Ocean Sedimentation and Carbon Dioxide Uptake by Aquatic Plants

Environmental Systems & Societies Internal Assessment

Word Count: 2241

Table of Contents

Background Information & Environmental Context

Environmental Issue

Mangroves provide a range of ecosystem services including supporting biodiversity and functioning as sediment sinks (Furuwaka), however, mangrove deforestation is becoming increasingly common ("Sediments and Mangroves"). Coral reefs have a symbiotic relationship with mangroves - the mangroves trap sediment and nutrients, preventing these deposits from washing into the ocean ("Mangrove Trees & The Great Barrier Reef"). The destruction of mangroves may impact the penetration of light into surface water due to increasing deposits of terrestrial sediment into the ocean. One example of this is the Great Barrier Reef, where the loss of mangroves increases agricultural sediment, which increases the turbidity of coastal waters. Increased turbidity decreases the amount of light available for photosynthesis, influencing primary and secondary productivity of the entire reef ecosystem.

The ocean is one of the largest carbon sinks in the world, sequestering an estimated 50% of anthropogenic CO_2 emissions ("Ocean Acidification"). Increased CO_2 in the atmosphere also increases the amount of CO_2 in the water due to atmospheric-oceanic gas exchange, causing ocean acidification. CO_2 combines with seawater (H_2O) to create carbonic acid (H_2CO_3), lowering the pH of the ocean and creating a higher concentration of hydrogen (H^+) ions, posing threats to organisms sensitive to changes in acidity (Acidification Chemistry). This then reduces the number of carbonate (CO_2^{-3}) ions which are vital to shell and exoskeleton growth in many marine organisms, including coral polyps. Thus, ocean acidification is intertwined with the destruction of coral reefs.

Research Question

How does modelling changes in turbidity through decreasing available light influence the photosynthesis rates of freshwater *elodea* as indicated by pH?

Connection to Research Question and Hypothesis

This question aims to model the changes in light level caused by increasing sedimentation in the ocean. *Elodea* is a species of aquatic plant and will represent aquatic ecosystems influenced by mangrove deforestation. Based on the scientific background given for ocean acidification, it can be hypothesised that the more CO_2 in a body of water, the more acidic the water becomes. As insolation is a limiting factor to photosynthesis, it can also be assumed that the less light available for photosynthesis, less CO_2 will be used by the plan. The experiment combines these two principles in examining how sedimentation in a body of water will influence photosynthesis in aquatic producers, as measured indirectly by the pH of the water. Therefore, the hypothesis for this investigation is: as the amount of available light decreases, the pH of water containing *elodea* will decrease, becoming more acidic.

Variables

Independent and Dependent Variables

Variable Name	Measurement Range & Units	Method of Management
Independent: Turbidity: representing available light	Number of wraps of mesh around each bottle (increments 0, 3, 5, 8 and total darkness using foil).	Clearly labelling the number of wraps for each bottle to avoid confusion. Securing with elastic bands to prevent changes mid-investigation.
Dependent: pH	Measured using a pH probe (uncertainty ±0.1).	Conduct three trials for each light level increment to ensure sufficient data.

Controlled Variables

Variable Name	Method & Justification of Controlling
Water	pH will differ depending on the source of water (eg. tap, saline, distilled). As salt-water tolerant plant species are not readily available, fresh water from the lab taps will be used for all trials. This minimises potential differences in productivity between each increment.
Species of plant	Different species of plant photosynthesise at different rates. Keeping species consistent minimises discrepancies in levels of primary productivity.
Size of plant	Plants with a large mass/size typically have larger surface areas, which theoretically increases PP. By maintaining all *elodea* clippings to 10cm in length, differences in PP are minimised.
Position of bottles	Different areas of the laboratory will be exposed to different amounts of sunlight depending on the time of day; in order to control the amount of sunlight that reaches the plants, the experiment will be placed in one spot.

