-averaged pH ranged from 8.03 in warmer offshore waters to 7.77 in cold CO_2-rich waters nearshore. Based on high-resolution micro-CT technology, we showed that shell thickness declined by 37 % along the upwelling gradient from offshore to nearshore water. " It can thus be strongly inferred that the increased acidity, which is closer to the shoreline, is far more detrimental to shell strength in marine organisms. This research also supports the obstacle that arose when completing this experiment, which is discussed in the 'Methods' section of this paper.

Figure 1. **Representation of living coral vs dead coral. Source: UNESCO**

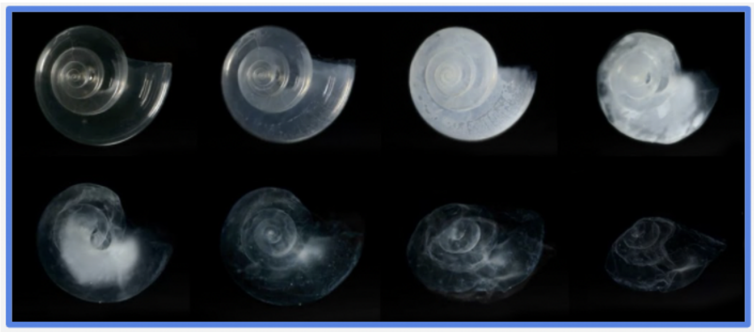

Figure 2. **Calcifer shell exposed to acidification - dissolving over time. Source: NOAA Environmental Visualization Laboratory**

1.2. Research Hypothesis

Macroalgaes, specifically Laminaria (kelp), can have a significant effect on Ocean Acidification and pH imbalance by absorbing CO_2 from the environment. It is hoped that this can open up numerous opportunities such as construction of larger Laminaria colonies and other Seaweed farms. It is believed that this experiment is to prove valid based on the research articles provided.

Null Hypothesis N(o): There is no significant effect that Laminaria can mitigate Ocean acidification and balance pH levels.

Alternative Hypothesis N(a) Laminaria (kelp), can have a significant effect on Ocean Acidification and pH imbalance by absorbing CO_2 from the atmosphere.

2. Methods

2.1. Preparation and Previous Experimental Design

Before starting the experiment, materials were ordered and ocean water, including sand, was collected by the nearby shore line. 10 pieces of Laminaria were added into each bin with 2 rocks for stabilization. 4 pumps of fertilizer were added into each bin. Originally, it was planned to use a CO_2 diffuser powered by two soda bottles, one with vinegar and water, and the other with baking soda and water, controlled by a regulator. This ultimately did not work, and the plan was changed where CO_2 cartridges were ordered instead. It also appeared that the pH of the ocean water collected was more acidic than expected, with a pH level around 6. This may have been due to the location the water was collected from. The coastal waters (where the water was originally collected) was more acidic due to the many different pollutants from the shore and the added bacteria. It also appeared that the Laminaria was dying. The Laminaria had dissolved into small pieces and floated to the top of the bins. This may have been due to the overly acidic water, or because of any microorganisms or bacteria that were inadvertently collected in the water or the sand. This plan did not work and was revised.

2.2. Final Experimental Design

It was ultimately decided to create ocean water from tap water and salt in order to prevent any further contamination of the Laminaria and to maintain an environment free from other influences (mainly from the shores.) Bins were washed out and scrubbed. 4,000 grams of tap water at a temperature of 62 ºF (about 16.7º C) was added to 140 grams of sea salt for each bin. This was then stirred until all of the salt was dissolved. Baking soda was added to increase the pH for the starting amount of each bin, since the tap water and salt mixture had a pH of around 6.9. Bin A was set at 7.09 (approximately 7.1) needing 1/8 of a teaspoon of baking soda. Bin B was at a pH of 8.1 needing 5 teaspoons of baking soda and bin C used 3 teaspoons of baking soda to reach a pH 7.8. The addition of baking soda was added in increments so that excess baking soda would not cause the pH of the water to be too basic. Furthermore, research by Kindle Ann Murray [9] states "As once large and persistent kelp forests are converted into fragmented landscapes of small kelp patches, kelp's ability to take up dissolved inorganic carbon and reduce nearby acidity and increase both dissolved oxygen and bio- available calcium carbonate may be reduced, preventing it from serving as an environmental stress-free 'oasis' of reduced environmental stresses for local marine organisms and affecting ecosystem dynamics." Based on this research, it was decided to use matured laminaria in this experiment. The laminaria was added into each bin once baking soda was stirred well. pH was measured while baking soda was added to make sure that measurements were correct and accurate. The water was allowed to sit for 3 days in order to allow baking soda to fully dissolve, and then pH measurements were taken everyday starting on day 3. CO_2 diffusers were unnecessary due to the pH already being lower than expected and having to be increased. Data was collected every day (24 hours) for 21 days (3 weeks). At the 3 week mark it was evident that the pH started to remain constant and was no longer increasing.

