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Histological conditions of farmed oysters during the rainy season in Welu Estuary, Thailand

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Abstract

The Welu Estuary, known for its large mangrove ecosystem, is suggested to be influenced by climate change. In the case of a prolonged rainy season, which has led to extended low-salinity conditions, it is difficult to maintain stable bivalve aquaculture in the upper estuarine area. This study reviews past instances of oyster mortality due to low-salinity and explores stabilization measures for oyster farming in tropical monsoon regions. In August 2013, the Welu Estuary experienced an oyster mortality rate of approximately 20%. Histological observations indicated poor feeding conditions in many oysters; however, organ damage was insignificant. Therefore, a prolonged period of low-salinity below 10 ppt adversely affects oyster feeding and increases mortality risk. A practical countermeasure to reduce mortality is relocating cultured oysters from the upper estuary to the lower estuary near the sea during the rainy season. These results suggest that different farming areas for oysters should be used during the dry and rainy seasons to stabilize farming.

Keywords: Low-salinity; Oyster farming; Mangrove estuary; Feeding assessment; Climate change.

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1. Introduction

Oyster farming is a significant coastal industry in Thailand and widely practiced along the Gulf of Thailand and the Andaman Sea (Sahavacharin, 1995; Day *et al*., 2000; Chalermwat *et al*., 2003; Szuster *et al*., 2008). Notably, Chon Buri, Surat Thani, and Phangnga have been identified as important oyster-farming regions (Chalermwat *et al*., 2003; Szuster *et al*., 2008). These areas are characterized by brackish water, a condition resulting from the mixing of freshwater and seawater. In particular, they are known to occur in high concentrations of diatoms, which are phytoplanktons that promote oyster growth (Limpsaichol *et al*., 1998; Sangmanee, 2021; Charoenvattanaporn and Vongpanich, 2023). Furthermore, oyster farming represents a significant source of revenue for local fishers, with exports destined not only for the domestic market but also for neighboring countries (Chalermwat *et al*., 2003). In the future, Thailand's oyster farming industry must aim to contribute significantly to the local economy while implementing sustainable fisheries management and environmental conservation (Nowland *et al*., 2020).

Various oyster farming techniques have been used in Thailand. The first method is “tray farming,” a straightforward method that involves installing bamboo or other materials in shallow waters and suspending oyster seedlings from shelves, making their management and harvest easy (Sahavacharin, 1995). Subsequently, "floating farming" is a method wherein spats are suspended using floats and cultivated close to the sea surface. This method is distinguished by its capacity for extensive deployment across large areas (Chalermwat *et al*., 2003). Finally, in “bottom-seeding farming,” seedlings are sown on a seabed and grown (Sungkasem and Tookwinas, 1994). Despite its low cost, this method is susceptible to the detrimental effects of currents and sludge (Appukuttan and Muthiah, 1996).

The eastern region of Thailand, situated along the Gulf of Thailand, has a long history of oyster farming and is recognized as one of the most productive marine areas in the country (Trivej and Kesjinda, 2018). In particular, the Welu Estuary in the southeast, characterized by a calm marine environment with a small mean tidal range of 0.8–1.2 m (Chen *et al*., 2020), has fostered the development of a rich brackish water environment ideal for oyster farming. Brackish water is rich in phytoplankton and contains diatoms that serve as food for oysters (Chaweepak *et al*., 2019; Chen *et al*., 2020), thereby providing an ideal environment for bivalve farming. Estuaries are relatively shallow, making hanging cultures with racks and floats a widespread practice (Wang *et al*., 2020; Yurimoto *et al*., 2021). The commonly known target species for oyster fishery in Thailand are *Crassostrea belcheri, C. iredalei*, and *Saccostrea cucullata* (Chalermwat *et al*., 2003; Klinbunga *et al*., 2003). In the eastern regions of Thailand, these species are believed to be cultured in a mixed manner (Okoshi, 2003).

In August 2013, fatalities were observed in cockle and oyster populations on bivalve farms situated within the Welu River Estuary. The impact on oysters grown on floats or shelves was approximately 20% of the total production. In contrast, the damage to cockle cultivation on the seabed was more extensive, with over 50% of the crop lost (Yurimoto *et al*., 2021). A hypothesis suggests that oysters suspended near the surface are more susceptible to the effects of freshwater than those cultured at the bottom. The lower mortality of oysters suggests that they have a stronger tolerance to low-salinity than that in cockles. In recent years, the number of deaths among farmed bivalve shells has increased owing to the effects of climate change (Soon and Zheng, 2020). Measures to address the prolonged low-salinity conditions caused by increased precipitation and extended rainy seasons are urgently needed (Yurimoto *et al*., 2021; Yurimoto *et al*., 2024a). The principal objective of this study was to collate previous data on oyster mortality resulting from low-salinity conditions and consider measures for the stabilization of oyster farming in tropical regions.

