A COMPARATIVE STUDY OF GROWTH BETWEEN A HAWAIIAN OYSTER, *Dendostrea sandvichensis* (G. B. Sowerby II, 1871), AND PACIFIC OYSTERS, *Crassostrea gigas* (Thunberg, 1793)

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We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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In memory of Geneva Clem, my grandmother, who made it possible for me to be here.

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ABSTRACT

Aquaculture in Hawai‘i has played an essential role in supplying local populations with the food needed to thrive. In particular, the traditional Hawaiian fishponds (*loko i'a*) have historically been highly productive resources that help fill this necessity. In recent years, the stewards of Hawaiian fishponds have aimed to return to their roots of providing food for surrounding communities, improving the overall quality of the ponds, and re-establishing native species populations. The managers of He‘eia fishpond are working to accomplish all three goals through producing a native oyster, *Dendostrea sandvichensis*, and the Pacific oyster, *Crassostrea gigas*. However, a challenge this pond faces is spat mortality, which is often the result of predation, a lack of food, or other environmental stressors. The intent of this research was to test the use of a floating upwelling system (FLUPSY) since this is the primary method of rearing juvenile oysters in open water. Having a FLUPSY designed specifically for local conditions would allow fishpond operators to achieve their goals faster and with greater success. The production of oysters can allow He‘eia fishpond to filter water, re-establish the native oyster populations, allow for sales to other producers, and provide an additional food source for the community. The results of this study show that both the *D. sandvichensis and C. gigas* spat grow significantly quicker in a FLUPSY than they would if they were grown using a more typical method, which is via hanging cages. These results underscore the advantages of utilizing a FLUPSY, even in small-scale oyster farming operations. Moreover, they pave the way for other local ponds to consider adopting similar devices in order to engage in efficient oyster production.

Keywords: *Dendostrea sandvichensis*, *Crassostrea gigas*, He‘eia fishpond, loko i‘a, FLUPSY.

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1.0 INTRODUCTION

1.1 Aquaculture in Hawai‘i

Aquaculture in Hawai‘i has deep-rooted traditions that are interwoven with the rich cultural heritage of the islands. One of the most impressive accomplishments in Hawaiian aquaculture is the use of fishponds, called "*loko i‘a*". These fishponds, developed over half a millennium ago, were essential in providing food security for local populations (Keala et al., 2007). Within the *ahupua‘a* model used in Hawai‘i, fishponds ensured an abundance of food for the individuals who relied on it. Upon Captain Cook's arrival to Hawai‘i, it was estimated that the ponds produced 2,000,000 pounds of fish per year (Costa-Pierce, 1987), and prior to 1788, approximately 488 *loko i‘a* existed across the islands (DHM, 1990). However, over time, most of these ponds fell into disrepair, and few fishponds have been restored or put into use today. These select few ponds have now become hubs for cultural restoration, educational outreach, and research initiatives.

The innovative design of *loko i‘a* is what fosters the remarkable productivity found at these sites. As shown in Figure 1 below, there are six general types of ponds, which are as follows: *loko i‘a kalo*, *loko wai*, *loko pu‘uone*, *loko kuapā*, *loko ‘ume‘iki* and *kaheka* / *hapunapuna*. The ponds are usually strategically placed along or near the coast, where they can access the ocean or freshwater sources. They are created using a combination of rock walls, typically lava rock or coral, and sluice gates. *Loko i‘a* are uniquely designed for the recruitment of small, juvenile fish which enter through the gates, or *makahā*, which are partially blocked by stick grates, as shown in Figure 2. Once the fish enter the pond, they can feed on *limu* and other plentiful vegetation. Over time, the fish become a harvestable size and ultimately too large to leave via the sluice gates (Costa-Pierce, 1987).

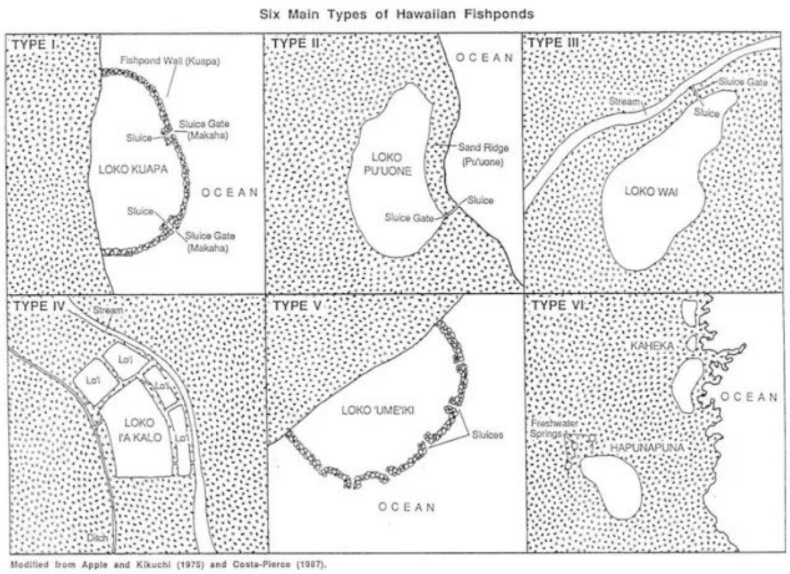

Figure 1. The six main types of Hawaiian fishponds (Costa-Pierce, 1987).

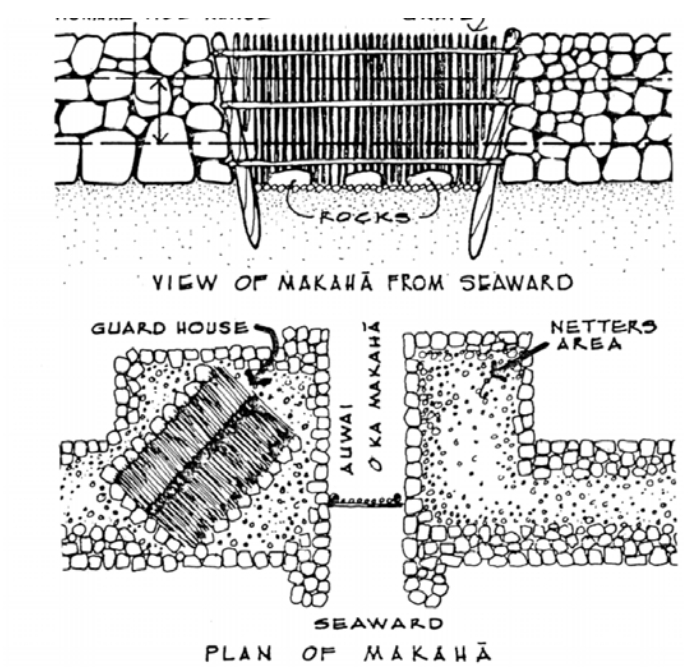

Figure 2. Illustration of makahā (Costa-Pierce, 1987).

1.1.1 He‘eia Fishpond

He‘eia fishpond is one of the traditional Hawaiian fishponds situated along the coast in Kāne‘ohe Bay located in He‘eia on the island of O‘ahu. The pond was originally built 600-800 years ago and is a *loko i‘a kuapā*, meaning that it is established along the shoreline, and a rock wall encloses a portion of the ocean. The pond contains 88 acres of brackish water, as freshwater enters the pond from He‘eia stream. Compared to the roughly 20 other ponds that had previously existed in Kāne‘ohe Bay, He‘eia fishpond is the second largest (Henry, 1975). Along the rock wall or *kuapā*, there are five *makahā* that allow the water to flow freely between the ocean and the pond. There are also an additional two *makahā* that allow for freshwater input from He‘eia Stream, which creates the northwest border of the pond. The pond is relatively shallow, typically ranging from 0.9 to 1.2 meters in depth (He‘eia Fishpond, n.d.).

Figure 3. Aerial photo of He‘eia Fishpond. Image by Keli‘i Kotubetey.

This pond has a unique history, and following the Great Māhele, the first recorded owner of the pond was High Chief Abner Kuhoʻoheiheipahu Pākī. He eventually transferred the property onto his daughter, who passed it along to Kamehameha Schools - today's current owners. In 1989, Mary Brooks, an aquaculturist, leased the fishpond. With the help of volunteers, she began to repair the damage that the pond had undergone, and she eventually partnered with the University of Hawaiʻi at Mānoa to further the restoration efforts. In 2001, the non-profit organization Paepae o Heʻeia, meaning "Support of Heʻeia," was established to further oversee and direct restoration efforts for the pond (Paepae o Heʻeia, 2019).

1.2 Bivalves in Hawaiʻi

In addition to fish and other diverse species that can be found inhabiting *loko iʻa*, bivalves emerge as a valuable component within these coastal ecosystems. Moreover, bivalve culture has long been identified as a possible activity for the *loko iʻa*. Bivalves, which include oysters, boast a significant ecological presence due to their feeding mechanism known as suspension feeding. In this process, they consume particulate matter suspended in the water column. Bivalves typically filter out algae, phytoplankton, heavy metals, nitrogen, and other pollutants (Crisp et al., 1985). In doing this, they can effectively remove harmful pollutants from ecosystems and return the filtered water to the environment. In addition to this critical function, oysters can also play valuable roles as bioindicators, as their ability to accumulate pollutants can allow them to act as gauges for contaminant exposure in waterways (Jahan & Strezov, 2019).