Materials List

Name of Resource	Quantity
Elodea aquatic plants	15 clippings, 10cm long
Graduated Nalgene plastic bottles	15
pH probe	1
Fresh water	Approx 3750ml, or enough to fill 15 bottles
Distilled water	500ml
Mesh	10cm wide strips, enough to wrap 12 bottles a total of 51 times
Aluminium foil	10cm wide strips, enough to fully cover 3 bottles
Tray	1, to hold all 15 bottles
Elastic bands	15

Masking tape	For labelling/securing mesh

Methodology

Part 1 - Setup

1. Place one *elodea* cutting into each square bottle and fill to just below the rim with fresh tap water, repeating this 15 times. Only one type of water and one species of plant must be used.
2. Cap all bottles and label trials and increments with masking tape to avoid confusion.
3. For the first increment of full light, leave three bottles unwrapped and place in the tray.
4. Cut and measure mesh strips 10 cm wide, long enough to wrap around one bottle once. Secure with masking tape and an elastic band around the rim.
5. Repeat step 4 for the remaining bottles wrapped 1 time.
6. Repeat steps 4-5 for the remaining increments of 3, 5, and 8 rounds of wrapping, measuring enough mesh to cover each bottle with the appropriate number of wraps.
7. For the final increment, cover the three bottles, including the caps, in aluminium foil, making sure no part of the bottle can be seen.
8. Place the tray containing all 15 bottles next to a window or another source of light. Ensure this position is consistent throughout the duration of the experiment (see fig. 1).

Figure 1. Final Lab Setup

Part 2 - Data Collection

1. Every two days, conduct pH readings for all trials.
2. Unscrew the cap and place the pH probe into the bottle, waiting 10 seconds for the value to stabilise before recording.
3. Resecure the mesh around the bottle and rinse the probe with distilled water between measurements.
4. Repeat steps 2-5 15 times for all bottles, for at least 3 days of data collection until sufficient data is generated.

Justification of Sampling Strategy

Changing light levels using mesh is a way of modelling increased turbidity as a result of sedimentation. As sunlight is needed for photosynthesis, if insolation is limited, the primary productivity of aquatic plants will also be limited. The number of layers of mesh for each increment was thus selected to model variations in turbidity. Three trials for each of the five increments are used to increase the validity and reliability of the experiment; the results will be measured over at least 3 separate days in order to interpret any trends in pH.

Risk Assessment and Ethical Considerations

This investigation does not deal with hazardous chemicals, however after the experiment, dispose of the aquatic plants sustainably. They can continue to be grown to minimise waste; alternatively, they can be treated as organic waste and used for composting. Remaining water from the bottles can be used to water existing plants rather than being discarded.

Data Collection

28th September				
	pH			
Light Level	Trial 1	Trial 2	Trial 3	Average
0	9.10	8.90	9.10	9.03
3	9.30	9.30	9.20	9.27
5	8.10	8.00	8.30	8.13
8	8.10	8.00	8.10	8.07
foil	7.90	7.80	7.50	7.73

3rd October				
	pH			
Light Level	Trial 1	Trial 2	Trial 3	Average
0	9.30	9.20	9.50	9.33
3	9.50	9.30	9.60	9.47
5	8.50	8.90	9.60	9.00
8	9.70	8.90	9.30	9.30
foil	8.10	8.70	8.10	8.30

9th October				
	pH			
Light Level	Trial 1	Trial 2	Trial 3	Average
0	9.50	9.70	9.50	9.57
3	9.10	9.40	9.30	9.27
5	9.70	8.90	9.20	9.27
8	9.80	9.00	9.20	9.33
foil	9.00	8.80	8.40	8.73

Figure 2. Tables 1-3: Raw Data Over Three Days

Sample Calculation of Mean

Formula	Example
$\bar{X} = \frac{\sum x}{n}$	$\bar{X} = \frac{(9.1+8.9+9.1)}{3} = 9.03$

Qualitative Observations

- Some plants became translucent and brown, or began to disintegrate (see fig. 3). Generally, this appeared to be plants receiving less light.
- Other plants had very visible new growth, regardless of the amount of light they received (see fig. 4).

Figure 3. Dead *Elodea*

Figure 4: New Growth on *Elodea*

Data Processing & Analysis

The following graphs were constructed based on the averages for each day of data collection.