2. Materials and methods

The Welu Estuary, located in eastern Thailand, exhibits topographical and hydrological conditions that are highly favorable for oyster aquaculture. The area is characterized by minimal tidal fluctuations and a calm environment, making it particularly suitable for floating oyster farming systems. Surrounding the estuary are extensive mangrove forests, which serve as critical habitats for a wide range of aquatic and terrestrial species (Suk-Ueng *et al*., 2017). Seasonal variations in salinity are a notable feature of this region. During the rainy season, increased freshwater inflow from inland sources leads to a significant reduction in salinity levels. Conversely, in the dry season, the influence of seawater from the coastal zone becomes more pronounced, resulting in elevated salinity concentrations (Chaweepak *et al*., 2019). Therefore, it is suggested that these fluctuations in salinity are important in affecting oyster growth and quality.

Between July and early August 2013, local shellfish farmers reported cases of blood cockle and oyster mortality in the waters surrounding Station 3 in the Welu River Estuary (Figure1). Based on information provided by fishermen, it was estimated that more than 50% of blood cockles and approximately 20% of cultivated oysters died at that time (Yurimoto *et al*., 2021). In this study, cultivated oysters (n = 21) with a weight of 1–5 g were collected from the waters surrounding a local oyster farm (Station 3) in mid-August 2013 and subsequently transported to the laboratory. The area is renowned for its hanging culture of *S. cucullata* (synonym: *S. forskahlii*; Krabuansang *et al*. 2020). Most oysters collected for survey purposes exhibited distinctive characteristics, including thick shells, flat and small upper shells, and wavy shell edges. Based on these observations, it was concluded that these oysters were predominantly *S.* cf. *cucullata*. The weight of each specimen was recorded, the shells were opened with an oyster knife, and the soft body parts were observed. Various organs (mantle, gills, midgut gland, digestive tract, and gonads) were immersed in 10% seawater formalin to fix the tissues. Subsequently, the fixed tissues were dehydrated in ethanol, replaced with lemosol, and embedded in paraffin. Paraffin-embedded tissue specimens were sectioned at a thickness of 5 μm using a microtome. The sections were stained with hematoxylin and eosin (H&E) and analyzed microscopically using an optical microscope (Eclipse 80i, Nikon, Japan) to assess tissue morphology. The presence or absence of tissue damage in the mantle and gills, as well as food in the digestive tract and epithelial cells of the caecum in the midgut gland, was examined. Furthermore, the gonads were classified based on the condition of the gonadal tissue, following the established system for developmental stages in bivalves (Yurimoto *et al*., 2014; Yurimoto *et al*., 2021).

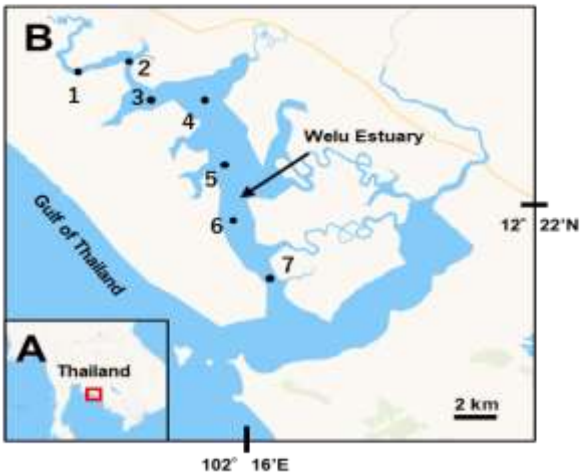

Figure 1. Water quality monitoring sites (Stations 1-7) and the farmed oyster collection site (Station3) in the Welu Estuary. Maps were obtained from the Sentinel-hub EO Browser (https://apps.sentinel-hub.com/dashboard/#/collections).

Surface salinity data from the oyster farming region were collected by the Chanthaburi Fisheries Center from April to October 2013 at seven fixed locations within the Welu River Estuary. The data were then organized into graphical representations. The salinity trends at Stations 1–4 from April to August were compiled into line graphs as mean ± standard deviation (SD) to illustrate and determine the salinity changes in the oyster farming area in the upper reaches of the river estuary. Furthermore, the salinity trends at each station from May to October were compiled into line graphs to ascertain the differences in salinity trends between the upper and lower reaches of the river estuary during the rainy season. Additionally, the salinity levels at each station from July to September, which corresponded to a period of low-salinity, were compiled into graphs as the mean ± SD from the data of each station. Monthly rainfall data for the study area were obtained from the website of the Japan Meteorological Agency (http://ds.da-ta.jma.go.jp/gmd/tcc/tcc/products/climate/). Rainfall trends from April to August were visualized using a bar graph that will be explained in the results' section.

