JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(1), 19–27
https://doi.org/10.12911/22998993/156003
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.09.29
Accepted: 2022.11.09
Published: 2022.12.01

Interrelationship and Determining Factors of Water Quality Dynamics in Whiteleg Shrimp Ponds in Tropical Eco-Green Aquaculture System

Muhammad Musa[1,2*], Mohammad Mahmudi[1,2], Sulastri Arsad[1,2,3], Evellin Dewi Lusiana[1,2,4], Sunadji[5], Wisnu Angga Wardana[1], Magdalena Florensia Ompusunggu[1], Dhea Novita Damayanti[1]

[1] Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Veteran street, Malang 65145, Indonesia

[2] AquaRES Research Group, Faculty of Fisheries and Marine Science, Universitas Brawijaya. Veteran street, Malang 65145, Indonesia

[3] Institute of Marine and Environmental Sciences, University of Szczecin, Mickiewicza 16a, 70-383 Szczecin, Poland

[4] Department of Mathematics, Faculty of Mathematics and Natural Science, Veteran street, Malang 65145, Indonesia

[5] Faculty of Animal Husbandry, Marine and Fisheries, Universitas Nusa Cendana, Kupang, 85001, Indonesia

* Corresponding author's e-mail: musa_fpi@ub.ac.id

ABSTRACT

Whiteleg shrimp (*Litopenaeus vannamei*) farming is a major activity in the coastal areas of many tropical countries. To meet the demand in this market, the culture system has expanded using intensive technology, which has resulted in the emission of effluents that threaten the surrounding aquatic ecosystem. Therefore, proper aquaculture management is needed to ensure both economic and ecological benefits. This led to the emergence of eco-green aquaculture. Water quality monitoring is a critical part of aquaculture management and when performed regularly, it yields a large and complex dataset. In this study, the authors aimed to analyse the dynamics of water quality characteristics and the relationships between these variables in whiteleg shrimp ponds in a tropical eco-green aquaculture system from 2020 to 2022. Since the data includes nine parameters and is quite complex, the principal component analysis (PCA) approach was used. This method enables to identify the factors that determine water quality, which will help ensure effective and efficient aquaculture management. Consequently, the water quality variables in the studied area were reduced to five dimensions and salinity, ammonia, and pH were found to be the key factors responsible for the changes in water quality characteristics. Hence, these variables should be the focus of farming management systems.

Keywords: aquaculture wastewater; intensive system; *Litopenaeus vannamei*; mangrove; PCA.

INTRODUCTION

Whiteleg shrimp (*Litopenaeus vannamei*) farming is a major activity in the coastal areas of many tropical countries [Bush et al., 2010]. Since the market demand for whiteleg shrimp is tremendous, intensification of this commodity culture system is unavoidable [Emerenciano et al., 2022]. This process generates organic waste, which is made up of feed byproducts and large amounts of shrimp excrement [Nirmal et al., 2020]. In intensive aquaculture systems, the high density of stocking has an impact on the waste load, which may affect the viability of the shrimp habitat as well as the aquatic resources near the aquaculture pond [Suwoyo et al., 2015; Musa et al., 2020]. These contaminants can lead to eutrophication and lower dissolved oxygen levels, as well as encourage the spread of a variety of pathogens [Peng et al., 2009]. While cultivation technologies aim to boost the output and quality of products, they should also be able to mitigate any unfavourable environmental and social consequences [Rurangwa et al., 2017].

Proper farm management and technology enhance the economic growth of the surrounding communities by creating jobs in the related fisheries industry [Asche, 2011]. In recent years, the concept of eco-green aquaculture has gained popularity [De-León-Herrera et al., 2015; Musa et al., 2019]. It refers to a technology used for developing traditional aquaculture towards intensive ponds by applying the silvofishery model. It originated as a hybrid system that integrated aquaculture ponds and mangrove ecosystems in coastal areas [Musa et al., 2020]. This approach, which is a combination of conservation and utilisation, makes it possible to preserve mangroves; this is important because, ecologically, they have relatively high productivity [Mahmudi et al., 2021]. Moreover, they function as traps and effective waste phytoremediators, as well as control the blooming of blue-green algae species. Therefore, the implementation of eco-green aquaculture appears promising in the coastal areas that have experienced degradation due to anthropogenic activities, such as industrial or domestic pollution and coastal development [Mahmudi et al., 2022].