1.2.1 *Dendostrea sandvichensis*

Dendostrea sandvichensis, formerly known as *Ostrea sandvichensis*, is an oyster that is endemic to Hawaiʻi (Lamprell & Healy, 1998) and was first identified by Sowerby in 1871. The documented Hawaiian name for this species is *mahamoe* or *pahikawa* in certain areas (Titcomb et al., 1978). These oysters, with a documented range from Hawaiʻi Island to Midway Atoll, have become increasingly rare but were once abundant across the islands (DeFelice et al., 1998). *D. sandvichensis* can be found primarily within coastal and estuarine settings, including fishponds.

Specific locations across Oʻahu that have documented the presence of these oysters are Kāneʻohe Bay, Ala Moana, and Pearl Harbor (Kay, 1979, 1994). Additionally, Dr. Maria Haws has found *D. sandvichensis* specimens on Hawaiʻi Island and Molokaʻi (Classen, 2013). Outside of Hawaiʻi, this species has been observed in various parts of the South Pacific, and off the coast of Queensland, Australia (Kay, 1971; DeFelice et al., 1998; Lamprell & Healy, 1998; Hoover, 2005; Huber, 2010). Additional studies have noted the presence of *D. sandvichensis* in the Indian Ocean and Andaman Sea (Bussarawit & Cedhagen, 2012), as well as off the coast of Madagascar (Dautzenberg, 1929). It is hypothesized that this species has spread widely across the Pacific by attaching to the hulls of ships (DeFelice et al., 1998).

D. sandvichensis reproduces through larval brooding (Haws, n.d.). In this type of reproduction, the eggs are retained within the female oyster's inhalant chamber where they are fertilized and held until they become larvae and are released. There are several advantages to this form of reproduction, including increased survival rates due to protection from predators, easy access to nutrients, and enhanced adaptability to environmental conditions (Foighil & Taylor, 2000). It has been observed that this species specifically experiences a tropical reproductive cycle, as trends in their gonadal stages have shown their active reproductive season to fall between April and October (Garriques, 2013). Despite limited available information about these oysters, grow-out trials at various locations across Hawaiʻi have indicated that they can grow to be around 6 cm in length (Haws, n.d.).

1.2.2 Pacific Oysters

Pacific oysters currently dominate the bivalve aquaculture industry worldwide due to their environmental tolerance, rapid growth rates, and overall hardiness. In recent years, the Pacific oyster has been responsible for approximately 98% of the world's cultured oyster production (Petton et al., 2021). They are native to Japan, found in marine intertidal zones, and have become the most transplanted oyster in the world. *C. gigas* was first brought from Japan to Kalihi, Oʻahu in 1926. Later in 1938 and 1939, additional shipments of Pacific oysters were sent to Pearl Harbor and Kāneʻohe Bay (Eldredge, 1994). These oysters are extremely popular in the Pacific Northwestern United States and Europe and have been documented in at least 50 countries worldwide. For many regions, the Pacific oyster was introduced as a means of replacement for native species that had declining populations (King et al., 2021).

Unlike *Dendostrea sandvichensis*, Pacific oysters reproduce through external fertilization. More specifically, they are broadcast spawners, where male and female oysters release their eggs and sperm into the water column for external gamete connection and fertilization. This process in Pacific oysters is heavily influenced by temperature, ideally occurring at around 20° C. During spawning, female oysters can release anywhere from 50 to 200 million eggs in intervals throughout a single event. After spawning and fertilization occur, the eggs develop into free-swimming larvae, which then find a suitable surface to settle on (Kobayashi et al., 1997). Pacific oysters can live for up to thirty years but are able to reproduce after just one year (Teixeira et al., 2021).

The Pacific oyster's popularity in aquaculture practices and commercial shellfish production is largely attributed to its remarkable growth rate. This species also makes up the majority of oyster culture in Hawaiʻi due to the availability of oyster seed. Pacific oysters normally reach a typical market size of three to four inches in the Pacific Northwest in about two to three years. However, Hawaiʻi is particularly suited for this species as the warm waters can allow Pacific oysters to reach the same market size much more rapidly. In a study carried out by Forrest Petersen, two different sites within Hilo Bay were chosen to determine the average growth rates for *C. gigas.* Site one experienced an average growth rate of 7.5 ± 2.1 mm per month. The second site within Hilo Bay experienced an average growth rate of 3.0 ± 1.7 mm per month (Petersen, 2016).

1.3 Floating Upwelling Systems (FLUPSY)

Floating upwelling systems (FLUPSYs) are innovative devices designed to optimize shellfish production. Traditionally, a disjunction has existed in the commercial shellfish production process, creating a disconnect between when hatcheries ship out spat and when farmers can safely introduce the shellfish into the environment with minimal risk of mortality. Hatcheries typically aim to send out their spat at the earliest opportunity to reduce the cost of shellfish rearing. Or, hatcheries may send eyed-larvae to farms where the larvae are then set on shell cultch. However, this often results in farmers receiving juvenile oysters smaller than preferred, sometimes only measuring around 2 millimeters in length. This discrepancy poses a considerable risk of mass mortality among the smaller spat due to environmental stressors and predation. Overall, this puts farmers at risk of loss of revenue, which can be catastrophic for small-scale, family-owned, or local farmers.

However, FLUPSYs work to mitigate this risk and essentially act as nurseries for shellfish. These systems create an upward water flow beneath the shellfish, simulating a natural “upwelling” movement. Studies have demonstrated that this upward flow of water significantly accelerates the growth rates of shellfish. As a result, farmers can efficiently nurture the incoming spat from hatcheries, allowing them to rapidly reach sizes that are suitable for transplantation into ponds where they can then grow until they reach the desired size for commercial sale. Overall, FLUPSYs expedite the process of shellfish cultivation and harvesting, offering a streamlined approach to shellfish aquaculture.

While FLUPSY designs may vary across systems, they typically share a common operational framework. Oyster spat are housed in bins, which have screens across the bottom. These screens allow for water flow within the system while preventing the oysters from falling through. The bins are connected to tubes that lead into a trough, which contains multiple pumps. These pumps draw down the water inside the trough and expel it through tubes outside of the FLUPSY. The water draw down by the pumps enables water to flow upward through the bins to refill the trough, generating the upwelling movement described earlier. A schematic diagram similar to the system used in this project is presented in Figure 4 below.

FLUPSYs are widely used in open water settings in other regions. However, this is not the case for Hawai‘i, so the system was modified to make it more suitable for *loko i‘a*: 1) it is fully solar powered, as many ponds lack electrical power in the areas where the FLUPSY would be located; and 2) it has an overall shallow draft since many of the ponds are also shallow in nature.

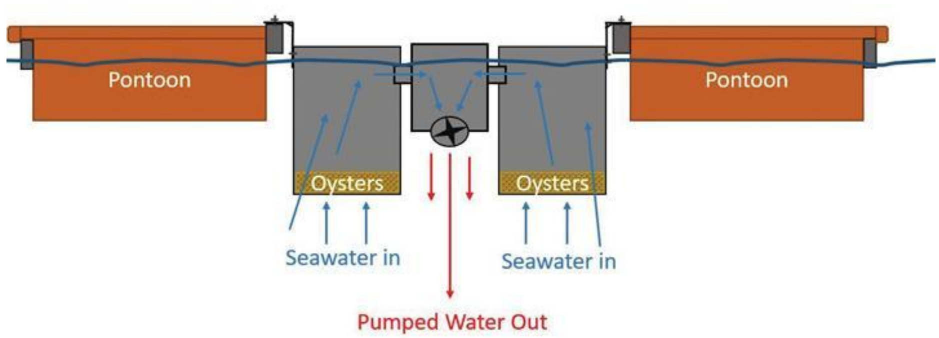

Figure 4. Diagram illustrating a FLUPSY (Pump Industry, 2023).

Figure 5. FLUPSY used in the project.

1.4 Water Quality

Understanding the role that water plays is crucial for optimizing oyster feeding and growth, as these bivalves rely on and prefer specific water quality parameters. First and foremost, the oysters in this study thrive in and favor brackish water, with the influx of freshwater serving as a vital nutrient source essential for their growth (Zhao et al., 2012). Key parameters assessed in this study include dissolved oxygen, temperature, salinity, pH, and conductivity.

Another consideration when evaluating the relationships between oysters and water is the profound impact that larger oyster aggregations can have on water quality. Oysters are able to clean water by filtering out heavy metals, bacteria, and other suspended particles. However, it is important to note that different oyster species exhibit varying capabilities in this regard. Certain species are capable of filtering a greater amount of water per day than other species. So, aggregations of oysters that can filter a large amount of water more rapidly will have a different impact on water quality than species that can filter less. Therefore, understanding each oyster species and its unique abilities is imperative for effective management and conservation efforts.