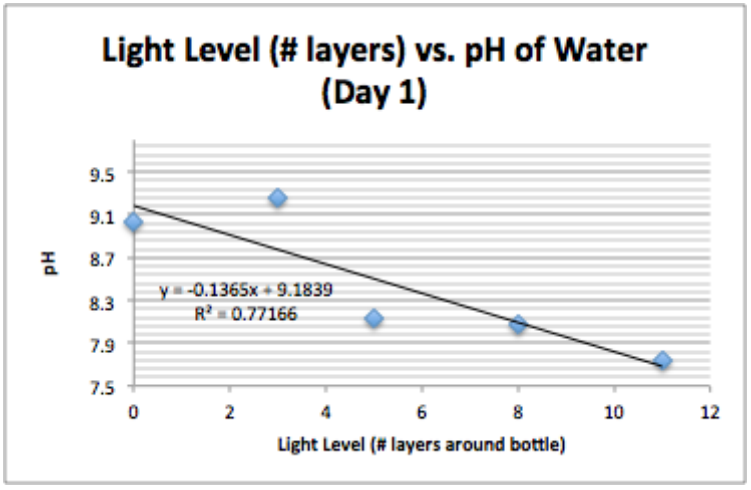

Figure 5. Day 1 Light Level vs. pH of Water

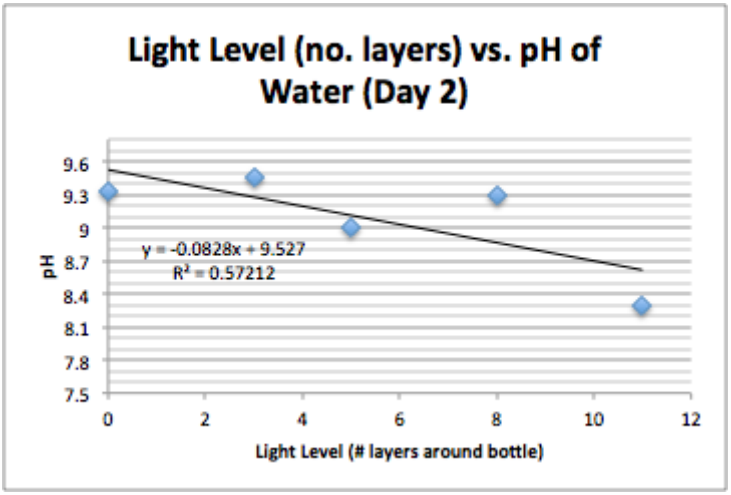

Figure 6. Day 2 Light Level vs. pH of Water

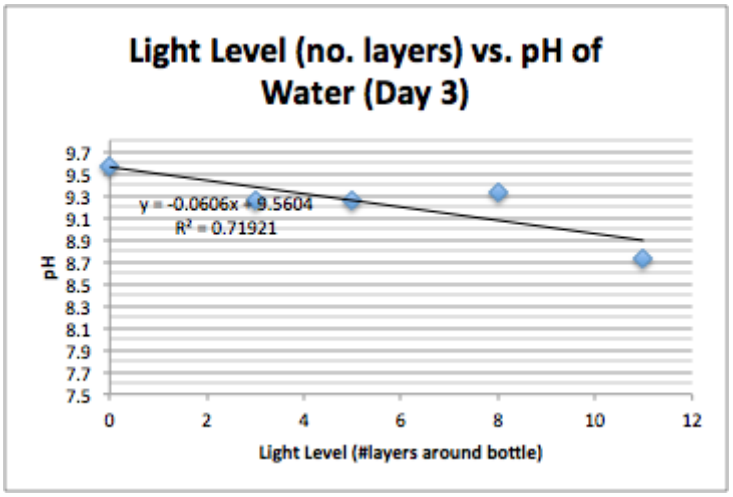

Figure 7. Day 3 Light Level vs. pH of Water

Trend and Pattern in Data

The r^2 value of 0.81674 for Day 1 indicates a strong correlation between light level and pH. As the amount of light available to the plant decreases, the pH of the water becomes more acidic. The bottles with full light had an average pH of 9.03, while the bottles with no light had an average pH of 7.73.

The r^2 value for Day 2 of data collection is 0.57212, indicating a weak to moderate relationship between the two variables. Still, the average pH level decreased for each increment: from 9.33 to 8.30 for the bottles with light and no light respectively. This trendline was the weakest out of all three days; notable anomalies include an increase in pH for the second increment to 9.47 before dropping suddenly to 9.00. The fluctuation in the spread of data suggests the relationship between pH and levels of light may not be as strong as originally hypothesised.

The r^2 value for the final day continues to indicate a moderately strong correlation between light levels and pH, at 0.71921. The pH begins at 9.57 and decreases to 8.73. The collective change in the pH over the 5 increments for all three days can clearly be observed to decrease. As available light is reduced, so the pH of the water becomes more acidic.

