# ENGPROJ102
# Sensing Systems for Sustainability
# Seagrass & pH

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**Abstract:** Seagrass is currently being looked at as a possible solution in combating the effects of ocean acidification on calcifying aquatic organisms. This is a fairly new field of research and is still being debated in the scientific community. The objective of our research project is to determine the difference in pH fluctuations in locations with abundance of seagrass and locations without. This was done after analyzing pre-existing data using factors such as time of the day, presence of seagrass, temperature and finally pH values. Pre-existing data had to be used due to time constraints. In this report, the evolution of the project will as well be discussed and the possible limitations and challenges faced during the process of this project. After doing the data analysis it was found that there is indeed a difference in pH fluctuations and values between locations with and without seagrass. Indeed a difference in pH value of 0.35 was found for the location with seagrass whereas a difference of only 0.30 was found in the location without seagrass. This thus answers the research question of this engineering project, there is a difference regarding pH between places with and without seagrass. 

## 1. Introduction

The rate of oceanic acidification has been rapidly accelerating the past few hundred years mainly due to human produced CO2 levels rising within our atmosphere (Doney et al, 2009; Rérolle et al, 2012). A significant portion of CO2 is absorbed by the oceans, and without it, serious adverse effects on a variety of terrestrial and aquatic ecosystems would occur (Fabry et al, 2008). Ocean acidification mainly impacts coral reefs by damaging their exoskeleton and increases in carbon dioxide to 560 ppm has the potential to decrease coral calcification and growth by as much as 40 percent due to the inability to form aragonite (an important component of a coral skeleton) (Hoegh-Guldberg et al., 2009). Recent scientific studies have shown that organisms, such as seagrass, have the capacity to change their chemical environment which could be used as a buffer against ocean acidification for calcifying organisms. However, additional studies using continuous and sustainable measurement collection devices must be performed to determine if this impact is significant. The following section will provide a detailed overview of ocean acidification and pH, the influence this has on calcifying organisms, and the potential seagrass has to mitigate these effects.

## 2. Theoretical Background & Related Work

The oceans act as a sink for CO2 (Doney et al, 2009; Fabry et al, 2008), and these sinks enable CO2 to diffuse into a variety of ions as well as an aqueous form of CO2 itself. The adding of these ions leads to a decrease in the concentration of CO3 2-, and thus a decrease in pH (known as ocean acidification). The pH of water is measured by the concentration of H+ hydrogen ions. Specifically, pH is represented as the following formula: -log [H+]. (Water Science School, 2019 ; Huber & Blaha-Robinson, n.d.) pH is a logarithmic function; that is, one unit change in pH indicates a ten times difference in H+ concentration. However, in actuality, the hydrogen ion activity is measured and not the concentration of hydrogen. Acids have many H+ ions, while bases have many OH- ions. pH ranges on a scale of 0 to 14, with seven being neutral. Furthermore, values below seven are considered acidic and above seven basic. Although basic solutions are alkaline, “basicity” and “alkalinity” are not the same thing. Basicity is the ratio of hydrogen ions in solution and is directly related to pH, whereas alkalinity is referred to the acid-neutralizing capacity. (Suter et al., n.d.) There are a variety of specific methods that can be used to measure ocean acidification (Rérolle et al, 2012), but functionally they all accomplish the same method of measuring the hydrogen-ion concentration in solution by measuring the pH levels. In addition to adverse biological impacts there are also more obscure physical impacts of ocean acidification such as sound and light propagation (Doney et al, 2009). There may even be compromises to our infrastructure at more severe levels of ocean acidification. Electrolysis and other chemical processes could also be affected (Doney et al, 2009).

Importantly, the process of ocean acidification poses an imminent threat to calcifying aquatic species. As carbon dioxide dissolves into the ocean, seawater becomes undersaturated with carbonate ions, reducing the total amount of calcium carbonate available, a substance essential for calcifying organisms such as coral reefs. Coral reefs depend on calcium carbonate to build their exoskeleton, and a change in pH levels, due to acidification, can harm the structural integrity and growth of these organisms (Hoegh-Guldburg et al, 2007). When the pH lowers, it takes more energy for the calcification process, and corals have not properly adapted to this new change in environment. (Kleypas et al, 2009). Coral reefs bleach, which is a loss in their color due to the changing environment, or die because of the low pH levels. According to Kleypas et al. (2009), a doubling of pre industrial atmospheric CO2 concentration results in about a 10–50% decrease in the calcification rate of reef-building corals and coralline algae. A data collection of corals from the Great Barrier Reef, which extends these records through 2005, indicates a 14% decline in calcification rates between 1990 and 2005 because of acidification and rising temperatures (Hoegh-Guldberg et al., 2009). Oceanic acidification affects other organisms as well such as echinoderms, mollusks, corals and a variety of calcifying algae (Hoffman  Bischoff, 2014). The effects on these organisms are different depending on the species, stage of growth and rate of calcification. As pH levels continue to lower and temperatures rise, important ecosystems will perish resulting in a loss of biodiversity and coastal protection.

Although ocean acidification has been shown to harm the structural integrity of most organisms, it might actually promote photosynthesis in others. For instance, in seagrass and several types of microalgae, growth has been shown to increase in these acidic environments. (Kleypas et al, 2009). Seagrass are angiosperm species present in shallow coastal areas; these are some of the most productive ecosystems in the world. According to Chou et al. (2018) if seagrass meadows cover only about 0.1% of the sea floor, they could be contributing to up to 10% of the organic carbon sequestration in the ocean. Over the past years, seagrass has been looked at as a possible chemical buffer for coral reefs or other calcifying organisms against the effects of Ocean Acidification (Koweek et al, 2018). This can be explained by the fact that seagrasses are known for modifying seawater carbon chemistry, importantly pH levels, through photosynthesis (Chou et al, 2018). Considering the important diurnal variability in the seawater levels of carbon, it has been found that seagrass could either mitigate or enhance ocean acidification depending on the time of the day (Chou et al, 2018). Indeed, during the day, seagrass will be photosynthesizing, taking the CO2 out of the water, but during the night, it will release some of the CO2 during respiration. If respiration and photosynthesis are two of the main impacts on surrounding pH and CO2 fluctuations, other species present within the meadow, such as epiphytes, calcifying organisms and benthic invertebrates, all might also have an important effect on pH fluctuations (Chou et al, 2018). This subject is still widely debated, therefore it is of great interest to the scientific community to conduct more research into the effect that seagrass has on pH fluctuations.

## 3. Purpose

The purpose of this research project was to create a sustainable sensing device to measure the light intensity, pH and temperature fluctuations in areas with and without seagrass to see if seagrass has a direct impact on pH. The fundamental research question addressed in this paper is, "How do the pH fluctuations, with relation to the temperature and light changes, differ in areas with seagrass and without?". The following hypotheses were tested.

*Null Hypothesis:* There will be no difference between the pH fluctuations in the selected areas with seagrass compared to the areas without seagrass.

*Alternative Hypothesis:* There will be a greater fluctuation of pH in the selected area with seagrass compared to the areas without seagrass.

The goals of this project are to test and calibrate all necessary sensors and create a sensing system to be deployed. The intention behind this device is to alleviate the need for researchers to physically collect water samples every hour, thus saving time and money. Unfortunately, although the sensors were able to measure the necessary data, the device was unable to collect usable data for analysis. This will be discussed later in the report.