Controlling the water quality of ponds is necessary to ensure shrimp production and farm profitability, especially in intensive culture systems. To achieve such control, water quality parameters must be monitored on a regular basis [Adnan et al., 2014; Orozco-Lugo et al., 2022]. This is because shrimp growth and survival rates are highly associated with the physicochemical and biochemical parameters of the water [Carbajal and Sánchez, 2008]. Given the numerous and complex changes in water quality, which are frequently difficult to interpret, monitoring initiatives and efficient estimation of water quality are crucial in culture management; they allow a comprehensive understanding of the extent of contamination in order to limit its impact [Ferreira et al., 2011].

This study aimed to assess the interactions and major factors that influence the changes in the water quality parameters in an eco-green aquaculture system implemented for conducting whiteleg shrimp farming. Typically, long-term monitoring is needed to detect changes in water quality [McQuatters-Gollop et al., 2009]. This process yields a vast and complex database. Various multivariate statistical methods, such as principal component analysis (PCA), can aid in understanding the complicated data matrix in order to perform a comprehensive analysis of the water quality; this also enables the identification of the potential components that influence the water system the most [Lusiana et al., 2022]. This is crucial for carrying out efficient and effective shrimp farming management in order to achieve sustainable fisheries aquaculture.

METHODS AND MATERIALS

Study area

The study area included the whiteleg shrimp ponds at the Brackish and Marine Water Laboratory at Brawijaya University. This facility is situated in Probolinggo Regency's coastal region and is encircled by mangrove vegetation (Figure 1). The study was conducted from 2020 to 2022.

According to Figure 1b, sampling was performed at four different locations. While Site 1 is a river-to-mangrove water inlet, Site 2 is a mangrove-to-pond water inlet. Site 3 includes water outlets from the pond to the mangrove, which contain waste materials. Site 4 is a mangrove-to-river water outlet.

Measurement of water quality parameters

Numerous water quality characteristics at the study sites were measured by analysing the water samples. A Lutron PDO-520 DO meter was used to monitor temperature (°C), dissolved oxygen (DO; mg/L), and pH. A secchi disc and refractometer were used to test transparency (m) and salinity (‰). Additionally, the levels of nitrate (mg/L), nitrite (mg/L), and ammonia (mg/L) were measured using test kits. Finally, ex-situ colourimetric and titrimetric analyses were performed on orthophosphates (mg/L) and total organic matter (TOM; mg/L).

Data analysis

Pearson correlation analysis

Pearson correlation analysis is a method that can be used to measure the closeness of the