An observation of the averages for each increment was that despite the pH decreasing for each increment on any given day, the overall pH of the bottles continued to increase. For example, the bottles with no light began with a pH of 7.73, which then increased to 8.73 by the end of the experiment. These changes are represented in the following graph.

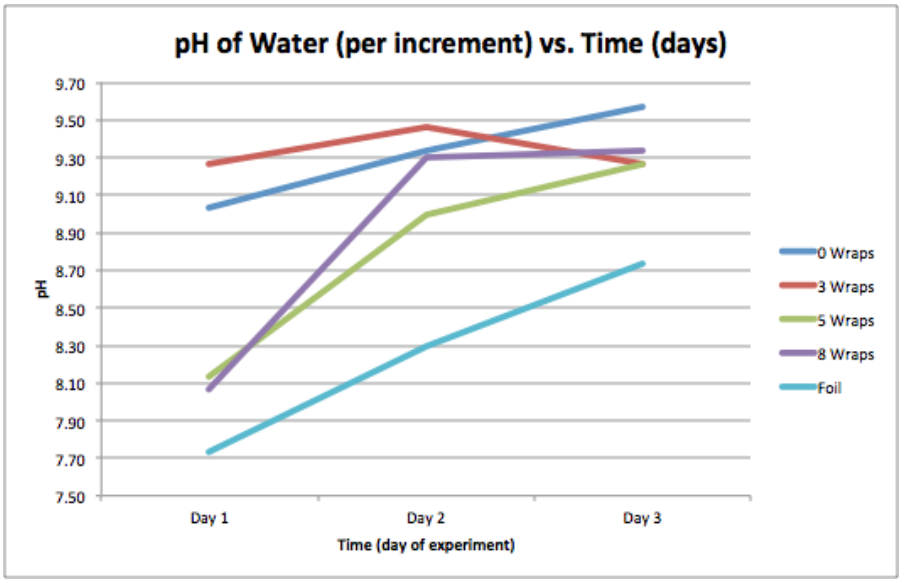

Figure 8. Changes in pH of Water vs. Time

Nearly all increments (except for the bottles with 3 wraps of mesh) are shown with an increase in pH over time, indicating that as the experiment progressed, the pH became increasingly alkaline.

Conclusion

The above analysis suggests that the pH of water decreases as the amount of light decreases, aligning with the original hypothesis. Though not an original part of the hypothesis, it is interesting to note the progression of pH over time towards alkalinity, rather than acidity. Despite the fact that the data supports the original hypothesis, there are certainly limitations to the method that may reduce the reliability of the data.

Evaluation

In Context of Environmental Issue

Based on the results of this experiment, changing light levels (representing increasing ocean sedimentation due to mangrove deforestation) does have an impact on aquatic pH. This supports the idea that mangrove ecosystem services benefit surrounding ecosystems like coral reefs. However, when considering the use of aquatic producers to reduce the impacts of ocean acidification, the results of this experiment do not align with this theory. The conclusion demonstrates an increase in alkalinity of the water as light was reduced, rather than an increase in acidity. Therefore, a decrease in ocean acidity cannot be reliably associated with the presence of aquatic producers.

Evaluation of Method

Weaknesses of the Experiment

The biggest limitation of this experiment is the uncertainty of the pH probe, used to measure the dependent variable. During the experiment, it was noted that two different pH probes produced readings with a difference of up to 2 (eg. one probe would read '7.5' and the other would read '9.5'), thus potentially impacting the results of this particular experiment.

Unawareness of how to care for aquatic plants like *elodea* may have impacted the rate of photosynthesis. It was noted in the qualitative observations that *elodea* became translucent or brown as the experiment progressed, indicating a deterioration to the health of the plant. This would have an impact on the ability of the plants to conduct photosynthesis, and thus the amount of carbon dioxide they were able to absorb, which would potentially impact the pH of the water.

Strengths of the Experiment

The use of mesh to control the amount of available light for each plant was appropriate, as was the number of wraps chosen for each increment. The gradual changes in light through the use of mesh were able to support the changes in pH seen from the experiment. Furthermore, the control variables were maintained relatively successfully. The water and species of plant used was the same for all trials, helping to control the reliability of results to some extent.