## 4. Measurements

The temperature was measured because when the temperature of the water increases, based on Le Chatelier's principle[1] the equilibrium will shift to lower the temperature to its initial value. That means more hydrogen and hydroxide ions will be formed. As a result, the pH of water decreases as the temperature increases. Note that pH and acidity are two different concepts, i.e., when the pH falls along with temperature increase, this does not mean that the water becomes more acidic. As mentioned previously, pH affects seagrass; thus, temperature implicitly affects seagrass by affecting the pH of the water (Chemistry, LibreTexts, 2020). Temperature also has a direct effect on seagrass. When the temperatures remain at a certain level for an extended period of time, seagrass can start experiencing some shoot-loss or a slower growth (Helber et al., 2021).. The increase of greenhouse gas in the atmosphere over the past century is undeniable. This rise in atmospheric CO2 has increased the average temperature by roughly more than 1ºC. Most of the heat produced by the increase of temperature is absorbed by oceans; in fact, the oceans absorb Ninety-three percent of the extra heat produced by global warming. Research indicates that as the water temperature increases up to a threshold temperature, the rate of photosynthesis in seagrass increases. Rising and passing this threshold, the rate of photosynthesis in seagrass rapidly declines. Thus, photorespiration does not increase linearly with the rise of temperature (Rushingisha, 2019). Overall, temperature has a direct and implicit effect on seagrass. On the other hand, seagrass photosynthesis affects the temperature of the water as well. Therefore, this parameter is of high importance in this research project.

The light variable was assessed because light has a direct impact on photosynthesis. In photosynthesis plants use sunlight, water and carbon dioxide to produce oxygen and energy in the form of sugar. Light intensity is particularly important for seagrass because they have unusually high light requirements ranging from 10 percent to as much as 37 percent of surface irradiance. This is compared to most macrophytes that only require .1 to 1 percent of surface irradiance (Zimmerman, 2009). These high light requirements can be tracked and the light dependent productivity of seagrass beds can be approximated by looking at the relationship between the irradiance and the photosynthetic rates. The photosynthesis rate of seagrass linearly increases with the availability of light, until the light conditions reach “saturation” where the photosynthesis rate cannot increase any further (Adams et al., 2016). Therefore, light promotes seagrass growth and photosynthesis rates thus impacting the pH levels of the surrounding water. This makes light levels a vital measurement for this study not only due to the impact on pH, but also because of the saturation conditions that could potentially be manipulated in future seagrass experiments.

Finally, as mentioned above the pH was measured because of its importance in ocean acidification. The pH fluctuations between areas with and without seagrass was the main effect tested in this experiment.

This report will first discuss the progress made during the course of the semester. Then it will discuss the methods used to create the sensing device; this includes the location selected to deploy the device, the physical design of the container and the build of the circuit as well as the sensors.. Finally, due to time constraints, pre-existing data from another experiment will be analyzed.

## 5. Project Progress

The draft of planning in figure 2was submitted on the 15th of April. Within this planning, multiple milestones had been set out for April and May. However, some of these milestones in this project were not achieved. The milestones that were not achieved were:

**25th April – 1st May** A depth test of the container was not conducted. The container itself was tested for its waterproof quality beforehand, but at the time, the project’s goal was to deploy the sensing system at a depth of 5m below sea level. However, now after the project, only the probes of the sensors would be deployed within a body of water. Within this week, additional testing and calibration of the pH sensor were conducted.

**2nd – 8th May** The device was not ready to be deployed in its current state. However, progress was made on soldering all the components into one unified circuit, but when the newly soldered circuit was tested, it did not work. The circuit did not work because the soldering was conducted incorrectly. Due to miscommunication within the engineering lab, the soldering was done on the wrong side of the board. Conversely, two holes were drilled in the container’s plastic lid, allowing the sensors to exit.

**9th – 15th May** Following the testing of the circuit, there were plans made to unsolder the circuit. Then after that had been conducted, there were two outcomes for the circuit. 1. Solder-it again or 2. Connect the components on a breadboard. The former would allow the device to have secure connections between the wiring and components. This more rigid connection would allow for minor potential error; thus, it was the most appealing choice for a final product.

| Week (Date) | Project Objective/Goal |
|---|---|
| March 1st | We will continue to work on improving our skills with Arduino boards and participate in the lectures. |
| March 7th | Focus our Arduino work on building sensors + delegate who will work on which sensor, Begin working on the pH sensor and design a prototype |
| March 14th | Continue working on the pH sensor and begin prototyping the water proof structure for the sensor |
| March 21st | Finish the pH sensor |
| March 28th | Finish prototype for water proof structure + begin working on light sensor and temperature sensor and current sensor |
| April 15th | Finish light/temperature/current sensor (depending on the amount of time available) |
| May 1st | Set up time slots for experiment and determine location of experiment + finish the sensors and entire physical project |
| May 5th to May 26 (Subject to change) | Set up experiment and log measurements |
| June 1st | Finish entire project |

Fig. 1. A table showing an earliest form of planning created in the start of semester

**16th – 22nd May** An overlay design of the device was created for ease of representation, and the circuit was fully un-soldered.

**23rd – 29th May** Due to the device not being deployed yet, a decision was made to use and analyse pre-existing data. This data would be similar to what would have been collected by this device. There was further progress on the entire circuit. This progress entailed connecting all the components and calibrating them in the primary circuit.

**30th May – 1st June** The device was ready to be deployed in a limited capacity. The device was taken out to a canal in Middelburg to test the sensor in an aquatic environment for 5 hours. However, an error occurred when storing the data and thus resulted in only a few points of collected data. On its own, this data is unusable. Therefore, additional data from outside sources was necessary. These published datasets were then analyzed.

Figure 3 represents a final version of the project's timeline with the most notable objectives and goals that were completed in each week of the semester.

Throughout the semester, many challenges and conflicts arose within the project. Be them from the pH sensor not arriving or simple scheduling conflicts that occurred and pushed back production. Due to these challenges, the project's planning went through many iterations, even towards the end of the project. There were occasions of a struggle for the time where specific tasks took precedence over others and thus were ultimately scrapped and put aside. The planning for goals has shifted over time. This planning shift can be seen in Figures 1, 2, and 3. Figure 1 is the project's initial planning, 2 is the midterm planning and updated goals, and finally, 3 is the final timeline of the project.

| Week (Date) | Project Objective/Goal |
| --- | --- |
| March 1st | Work on improving skills with Arduino. |
| March 7th | Deciding how to incorporate sensors within our project. Discuss potential designs of the project. |
| March 14th | Deciding where to conduct research. Contacting representatives of possible locations. |
| March 30th | Testing of waterproof container. Ordering of components. |
| April 4th | Testing of light and temperature sensors. Work on midterm report. |
| April 11th | Continued testing of sensors, and container. Discussion with Erik de Jonge. |
| April 18th | Finish testing and calibrating of sensors. Potentially begin testing newly acquired pH sensor. |
| April 25th | Depth test of container. After the depth test, potentially discover ways to improve the container. |
| May 2nd | Deploy devices within field of operations. Allow the device to gather data. |
| May 9th | Device maintenance. Potential device recovery upon further decision. |
| May 16th | If the device is left in the field, then second maintenance shall occur. However, data organization and analysis may begin if the device is retrieved. |
| May 23rd | Further data analysis and organization. |
| May 30th | Final project due. |

Fig. 2. A table depicting the previous midterm planning outline

| Week (Date) | Project Objective/Goal |
|---|---|
| March 1st | Work on improving skills with Arduino. |
| March 7th | Deciding how to incorporate sensors within our project. Discuss potential designs of the project. |
| March 14th | Deciding where to conduct research. Contacting representatives of possible locations. |
| March 30th | Testing of waterproof container. Ordering of components. |
| April 4th | Testing of light and temperature sensors. Work on midterm report. |
| April 11th | Continued testing of sensors, and container. Discussion with Erik de Jonge. |
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| May 2nd | Deploy devices within field of operations. Allow the device to gather data. |
| May 9th | Device maintenance. Potential device recovery upon further decision. |
| May 16th | If the device is left in the field, then second maintenance shall occur. However, data organization and analysis may begin if the device is retrieved. |
| May 23rd | Further data analysis and organization. |
| May 30th | Final project due. |

Fig. 3. A table showing the final and completed timeline of the project

### 6. Removed sensor - Flow Meter

Along with measuring light, temperature, and pH, there was initially planning to measure the flow of the water. Although, we excluded this parameter from our research. The main reason was that most turbines we saw were expensive or required a pipe to work. The problem is that having a pipe does not get the waves and current directly and accurately. If the waves are, for instance, 90 degrees to the direction of the fixed pipe, we will not have any - or will have limited - current captured by the flow meter. Therefore, the flow meter was ultimately excluded from the design and the device.