As mentioned previously, *Dendostrea sandvichensis* needs to be further studied regarding their capabilities. However, they are estimated to filter between 5 and 10 gallons of water per day because an oyster of similar size, *Ostrea lurida*, typically filters that same amount each day (Ermgassen, 2013). While these oysters thrive in brackish water, they can be fragile to high amounts of freshwater, leading to die-offs (Haws, n.d.).

On the other hand, Pacific oysters are more well-studied and can filter up to 50 gallons of water per day (NOAA, 2023). In large aggregations, these oysters can make a noticeable difference in the water quality of some bodies of water. Pacific oysters thrive in Hawaiʻi's warm waters, flourishing year-round due to the favorable climate, and overall exhibiting greater tolerance to temperature and salinity fluctuations.

1.5 Significance

This project holds immense significance as it brings Heʻeia fishpond closer to its goal of reclaiming its original purpose in today's more modern world. The presence of these oysters offers several benefits to the pond. They can 1) filter water in the pond, 2) help re-establish a native species population, and 3) provide a food source for the community. The effective use of a FLUPSY also provides ponds with the capability to produce spat commercially. A FLUPSY in a *loko iʻa* can help bridge the gap between the small spat that can be supplied directly from a hatchery to the larger spat most commercial producers of practitioners of restorative aquaculture require. This study not only supports He‘eia fishpond in achieving all three of these goals but it also proves an opportunity for other ponds to adopt similar devices in the future. By cultivating oysters, it showcases the potential of such systems, educating farmers and encouraging them to implement the same methods for oyster cultivation in their own ponds. Additionally, the results from this study can prove valuable in refining the timeline for the growth rates of *D. sandvichensis* and the Pacific oyster, enabling He‘eia fishpond to streamline production processes and enhance efficiency. This optimization can ultimately contribute to more sustainable and successful oyster cultivation practices.

2.0 METHODS

2.1 Site Selection

This project was conducted at He‘eia fishpond in Kāne‘ohe Bay. As depicted in Figure 4, the FLUPSY is positioned approximately 100 meters away from the inland shoreline. According to Keli‘i Kotubetey, Assistant Executive Director at Paepae o He‘eia, this location was selected due to previous oyster cultivation success in the FLUPSY roughly one decade prior. A smaller version of the FLUPSY was deployed in this location as there was previously a small island inhabited by nesting cattle egrets. The waste from these birds produced a microalgae-rich site. This island was later removed, making the water quality roughly equivalent to the rest of the pond. Additionally, this is one of the deeper areas of the pond, which is ideal for the FLUPSY.

The site is approximately 150 meters away from the incoming freshwater stream, He‘eia Stream, towards the rear of the pond. This freshwater drains from the top of the Ko‘olau mountains and passes through the *lo‘i kalo* farm between the mountains and the pond. As a result, the water is enriched with nutrients when it seeps into the pond through the closest *makahā*. This allows the oysters in the FLUPSY to access more nutrients than they would if they were solely in seawater. However, as they can be sensitive to freshwater, the location had to be far enough away from the stream input that the oysters would not be at risk if a severe storm or flood caused an unusual influx of freshwater into the pond.

Figure 6. Aerial Photo of He‘eia fishpond showing FLUPSY location (Pacific Worlds, n.d.).

2.2 Site Setup

This study took place within a fenced area, as shown in Figure 7 below. The fence, erected to keep *limu* away from the system, is approximately 50 feet long by 35 feet wide, with one five-foot wide entrance for boat entry. Located within the fence is the FLUPSY (see Appendix A for instructions on FLUPSY construction), which is secured by ropes positioned at each corner and anchored to fence posts approximately 5 feet away from these corners. Inside this area are also three additional fence posts. A rope is strung roughly 1.5 feet from the sea floor on these fence posts, and three 15 L SEAPA™ cages are hung from the rope, as shown in Figure 8.

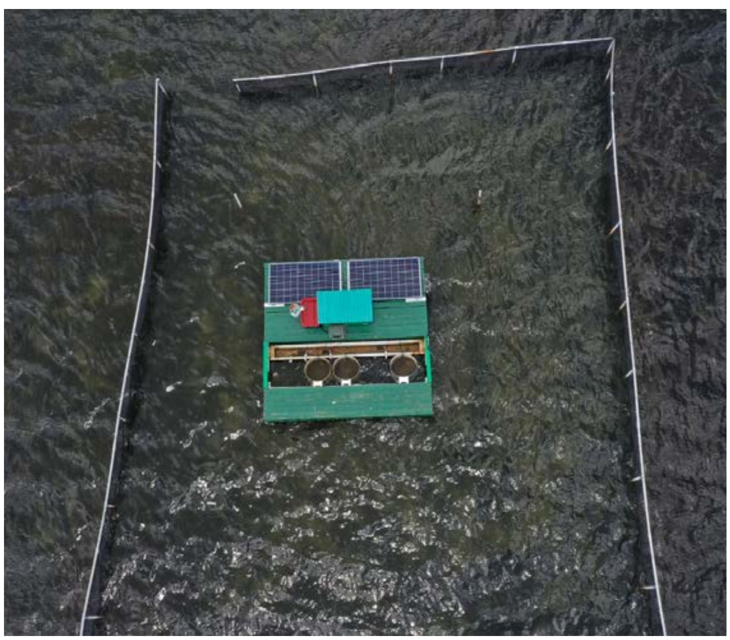

Figure 7. Aerial photo of FLUPSY. Image by Keli'i Kotubetey.

Figure 8. 15 L SEAPA cages used in the project.

2.3 Study Samples

This study focused on two oyster species: *Crassostrea gigas,* also known as the Pacific oyster, and the native oyster *Dendostrea sandvichensis*, which does not have an accepted common name. The experiment examined both diploid and triploid variations of the Pacific oyster, with the hypothesis that triploid oysters would exhibit faster growth rates due to their lack of reproductive energy expenditure. All oysters utilized in the study were bred at PACRC and shipped to He‘eia.

The Pacific oyster was chosen for this study as it is the most commonly cultured oyster in Hawai‘i. These oysters are often the preferred choice for agriculture due to their remarkable hardiness, as they are more tolerant to temperature and salinity fluctuations. Additionally, their rapid growth rates facilitate swift commercial production. *Dendostrea* *sandvichensis* was also chosen for this study because it is a native species with a declining population. As an endemic species, they are essential in Hawaiian fishponds, and this research project aimed to comprehend efficient methods to promote more rapid growth rates in order to support restoration efforts.

2.4 Study Preparation

The spat for each type of oyster was initially split into two equal groups for this experiment. One set was placed inside an oyster cage lined with a spat bag. The second set was placed inside a bin within the FLUPSY, which is designed to enhance growth. This division process was applied to both the diploid and triploid Pacific oysters and *Dendostrea sandvichensis*, resulting in 6 distinct groups in the study. Due to the spat's extremely small size, the oysters were divided by weight. The native oyster spat was approximately 1.5 mm in length when initially received, and the Pacific oyster spat was around 2 mm in length.

2.5 Oyster Growth Data Collection

Throughout this experiment, weekly measurements were taken from a subset of each group. Out of each population, thirty individual oysters were randomly selected for measurements. After selection, three measurements-length, width, and depth-were taken for each oyster, as shown in Figure 7 below, and recorded. Then, the measurements were averaged for each metric. Table 1 provides an example of the measurements taken for one group of oysters. Each week, a total of 180 oysters were measured, and the data was recorded for each group from which the oyster came.

Calipers were used to measure the oysters, and every few measurements they were re-calibrated to ensure accuracy. Additionally, every oyster was measured the same, with the same progression and practice of measuring applied to each oyster. The length measurements were taken first, starting from the oyster's hinge and ending at the furthest point on the lip of the oyster. The second measurement was width, which is taken perpendicular to the length and at the widest point of the oyster. The last measurement is the depth, which is taken vertically over the thickest part of the oyster. This systematic approach allowed for a comprehensive understanding of the growth for each type of oyster under various conditions.

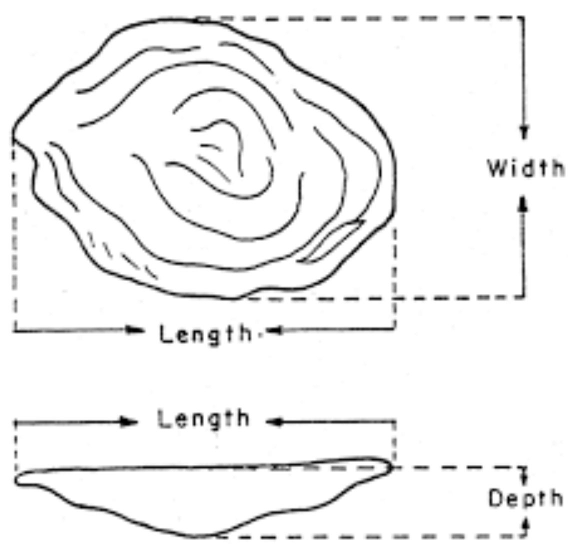

Figure 9. Diagram of oyster measurements (Measurement of Fish and Shellfish, n.d.).

