



**Smart Recirculating Aquaculture System (RAS) farm for Cultivating  
*Crassostrea belcheri* oysters**

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**30<sup>th</sup> January 2026**

## Abstract

Oyster culture, particularly *Crassostrea belcheri*, faces challenges in water quality control during the nursing stage due to the high sensitivity of juvenile oysters to fluctuations in temperature, salinity, and pH, as well as the accumulation of nitrogenous wastes. Conventional water management practices are unable to provide continuous monitoring and rapid response to environmental changes.

This study aimed to design and develop a smart recirculating aquaculture system (Smart RAS) integrated with wastewater treatment for oyster culture and to evaluate its efficiency in water quality control and pollutant reduction. The system consisted of culture and filtration tanks incorporating sequential physical, aerobic biological, and anoxic biological treatment processes, using oyster shells as biofilter media. Sensors for temperature, pH, and salinity were integrated with an ESP32 microcontroller, enabling real-time monitoring via the Blynk application.

The results showed that the Smart RAS effectively maintained stable water quality. Water temperature after treatment was 27.5 °C, close to the pre-culture value of 27.3 °C, while pH remained stable within 7.4–7.5. Dissolved oxygen increased from 6.14 to 6.38 ppm after treatment. Nitrite ( $\text{NO}_2^-$ ) concentration increased to 3 ppm after culture but decreased to 1 ppm after treatment, corresponding to an approximate removal efficiency of 66.7%. The automated monitoring system showed average measurement errors of 0.36 °C (1.23%) for temperature and 0.37 (5.03%) for pH. Oyster growth over 25 days confirmed system suitability, with shell length increasing from 3.723 to 10.061 mm and the combined weight of five oysters increasing from 0.057 to 0.49 g.

In conclusion, the developed Smart RAS is suitable for oyster culture and demonstrates strong engineering potential for wastewater treatment by reducing nitrogen accumulation, maintaining stable water quality, and minimizing effluent discharge to the environment, thereby supporting sustainable aquaculture practices.

**Keywords:** Oyster; Recirculating Aquaculture System; Blynk

## Research Questions

1. How can a smart Recirculating Aquaculture System (RAS) integrated with wastewater treatment be designed and developed for oyster culture?
2. How efficient is the smart RAS in terms of wastewater treatment and water quality control for oyster culture?

## Hypothesis

1. The smart RAS is suitable for oyster culture and effectively supports water quality control within the system.
2. The smart RAS can reduce pollutant loads from oyster culture wastewater and maintain stable water quality within the culture system.

## Introduction

At present, oysters are economically important aquatic species for coastal aquaculture in Thailand and many countries in Southeast Asia, as they are a highly nutritious food source rich in protein and essential minerals, and they continue to be in strong market demand. Oyster farming therefore plays a significant role in generating income for coastal farmers and supporting the economic development of local communities. In particular, the white scar oyster (*Crassostrea belcheri*) is widely cultured in Thailand due to its favorable growth performance and its relatively broad tolerance to coastal environmental conditions (Department of Fisheries, 2019).

However, although oyster culture at the adult stage exhibits a certain degree of stability, high mortality rates remain a major challenge during the larval and nursing stages. Juvenile oysters are highly sensitive to environmental fluctuations, especially key water quality parameters such as temperature, salinity, and pH. Rapid changes in these factors can induce physiological stress, directly affecting survival rates and growth performance (Supawadee et al., 2020; Worawit et al., 2021).

Field surveys and data collection conducted at oyster hatchery and nursery centers revealed that conventional water management practices, which rely on periodic manual monitoring, are insufficient for effective environmental control within culture tanks. In particular, water temperature regulation was identified as a critical factor influencing juvenile oyster survival. During episodes of sudden weather changes, such as prolonged heavy rainfall, water temperature in the culture tanks was observed to decrease rapidly. As a result, several thousand juvenile oysters in the nursing stage died within less than 24 hours. This incident highlights the vulnerability of juvenile oysters to temperature fluctuations and underscores the

limitations of traditional water management systems, which are unable to continuously monitor and respond promptly to abrupt environmental changes.

In addition, wastewater generated from oyster culture processes contains accumulated metabolic wastes, uneaten feed, and organic sediments, leading to the buildup of nitrogenous compounds. Without appropriate management, this deterioration of water quality can adversely affect the culture system and may cause negative impacts on the surrounding coastal environment when effluent is discharged.