2.3. Controlled Experiment Conditions

Conditions such as light, nutrients in the water, type of container, and temperature were controlled. Along with this, each bin had the same amount (oz) of Laminaria.

3. Quantification of Data

As shown in the Appendix A, the calculations required to quantify the data were completed. However, based on the Appendix A, less Laminaria would be needed per cubic mile, as the Laminaria would not be packed so tightly together in stacks.

3.1. Acidity and Laminaria Usage

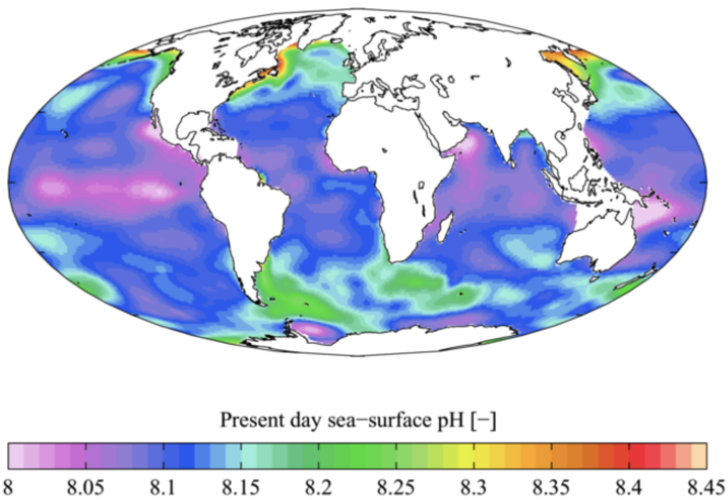

Figure 3. **Map of the different pH levels of the Ocean: Blue (approximately a pH of 8) is the normal pH of the ocean, while the purple is acidic. Source: Kiddle Encyclopedia**

The amount of Laminaria that was calculated is a wide approximation due to the fact that the Laminaria would not be packed together, filling the volume of the ocean in a specific area, but instead it is the maximum amount of Laminaria that could be added. Realistically, an exceedingly lower amount would be used.

In Figure 3, the areas that are more acidic, shown in purple on the map, may require more Laminaria, while the less affected areas, those shown in blue, will likely need less, or even no Laminaria. As seen in Figure 4, the seaweed farms would be placed similarly, in sporadic rows.

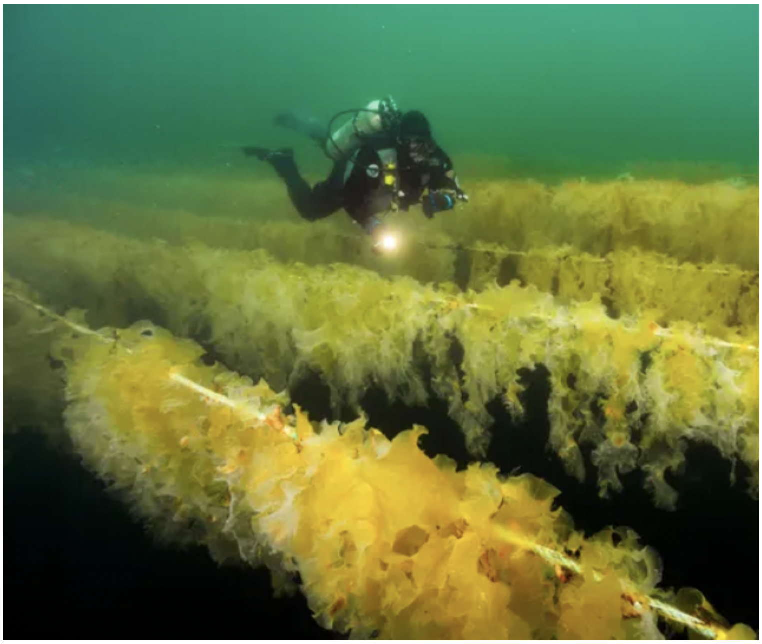

Figure 4. **A Similar Aim: Scientists constructed a seaweed farm in Alaskan Waters. Source: The Gaurdian Photograph: Brian J. Skerry/NGC/Alamy**

4. Results

Table 1. **Total pH Increase Over The 21 Day Period For Bin A, Bin B, and Bin C**

Bin:	(A)	(B)	(C)
Total pH Increase By % (Day 1 to 21):	11.57 %	10.25 %	13.46 %

The results of this research represents the increase in pH which thus expresses the decrease in acidity in the water (Table 1). Bin A clearly had a starting pH of 7.09 and an ending pH of 7.91 after 19 days. Bin B had a starting pH at 8.10 and an ending pH at 8.93 after the 19 days. Finally, Bin C had a starting pH of 7.80 and a finishing pH of 8.85 after the 21 day period. The quantitative data which was collected was accurately measured as the pH meter was cleaned between every measurement taken. The overall rate of change for Bin A was 4.32 percent, Bin B was 4.37 percent, and Bin C was 5.53 percent.