3. Results

3.1. Environment of the Welu Estuary

Following June, precipitation levels in the Welu Estuary region demonstrated a notable increase, exceeding 400 mm and reaching a peak of approximately 1,000 mm in July. There was a subsequent decline in precipitation in August; however, the total precipitation remained above 400 mm (Figure 2A; Japan Meteorological Agency, 2024). Similarly, surface salinity in the aquaculture area declined after June, dropped below 20 ppt, and reached a minimum of 6 ppt in July before stabilizing at 8 ppt in August (Figure 2B). A line graph illustrating the surface salinity trends during the rainy season for the wider Welu Estuary is presented in Figure 3A. In the lower estuary (Stations 5–7), the decline below 10 ppt was confined to July, with salinity increasing from August onwards. In the upper estuary (Stations 1–3), the salinity remained below 10 ppt from July to September. On the other hand, salinity trends at Station 4 exhibited instability from July to September, reaching a salinity of 11 ppt in August before declining to 9 ppt in September. The mean surface salinity (mean ± SD) of each station during the low-salinity period from July to September is presented in a graph (Figure 3B). Station 1 exhibited the lowest average salinity at 5 ppt, and there was a discernible tendency for the salinity values of the estuary to increase gradually from the upstream to the downstream segments. Furthermore, there was a notable discrepancy in the salinity values between Stations 5–7 and those between Stations 1–3.

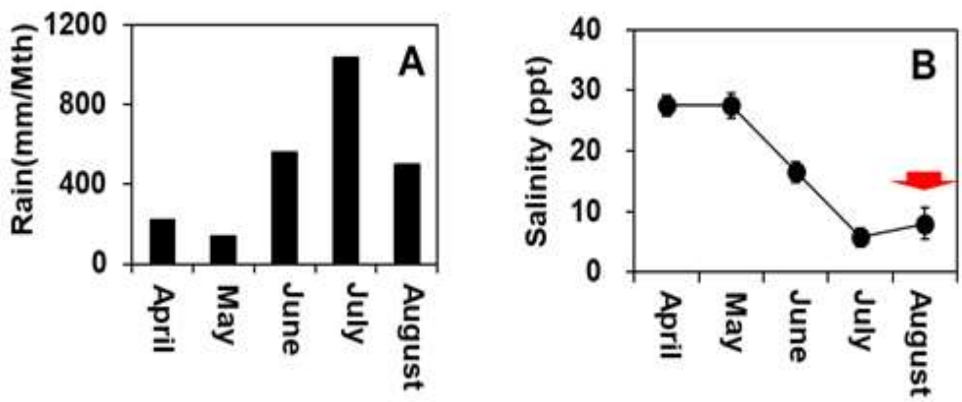

Figure 2. Monthly rainfall (A) in the region and mean surface salinity changes (B) at stations 1-4 before the mortality event in 2013. The arrow indicates the sampling date of the farmed oysters used for this study. Vertical bars in B indicate standard deviation (SD).

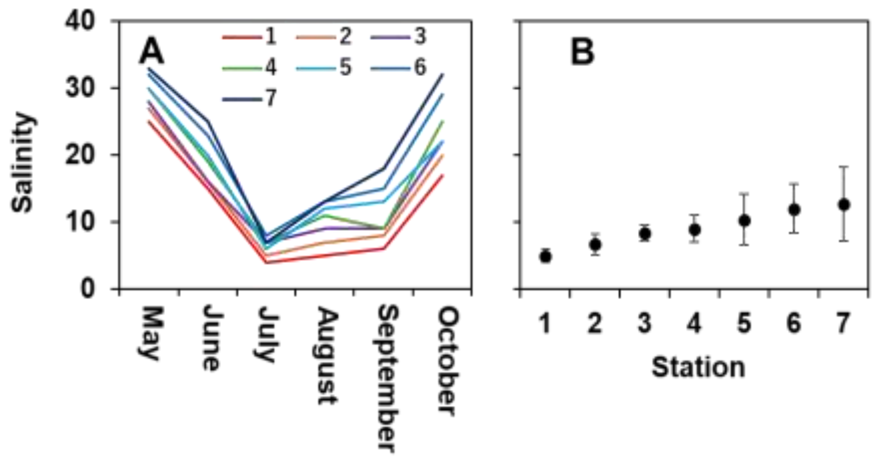

Figure 3. Surface salinity changes at the seven stations (A) from May to October and average surface salinity at each station from July to September (B) in 2013. Vertical bars in B indicate standard deviation (SD).