	6-22-2023		
Oyster Number	Length (mm)	Width (mm)	Depth (mm)
1	3.7	3.2	1.1
2	4.3	3.9	2.4
3	3.8	3.6	1.8
4	4.3	4.7	2.5
5	4.7	4.8	2.3
6	5.9	5.2	2.1
7	3.9	3.8	1.6
8	5.1	5	1.6
9	5.6	5.5	2.1
10	4.4	3.7	1.3
11	5	5	1.3
12	4.3	4.2	2.6
13	5.6	5.1	2.6
14	4.5	4.5	2.3
15	4.9	4.2	1.7
16	4.2	3.7	2.5
17	5.2	3.9	1.3
18	4.4	3.7	2.6
19	3.6	3.7	1.9
20	3.9	2.1	1.8
21	3.7	2.8	1.4
22	3.7	2.9	1.5
23	3.9	4.4	1.4

24	3.7	3.1	1.1
25	3.7	2.6	1.1
26	3.5	2.9	0.8
27	4.2	4	0.9
28	4.6	3.9	2.1
29	3.7	3.9	1.7
30	4.4	4.6	1.8
Mean ± S.E.	4.3467 ± 0.12	3.9533 ± 0.153	1.7733 ± 0.099

Table 1. Example of length, width, and depth measurements.

2.6 Water Quality Sensors and Data Collection

There were two sensors deployed throughout this project. They were attached to the side of the FLUPSY and recorded data relevant to both the oysters in the FLUPSY and the cages. Each sensor was solar-powered and took measurements remotely, where the data was recorded and graphed through Smartcoastlines.org. The data was then downloaded, analyzed, and graphed for this project.

Figure 10. Solar panels that power the sensors.

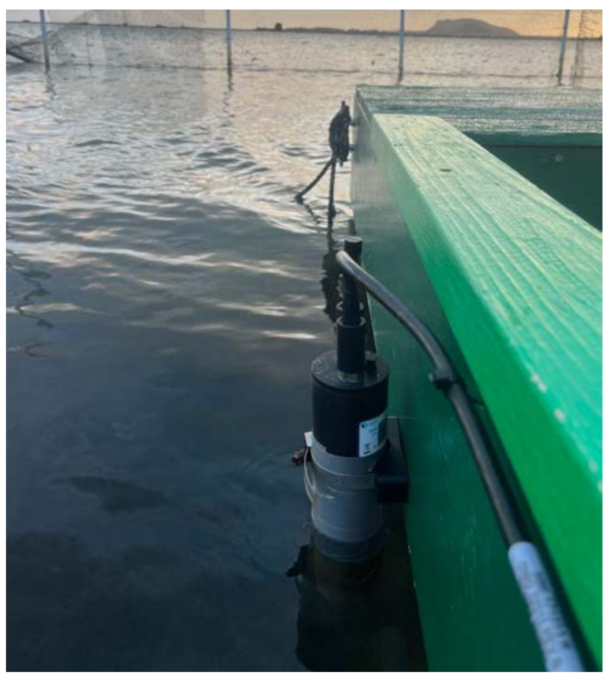

Figure 11. Sensors attached to the FLUPSY.

2.6.1 Aanderaa Conductivity Sensor 4319

The Aanderaa Conductivity Sensor 4319, shown below, is used to measure the specific conductivity of seawater. Specific conductivity measures how well a material can conduct an electrical current. In seawater, inorganic dissolved solids and the temperature of the water are influential to the conductivity of the water. This sensor can measure conductivity (mS/cm) and temperature (C°). Using these measurements, the sensor calculates salinity (PSU), water density (kg/m3), and the speed of sound (m/s) (AADI, 2013).

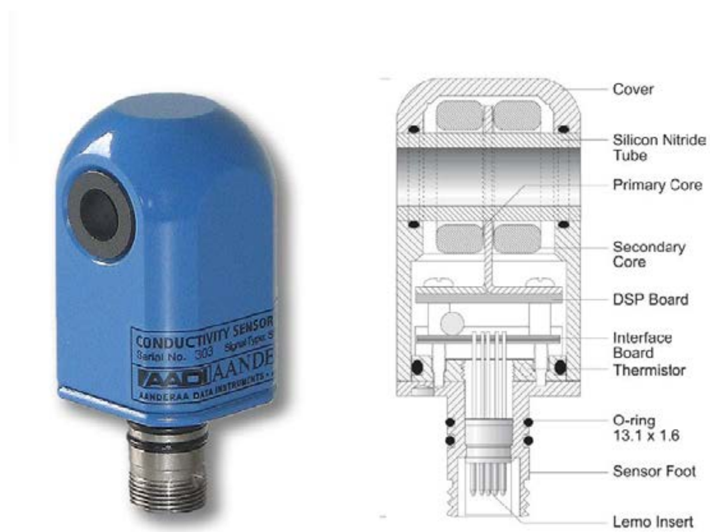

Figure 12. Aanderaa Conductivity Sensor 4319 (AADI, 2013).

2.6.2 Aanderaa Oxygen Optode 4531

Additionally, the Aanderaa Oxygen Optode 4531 was also used to measure oxygen concentration (µm), air saturation (%), and temperature (C°) at the test site (Aanderaa, 2018).

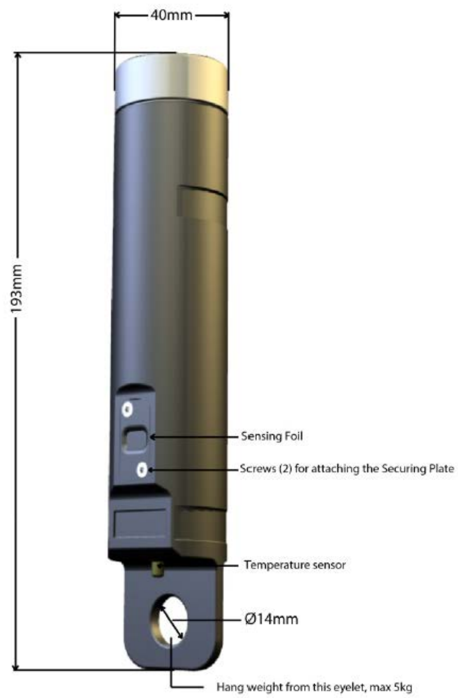

Figure 13. Aanderaa Oxygen Optode 4531 (Aanderaa, 2018).

2.7 Maintenance

In order to sustain a functioning system, routine maintenance was performed each week to ensure the FLUPSY and all sensors were operating as intended. The FLUPSY trough and sensors were cleaned once per week. To clean the trough the most effectively, end caps were put on the trough so that it would drain, and then it was scrubbed and flushed out. The sensors were cleaned using a toothbrush and inspected to ensure they were not damaged or had excessive build-up. All of the bins were removed and scrubbed twice a week. For the first month, the oysters were too small to remove before cleaning, so the screens of the bins were only scrubbed from underneath, and both the interior and exterior walls of the bins were cleaned and rinsed as well. Once the oysters were large enough, they were removed and rinsed in a separate bucket, and the bin was fully scrubbed on the interior and exterior. The cages were also scrubbed twice a week externally and agitated to loosen and rinse out any sediment buildup on the spat bag on the inside.

2.8 Growth Data Analysis Using Matlab

Matlab was used to enhance the visualization of the oyster growth data, making it more comprehensible. Each week, the average length, width, and depth measurements were calculated for each of the six oyster sets. These measurements were recorded from 06/15/2023 to 09/07/2023 for most groups, with the exception of the diploid and triploid Pacific oysters in the FLUPSY, which had an additional week of measurements, ending on 09/14/2023. Subsequently, these measurements were then plotted to facilitate a week-by-week comparison of each metric across all groups.

2.9 Water Quality Data Analysis Using Matlab

Matlab was also used to visualize the fluctuations and changes in various water quality parameters. As mentioned previously, the sensors collected samples and recorded data, which was stored on Smartcoastlines.org. Afterward, the data for each parameter was downloaded and graphed. Due to the extensive data collected, daily averages of measurements for each parameter were calculated to improve graph readability.

3.0 RESULTS

3.1 Physical Conditions at the Study Site

For the duration of this project, two sensors measured and recorded salinity (PSU), temperature (°C), air saturation (%), and oxygen concentration (µm). Since the sensors continuously collected data, we plotted the daily average for each of these metrics below in Figures 12, 13, 14, and 15, respectively.

The first parameter, salinity, was measured in PSU, or practical salinity units. The salinity at the FLUPSY primarily stayed between 20 and 25 PSU, which is ideal for the oysters as they thrive in brackish water. If they were solely in seawater, the salinity would be closer to 35 PSU. The sensor used to measure salinity, Aanderaa Conductivity Sensor 4319, was attached to the side of the FLUPSY and was approximately 6 inches below the water's surface. Figure 12 shows a significant dip in salinity from 06/27/2023 to 07/03/2023, with the salinity being between 0 and 5 PSU. This can be attributed to the more frequent rain that occurred during this timeframe, resulting in a freshwater lens on the pond in which the sensor was located.