A promising finding of this experiment was that the three bins, A, B, and C, increased a very similar amount. The pH of Bin A went up by 11.57 percent, Bin B went up by 10.25 percent, and Bin C went up by 13.13 percent. The overall pH increase from day 1 to 19 was in the 10 - 15 percent range. A more detailed analysis of measurable pH increases are shown in Table 2.

htbp!

Table 2. **This table represents the daily changes in pH levels within Bin A, Bin B, and Bin C over the 21 day period.**

	Bin A	Increase in pH (A)	Bin B	Increase in pH (B)	Bin C	Increase in pH (C)
Starting pH	7.09	Starting	8.10	Starting	7.80	Starting
Day 3	7.52	+0.43	8.58	+0.48	8.46	+0.66
Day 4	7.61	+0.09	8.63	+0.05	8.47	+0.01
Day 5	7.64	+0.03	8.74	+0.11	8.56	+0.09
Day 6	7.65	+0.01	8.78	+0.04	8.59	+0.03
Day 7	7.70	+0.05	8.79	+0.01	8.63	+0.04
Day 8	7.72	+0.02	8.80	+0.01	8.66	+0.03
Day 9	7.73	+0.01	8.81	+0.01	8.69	+0.03
Day 10	7.75	+0.02	8.82	+0.01	8.72	+0.03
Day 11	7.80	+0.05	8.84	+0.02	8.74	+0.02
Day 12	7.83	+0.03	8.87	+0.03	8.75	+0.01
Day 13	7.83	+0	8.88	+0.01	8.75	+0
Day 14	7.84	+0.01	8.89	+0.01	8.76	+0.01
Day 15	7.86	+0.02	8.91	+0.02	8.80	+0.04
Day 16	7.88	+0.02	8.92	+0.01	8.81	+0.01
Day 17	7.90	+0.02	8.93	+0.01	8.83	+0.02
Day 18	7.91	+0.01	8.93	+0	8.84	+0.01
Day 19	7.91	+0	8.93	+0	8.85	+0.01
Day 20	7.91	+0	8.93	+0	8.85	+0

5. Discussion

This experiment further confirmed that Laminaria is able to mitigate effects of ocean acidification by absorbing carbon dioxide from acidic ocean water. Data shows that Laminaria was greatly effective in raising water pH levels, in a smaller model ocean environment, supporting past research studies. As with every experiment, there are potential sources of error. For instance, this experiment was done with tap water and salt, not with actual ocean water, since, as aforementioned, the ocean water originally collected was much more acidic than expected. While the tap water and salt mixture does closely resemble ocean water in terms of salinity, it is obviously not identical to the real environment. It is possible that Laminaria could have a slightly different effectiveness in real ocean water since there are other factors present such as other organisms, minerals, and microorganisms. Another potential source of error is the use of baking soda. Since the tap water and salt solution was neutral, at a pH of 7, the pH levels had to be raised to the appropriate amounts, not lowered with CO_2 as originally planned. This poses the possibility that the baking soda interfered with the Laminaria's ability to absorb CO_2, making it more or less effective. These errors can be solved in future studies simply by using ocean water collected from the deep ocean. The water collected for original use in this experiment was collected near the shoreline, since it was easily accessible. However, this posed an issue later since the water was found to be overly acidic, with a pH close to 6. Ocean water closer to the coastline is more acidic since it is closer to human activity like factories, cars, and other sources of CO_2. If the water were to be collected from the deep ocean, much further away from human interference the pH would likely be closer to what is expected, with a pH of 8.1. This would solve the potential error of using tap water with salt, as well as the error presented in using baking soda to raise pH levels. With water from the deep ocean, the experiment could have been conducted as originally planned, with the use of CO_2 to manipulate the pH of the water to proper starting amounts. All in all, the results of this experiment affirm prior research presenting macroalgaes, and specifically Laminaria as solutions to ocean acidification. This would greatly help the oceans as well as humanity, due to ocean acidification becoming a more prevalent climate issue in the modern day. The information obtained from this experiment is important to the fight against global climate change and ocean acidification. Research and experiments like this one are essential steps to the large-scale establishments of macroalgaes in the ocean that can prevent, and possibly reverse, the effects of ocean acidification.