3.2. *Histological observations*

Macroscopic observations on the soft body showed that the internal organs, especially the midgut gland and gonadal tissues, were still swollen in all test shellfishes, indicating that the gonads were still developing. Furthermore, none of the test shellfishes were extremely thin or had the appearance of water oysters, and none were visibly weakened. Histological observations of each organ showed that the muscle tissue of the mantle was reduced in some specimens; however, the endothelial cells of the mantle blood vessels were not damaged and within the normal range (Table 1). Additionally, the majority of specimens showed no tissue damage in the gills (Figure 4A). However, gill tissue collapse was evident in three organisms/samples (Figure 4D). No food accumulated, and the digestive tract was empty in many observed individuals (Figures 4B, 4E). Additionally, most individuals exhibited partial flattening of epithelial cells in the digestive gland (Figures 4C, 4F). Subsequently, the reproductive tissues of each individual were observed to distinguish between males and females. Two were identified as males and 19 as females (Table 2). Furthermore, in both males and females, spaces were observed within the follicles of the gonadal tissue, and in some cases, connective tissue was also noted. Therefore, most individuals were in the spawning stage (Figures 5A, 5B).

Table 1. Histological observations of various organs in farmed oysters (n = 21) from the Welu Estuary

Organ	Mantle		Gill		Food in tube		Digestive gland		
Tissue condition	N	D	N	D	F	E	N	PF	EF
Number of samples	21	0	18	3	4	17	9	12	0

N = normal, D = damage, F = filled in digestive tube, E: empty in digestive tube, PF: partially flattening, EF: extensive flattening.

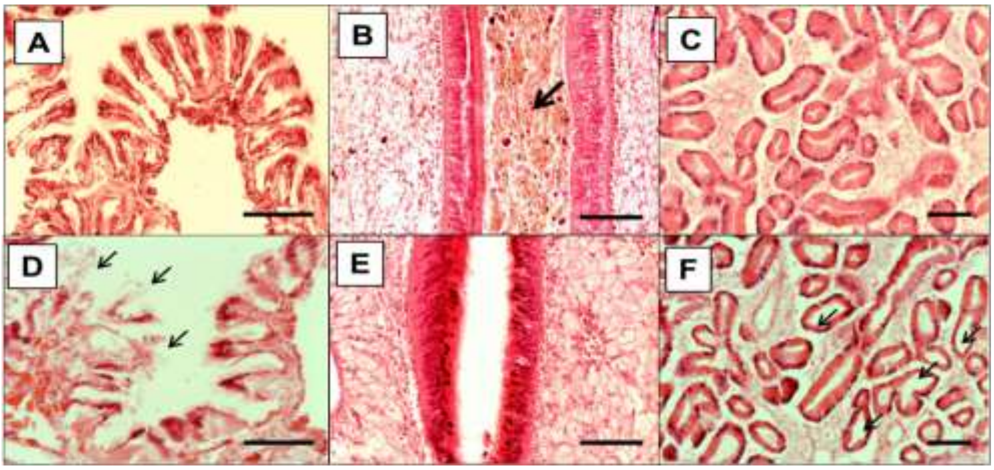

Figure 4. Histological conditions of organs with observed tissue changes. A) Gills showing normal tissue image, B) Digestive tube filled with ingested food (arrow), C) Digestive gland showing normal tissue image, D) Gills showing tissue collapse (arrow), E) Digestive tube with no food, F: Digestive gland showing flattening of part of the epithelium (arrow). Bars indicate 100 μm.

Table 2. Gonad tissue condition in farmed oysters (n = 21) from the Welu Estuary

Sex	Male		Female	
Tissue condition	Mature	Spawning	Mature	Spawning
Number of samples	0	2	2	17

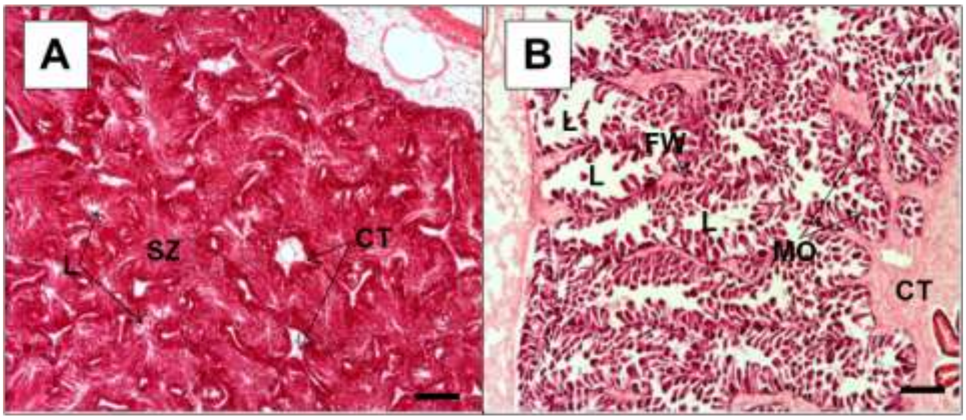

Figure 5. Histological images of the spawning stage mainly observed in the gonads of farmed oysters. A) Testis. B) Ovary.