In response to these challenges, this study proposes the development of a smart aquaculture system that emphasizes continuous monitoring and stabilization of water temperature in conjunction with real-time water quality assessment. The developed system integrates sensors for water temperature, salinity, and pH, connected to an ESP32 microcontroller that processes data and transmits it in real time to the Blynk application for monitoring and management of the culture environment. This system is combined with a closed-loop recirculating aquaculture system (Recirculating Aquaculture System: RAS) to maintain stable water quality conditions within the culture tanks. Particular emphasis is placed on the treatment and management of culture water prior to recirculation in order to reduce waste accumulation within the system, minimize wastewater discharge to the environment, and enhance survival and growth rates of juvenile *Crassostrea belcheri* during the nursing stage. Ultimately, this approach aims to promote sustainable oyster aquaculture in Thailand in alignment with future smart farming practices.

## Materials

- |   |  |
|---|--|
| 1. Culture tank (14.5 L)                            | 13. Salinity meter   |
| 2. Filtration tank (19.5 L)                         | 14. Dissolved Oxygen meter (DO meter)  |
| 3. Sterilized seawater (30 L)                       | 15. Nitrite test kit   |
| 4. Airline tubing                                   | 16. ESP32 microcontroller board  |
| 5. Air pump   | 17. Temperature sensor   |
| 6. Water pump (5 W)                                 | 18. pH sensor  |
| 7. PVC pipe (½ inch)                                | 19. Salinity sensor  |
| 8. Tubing (8 mm diameter)                           | 20. Relay module   |
| 9. Fiberglass filter pads<br>(25 × 12 cm), 2 pieces | 21. Juvenile white scar oysters ( <i>Crassostrea belcheri</i> ), 200 individuals |
| 10. Small-sized oyster shells                       | 22. Cooling fans (2 × 2 inches), 4 units   |
| 11. Thermometer                                     | 23. Heater   |
| 12. pH meter  | 24. Microalgae <i>Tetraselmis</i> sp.  |

## Methods

### 1. Study site



**Figure 1** shows the study area of Princess Chulabhorn Science High School Trang, No. 196, Village No. 4, Trang–Sikao Road, Bang Rak Subdistrict, Mueang Trang District, Trang Province.

Coordinates  $7^{\circ} 33' 12''$  N  $99^{\circ} 33' 28''$  E



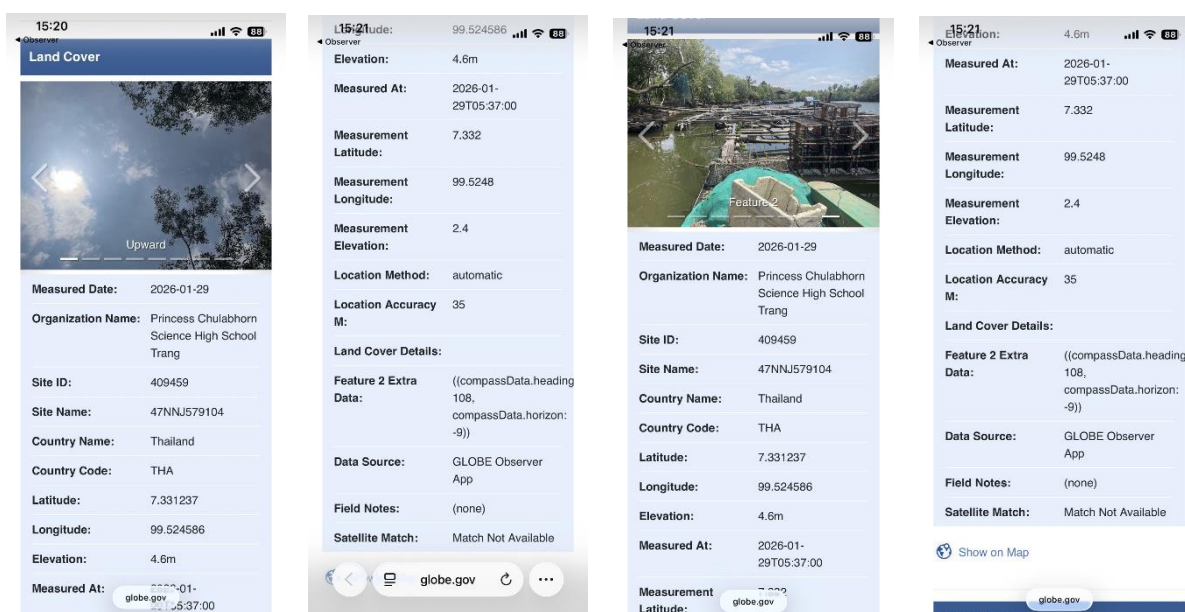
**Figure 2** shows the study area of Ban Tae Ram, Kantang, Trang Province.