6. Conclusions

The addition of Laminaria to acidic water increased the pH of the water. As time passed, the pH of the water increased over the 21 day experimental period before reaching a final pH level. Thus, the hypothesis that "Macroalgaes, specifically Laminaria (kelp), can have a significant effect on Ocean Acidification and pH imbalance by absorbing CO_2 from the environment", is greatly supported by the data that was collected over the experimental period.

7. Future Research

The conducted experiment, The Effectiveness of Laminaria on Mitigating Ocean Acidification, has created a significant amount of information on how the specific sea plant *laminaria digitata lamour* can positively affect oceanic environments by increasing pH while decreasing acidification. In this experiment it was found that after 3 weeks, pH levels increased by around 1.00, depicting the enormous effects of this plant. In order for this experiment to be considered for actual use, large amounts of Laminaria must be grown to its fullest and placed in ocean beds where acidification is no less than 7, $m \geq 7.00$, m standing for the measure in pH. If acidification is less than 7.00, it is too low for the Laminaria to aid in pH increase and acidification decrease. Anything lower than 7.00, will also cause the Laminaria to die, as it was experienced in this experiment. To make this experiment even more valid, multiple of the same 3 week trials must be done along with more groups at the same pH levels. Also, the water in which a scientist gathers for this experiment is extremely crucial, in that it was experienced that if the water is gathered by the shore line it is way more acidic than regular ocean water, thus a replication of ocean water is necessary. In future experiments it would be preferable to test the capabilities of various other laminaria species, due to the excellent result of *laminaria japonica* and others. According to Xiao et al. [10], "*Saccharina japonica* showing the highest capacity of 0.10 pH increase within the aquaculture area, followed by *Gracilariopsis lemaneiformis* (Delta pH = 0.04) and *Porphyra haitanensis* (Delta pH = 0.03)." Thus, the affects of these species of Laminaria, could possibly have a more significant affect that would need to be further studied. When doing this experiment in the future, the environment in which this is tested is also crucial. The bins must be kept in the same area at all times to reduce the amount of outside influence on the experiment. In this experiment we also found that the UV lights were unnecessary in that the Laminaria was already grown to its maximum height. This research should be taken into great consideration in that it opens up new, improved, efficient, effective, and environmentally safe opportunities for combating climate change.

Acknowledgments

First, we would like to thank Mr. Matthew Woo, our Competitive Research mentor, for his outstanding guidance throughout our experiment. We would like to thank Ms. Boosang Kim, Assistant Principal of Science at Forest Hills High School, for her support of our research and for the time she spent securing and obtaining the materials needed for this project. Finally, we would like to thank Principal Paul Wilbur and the entirety of the Carl Sagan Research Program at Forest Hills High School for the support and funding of this experiment.

Conflict of Interest

Authors of this article declare that they have no conflict of interest.

Human Studies/Informed Consent

No human studies were carried out by the authors for this article.

Animal Studies

No animal studies were carried out by the authors for this article.

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Appendix A: Calculations required to quantify the data

Volume of Bin: 9.75”W x 10.5”L x 12.25”H= 1,254.093
4,000 grams of water + 140 grams of sea salt
Amount of Laminaria per bin: 11 gram weight (1 piece of laminaria)

11 grams of laminaria per every 4,140 grams of water.
321,003,271 cubic miles of water is in the ocean
4,168,181,825 cubic meters of water are in a cubic mile

1 cubic meter of water weighs 2,206.07 lbs. or 1.103035 tons

(321,003,271 cubic miles) x (4,168,181,825 cubic meters) =$1.338x10^{18}$ cubic meters of water in the ocean

($1.388x10^{18}$ cubic meters of water) x (1.103035 tons) = $1.47586083x10^{18}$ tons of water (weight of water in the ocean)

(4,140 grams) x ($1.10231x10^{-6}$ tons) = 0.004563569 tons of water (weight of experimental water sample)
(11 grams) x ($1.10231x10^{-6}$ tons) = $1.2125x10^{-5}$ tons of Laminaria

Dimensional analysis:

$$\underset{\text{This experiment}}{\frac{1.2125x10^{-5}\ \textit{tons of Laminaria}}{0.004563569\ \textit{tons of water}}} \mathbf{x} \underset{\text{The ocean}}{\frac{x\ \textit{tons of Laminaria}}{1.47586083x1018\ \textit{tons of water}}} = 3.92x10^{15} \text{ tons of}$$

Laminaria needed for the entire ocean

($3.92x10^{15}$ tons) / (321,003,271 cubic miles) = 12,211,713.57 tons

For every 1 cubic mile of water, 12,211,713.57 tons of Laminaria is needed to reverse the effects of ocean acidification.