CT: connective tissue, FW: follicle wall, L: lumen, MO: mature oocyte, SZ: spermatozoa. Bars indicate 200 µm. Sections showed some lumens due to partial spawning.

4. Discussion

4.1. Environment of the Welu Estuary

The seabed of the Welu Estuary is primarily composed of silt (Wang *et al*., 2020), and a vast mangrove forest is developing along its coastline. A total of 26 mangrove species have been identified in the area, including *Avicennia* spp., *Rhizophora* spp., and *Sonneratia* spp. (Suk-Ueng *et al*., 2013). For this reason, the Welu Estuary is regarded as a healthy mangrove ecosystem. The Welu Estuary is characterized by high dissolved oxygen concentrations and an abundance of phytoplankton, which create an ideal environment for bivalve mollusks (Chaweepak *et al*., 2019; Chaicharoen *et al*., 2020). In particular, during the rainy season, a substantial influx of inorganic nutrients from the land is observed, which likely contributes to its high primary productivity (Buranapratheprat *et al*., 2018). However, the impact of climate change in recent years has raised concerns, as the peak of the rainy season has shifted from August in the 1980s to July in recent years. This shift has prolonged the low-salinity conditions in the estuary (Trivej and Kesjinda, 2018; Yurimoto *et al*., 2021). This extended period of low-salinity has created instability for bivalve aquaculture production during the rainy season, making it challenging, especially in the upper reaches of the estuary (Stations 1–3), where river water influence is more pronounced.

In this study, the results of salinity monitoring in estuaries were analyzed. At Stations 1–3, situated in the upper reaches of the Welu Estuary, a decline in salinity was documented from July, with the low-salinity environment persisting until September (Figure 3). Conversely, at Stations 5–7, a decline in salinity was observed in July, followed by a gradual increase from August to September. This short-term of low-salinity environment indicates that this downstream area has a high rate of seawater exchange due to the inflow of seawater from the outside. Additionally, salinity at Stations 5–7 (Figure 3B) tended to be high in areas closer to the sea, even during the rainy season, with notable salinity fluctuations in Station 4. This suggests that the influxes of freshwater from the river and offshore seawater converge in this area during the rainy season. Conversely, during the dry season, the salinity in the upstream of the estuary reached the high 20s or even exceeded 30 ppt at certain times (Chaweepak *et al*., 2019), indicating that the influence of freshwater from the river is negligible during the dry season (Figures 2B and 3A).

4.2. Salinity tolerance of farming oysters

The following information is available regarding the effects of salinity on *S. cucullata*: Gametogenesis occurs at salinities of 33.37 ppt –34.65 ppt, and full maturity is achieved at a salinity of 35 ppt (Sukumar and Joseph, 1988). The minimum salinity required for reproduction is 20 ppt (Kalyanasundaram and Ramamoorthi, 1986). However, there is currently insufficient information available regarding the low-salinity tolerance of this species. The closely related species, *S. commercialis*, has the capacity to osmotically acclimate and feed sufficiently at 15 ppt –45 ppt. However, it is postulated that this species may experience difficulty acclimatizing to 5% salinity (Nell and Dunkley, 1984). Furthermore, in the case of *S. glomerata*, an experiment was conducted wherein oysters were exposed to a salinity of 10 ppt at a room temperature of 22 °C for a period of one week. During this time, the shells remained closed, and no feces or pseudofeces were released (Ertl *et al*., 2019). In a study conducted by Marshall *et al*. (2021), the salinity tolerance of oysters (*C. virginica*) across various production areas was examined using a survival test. The oysters were not acclimated to salinity prior to the test, and significant mortality (exceeding 70% in many groups) was observed after 1–2 weeks of exposure to salinities of 4 ppt and 2 ppt, irrespective of the production area. However, prior acclimation to saline conditions significantly reduced the oyster mortality. Even at a salinity of 2 ppt after 11 weeks of testing, the majority of the groups exhibited a mortality of 20% or less (Marshall *et al*., 2021).