Coordinates  $7^{\circ} 18' 53.0''$  N  $99^{\circ} 29' 34.0''$  E

## 2. Collection and Analysis of Source Seawater Quality

Seawater samples were collected from a coastal area to serve as source water for a closed recirculating aquaculture system (RAS) for oyster culture. The sampling sites represented typical environmental conditions of oyster farming areas. Water quality analysis was conducted as follows:

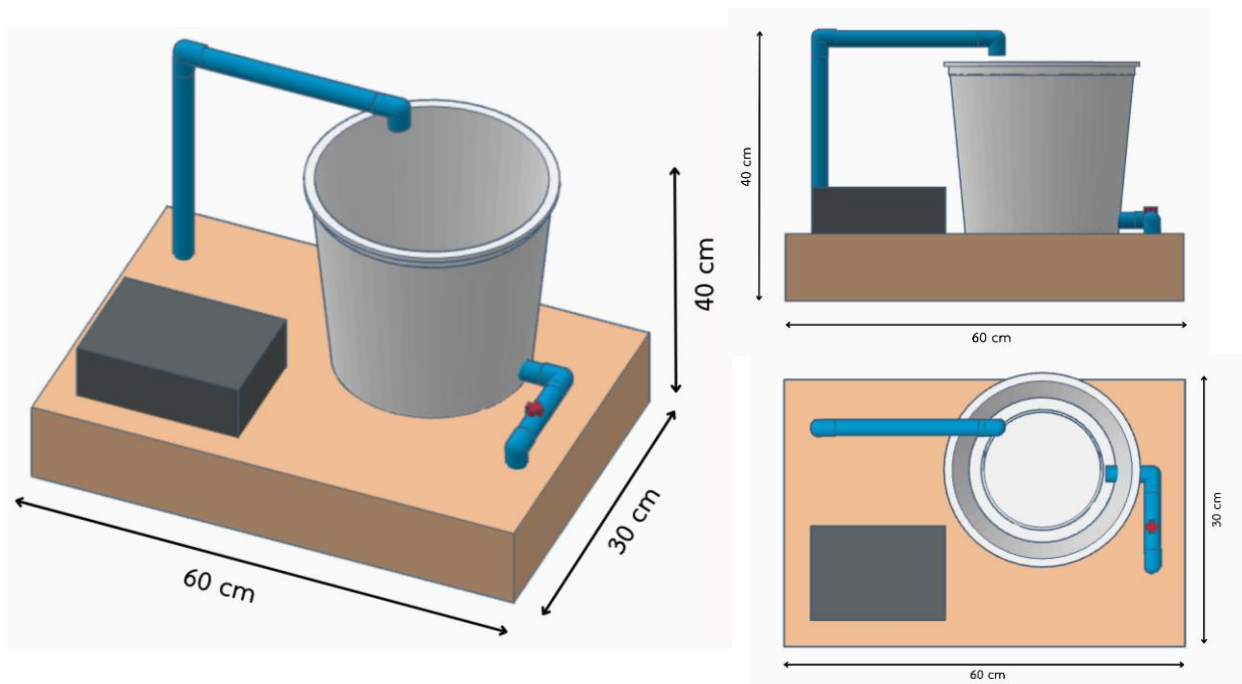
1. Analyzing physical parameters, including water temperature and salinity.
2. Analyzing chemical properties, including pH, dissolved oxygen (DO), and nitrite concentration.
3. Conducting measurements three times in accordance with GLOBE measurement principles, and calculating the mean and standard deviation.
4. Send the information to GLOBE Data Entry.