### 7. Assumptions

Assumptions were made in this project that it would be relatively simple to obtain a place where the device could be deployed, but this was utterly false. There was an immense struggle to contact those who oversaw the desired areas where the device would operate. There were also assumptions about delivery timings. There was an assumption that the device's pH sensor would have arrived at a good time. However, it never did. This assumption led to a long lapse in the time of the device's progress. The pH sensor not arriving also resulted in a loss of research time when deciding which pH sensor to use. Admittedly, this research was necessary, but the research into how the Grove - PH Sensor Kit (E-201C-Blue) operates and how to calibrate it was futile.

Furthermore, there was occasional ignorance within the project as well. There was a massive overlook of how the tides themselves would affect at what depth the device would be deployed. Likewise, there was ignorance about the device's waterproofing. It was initially researched and determined that coating the components in clear nail polish would be beneficial to the waterproofing, which it would have been, but this could have also led to its slew of issues. In addition, the waterproofing of the container was to be a PVC box initially and then a PVC pipe. The inspiration for the project was initially drawn from Figure 4 and Figure 5. The design then shifted to a more manageable and convenient design inspired by Figure 6. The project shifted to have the container of the circuitry be a second-hand waterproof Ikea Box that was already on hand (IKEA, n.d.).

Fig. 4. A Hydrometric Pendulum device. (Developing a FLOW Sensor — Underwater Arduino Data Loggers)

Fig. 5. A DIY Underwater Housing for Arduino Data Loggers made from PVC pipe(edmallon, 2015)

Additionally, the concept of how the device would be powered was only deliberated halfway through the project. It was determined that a 9V battery would have been used. Upon further inspection, it was clear that one singular 9V battery would be insufficient to power the entire device for extended periods. Thus, the assumption of how the device moved forward through the idea of using multiple batteries, battery packs, and then finally, a 5V power bank.

As a result of feedback during the midterm presentation of the project, it was determined that having the circuit on a breadboard was not an optimal decision. It was more appropriate to have a thoroughly soldered circuit on a PCB board for the final device. This decision was made as the initial operating environment may have impacted the security of the device's wiring, and this was a risk the project had to avoid.

Since the beginning of this project, it was determined that the device would compare pH values within areas with and without Seagrass. However, this eventually evolved into Seaweed as there is a definitive lack of areas with Seagrass within this region of the Netherlands. Moreover, there were issues in contacting the representatives of desired locations. Thus, the deployment destination was constantly shifting.

There were also countless debates about how the device would be deployed. It was a back and forth between submersing the entire container or creating some buoy where only the sensors would be submerged. In the end,


Fig. 6. Pro Mini Classroom Datalogger (edmallon, 2020)

the device was deployed in OPTION C. In this deployment, only the probes of the sensors within the water.

## 8. System Design

### *8.1. Physical Apparatus Design*

The purpose of the project was to design a sustainable sensing system. This was accomplished by designing a device that uses reusable old parts (such as an IKEA container and a powerbank), and could continuously measure data without the need to personally and physically take samples. This saves scientists time, energy and money and reduces the amount of waste used in sample collecting.

The system design was created using a tightly sealed and transparent Ikea container. The lid is a snap and lock lid with a three ringed rubber seal around it to ensure that it is airtight. Since the sensors were thought to, at first, be deployed underwater, all the components used had to be waterproof. At first, a pilot test was conducted to measure the container air-tightness by placing a piece of paper in the IKEA container and submerging it under water for an extended period of about 20 hours. After the test, it was concluded that the paper was completely dry, and no water had seeped in. Furthermore, the sensors that were used were all waterproof sensors situated outside of the actual container in order to measure the temperature and pH levels. The light sensor stayed inside of the container because it is transparent, so light levels can still be measured.

The original design consisted of the Ikea container with two holes drilled in the lid, for the temperature sensor and pH sensor to go through and the light sensor and LED situated inside of the container. It was first decided that the holes would be super glued to prevent water from seeping in. The apparatus was originally made to have a 3D printed case that had two levels. The first level would have contained a 5V battery and a cable, and the second level would have contained the Arduino board, the circuit board and the SD card to collect data (see figure 7). Unfortunately due to time restraints, the 3D printed structure was not created so a cardboard structure was used instead.

### *8.2. Circuit Design*

Following that, the circuit was designed; according to which we connected our sensors together. This was an important step in the project as we planned to connect the sensors together by soldering them on a PCB board. The reason for this decision was that we wanted to stabilize the device during the experiment so that no wires or sensors would get disconnected while running the experiment and collecting data. For designing the circuit, as shown in figure 8, it was planned to connect the devices in parallel. By doing so, if one component suddenly stopped working it would not jack our whole device and we would still have current, and data received from the other sensors. Thus, a parallel circuit was mainly used so that if one sensor broke down, the entire circuit would not be affected. In the parallel circuit, the current was divided between the different branches and the voltage remained constant in the two nodes of each branch; that is, in the two sides of each sensor. Therefore, each sensor received the same amount of voltage. This is another advantage for our purpose as the chosen sensors required approximately the same voltage range. As seen in figure 8 after the light sensor (photoresistor) there is an additional resistor. This resistor was initially used when experimenting out light sensors solely and it is also for protecting the light sensor

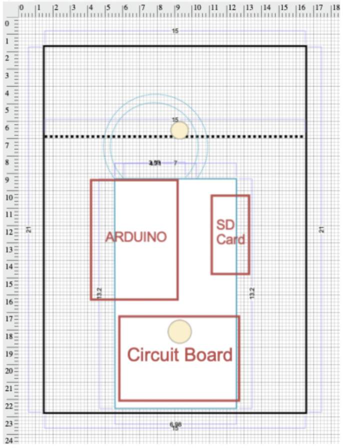


Fig. 7. The design of the IKEA apparatus. The blue represents the battery (5V) and cable (first level), the red shows the Arduino, SD card and circuit board (second level), and finally the yellow shows the holes in the lid where the pH and temperature sensors go(third level).

so that it does not receive a very high voltage. We could have put this resistor inside the main branch of our circuit but then all our sensors would have needed to be re-calibrated. Ultimately, the circuit included an LED that is on the main branch of the system. It was used to quickly check if the system is still functioning or not. In other words, if the LED was turned off that meant that we were not receiving any data as the circuit was not connected properly. The power source was the 5V battery which has a 10,000 mAh cell capacity. Take note that Ohm's Law relationship states that the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it and inversely proportional to the resistance at constant temperature (Basic Electronics Tutorial, 2021).