Based on these findings, it is believed that *S. cucullata* can tolerate a certain degree of environmental stress if the salinity drop is gradual and physiological adaptation is possible, even if the environment is below 5 ppt for a prolonged period of approximately 2 mo. However, this study suggested that prolonged exposure to low-salinity (below 10 ppt) adversely affects feeding activity and increases the risk of weakening and mortality. In particular, the oysters cultivated at the Welu River mouth during this time coincided with the spawning period (Trivej and Kesjinda, 2018), indicating that this period is when the environmental tolerance of oysters is reduced. The mortality of oysters during the survey was approximately 20%, which is consistent with the findings of the experiment conducted by Marshall *et al*. (2021). Despite no significant organ damage, many individuals had empty digestive tracts. In addition, the epithelial cells of the digestive gland, which are responsible for nutrient absorption, display a partially flattened morphology. This suggests that prolonged exposure to low-salinity environments results in poor ingesting conditions in oysters (Ellis *et al*., 1998; Yurimoto *et al*., 2014; Yurimoto *et al*. 2021; Yurimoto *et al*. 2024b). Furthermore, the observed sex ratio of oysters in the present study exhibited a pronounced bias towards females. This may be due to various factors, such as the low-salinity environment and spawning season (Harding *et al*., 2013; Powell *et al.*, 2013; Sukumar and Joseph, 1988).

In particular, it has been highlighted that the pronounced bias in the sex ratio (male:female = 1:9) may give rise to a potential issue whereby spawning stimulation from the release of sperm by males does not reach females in sufficient quantities, leading to inadequate fertilization if the number of females becomes too large (Kennedy, 1983; Parker *et al*. 2018). This topic, including the influence of the sea area characteristics, represents a potential avenue for future research.

4.3. Measures for oyster farming in the rainy season

According to Trivej and Kesjinda (2018), a revised oyster farming cycle was proposed in response to the impacts of climate change in the Welu Estuary. Their countermeasure suggests collecting oyster seedlings in December and harvesting them in June, before the onset of the peak rainy season. Nevertheless, in practice, a considerable number of oysters continue to be cultivated during the rainy season and are harvested based on their physiological condition. Oyster farming in the Welu Estuary is predominantly conducted using a hanging culture technique on floating structures. However, the shallow depth of the area (typically less than 5 m) limits the ability to adjust the hanging water depth to avoid low-salinity (Wang *et al*., 2020; Yurimoto *et al*., 2021). Additionally, oysters are suspended at a height of several tens of centimeters above the sea surface, rendering them susceptible to freshwater influx from the rivers. Therefore, to mitigate the effects of low-salinity, it is recommended that oysters currently suspended in the upstream estuary (Stations 1–3) be relocated to the downstream (Stations 5–7), where seawater inflow is guaranteed. In the event of a change in precipitation patterns during the rainy season due to the effects of climate change (Trivej and Kesjinda, 2018; Yurimoto *et al*., 2021), it will be necessary to utilize different oyster farming areas for the dry and wet seasons to stabilize oyster farming in this region. To this end, developing a system for the convenient relocation of oysters using floating bodies between fishing grounds via small boats and reviewing the current administrative regulations governing coastal fishing grounds, may be essential.

Conclusion

The Welu Estuary experienced about 20% oyster mortality in August 2013. Histological observations indicated low feeding conditions but minimal organ damage in farmed oysters. Although, oysters have some environmental resistance, prolonged low-salinity below 10ppt, harms feeding and increases mortality risk. In conclusion, stabilizing oyster farming in the Welu Estuary requires using different farming areas for the dry and rainy seasons and relocating oysters from upstream to downstream during the rainy season.

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References

Appukuttan, K.K., and Muthiah, P. 1996. Technology of edible oyster culture. CMFRI Bulletin-Artificial Reefs and Seafarming Technologies, 48: 64–69.

Buranapratheprat, A., Kan-Atireklarp, S., Yuenyong, S., and Kan-Atireklap, S. 2018. Fluxes of suspended sediment and dissolved inorganic nutrients at the Welu River mouth in dry and wet seasons in 2014. Burapha Science Journal, 23(1): 546–556.

Chaicharoen, R., Chiwapreecha, B., and Piyapong, C. 2020. Diversity of phytoplankton and zooplankton in Welu River in Chantaburi Province. Burapha Science Journal, 25(2): 822–837.

Chalermwat, K., Szuster, B.W., and Flaherty, M. 2003. Shellfish aquaculture in Thailand. Aquaculture Economics & Management, 7(3-4): 249–261. https://doi.org/10.1080/13657300309380343.

Charoenvattanaporn, J., and Vongpanich, V. 2023. Distribution of marine phytoplankton along the coast of Ranong Province, Thailand. Phuket Marine Biological Center Research Bulletin, 80: 107–120. https://doi.org/10.14456/pmbcrb.2023.5.

Chaweepak, T., Yurimoto, T., Matsuoka, K., and Sangrungruang, K. 2019. Monitoring and risk assessment of paralytic shellfish poisoning (PSP) toxins in two estuaries at Chanthaburi province, Thailand. Asian Fisheries Science, 32(3): 131–137. https://doi.org/10.33997/j.afs.2019.32.3.006.