**Figure 3** Land Cover Observation

### 3. Design and Development of the Smart RAS Model Based on Environmental Engineering Principles

#### 3.1 Culture Tank Design

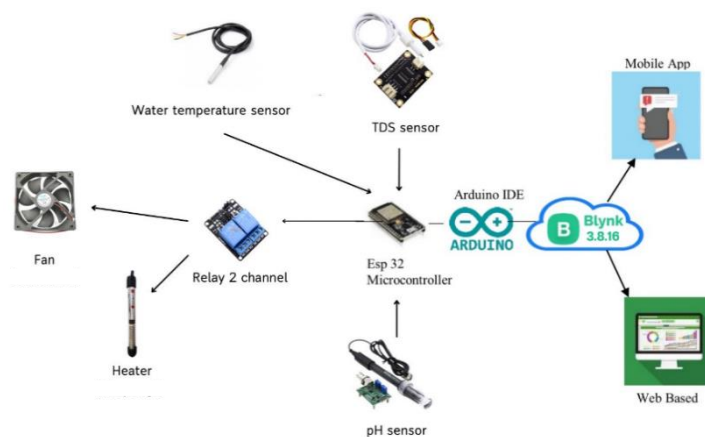


**Figures 4** illustrate the side, front, and top view diagrams of the RAS model.

1) The culture tank had a volume of 14.5 liters and was designed for oyster culture under a closed recirculating aquaculture system (RAS). The design accounted for metabolic waste produced by oysters, which, if not properly managed, can lead to the accumulation of nitrogenous compounds and negatively affect water quality and oyster health.

2) Four ventilation fans ( $2 \times 2$  inches) were installed at the top of the culture tank to regulate and maintain water temperature within an appropriate range. Stable temperature conditions help reduce physiological stress in oysters caused by sudden temperature fluctuations and contribute to the overall stability of the recirculating system.

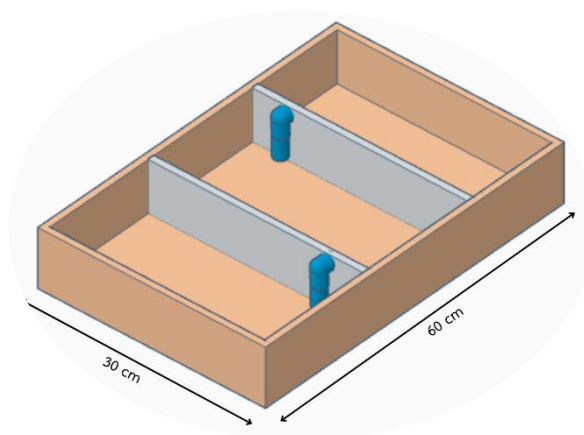
3) Sensors for monitoring water temperature, pH, and salinity were installed in the culture tank and connected to an ESP32 microcontroller. This system enables systematic monitoring and control of water quality, supporting effective environmental management and improving the efficiency of wastewater treatment processes within the RAS.



**Figure 5** illustrates the operational diagram of the sensor system used in this study.

### 3.2 Filtration and Water Treatment System Design

The filtration tank had a total volume of 19.5 liters and was divided into three sequential treatment compartments based on environmental engineering principles and wastewater treatment processes, as described below.



**Figure 6** shows the side-view diagram of the internal structure of the filtration tank.

#### 1) Compartment 1: Physical Treatment

Water from the culture tank first flowed into the physical treatment compartment, where fiberglass filter media with porous characteristics were installed to remove suspended solids. This compartment was designed to trap total suspended solids (TSS), uneaten feed, and organic sediments generated from oyster culture.

This step reduced the organic and solid load entering the subsequent biological treatment units, thereby enhancing the efficiency of nitrogen removal processes in the system.

#### 2) Compartment 2: Aerobic Biological Treatment

The second compartment was filled with small oyster shells, which provided a porous surface area for the attachment and growth of nitrifying bacteria, such as

Nitrosomonas and Nitrobacter. Continuous aeration was supplied to maintain aerobic conditions and promote the oxidation of ammonia ( $\text{NH}_3/\text{NH}_4^+$ ) into nitrite ( $\text{NO}_2^-$ ), a critical step in the nitrogen cycle within the RAS.

### 3) Compartment 3: Anoxic Biological Treatment

Water from the aerobic compartment flowed into the third compartment, which was also filled with oyster shells but operated without aeration to create an anoxic environment suitable for denitrifying bacteria. These bacteria converted nitrite ( $\text{NO}_2^-$ ) into nitrate ( $\text{NO}_3^-$ ), which is less toxic to oysters.

After treatment, the water was pumped back into the culture tank, thereby reducing the accumulation of toxic nitrogenous compounds and maintaining water quality in the closed-loop system.