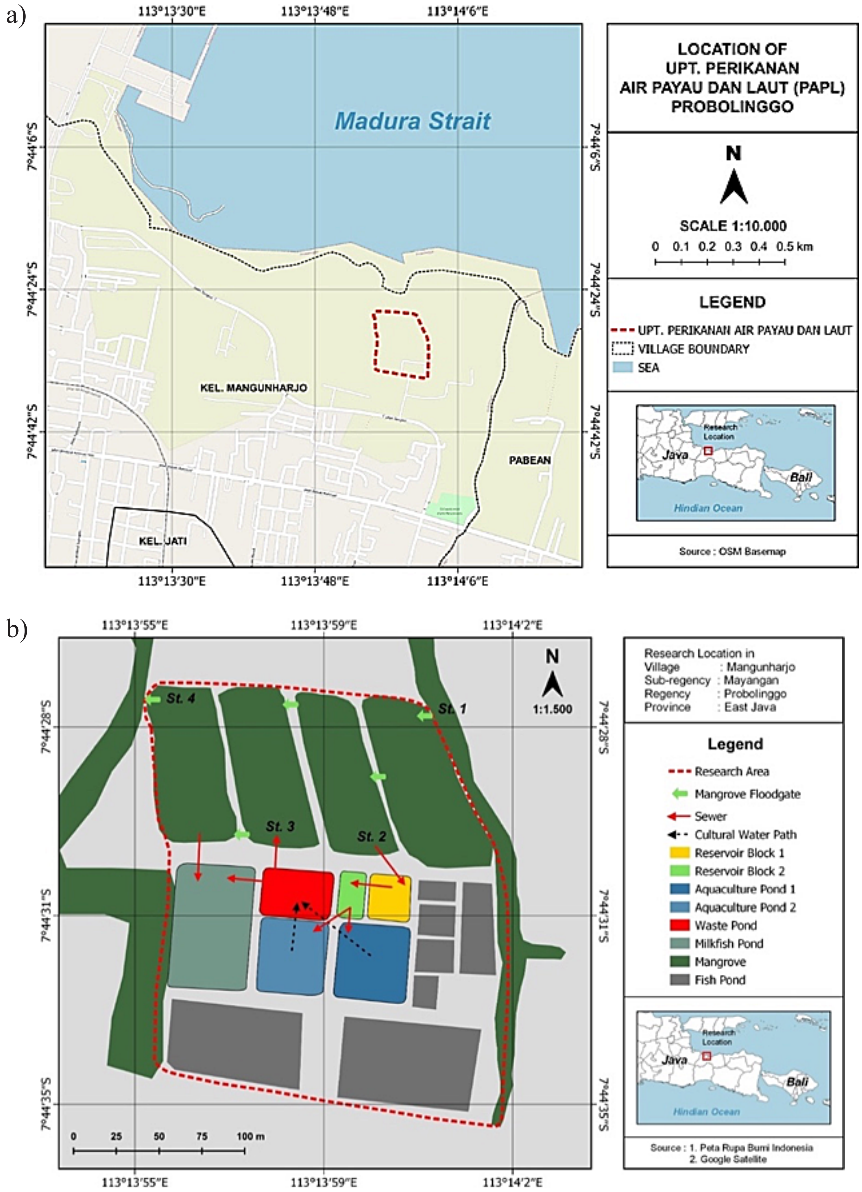

Figure 1. Study area at Brawijaya University's Brackish and Marine Water Laboratory (a) research location; (b) sampling sites

relationship or interaction between two quantitative variables. This method measures the strength of the association and the direction of the relationship between variables and is expressed as a numerical measure known as the Pearson correlation coefficient. If the coefficient is close to -1 or +1, it indicates a strong relationship between variables. If it is close to 0, it indicates there is no relationship between the variables. The significance of the results can be evaluated by using the t-test [Lusiana and Mahmudi, 2020].

Principal component analysis

Principal component analysis (PCA) is a technique used to simplify data by reducing the number of dimensions of the dataset while maintaining as much variation in the data as possible. Therefore, the characteristics of the data are not significantly altered. This method changes those variables that are originally correlated to a new set of variables that are smaller and independent, meaning that they are no longer correlated [Jolliffe and Cadima, 2016]. The principal components (PCs) generated through this process can contribute to explaining the variation in the data with a large percentage of ordered data. For instance, the percentage of variation that can be explained by PC1 is greater than that of PC2, and so on. Thus, PCA dimension reduction is carried out by determining the number of PCs that can explain at least 80% of the total variability in the data [Rencher and Christensen, 2012]. In addition, the use of PCA is based on the fulfilment of the assumptions of sample adequacy using the KMO test and the homogeneity of the data using the Bartlett test. The variables that determine the variation of the data the most are identified based on the value of the loading factor [Jolliffe and Cadima, 2016].

RESULTS AND DISCUSSION

Water quality characteristics

The results of the nine types of water quality measurement are presented in Table 1 and then compared to the Indonesian national standard values for aquaculture practice. The majority of the water quality parameters satisfied the standard criteria, including temperature, DO, nitrate, orthophosphate, and TOM. However, the mean value of salinity was lower than the standard value, while that of ammonia was higher. Moreover, although the average values of pH and transparency lay within the standard range, their minimum values were below the lower threshold values.