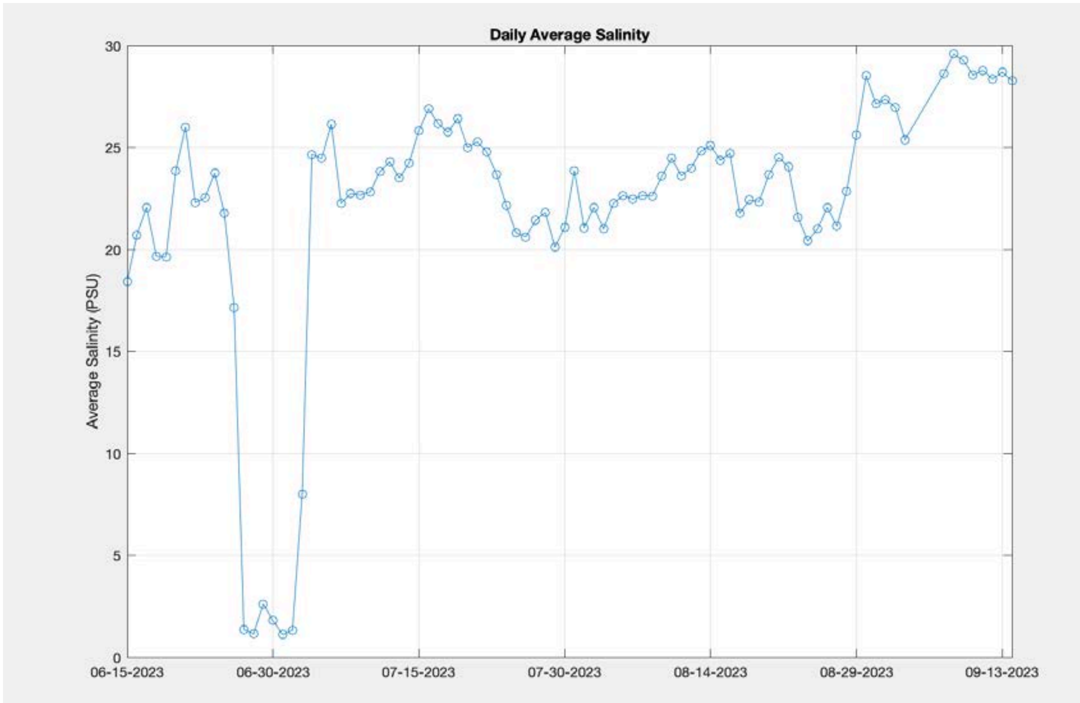

Figure 12. Daily average salinity (PSU) graph.

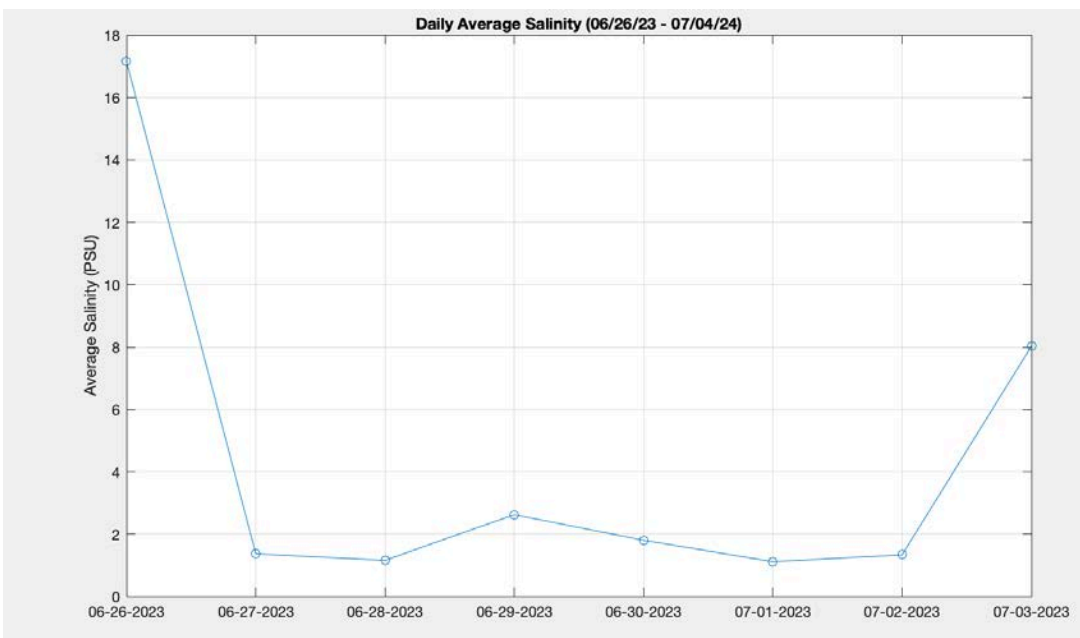

Figure 13. Low salinity event from 06/26/23 to 07/04/2023.

The next parameter, temperature (°C), was measured by both sensors, but for this project the data was sourced from Aanderaa Conductivity Sensor 4319. There was clear fluctuation in the temperature throughout the project. However, the average temperatures stayed between 24.92 °C and 29.26 °C. These moderate temperatures were crucial for the oyster growth rates, as higher temperatures can promote faster growth. The decrease in salinity from Figure 12 aligns slightly with a dip in temperature on 07/01/2023, most likely as the water from the rain caused the saltwater lens to be cooler than the underlying seawater.

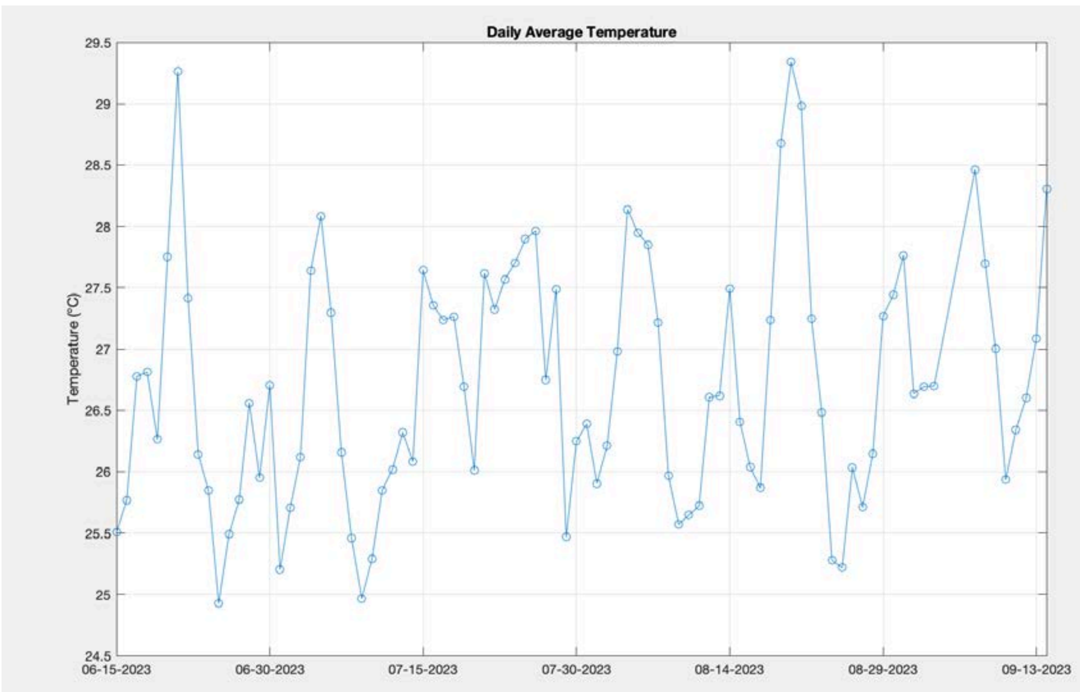

Figure 14. Daily average temperature (°C) graph.

Air saturation (%) measurements were taken from the Aanderaa Oxygen Optode 453 sensor, and the daily averages are shown below in Figure 15. The majority of the time the air saturation stayed at or above 100%, with the highest peak in air saturation being 248.114 % on 07/06/2023.

Oxygen concentration (µm) data was also recorded using the Aanderaa Oxygen Optode 453 sensor. This graph is nearly identical to the air saturation graph, so the two parameters have been plotted below with separate axes. However, in this case, the oxygen concentration typically stayed at or above 200 µm, with the highest reading being 600.646 µm. There is a significant dip in the graph for both parameters in September. However, this can be attributed to the sensor being too far out of the water to gather accurate data.