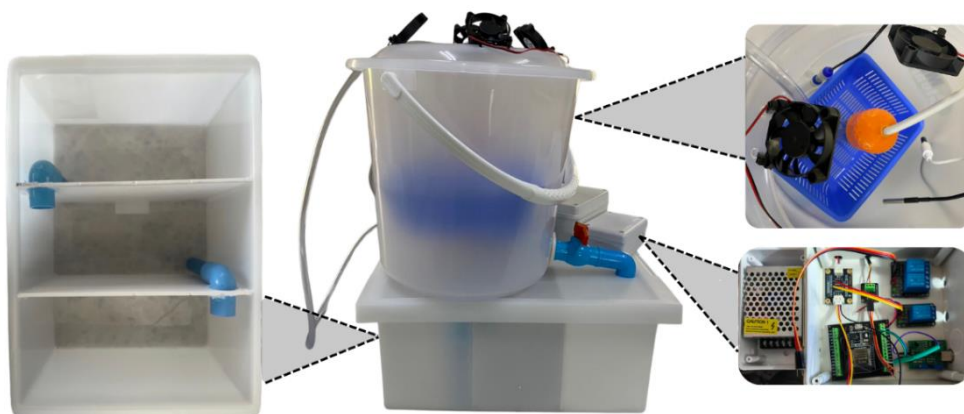
## 4. Evaluation of Wastewater Treatment Performance in the RAS

Water samples were collected from the system before entering the treatment process (influent) and after treatment within the RAS (effluent) for comparative analysis. The evaluated parameters included water temperature, pH, salinity, dissolved oxygen (DO), and nitrite concentration ( $\text{NO}_2^-$ ).

The comparative results were used to assess the effectiveness of the RAS in reducing nitrogen-related pollutants and maintaining stable water quality suitable for oyster culture.

## 5. Assessment of the Environmental Engineering Potential of the System

The water quality data obtained before and after treatment were analyzed comparatively to evaluate the potential of the RAS in treating wastewater generated from oyster culture. The assessment focused on the system's ability to reduce wastewater discharge to the environment and to support sustainable aquaculture practices in accordance with environmental engineering principles.



**Figure 7** illustrates the physical prototype of the RAS system.

## Data Analysis

The data were analyzed using descriptive statistical methods as follows:

1. **Mean ( $\bar{x}$ ):**

Used to determine the average values of water quality parameters, including water temperature, pH, salinity, dissolved oxygen (DO), and nitrite concentration ( $\text{NO}_2^-$ ), representing the overall operating conditions of the RAS.

2. **Standard Deviation (S.D.):**

Used to evaluate the variability and stability of the measured water quality parameters over time, indicating the effectiveness of environmental control within the system.

3. **Comparative Analysis:**

Mean and standard deviation values of influent and effluent water quality were compared to assess the performance of the filtration and biological treatment processes in the RAS.

## Results

**Table 1** shows a comparison of seawater quality parameters before and after shellfish culture and treatment.

Measured parameters	Seawater conditions		
	Before shellfish culture	After shellfish culture	
		Before treatment	After treatment
Temperature (°C)	27.3	27.9	27.5
pH	7.4	7.5	7.4
Salinity (ppt)	25	27	25
DO (ppm)	6.24	6.14	6.38
Nitrite (ppm)	0	3	1

**Table 2** shows the performance test of temperature and pH measurements of the automated farm.

Trial	Temperature				pH			
	Measured value (°C)	Blynk value (°C)	$\Delta T$ (°C)	Error (%)	Measured value	Blynk value	$\Delta pH$	Error (%)
<b>1</b>	29.70	29.94	0.24	0.81	7.30	6.84	0.46	6.30
<b>2</b>	29.20	29.65	0.45	1.54	7.40	7.00	0.4	5.41
<b>3</b>	28.90	29.26	0.36	1.25	7.10	6.86	0.24	3.38
<b>Mean</b>	29.26	29.62	0.36	1.23	7.27	6.90	0.37	5.03