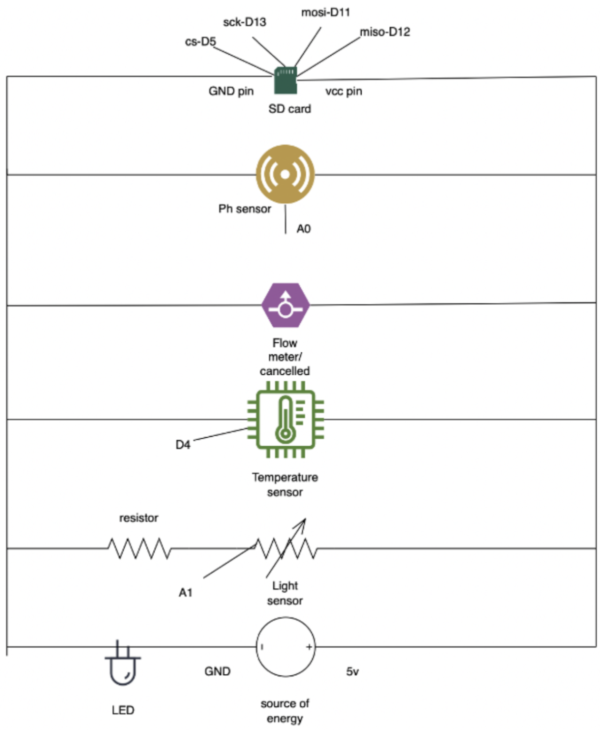


Fig. 8. A diagram of the device's circuit

*8.3. Systems design on PCB board:*

We will first have a look at why we chose a PCB board over a breadboard and what kind of PCB board was chosen for our system design. The PCB was chosen mainly due to its re-workability, low cost, and stability of the device, and the fact that we could not solder on a breadboard. We were provided with two types of PCB boards, one that had no connections and the other that was by default horizontally connected as can be seen in the figure below. Given that we wanted to build a parallel circuit the latter was meeting our needs and thus became our first choice. After choosing our PCB board, we converted our circuit from the design below, which indicates the points on the PCB board and thus where each sensor must be connected, to the actual PCB board (remember that all horizontal lines are connected; that is, they share the same voltage value). The electronic components were horizontally affixed to one-side of the printed circuit board (PCB).

Fig. 9. A perforated PCB board

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5v | light | temp | ph | SD card | | | | | |
| A0 | | | ph | | | | | | |
| A1 | light | | | | resistor | | | | |
| D4 | | temp | | | | | | | |
| D5 | | | | SD card | | | | | |
| D11 | | | | SD card | | | | | |
| D12 | | | | SD card | | | | | |
| D13 | | | | SD card | | | | | |
| anode | | temp | ph | SD card | resistor | LED | | | |
| GND | | | | | | LED | | | |

Fig. 10. A diagram representing the circuit on the PCB board. The circuit diagram translated to the PCB board. Figure shows the circuit implemented onto the PCB board with each row connected.

In detail the light sensor had two pins; one was connected to the 5V and one to the A1 pin which was connected to the LED through the resistor. Through the LED the circuit was connected to the ground. For the temperature sensor, one pin was connected to the 5V; the other to D4 and the last one to the positive side of the LED, and thus once again, to the ground. Furthermore, the pH sensor had three pins as well; one was connected to 5V, the other to pin A0 and the last one to the positive side of the LED. Same description is used for the SD card but take note that the SD card contains more pins. The way we implemented our device was that we soldered all devices on the PCB board as shown in the figure 11. We then connected for instance the first row of our board to the 5V of the Arduino so that all device pins soldered on the first row were connected to the 5V. We continued the process and finally got to the device below.

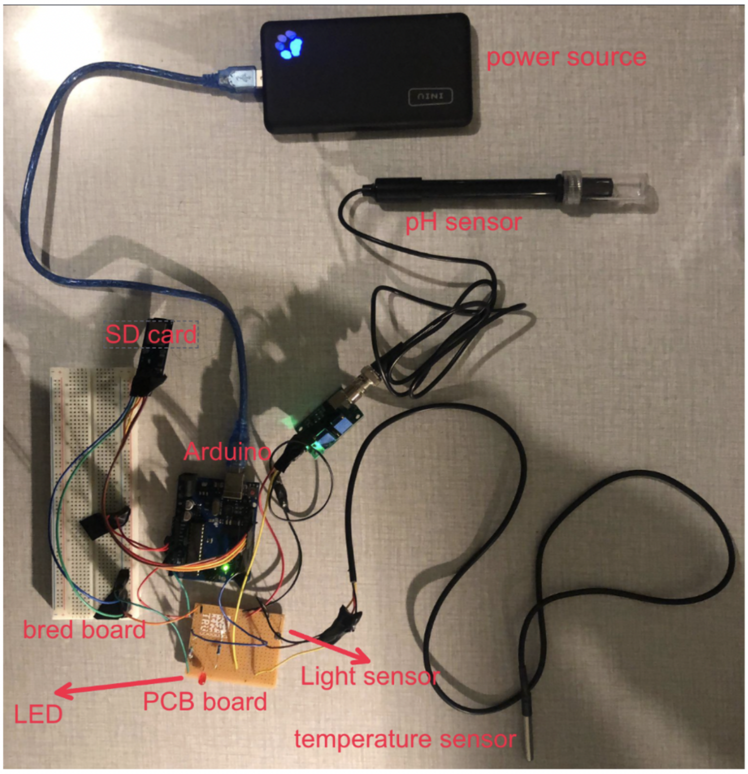


Fig. 11. The completed circuit of the device with labeled components.

As it can be seen, there is a breadboard in our device to which only the SD card is connected- and obviously the pins related to the Arduino. Although we tried not to include a breadboard given that our device might be disconnected during the project, due to the limited access to the laboratory we could not schedule a new time for connecting the SD card. It was thus connected via a breadboard. To increase stability, we bought tapes and used them to prevent wires falling off.

Now that the physical hardwares have been connected, the necessary software needs to be provided for the device to collect data. The codes used and uploaded on the Arduino Uno can be found on the following link: https://docdro.id/4RbfXJd. The link provides the codes we used; it is uploaded so that it can be accessible for potential further experiments. We wrote the codes concurrent so that simultaneously data from light sensor, temperature sensor and pH sensor can be collected and stored in the SD card.

## 9. Testing

Before deploying the device in our selected area, we ran a test; the video of which can be seen in the following link: https://streamable.com/lifmqx. As you can see, in each unit of time we get the temperature value, light value and pH value. If you look at the light value during the first 15 seconds- it is written in front of "LDR value is: "- it goes from 36 up to roughly 380, this is after a light source was put above it. Then when the photoresistor was covered, the light value went down to 5. This clearly indicates that our light sensor is working. For the temperature sensor as you can see in our test video there are some -127 degrees. This does not mean that the temperature at that moment was of -127 degrees. It was instead due to the temperature sensor being a bit dysfunctional and that sometimes it would disconnect (even changing the wires did not help). Throughout the second part we rubbed our temperature sensor and we can clearly see that the value went up to nearly 32 degrees and when putting it inside a bottle of lukewarm water it went down to 24 degrees. Take note that the experiment was done inside a room with a temperature around 26 degrees. Moreover, another observation was that our temperature sensor did not react as fast to variations in temperature in comparison to the light sensor's reactivity to light. Lastly, we tested our pH sensor and calibrated it and after puting it in different substances, it was found that the pH value was changing, this thus shows that the pH sensor was working.