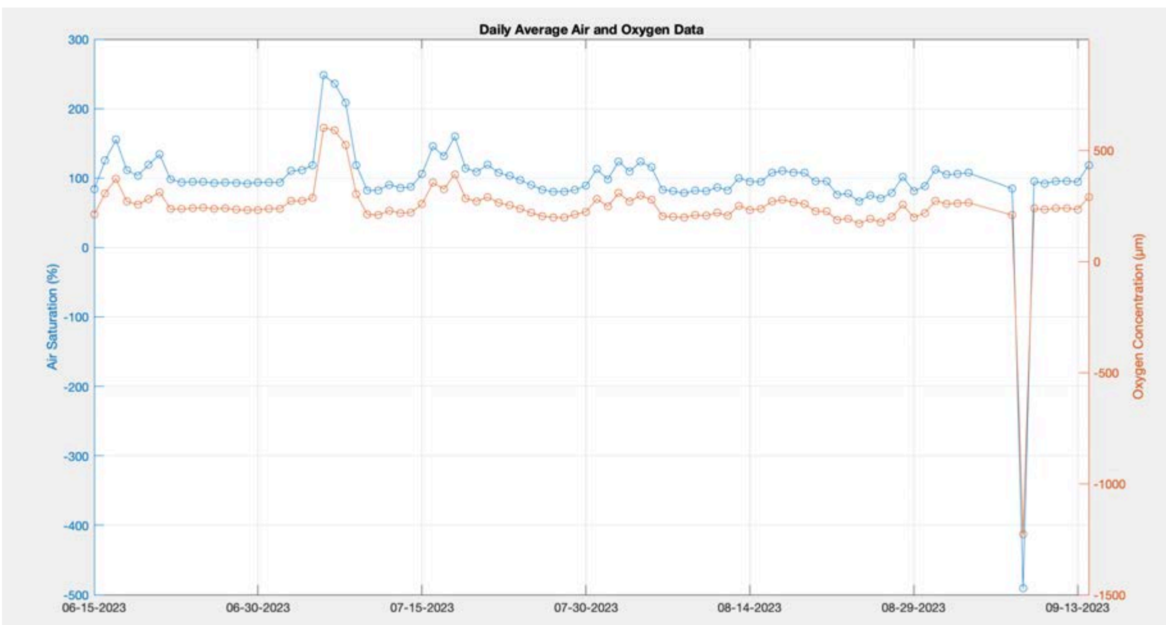

Figure 15. Daily average air saturation (%) graph and oxygen concentration (µm).

3.2 *Dendostrea sandvichensis* Growth Data

The growth rates of *Dendostrea sandvichensis* were significantly higher for those held in the FLUPSY as compared to those in the cages. The oysters were received from PACRC on 06/08/2023, with initial measurements conducted on 06/15/2023 and final measurements on 09/07/2023. Ideally, another measurement would have been taken on 09/14/2023, however, an equipment malfunction hindered data collection that day.

To evaluate how the FLUPSY and cages affected oyster growth across all three metrics, the average of 30 measurements was recorded and plotted weekly. For the first measurement, the oysters for each group were very similar in size, with the set from the FLUPSY having an average length of 1.64 ± 0.094 mm and the average from the set in the cage length being 1.56 ± 0.093 mm. However, by the final measurement, the FLUPSY cohort increased by a profound 256.1%, reaching an average length of 5.84 ± 0.45 mm. In contrast, the cage cohort saw a more modest increase of 12.8%, averaging 1.76 ± 0.07 mm in length by the end of the trial.

A t-test was conducted to support and further verify these findings, showing that the oysters in the FLUPSY grew significantly faster in all areas: length (p-value: 1.9414e-05), width (p-value: 3.6618e-06), and depth (p-value: 7.0991e-06). Based on these results, it is clear that the FLUPSY facilitated substantially greater growth than the cages, as illustrated in Figure 16 below.

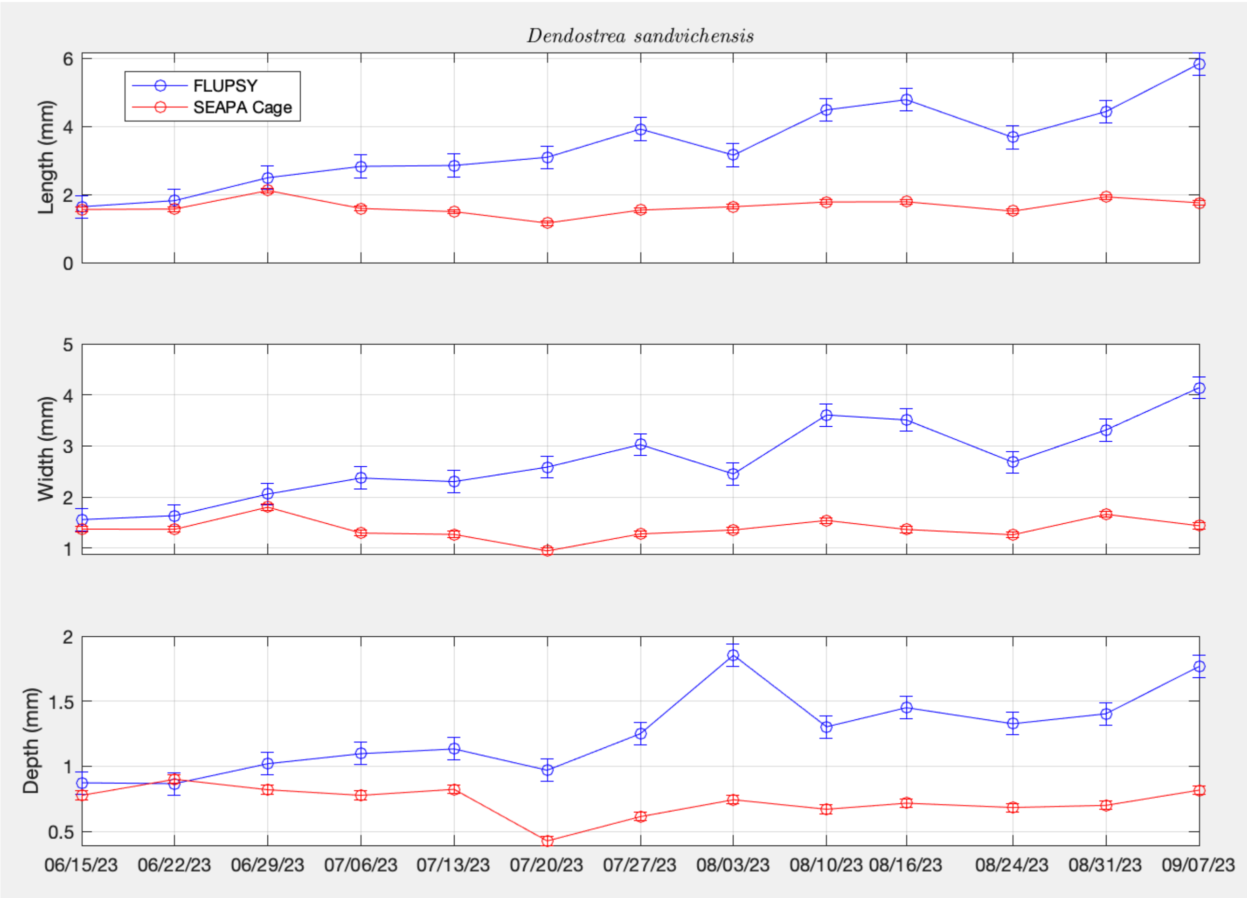

Figure 16. *Dendostrea sandvichensis* growth.

3.3 Diploid Pacific Oyster Growth Data

The diploid Pacific oysters also saw significantly enhanced growth rates across all three measurements while in the FLUPSY. These oysters were also received from PACRC on 06/08/2023, with initial measurements conducted on 06/15/2023. One final measurement was conducted for the FLUPSY set on 09/14/2023, but due to equipment failure, the final measurement for the cage set was on 09/07/2023.

The growth data for all three metrics is plotted for both sets of diploid Pacific oysters in Figure 17 below. The oysters in each group started at similar sizes, with the average length for the FLUPSY group being 3.66 ± 0.178 mm and the average length for the oysters in the cage being 3.22 ± 0.158 mm. The FLUPSY cohort again experienced significantly higher growth rates, increasing in length by 400.64% and reaching an average length of 18.34 ± 0.571 mm by the final measurement. The cage set increased in length by only 36.58%, resulting in an average length of 4.40 ± 0.174 mm by the final measurement. Throughout the experiment, the caged oysters only experienced minimal growth and remained small in length, width, and depth. However, the diploid Pacific oysters increased significantly in all three metrics while in the FLUPSY.

A t-test was also conducted on this data and yielded a significant difference in growth rates between the FLUPSY and cages for all metrics: length (p-value: 6.5231e-07), width (p-value: 8.5933e-08), and depth (p-value: 2.7324e-07). The rejection of the null hypothesis with a confidence level of 1 underscores the effectiveness of the FLUPSY in promoting oyster growth over the cages.