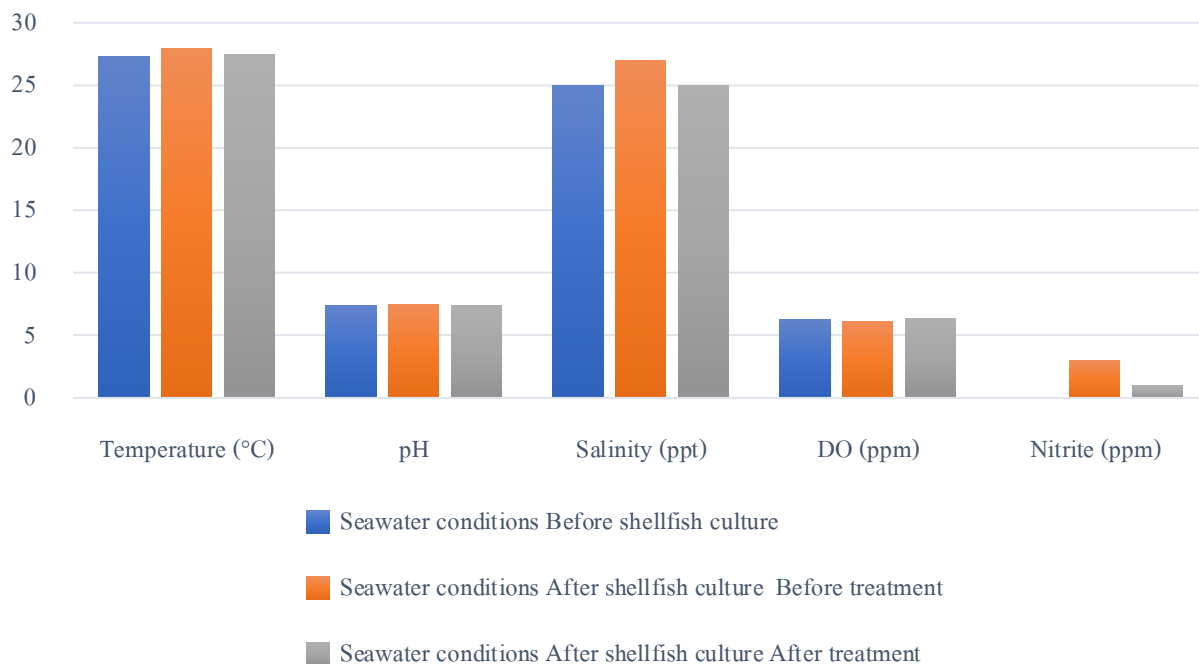
**Note:**  $\Delta T$  = actual measured temperature — Blynk temperature;

$\Delta pH$  = actual measured pH — Blynk pH.

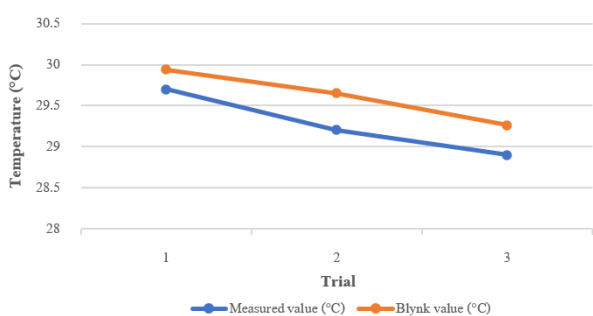
**Table 3** shows the growth of white scar oysters cultured in an automated farm.

Date	Size (mm)	Weight of five shellfish (g)
<b>0</b>	3.723	0.057
<b>5</b>	5.648	0.083
<b>10</b>	8.438	0.24
<b>15</b>	9.506	0.30
<b>20</b>	9.812	0.395
<b>25</b>	10.061	0.49

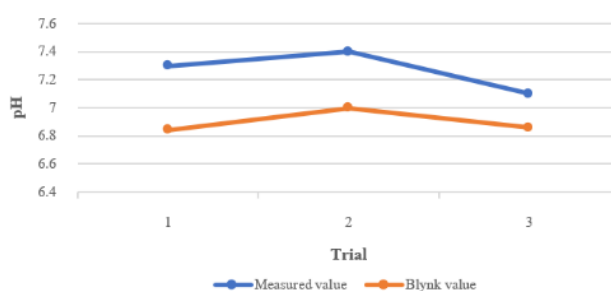
## Comparison of Seawater Quality Parameters before and after Shellfish Culture and Treatment



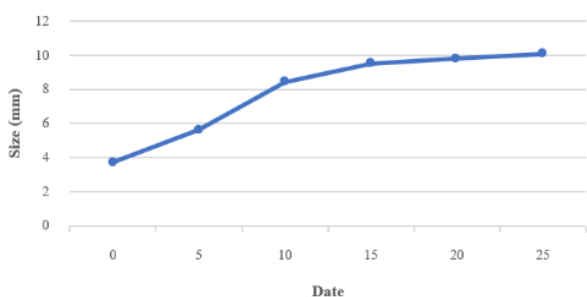
**Performance Evaluation of Temperature Measurement in the Automated Farm**



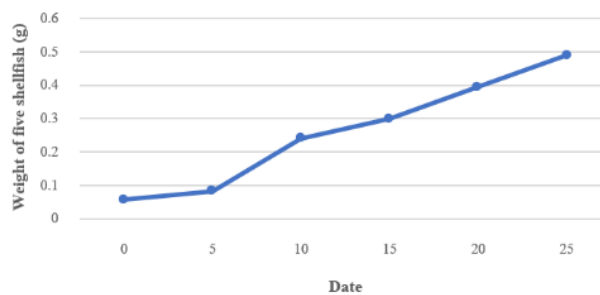
**Performance Evaluation of pH Measurement in the Automated Farm**



**Growth of Oyster Size over a One-Month Period**



**Growth of Oyster Weight over a One-Month Period**



## Discussion and Conclusions

The results of this study demonstrate that the recirculating aquaculture system (RAS) designed based on environmental engineering principles is effective in controlling water quality and reducing pollution loads from wastewater generated during oyster culture.