## 10. Sensors

### *10.1. Light Sensor*

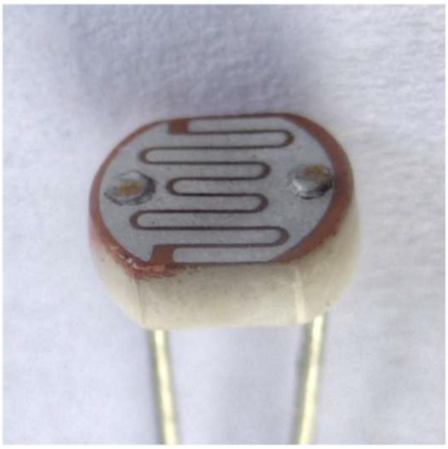

Fig. 12. A Photoresistor - LDR. Image by Nevit Dilmen (“Photoresistor” 2022)

A photoresistor (Light Dependent Resistor) that records the degree of incident light projected upon the device was utilized (“Photoresistor” 2022). This sensor can be easily incorporated into a circuit. Additionally, the LDR (Light Dependent Resistor) was within the engineering kit at the beginning of the semester. Thus it proved convenient to use. The variable resistance produced within this circuit due to the amount of light intensity changing will change the amount of voltage. This change in voltage can be measured analogously. This measurement will provide a range of integer values (precisely 4.9mV per unit), thus a range in how much light there is. This analog value is captured by introducing a jumper wire connected near the LDR in the circuit. This jumper wire then connects to an analog pin in the Arduino Uno.

Furthermore, the analog result provided from the LDR is challenging to interpret. Thus it was decided to create categories for incident light upon the device. This categorisation is to be simultaneously stored alongside the raw LDR data. This conjunction of the data was for ease of interpretation during collection and analysis. These ranges of categories were calibrated. The categories of incident light were predefined (Arduino, n.d.) but were redefined in testing. The “Dark” category was calibrated while the sensor operated in complete darkness in an enclosed room.

Additionally, the “Very Bright” category was calibrated by directly shining a light source onto the sensor. The remaining categories of incident light were calculated by manipulating the original categories. The LDR values remained untouched and uncalibrated. The categories, however, were altered once more when testing within the completed circuit with the same process as aforementioned. Moreover, the reason incident light is measured in the first place is that since the photosynthesis and the respiration of seagrass is dependent on light, thus, the more light there is, the higher the photosynthesis levels are and thus the higher the expected fluctuations in pH level will be. This altogether makes light a crucial factor to assess when looking into pH fluctuations due to seagrass.

### *10.2. pH Sensor*

Furthermore, the project’s primary and most important sensor is the pH sensor. The desired sensor was the Grove - PH Sensor Kit (E-201C-Blue). However, this pH sensor did not arrive in time for testing. Thus it was replaced with the pH Electrode E201-BNC. This sensor was provided directly by the engineering department. Unfortunately, there was no source material on the pH sensor, and additional research was conducted. The pH sensor measures the entire pH spectrum from 0-to 14 pH (E201-BNC General Purpose PH Electrode - Bante Instruments).

Additionally, the engineering department provided an interfacing component with the pH sensor. This interfacing component was highly beneficial as it allowed for easy connection and communication to the Arduino Uno of the device. When creating the device, the interfacing component remains within the waterproof container. At the same time, the sensor probe will be placed outside the container as it must make direct contact with the

Fig. 13. A pH Electrode E201-BNC.

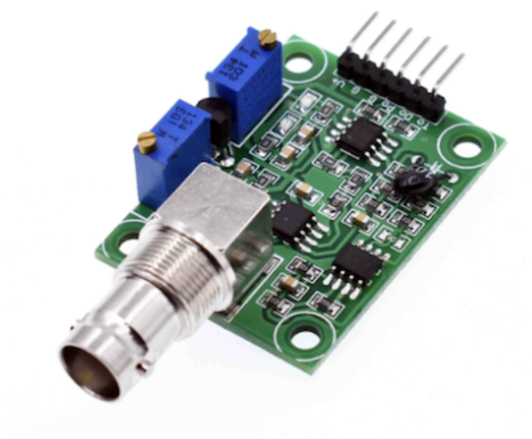

Fig. 14. The Liquid pH Value Detection Sensor for Arduino (interfacing component)

water to read values.

Conveniently, the first researched source (Electronic Clinic, 2020) (PH Meter Arduino, PH Meter Calibration, DIYMORE PH Sensor Arduino Code, 2020) for a pH sensor utilised a similar pH sensor and interfacing component to the one utilised in this project. The source included the calibration of the sensor and interfacing component. Thus it was a simple process of following instructions.

Firstly, the Arduino Uno connects to the interfacing component with 5 volts. The component is then connected to an analog port on the Arduino Uno.Secondly, the BNC connector on the interfacing component must be shorted using a wire. When measuring the analog output of the shorted interfacing component, a reading of 2.5 volts should be given. However, if the component is not calibrated, this value may be incorrect. Thus one of the blue tremors on the component must be adjusted. The voltage can be adjusted to 2.5 volts by measuring the analog output in real-time while adjusting the blue tremor.

Code was created that resembled that of the researched source (Electronic Clinic, 2020) (PH Meter Arduino, PH Meter Calibration, DIYMORE PH Sensor Arduino Code, 2020). The analog value is converted to a value of pH. With the code and calibrated sensor, the pH of the control solution was measured. Furthermore, the pH sensor has an attached solution of distilled water. This distilled water has a pH value of 6.9 to 7. However, an additional calibration unit was required to provide a result of 6.9 to 7 pH.

Similarly, these steps of adjusting the blue tremor on the interfacing component and adjusting the calibration unit were necessary when the pH sensor was incorporated within the complete circuit of the device.

Admittedly, the pH sensor might not be accurate over extended periods, but this testing did not occur. There were also attempts at scheduling testing with varying solutions of known pH values, but due to many scheduling conflicts, this also did not occur. Furthermore, the pH sensor may need occasional maintenance in an aquatic environment due to build-up on or around the sensor. This build-up may influence the sensor results and, in turn, lead to the collection of erroneous data.

There was speculation about the pH sensor's connection to the circuit. 1. To directly solder the interfacing component's pins to soldered male to male jumper wires, or 2. connect the pins by a female jumper wire and solder the male end onto the circuit. A decision was made to follow the latter and use male-to-female jumper wires instead of male-to-male jumper wires. Despite this decision, due to limited resources during the soldering process, the wire connecting to the voltage pin of the component was a male-to-male wire. Later in the design, this error was corrected by connecting the wire to a male-to-female wire by insulating electrical tape. There were attempts to correct the issue by scheduling an additional lab meeting to re-solder the cabling, but due to lack of remaining time, this session of re-soldering did not occur.

### *10.3. Temperature Sensor*

We used the LinkerKit LK-Temp2 sensor to measure water temperature, which was not our initial choice. We already had an LM35 temperature sensor, so our initial plan was to waterproof the LM35 sensor to utilize it for our experiment (Instructables, no date: online). Nonetheless, due to the potential inaccuracy caused while waterproofing the sensor, we decided to buy a waterproof one. LM35 waterproof temperature sensor was our second choice (GROBOTRONICS. 2011: online). The feature of this sensor is very similar to LinkerKit LK-Temp2; hence, due to the accessibility of the later mentioned sensor, we are using it. This sensor can measure the temperature from -55° to 125°C; the recommended max is, however, 100°C. This range suffices our needs for our projects as we estimate the water temperature during this time of year will vary between -10° to 20°C. The sensor is waterproof, has only one wire, and is a length of 1 meter. We can pop out the temperature from our box via the holes for its geometrical shape, making it suitable for our device. Ultimately it required a voltage of 3.0V—5.5V, making it compatible with the Arduino Uno we have. (Joy-it, no date: online). One of our main problems while deploying our device was the temperature sensor. The issue was that the pins of the temperature sensor were not stable and thus, sometimes the circuit connected to the temperature sensor had no current. As a result in our data we received -127 degree as the temperature which was obviously incorrect. The reason was that when the temperature sensor got disconnected it by default showed -127 degrees. Therefore, to reduce this issue we bought some tapes and as it can be seen in the test data the amount of disconnection- the amount of -127 degrees is highly reduced. If we had managed to get real data from our deployed device without failure we would have definitely excluded these -127 degrees as they were not the data measured by the sensor.