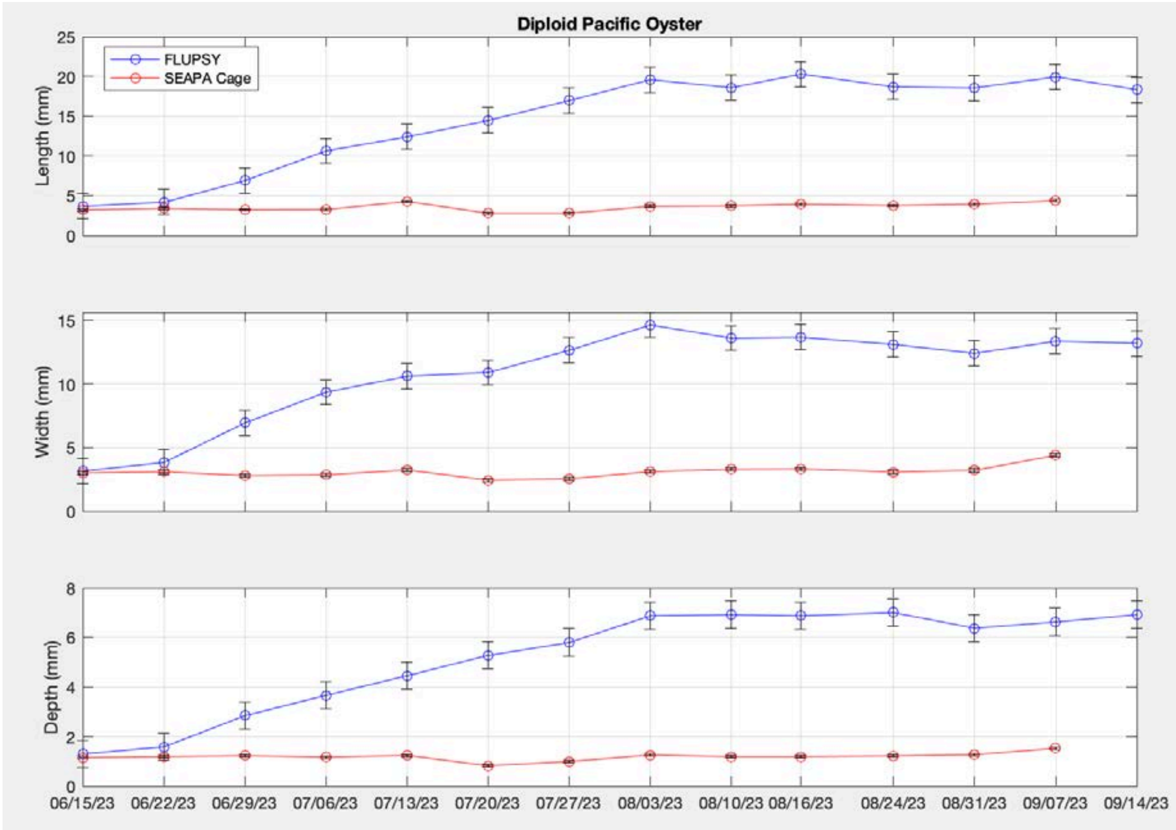

Figure 17. Diploid Pacific oyster growth.

3.4 Triploid Pacific Oyster Growth Data

The last group of oysters, the triploid Pacific oysters, also experienced significantly greater growth rates in the FLUPSY. The triploid Pacific oysters were received in the same shipment as the others from PACRC on 06/08/2023, with the first set of measurements occurring on 06/15/2023. The final measurements for the FLUPSY set were conducted on 09/14/2023, but for the cage set, the final measurements were taken on 09/07/2023.

The growth data for the triploid Pacific oysters is shown in Figure 18 below. The oysters initially began at comparable sizes, with the average length for the FLUPSY set being 3.28 ± 0.115 mm. The FLUPSY set experienced faster growth rates than its caged counterparts, as they increased in length by 268.35%, ending with an average length of 17.26 ± .600 mm. The oysters in the cage stayed relatively consistent in size throughout the experiment and saw only a modest increase in size. They began with an average length of 2.89 ± 0.098 mm, and their final measurement was 3.14 ± 0.087 mm, which is an 8.65% increase. Overall, the triploid Pacific oysters in the FLUPSY grew more rapidly than their caged equivalents.

T-tests were conducted on the triploid oyster data to confirm the significant growth differences between the FLUPSY and cage groups for length (p-value: 6.5231e-07), width (p-value: 8.5933e-08), and depth (p-value: 2.7324e-07). These results reaffirm the FLUPSY's effectiveness in promoting oyster growth over the cages.

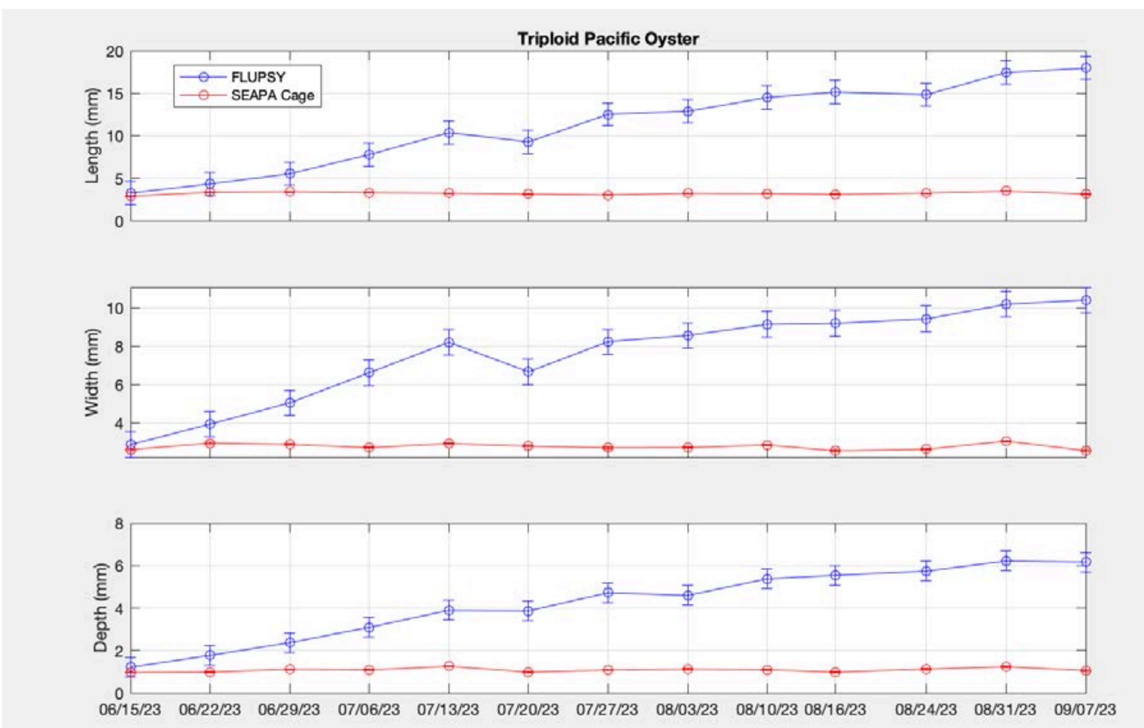

Figure 18. Triploid Pacific oyster growth.

4.0 DISCUSSION

A floating upwelling system proves to be a valuable asset for oyster production, as it offers the potential to expedite the process and help ponds achieve their goals more rapidly. This innovative device accelerates oyster growth rates significantly, leading to an overall reduction in mortality rates. Reduced mortality rates are not only important on a business level, but an ecological one as well. Oysters hold immense ecological value and are essential components of marine ecosystems as filter feeders. Therefore, oyster production plays a vital role in strengthening the health of these ecosystems, as oysters actively remove toxins and heavy metals from the water column. This section aims to explain the comprehensive value of oysters, emphasize the importance of the data from this project, address challenges, and explore plans for future efforts in this area.

4.1 Value of Oysters

Oysters are valuable from an ecological perspective, but they are also valuable on an economic level as well. First, they can help provide food security for surrounding populations, as they can be a sustainable source of nutrition and sustenance. On top of this, oyster cultivation and harvesting can help generate revenue and support livelihoods within coastal communities. However, one challenge He‘eia fishpond has to overcome is the food safety regulations implemented by the Department of Health (DOH). To be permitted for commercial shellfish sales, the fishpond has to pass the DOH shellfish growing classification process. He‘eia fishpond attempted to get certified approximately ten years ago, but unfortunately they were not approved. Nonetheless, oysters provide other benefits as their filter-feeding capabilities can not only help maintain water quality but can promote a healthier environment by mitigating pollution. Due to this unique feature, oysters also act as excellent bioindicators, reflecting the overall conditions of their habitats. Therefore, recognizing the diverse advantages of oysters highlights their crucial role in supporting both the environment and local economies in coastal areas. Additionally, it highlights the importance of oyster conservation and employing sustainable management practices to optimize growth and reduce mortality rates through initiatives such as the FLUPSY.

4.2 Significance of the Data

The measurements and data taken throughout this project are significant as they enable Paepae o He‘eia to gain deeper insights into oyster growth rates, particularly during the summer season. This data helps to optimize the overall efficiency of oyster production at the pond by enhancing the ability to anticipate the optimal timing for both receiving oyster spat and selling grown oysters to potential buyers. Altogether, it streamlines the oyster production process to ensure that the system is used most effectively to help the pond achieve its goals.

4.3 Challenges

There were several challenges when completing this project. One of the first issues we faced was with the depth of the pond. When the FLUPSY was first placed in the pond it was found that it was much too shallow during low tides, and that the bins holding the oysters were sitting on the ground. To troubleshoot this problem, we created shorter bins, so that the bottom of the bins did not touch the seafloor during lower tides. An additional obstacle we faced was predation. We frequently found crabs inside the trough or the bins of the FLUPSY. To combat this issue we created a mesh screen that covers the tubes from the bins into the trough, which has drastically reduced the number of crabs found in the system. The last challenge that we dealt with was harsh and unfavorable weather conditions leading to equipment failure. We measured the oysters using calipers, which are incredibly sensitive to water. Due to this threat, we kept multiple pairs of calipers on the FLUPSY in the event that water hindered them. However, we did experience incredibly heavy rain on 09/14/2023, which interfered with every pair of calipers we had available and forced us to halt measurements.