Comparison of water quality before and after culture showed only minor changes in water temperature, increasing from 27.3 °C to 27.9 °C, and stabilizing at 27.5 °C after treatment, indicating good thermal stability of the system. The pH remained relatively constant within the range of 7.4–7.5, while salinity decreased from 27 ppt after culture to 25 ppt after treatment, demonstrating the system's ability to maintain appropriate physical and chemical conditions for aquaculture.

In terms of biological water quality, dissolved oxygen (DO) increased from 6.14 ppm to 6.38 ppm after treatment, reflecting the effectiveness of the aerobic treatment process. Nitrite ( $\text{NO}_2^-$ ) concentration increased to 3 ppm after oyster culture but decreased to 1 ppm following treatment by the RAS, corresponding to an approximate removal efficiency of 66.7%. This result highlights the effectiveness of the integrated physical–aerobic–anoxic treatment processes in reducing nitrogen-related pollutants within the closed-loop system.

The use of oyster shells as biofilter media provided a large surface area for the attachment of nitrifying and denitrifying microorganisms, enhancing nitrogen transformation processes and supporting resource reuse in accordance with environmental engineering and circular economy concepts.

Performance evaluation of the automated monitoring system showed average measurement errors of 0.36 °C (1.23%) for temperature and 0.37 (5.03%) for pH. These results indicate that the sensor system integrated with the ESP32 microcontroller and the Blynk platform provides sufficient accuracy for real-time water quality monitoring and system management.

Furthermore, oyster growth over a 25-day period confirmed the suitability of the treated water for culture, with shell length increasing from 3.723 to 10.061 mm and the combined weight of five oysters increasing from 0.057 to 0.49 g.

In conclusion, the developed RAS demonstrates strong engineering potential for treating wastewater from oyster culture by reducing nitrogen accumulation and minimizing effluent discharge to the environment. The system supports sustainable aquaculture practices and shows promise for future application at the farm scale.