Fig. 15. The LinkerKit LK-Temp2 sensor

## 11. Power Source

The device utilised a 5V power bank to power the Arduino Uno and all the components connected in the circuit. This choice was made because the provided power bank (Figure 15) has 10 000 mAh. This mAh allows for sufficient charge to be supplied to the Arduino Uno and the components to run for extended periods. These long periods were necessary for initial operating conditions. Furthermore, the Arduino Uno contains voltage regulators. One voltage regulator on the USB port of the Arduino Uno is exactly 5V (UNO R3 — Arduino Documentation). This voltage matching was beneficial as there would be no power loss within the system and no excess heat produced. Additionally, the power bank was also chosen due to its ease of accessibility in this project. It was more cost-effective to reuse a 3-month-old power bank than to acquire a new battery pack and new batteries.


Fig. 16. An image of the USB power bank used. (INIU PowerPaw Slim 10000mAh Portable Charger)

## 12. Field Deployment

How did you deploy the sensor? What is the environment like? Why did you choose this environment? How did you obtain access to this environment? What were the hazards in this environment, and how did you counter them?

This section will describe the three main locations selected to deploy said sensing system. It is important to note, that due to time constraints and the complications experienced during the making of a self-sustaining device, none of the following locations were selected in the end. Instead, the device was deployed in a canal in Middelburg to test if the device would collect data (see progress section).

The initial plan was to deploy the device in the North Sea near Goes.Various locations near Middelburg and Goes were selected through the Seagrass Spotter website (a website where researchers and seagrass enthusiasts document seagrass) (Project Seagrass, 2014).Figure 17 shows an overview of the main locations chosen to deploy the device. Upon further investigation it was determined to deploy the device near the Oosterschelde and Goes as can be seen in figure 16 with the gray arrow. The location without seagrass would also be in the North Sea, approximately 30 kilometers from Goes, in Vlissingen where no seagrass was spotted. Notably, Seagrass are sensitive especially to eutrophication, turbidity, hydrodynamics, sediment instability, and extreme changes in temperature and salinity. Therefore, there has been an overall decrease in the amount of seagrass in the Netherlands, and the most abundant seagrass is found in the Wadden Sea (Folmer, et al.,2016). So, the locations chosen showed only a limited amount of seagrass present which could negatively impact the validity of the study. Moreover, there were many concerns with selecting this location because it was unknown if the area was protected and if so, who was in charge of it. There were also concerns regarding the state of the sensing system since it would have to be completely submersible and resistant to tides (See system design section). The device would also be susceptible to damage and could possibly be tampered with by onlookers.

Due to these concerns, it was then decided to change the location to a more secure area. Klaas Timmermans, the Head of the Scientific Department at the Royal Netherlands Institute for Sea Research (Nioz), was contacted for suggestions on the best area to conduct seagrass research. Nioz specializes in seaweed research, and permission was granted to deploy the system in one of the Nioz research facilities (see figure 18). Nioz has a Seaweed laboratory consisting of twenty cultivation tanks of 1500 liters each (NIOZ, 2021). The tanks are designed for seaweed cultivation and research, moreover, by using aeration, turbulent conditions are created in the tanks to keep the seaweed moving and mimic the North Sea tides (see figure 19).

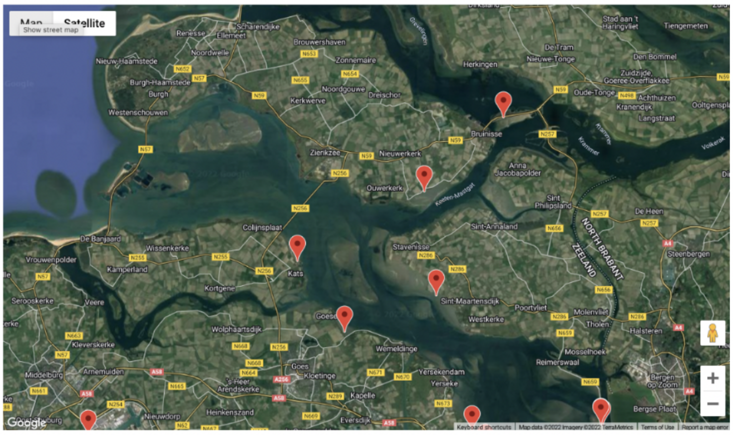

Fig. 17. The original seagrass location chosen to deploy the device (near Goes).

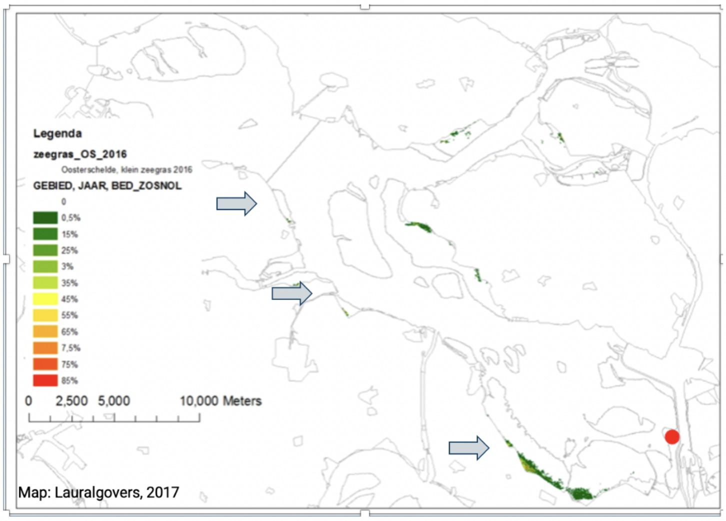


Fig. 18. The two different locations (Goes and NIOZ) compared to the amount of seagrass available (note the legend), which both lie on the North Sea.

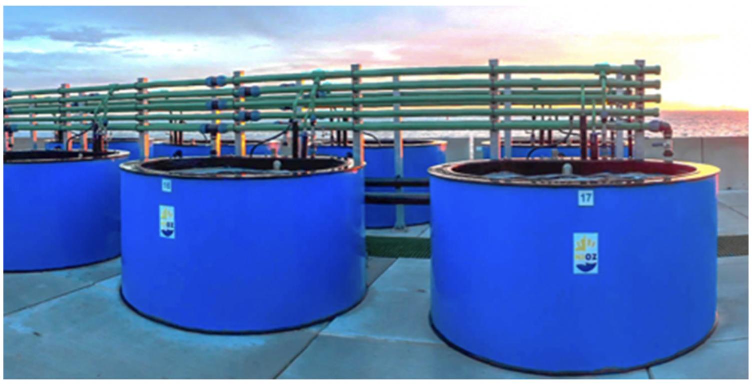

Fig. 19. The seaweed cultivation tanks used at the Royal Netherlands Institute for Sea Research.