Chen, M., Qi, H., Intasen, W., Kanchanapant, A., Wang, C., and Zhang, A. 2020. Distributions of diatoms in surface sediments from the Chanthaburi coast, Gulf of Thailand, and correlations with environmental factors. Regional Studies in Marine Science, 34: 100991. https://doi.org/10.1016/j.rsma.2019.100991.

Day, A.J., Visootiviseth, P., and Hawkins, A.J. 2000. Genetic diversity among cultured oysters (*Crassostrea* spp.) throughout Thailand. Science Asia, 26: 115–122.

Ellis, M.S., Barber, R.D., Hillman, R.E., Kim, Y., and Powell, E.N. 1998. Histopathology analysis–Sampling and analytical methods of the national status and trends program Mussel watch project (ed. Lauenst, G.G., and Cantillo, A.Y.). NOAA Technical Memorandum NOS ORCA, 130: 199–226.

Ertl, N.G., O'Connor, W.A., and Elizur, A. 2019. Molecular effects of a variable environment on Sydney rock oysters, Saccostrea glomerata: thermal and low salinity stress, and their synergistic effect. Marine genomics, 43: 19–32. https://doi.org/10.1016/j.margen.2018.10.003.

Harding, J.M., Powell, E.N., Mann, R., and Southworth, M. J. 2013. Variations in eastern oyster (*Crassostrea virginica*) sex-ratios from three Virginia estuaries: protandry, growth and demographics. Journal of the Marine Biological Association of the United Kingdom, 93(2): 519–531. https://doi.org/10.1017/S002531541200032X.

Japan Meteorological Agency. 2024. Monthly climate statistics. Japan Meteorological Agency, Tokyo, Japan. https://ds.data.jma.go.jp/gmd/tcc/tcc/products/climate/.

Kalyanasundaram, M., and Ramamoorthi, K. 1986. Temperature and salinity requirements for embyronic development of *Saccostrea cucullata* (Born). Mahasagar, Bulletin of the National Institute of Oceanography, 19(1): 53–55.

Kennedy, V.S. 1983. Sex ratios in oysters, emphasizing *Crassostea virginica* from Chesapeake Bay, Maryland. Veliger, 25: 329–338.

Klinbunga, S., Khamnamtong, N., Tassanakajon, A., Puanglarp, N., Jarayabhand, P., and Yoosukh, W. 2003. Molecular genetic identification tools for three commercially cultured oysters (*Crassostrea belcheri*, *Crassostrea iredalei*, and *Saccostrea cucullata*) in Thailand. Marine Biotechnology, 5:27–36. https://doi.org/10.1007/s10126-002-0047-4.

Krabuansang, K., Swatdipong, A., Samipak, S., and Beckles, D.M. 2020. Genetic diversity of Saccostrea forskali rock oyster in the Gulf of Thailand. Applied Science and Engineering Progress, 13(2): 158–165. https://doi.org/10.14416/j.asep.2020.03.001.

Limpsaichol, P., Khokiattiwong, S., Bussarawit, N., and Sojisuporn, P. 1998. Environmental factors influencing the health and productivity of Phang-nga Bay: Community-Based Fisheries Management in Phang-nga Bay, Thailand. In Proceedings of the National Workshop on Community-based Fisheries Management (Phuket, Thailand, 14-16 February 1996), pp.85–120.

Marshall, D.A., Casas, S.M., Walton, W.C., Rikard, F.S., Palmer, T.A., Breaux, N., and *et al*. 2021. Divergence in salinity tolerance of northern Gulf of Mexico eastern oysters under field and laboratory exposure. Conservation physiology, 9(1): coab065. https://doi.org/10.1093/conphys/coab065.

Nell, J. A., and Dunkley, P. R. 1984. Effects of temperature, nutritional factors and salinity on the uptake of L-methionine by the Sydney rock oyster *Saccostrea commercialis*. Marine Biology, 80: 335–339.

Nowland, S.J., O'Connor, W.A., Osborne, M.W., and Southgate, P.C. 2020. Current status and potential of tropical rock oyster aquaculture. Reviews in Fisheries Science & Aquaculture, 28(1): 57–70. https://doi.org/10.1080/23308249.2019.1670134.

Okoshi, K. 2003. Current status and prospects of oyster culture in Thailand. Japanese Journal of Benthology, 58: 106–107. https://doi.org/10.5179/benthos.58.106.

Parker, L.M., O'connor, W.A., Byrne, M., Dove, M., Coleman, R.A., Portner, H., and *et al*. 2018. Ocean acidification but not warming alters sex determination in the Sydney rock oyster, *Saccostrea glomerata*. Proceedings of the Royal Society B: Biological Sciences, 285(1872): 20172869. https://doi.org/10.1098/rspb.2017.2869.