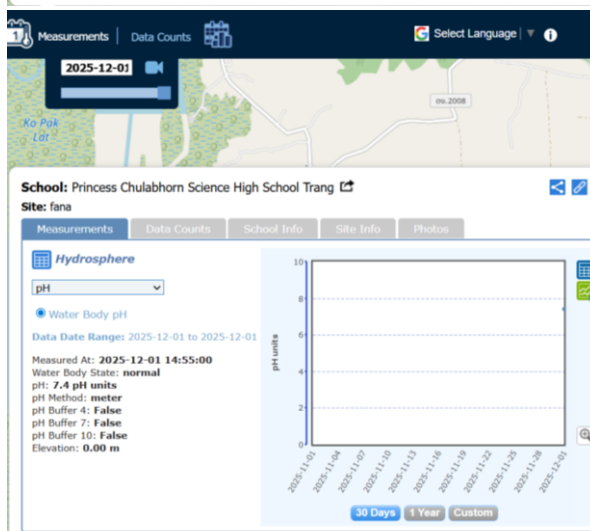
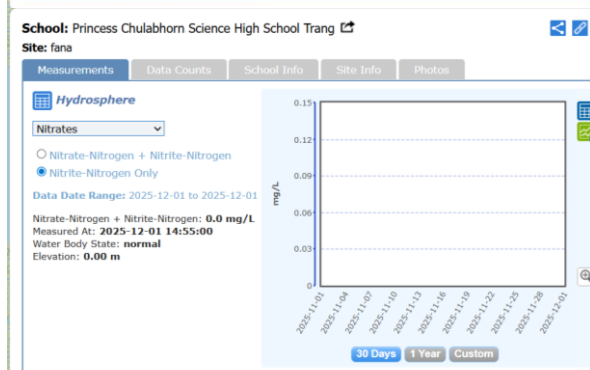
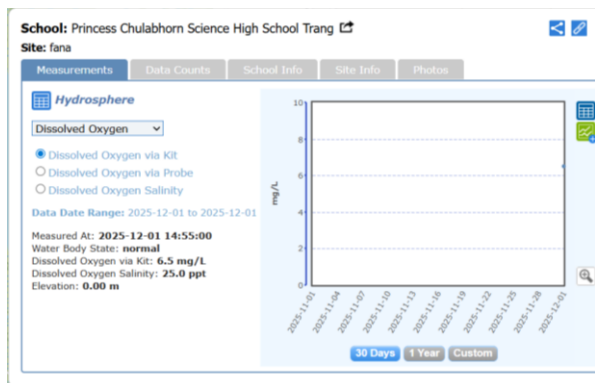
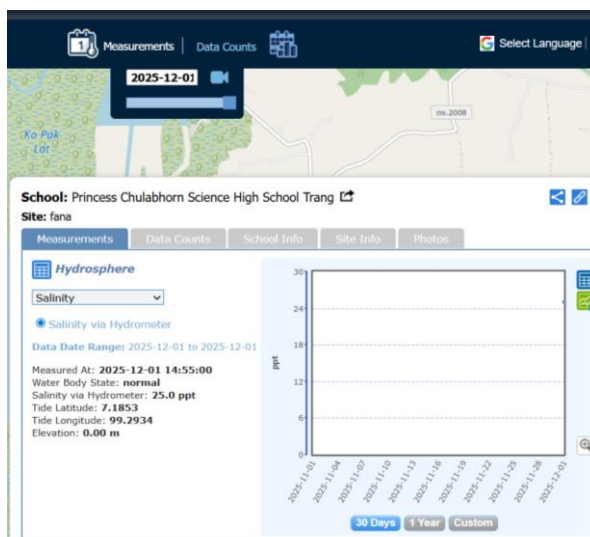
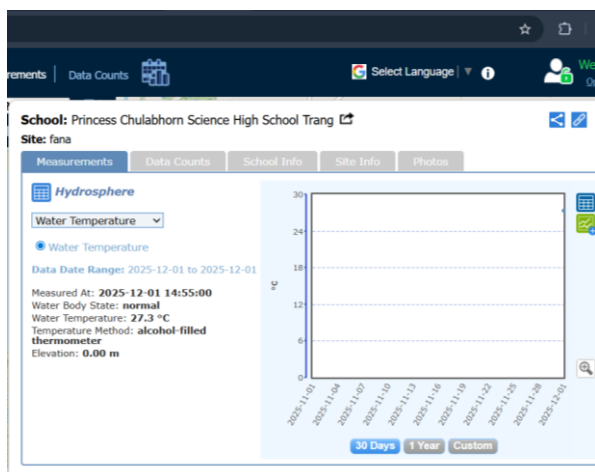
## Acknowledgements

This project was successfully completed with all objectives achieved. The authors sincerely thank Miss Preeyanun Srisuwan, Miss Rungdao Onchum, and Mrs. Pacharee Chaipetch for their valuable guidance and continuous support. Special appreciation is extended to Asst. Prof. Dr. Supatcha Chusiangaew for her expert advice on oyster culture and academic review. The authors also gratefully acknowledge IVSS for its support in field operations and experimentation, and Rajamangala University of Technology Srivijaya, Trang Campus, for providing facilities and assistance. Finally, sincere thanks are given to the authors' families and fellow students for their encouragement and support.

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# GLOBE's databases



## **(Optional) Badges (3 Badges)**

### **1) I AM A PROBLEM SOLVER**

Through the study of oyster growth behavior, water quality was identified as the key factor directly influencing growth. By analyzing this challenge, we focused on developing effective solutions to control and optimize water conditions for oyster farming. This problem-solving approach led to the development of a smart aquaculture farm utilizing a Recirculating Aquaculture System (RAS) for the efficient cultivation of white-lip pearl oysters.

### **2) I AM AN ENGINEER**

A Smart Recirculating Aquaculture System (RAS) farm for Cultivating *Crassostrea belcheri* oysters is engineered based on critical growth-influencing parameters. The system integrates sensor-based monitoring, automated control, and water recirculation technologies to precisely regulate water quality and environmental conditions, thereby optimizing growth performance, enhancing survival rates, and improving overall system efficiency.

### **3) I AM A COLLABORATOR**

The development of innovation in oyster farming requires strong collaboration and unity among all members. Working together ensures that oyster care and management are carried out efficiently and smoothly, leading to healthy oyster growth. In addition, collaborative data collection and analysis play a crucial role in planning and improving farming practices. Therefore, teamwork is an essential factor in achieving the highest level of success in oyster farming.