By choosing this location it would change a few aspects of the study. Firstly, the laboratory cultivates seaweed, not seagrass. Seaweed differs from seagrass in that they are multicellular algae that have almost no vascular tissues. Alternatively, seagrass are vascular plants that have roots, stems and leaves (FFAWCC, n.d.) Nevertheless, seaweed are still photosynthesising organisms, therefore they impact the pH of their surrounding area, similarly to seagrass. Seaweed has a diffusive boundary layer (DBL) that allows them to modify their chemical environment based on light levels. Depending on the structure of the DBL, seaweed has the potential to buffer the pH of the surrounding area and provide refuge for calcifying organisms at risk of the effects of ocean acidification (Noisette  Hurd, 2018). Similar to seagrass, in the day time photosynthesis occurs which temporarily increases the pH levels. This means that seaweed could have been used for this experiment, since it still falls under the scope of the project, even though it ultimately was not chosen.

Secondly, because the system would have been deployed in a tank and not the sea, it would be attached to the side of the tank and not fully submerged under water. This changed the design of the system in terms of how water resistant it needed to be (see design section). The sensing system was planned to hang to the side of the cultivation tank via a metal clamp, so that only the temperature and pH sensors would be fully submerged underwater. Ultimately, however this location was not chosen because the device was not fully functional in time for NIOZ to deploy it due to challenges with soldering the components (see progress section).

Therefore, the device was deployed at our final location, shown in figure 20, in the Middelburg canals. In the canal, the device was not submerged underwater, instead the pH and temperature sensors dangled from the outside of the container while the container stood on the ledge of the canal (see figure 21).

Fig. 20. the sensing device deployed in the canal next to Bagijnhof field.

Fig. 21. The final sensing system deployed at a Middelburg canal.