Powell, E.N., Morson, J.M., Ashton-Alcox, K.A., and Kim, Y. 2013. Accommodation of the sex-ratio in eastern oysters *Crassostrea virginica* to variation in growth and mortality across the estuarine salinity gradient. Journal of the Marine Biological Association of the United Kingdom, 93(2): 533–555. https://doi.org/10.1017/S0025315412000215.

Sahavacharin, S. 1995. Coastal aquaculture in Thailand. In Towards sustainable aquaculture in Southeast Asia and Japan: Proceedings of the Seminar-Workshop on Aquaculture Development in Southeast Asia, Iloilo City, Philippines, Aquaculture Department, Southeast Asian Fisheries Development Center (26-28 July, 1994), pp. 149–157.

Sangmanee, N. 2021. Diversity and Abundance of Phytoplankton in the Ports of Chonburi and Rayong Provinces, the Eastern Gulf of Thailand. Ramkhamhaeng International Journal of Science and Technology, 4(2): 1–10.

Soon, T.K., and Zheng, H. 2020. Climate change and bivalve mass mortality in temperate regions. Reviews of Environmental Contamination and Toxicology, 251: 109–129. https://doi.org/10.1007/398_2019_31.

Suk-Ueng, N., Buranapratheprat, A., Gunbua, V., and Leadprathom, N. 2013. Mangrove composition and structure at the Welu estuary, Khlung district, Chanthaburi province, Thailand. IOSR Journal of Environmental Science, Toxicology and Food Technology, 7(5): 17–24.

Suk-Ueng, K., Buranapratheprat, A., Gunbua, V., and Leadprathom, N. 2017. Application of Remote Sensing Technique for Mangrove Mapping at the Welu Estuary, Thailand. Burapha Science Journal, 22(1): 361–371.

Sukumar, P., and Joseph, M.M. 1988. Annual reproductive cycle of the rock oyster *Saccostrea cucullata* (von born). Proceedings of the First Indian Fisheries Forum, Asian Fisheries Society, pp. 207–210.

Sungkasem, P., and Tookwinas, S. 1994. Seafarming and searanching in Thailand. In seminar-workshop on aquaculture development in Southeast Asia and prospects for seafarming and searanching (19-23 August 1991, Iloilo City, Philippines), Aquaculture Department, Southeast Asian Fisheries Development Center, pp. 122–128.

Szuster, B.W., Chalermwat, K., Flaherty, M., and Intacharoen, P. 2008. Peri-urban oyster farming in the upper gulf of Thailand. Aquaculture Economics & Management, 12(4): 268–288. https://doi.org/10.1080/13657300802494438

Trivej, P., and Kesjinda, K. 2018. The onset and withdrawal of the rainy season in Thailand and their effects on oyster farming. Environmental Development, 27: 118–123. https://doi.org/10.1016/j.envdev.2018.05.002.

Wang, C., Chen, M., Qi, H., Intasen, W., and Kanchanapant, A. 2020. Grain-size distribution of surface sediments in the Chanthaburi Coast, Thailand and implications for the sedimentary dynamic environment. Journal of Marine Science and Engineering, 8(4): 242-258. https://doi.org/10.3390/jmse8040242.

Yurimoto, T., Kassim, F.M., Fuseya, R., and Man, A. 2014. Mass mortality event of the blood cockle, *Anadara granosa,* in aquaculture ground along Selangor coast, Peninsular Malaysia. International Aquatic Research, 6: 177–186. https://doi.org/10.1007/s40071-014-0077-3.

Yurimoto, T., Chaweepack, T., Matsuoka, K., and Sangrungruang, K. 2021. Histological observations of the blood cockle, *Tegillarca granosa* (L.), after a mass mortality event in Welu estuary, Thailand. Fisheries & Aquatic Life, 29: 230–238. https://doi.org/10.2478/aopf-2021-0025.

Yurimoto, T., Kassim, F.M., and Rahim, M.A. 2024a. Mass mortality event of aquaculture oysters caused by high precipitation in Setiu Lagoon, Peninsular Malaysia, during the wet season. EQA-International Journal of Environmental Quality, 63: 1–11. https://doi.org/ 10.6092/issn.2281-4485/19760.

Yurimoto, T., Kassim, F.M., Man, A., and Rahim, M.A. 2024b. Reproduction status of the angelwing clam, *Pholas orientalis* (Gmelin, 1791), obtained from Selangor, Malaysia. EQA-International Journal of Environmental Quality, 59: 33–41. https://doi.org/10.6092/issn.2281-4485/18021.