Improvements and Further Areas of Research

The bottles were placed upright during the experiment, providing a low surface area for light to penetrate (see fig. 1 - Final Setup). The close alignment of the bottles may have lead to different trials receiving differing amounts of light. One improvement to address this issue and thus improve the reliability of the experiment would be to use an artificial light source (a grow light) instead of natural light. This would allow a more consistent, higher concentration of light to reach the bottles, which may yield more distinct differences in pH. The ± 0.1 uncertainty for the digital pH probe used to collect data could be addressed through the use of a different pH probe connected to a digital program such as LoggerPro. This would allow changes in pH to be tracked over time, and more accurate conclusions regarding the influence of light levels on pH to be drawn.

Applications

Application to Environmental Context

The photosynthesis and primary productivity of producers removes roughly 25% of CO_2 from the atmosphere ("Plants Absorb More CO_2"). As one form of solution for rebalancing oceanic pH, aquatic primary producers can be introduced to increase rates of photosynthesis. Phytoplankton blooms and photosynthesis can be encouraged through iron fertilisation, increasing the amount of carbon dioxide absorbed from the atmosphere ("Ocean Acidification: Geoengineering"). Organic carbon absorbed by blooms at the surface is sequestered into mid-ocean waters when decomposers and zooplankton consume the phytoplankton ("Fertilising the Ocean With Iron"), effectively preventing the carbon from continuing to acidify vulnerable surface ocean ecosystems. In this investigation, the *elodea* plants represent the phytoplankton as both are producers, helping to remove CO_2 from an aquatic environment. The results of the experiment indicate that water increases in alkalinity as light levels are reduced, meaning in coastal reef areas affected severely by both ocean acidification *and* sedimentation, aquatic producers could form part of the solution to reducing the acidity of the water.

Evaluation of Effectiveness

However, based on the minimal reliability of the data from this experiment, it is unclear whether the use of aquatic producers like phytoplankton will have long term success in mitigating ocean acidification. Additionally, in real life, there is insufficient evidence to suggest that as light levels are reduced, the alkalinity of a body of water increases. Small iron fertilisation experiments have been conducted (12 since 1993), however the long-term impacts of increased phytoplankton blooms on aquatic food webs have not been fully assessed. Out of the 12 experiments, only 3 demonstrated carbon sequestration by producers ("Fertilising the Ocean With Iron"). Some detrimental impacts of using aquatic producers as a method of carbon sequestering include the depletion of essential nitrates and phosphates in the water, which could alter the available nutrients for fish and other secondary consumers.

When considering mangrove deforestation and increases in sediment deposits, this solution may not be as viable, as insolation is a key factor limiting the primary productivity of aquatic plants, which has indirect impacts on the amount of CO_2 these producers are able to remove from the oceans. Furthermore, this solution does not directly address the roots of the environmental issue - the deforestation of mangroves which results in increased sedimentation, as well as the increase in anthropogenic carbon dioxide emissions which increase the acidity of ocean water, limiting its effectiveness.

Works Cited

Furukawa, Keita, and Eric Wolanski. "Sedimentation in Mangrove Forests." *Mangroves and Salt Marshes*, vol. 1, no. 1, Mar. 1996, pp. 3-10, doi:10.1023/A:1025973426404. Abstract.

"Mangrove Trees & the Great Barrier Reef." *Canisius Ambassadors for Conservation*, Institute for the Study of Human-Animal Relations, www.conservenature.org/learn_about_wildlife/great_barrier_reef/mangrove_trees.htm.

"Ocean Acidification." *National Geographic*, Apr. 2017, www.nationalgeographic.com/environment/oceans/critical-issues-ocean-acidification/.

The Ocean Portal Team. "Ocean Acidification." Edited by Jennifer Bennett. *Ocean Portal*, Smithsonian Institution, ocean.si.edu/ocean-life/invertebrates/ocean-acidification.

"Plants Absorb More CO2 than We Thought, but …." *The Conversation*, Oct. 2014, theconversation.com/plants-absorb-more-co2-than-we-thought-but-32945.

Powell, Hugh. "Fertilizing the Ocean with Iron." *Oceanus Magazine*, vol. 46, no. 1, Jan. 2008, www.whoi.edu/oceanus/feature/fertilizing-the-ocean-with-iron.

Swales, Andrew, editor. "Sediments and Mangroves." *National Institute of Water and Atmospheric Research*, Nov. 2012, www.niwa.co.nz/freshwater-and-estuaries/research-projects/sediments-and-mangroves.