## 13. Data + Analysis:

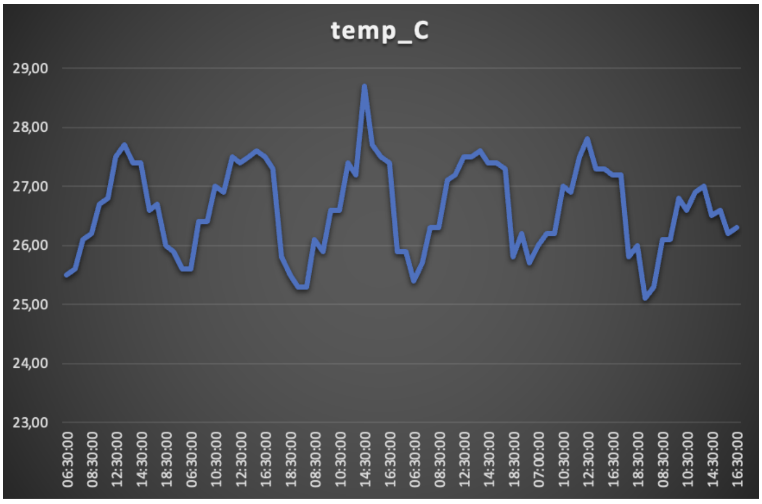


Fig. 22. Location defined as Sparse: Temperature vs time

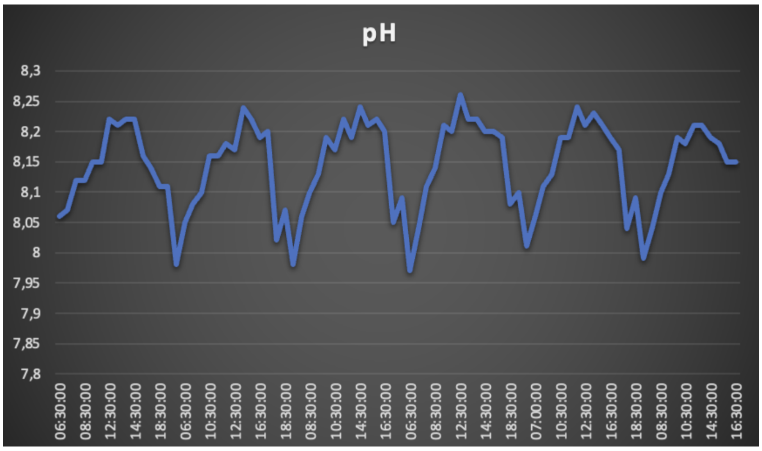


Fig. 23. Location defined as Sparse: pH vs time

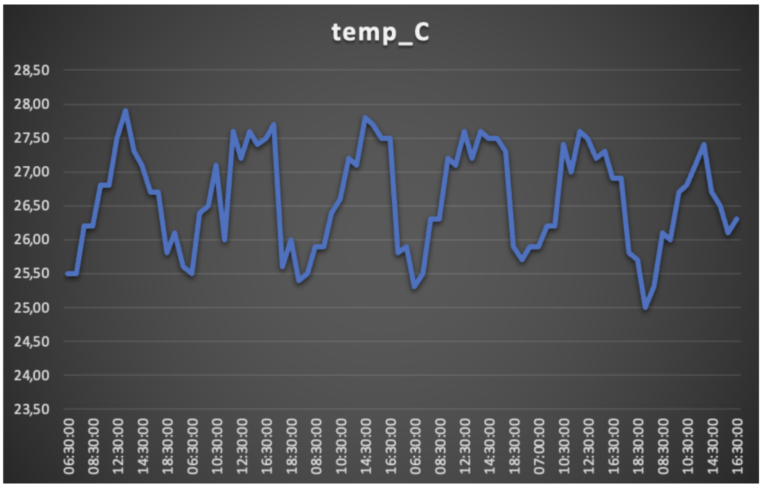


Fig. 24. Location defined as Bare: Temperature vs time

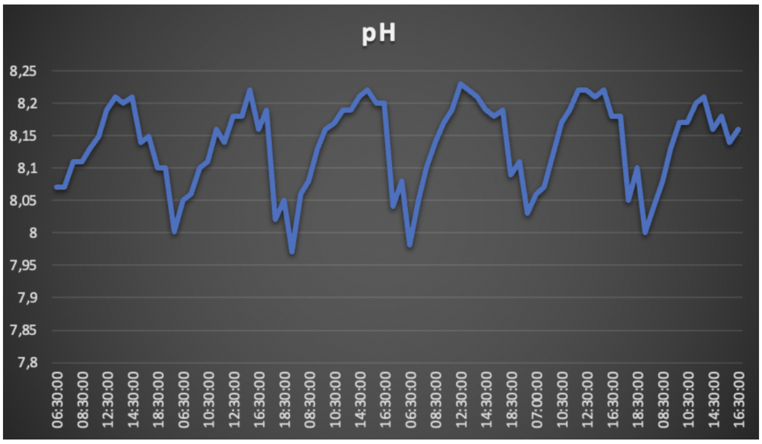


Fig. 25. Location defined as Bare: pH vs time

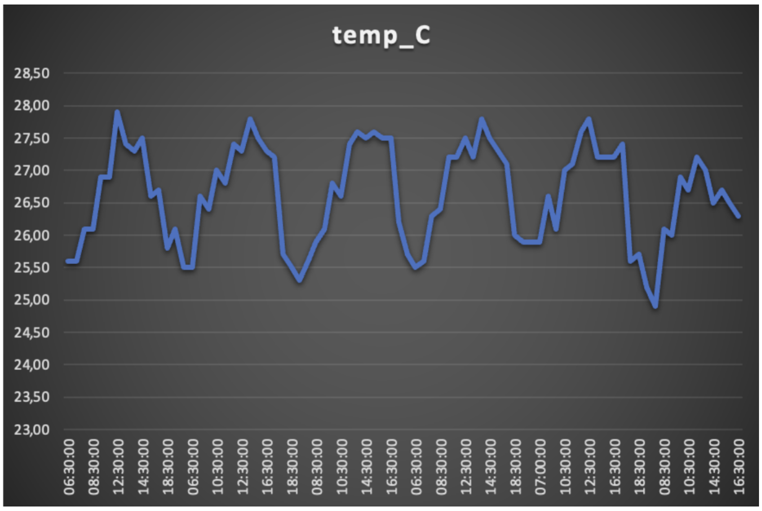


Fig. 26. Location defined as Dense: Temperature vs time

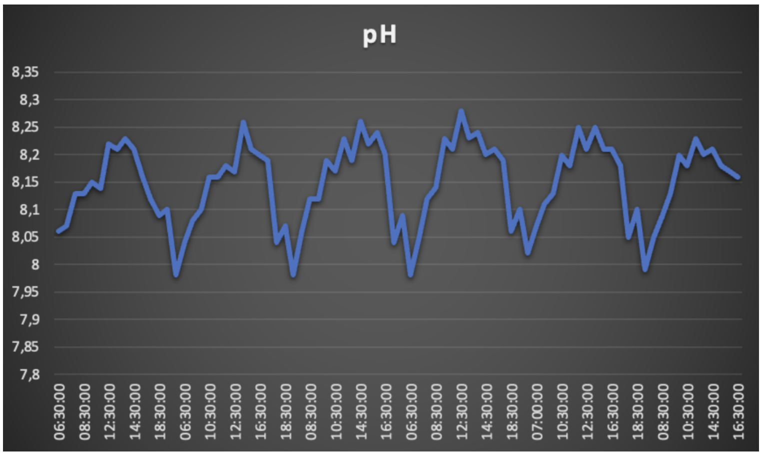


Fig. 27. Location defined as Dense: pH vs time

## 14. Analysis/ Discussion of the results:

In this subsection, the results and graphs from pre-existing data will be looked at. Firstly, the nature of the data used will be explained as well as the method used to analyze them. The data used in this report are the data from an article written by James et al. (2019). The experiment took place on the eastern side of St Martin, an island in the Caribbean sea. This experiment was conducted between October 2015 and February 2016 (James et al., 2019). Mainly they examined the effect of vegetation on the diurnal pH fluctuations and subsequently temperature fluctuations. They used a "ROSS Ultra epoxy gel-filled pH/ATC electrode" connected to an "Orion Star A325 portable meter" (Thermo Fisher Scientific™, Waltham, USA) and corrected with "TRIS" to measure the pH. The measurements were done through 6:30 to 18:30 each day over a period of 6 days.

In the analysis of these data, it was decided that in order to answer the research question: "what is the difference in pH fluctuations of places with and without seagrass?", the data would be put in three different so called "vegetation" categories based on the density of seagrass present at the sampling site: Bare, Sparse and Dense. Vegetation was known as dense (100% cover), sparse (50% cover), or bare (0% cover). To analyze the data recorded we first of all created a table of all of the data recorded. The table was then filtered three times; once the table was only filtered in order to get the data records labeled as dense; that is, with 100% cover. Then the data was filtered to get the records labeled as sparse; with 50% cover. Finally, the data sheet was filtered to get the records which only had 0% vegetation cover, or so called Bare. (It was not possible to filter beforehand; i.e. python could have just been used and the data extracted with a certain label, while creating the data frame and chart. But in the former way it was clearer and easier to understand what the data looks like for each category). Now for each of these three categories using Python and the Pandas library, a list of all pH values and temperature values and their corresponding time for each category was created. Then using the Matplotlib library, a time based continuous plot for temperature and pH values of each of the categories was created. All the data records were included since it was assumed that they are all valuable. In other words, none of the data records were excluded and this, because it was assumed that in the research/ experiment they had already canceled out the outlier data. In the following link, https://docdro.id/6p0hYDZ, it is possible to see an example of the charts for pH and temperature variations regardless of the vegetation type along with the codes used to extract such charts.

In this subsection, the focus will mainly be on two of the categories: Bare and Dense since these two are the most representative of what areas with seagrass (Dense) and without (Bare) would be. In the graphs above, the data was gathered between the 1st of March 2017 and the sixth (James et al., 2019). It was decided that data over 6 days would be sufficient to answer the research question, because it was clearer to observe the diurnal fluctuation of pH due to respiration and photosynthesis over a few days, rather than over a longer period of time where it would have been harder to see such changes over the day and night. In other words, by zooming in, in this case, it was better to really see these fluctuations.

The graph used was a time series graph because the diurnal fluctuation can be seen really well in the graphs above. A lower pH value at the beginning of the day, followed by a sharp increase in pH value over the day until it decreases again due to either a decrease in light density later in the afternoon, leading to a decrease in photosynthesis or due to the light saturation of these seagrasses being reached earlier on in the afternoon leading to a decrease in photosynthesis efficiency and thus a decrease in pH value (Chou et al., 2018). A time series graph distinctly shows the fluctuations in pH and temperature over time which is essential to the analysis of the experiment due to the fact that photosynthesis and respiration vary between night and day, as well as over longer periods of time. Furthermore, the temperature changes over time which in turn affects the pH levels shown (see introduction section). The biggest advantage of using the time series graph is that it could be used to easily identify patterns and remove major outliers in the data due to experimental error. It can also be used to forecast possible changes of pH in the future which is important for seagrass and ocean acidification research and development.

In order to answer the research question, the different graphs have to be compared. Firstly, one can notice that the line from temperature follows the same trend as the pH line, and this pattern is consistent for the three locations. This can be explained by the water being heated up over the day due to sunlight and then decreasing at night due to the lack of it, this could be the reason why pH value follows the same trend, since they are both linked to the presence or absence of sunlight. However, further research must be conducted to explore this trend and changes present over different conditions.

When comparing the graphs, it can be observed that even if a diurnal fluctuation in pH can be observed in the bare location, the difference of pH over the day is lower in Bare locations than in Dense locations. Moreover, The largest difference in pH value for the Dense location is 0.35 pH units whereas for the Bare location, it is about 0.30. The value for Sparse is similar to the one of the dense location, highlighting the effect of seagrass when present. If this difference seems quite small, it is important to remember that as mentioned in the background section of this report, pH is a logarithmic scale, meaning that even a small change of 0.0 5pH unit already represents a quite important change (Water Science School, 2019 ; Huber  Blaha-Robinson, n.d.). The reasons why the bare location could also be experiencing a diurnal fluctuation in pH could be due to the presence of other photosynthesizing organisms such as algae or phytoplanktons that could also influence the surrounding pH (Chrachri et al., 2018).

Another important thing to notice here is that during James et al. (2019) experiment, the light levels were not recorded over the whole day but only once everyday, considering this, it was not relevant to add that information in this analysis since it would not give information of the changes in light levels over the day.

## 15. Conclusion

To conclude, even if it became impossible for this group to gather its own data due to many factors, it was still possible to answer the research question. Indeed, in light of the pre-existing data used in this report, it can be understood that there is a difference in pH fluctuations and more specifically values between locations with and without seagrass. If the difference is not tremendous when quickly looking at the pH graphs, when looking at the difference in pH value over time, it can be observed that there is a bigger difference in pH in locations with than without seagrass (respectively: 0.35 and 0.30). However, additional experiments should be conducted to determine if this difference is significant, to further explore the relationship between pH and seagrass. From the point of view of our sensing system, we believe that with just a few more adjustments, it would be working properly but due to time constraints, it was not possible to gather more than a few hours of data.

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