4.4 Future Efforts

Paepae o He‘eia is still testing the FLUPSY and determining how oyster growth changes throughout the year due to environmental shifts and seasonal changes. Using this information, they plan to optimize production methods and hope to eventually sell oysters commercially. On top of this, they hope to encourage other ponds to implement similar devices in order to engage in efficient and effective oyster cultivation.

5.0 CONCLUSION

The results of this project have highlighted the promising potential of using a FLUPSY to maximize oyster growth and production. Both *Dendostrea sandvichensis* and the Pacific oyster showed significantly increased growth rates in a FLUPSY compared to a standard 15 L SEAPA™ cage. The benefits of faster growth rates in oysters are evident when considering their role in ensuring food security, boosting local economies, and reducing environmental pollution. Utilizing a FLUPSY not only increases yields but also ensures a more sustainable and environmentally friendly approach to oyster farming, and can help local fishponds achieve their goals.

APPENDIX A

FLUPSY Construction

The FLUPSY used for this particular study was a reconstructed version of a FLUPSY built by University of Hawaiʻi at Hilo students for the pond a little over a decade prior. The design of a FLUPSY can be broken down into four general sections: the dock, trough, bins, and electrical components. The details for each section are explained below to allow for replicability of this specific FLUPSY design.

DOCK

The FLUPSY is 12 by 12 feet, with dock floats on the underside. The dock is divided into 2 sections, as there is a 43 inch wide gap that exposes the water below that is used for the trough and bins. One section of the dock is empty and provides a work space, and the other section acts as a base for the solar panels and battery. The dock was created by assembling plywood around the floats. The plywood was also coated with a marine paint that has coarse sand mixed in to create a non-slip surface for users.

Figure 19. Dock floats used in the construction of the FLUPSY.

Figure 20. Frame of the FLUPSY with dock floats.

Figure 21. Flooring on the FLUPSY, showing the 43-inch gap used for the trough and bins.

TROUGH

The trough used for the FLUPSY is 128 inches long x 8 inches deep x 8 inches wide. The trough was attached to the FLUPSY inside of the gap using brackets at the ends. It is made of fiberglass and was constructed by an outside source for UH Hilo. There are 5 tubes on the front of the trough that are 2 inches wide which allows the seawater to flow into it. There are also 3 smaller tubes made of PVC that are connected to bilge pumps inside of the trough. The pumps push water from inside the trough to the outside, thus creating upwelling inside the system.

Figure 22. Bilge pump and PVC pipe for water exiting the trough.

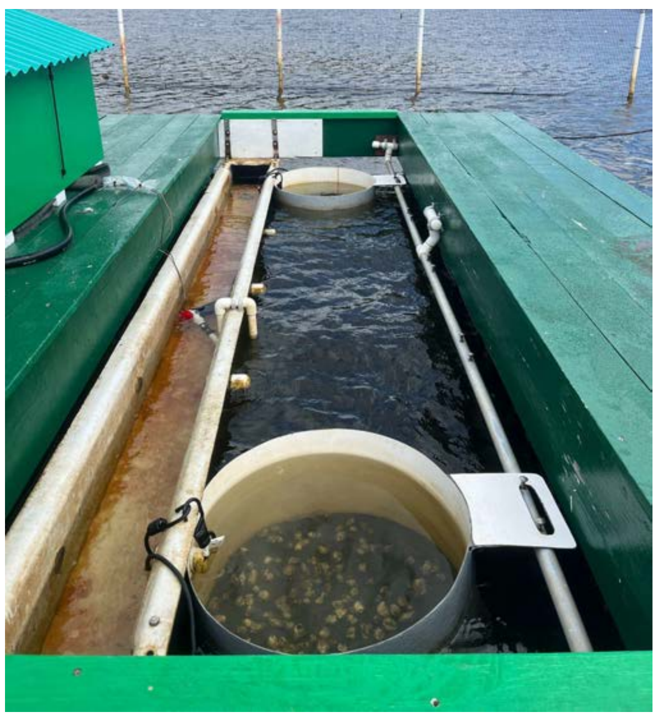

Figure 23. Trough and Bins in FLUPSY.

BINS

The FLUPSY can fit five round bins that have a 22.5 inch diameter and are 16 inches deep. The bins are made out of fiberglass and were made for UH Hilo by an outside source. The screen on the bottom of the bins is window screening that has been pulled taut and epoxied to the rim. Small bungees are used to secure one side of the bins to the trough to ensure they do not come loose in rougher conditions. The other side of the bin rests on and is secured to a metal pole. Due to shallow conditions at the site, an additional hole was added to the bin closer to the screen in order to raise it further out of the water. In this case, L brackets were screwed into the wood portion of the FLUPSY so the tab on the non-trough side had a higher surface to rest on as well.

ELECTRICAL COMPONENTS

The FLUPSY is completely powered by solar panels. There are two solar panels whose incoming energy is regulated by a Tracer AN Series (10~40A) MPPT Solar Charge Controller created by EPEVER. The solar charge controller helps to manage the voltage and current from the solar panels and distribute it to the battery so that it does not cause damage to the components. The battery size was chosen to ensure it can retain enough energy to power the FLUPSY for three consecutive days in little to no sunlight on a full charge. The 3 bilge pumps are also connected to the controller and run 24 hours per day. We used 12 V, 500 GPH, 25DA Standard Bilge Pumps from Rule for this project resulting in 1500 gallons of water circulating through the FLUPSY per hour, and 36,000 gallons per day. All of the electrical components on the FLUPSY were secured in a box with a lid to ensure it would not be affected by the elements.

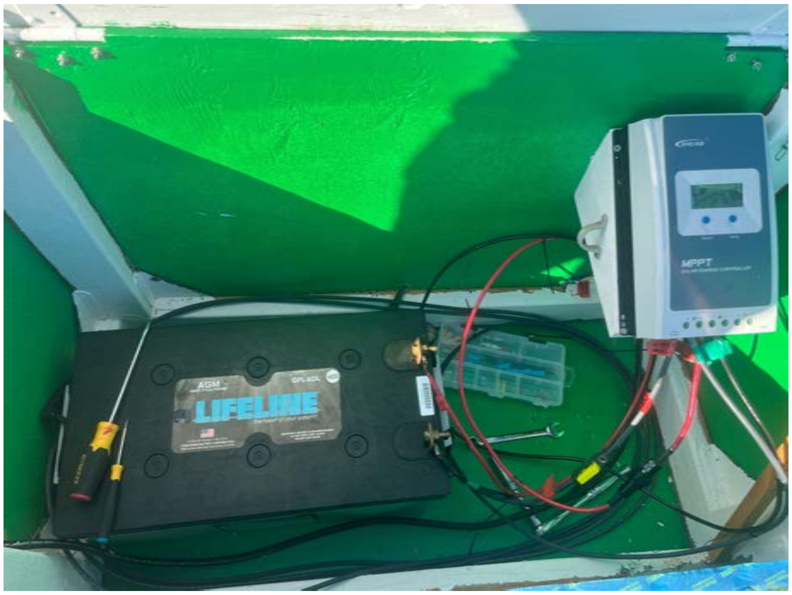

Figure 24. FLUPSY battery and Solar Charge Controller.

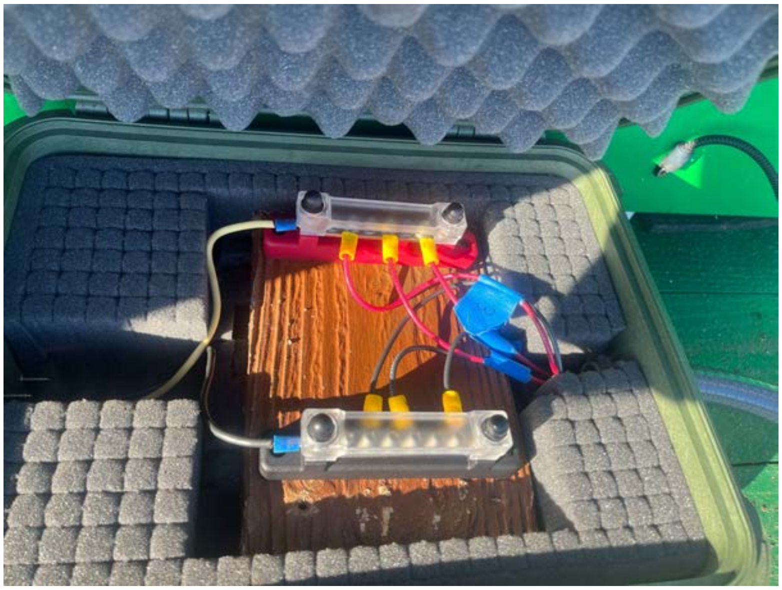

Figure 25. Wiring for three bilge pumps.

Figure 26. Solar Panels on the FLUPSY.

Figure 27. Trough with bins and oysters.

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