Whiteleg shrimp is known for its tolerance to a broad range of environmental conditions, including low salinity [Esparza-Leal et al., 2010]. Previous research suggests that salinity as low as 1 ppt in whiteleg shrimp ponds has no significant impact on the feed conversion rate [Jaffer et al., 2020]. However, other studies show that a salinity value of 2 ppt can influence both their growth indicator and survival rate [Gao et al., 2016]. Meanwhile, a high level of ammonia in intensively cultured ponds could be the result of a higher feed rate, which causes a rapid buildup of sludge at the pond's bottom; this is waste material comprising of leftover food, excrement, rotting plankton, aerial particles, erosion soil, and microorganisms [Koyama et al., 2020].

The unfavourable pH values in aquaculture ponds result in a decline in the growth of cultured biota [Tumwesigye et al., 2022]. Lower pH values can limit the degradation of organic matter and allow it to accumulate in pond soil, leading to a high oxygen demand at the intersection of the bottom soil and pond water [Boyd, 2017; Hasibuan et al., 2021]. In the case of shrimp, it has been observed that the exposure to low pH values may result in a loss of weight in the carapace, a slight decrease in strontium concentration, and an increase in magnesium content while maintaining the calcium levels [Wickins, 1984]. Furthermore, low transparency of the cultured pond may affect the photosynthetic activities of autotrophic organisms, such as phytoplankton [Lusiana et al., 2019].

Correlation between water quality variables

The results of the Pearson correlation analysis, as shown in Table 2, suggest that pH is significantly correlated with transparency, DO, orthophosphate, and TOM. It is assumed that these factors can be regarded as the characteristics related to organic substances in aquaculture ponds. In recent years, shrimp farming has been intensified through high rates of stocking and technological advancements, such as high-protein feed. According to reports, although shrimp diets have 30–40% protein content, only 20–25% of this is used, leaving the remainder as sewage sludge. For every kg of shrimp fed, up to 50 g of ammonia nitrogen is generated [Iber and Kasan, 2021]. Moreover, the decomposition of organic materials in water consumes oxygen via the processes aided by aerobic or oxygen-requiring organisms, thus lowering the DO levels in ponds [Wu et al.,

Table 1. Results of water quality measurement

No	Variable	Min	Max	Mean	Std. Dev	Standard value
1	Temperature (°C)	28.5	35.3	30.77	1.61	28–32
2	Transparency (cm)	7	69	28.97	13.24	20–40
3	pH	4.37	9.46	6.60	1.57	6-9
4	DO (mg/L)	5	15.5	9.23	3.16	> 3
5	Nitrate (mg/L)	0.28	10	4.98	3.34	< 20
6	Ammonia (mg/L)	0.39	3	1.48	0.71	< 0.05
7	Salinity (ppt)	16.06	32	23.15	3.87	26–32
8	Orthophosphate (mg/L)	0.05	2.34	0.34	0.41	< 5
9	TOM (mg/L)	5.06	236.37	71.84	62.30	< 90

Table 2. Matrix of Pearson correlation coefficient and significance test for water quality variables

Parameter	Temp	Transparency	pH	DO	Nitrate	Ammonia	Salinity	Orthophosphate	TOM
Temp	1	-0.03	0.09	-0.18	-0.09	-0.26	0.21	-0.18	-0.24
Transparency	-0.03	1	-0.34*	-0.07	-0.04	-0.14	0.48*	0.08	0.23
pH	0.09	-0.34*	1	-0.53*	-0.06	-0.43*	-0.28	-0.35*	-0.70*
DO	-0.18	-0.07	-0.53*	1	-0.03	0.49*	-0.01	0.37*	0.43*
Nitrate	-0.09	-0.04	-0.06	-0.03	1	0.26	-0.29	-0.24	-0.1
Ammonia	-0.26	-0.14	-0.43*	0.49*	0.26	1	-0.25	0.25	0.28
Salinity	0.21	0.48*	-0.28	-0.01	-0.29	-0.25	1	0.14	0.27
Orthophosphate	-0.18	0.08	-0.35*	0.37*	-0.24	0.25	0.14	1	0.30
TOM	-0.24	0.23	-0.70*	0.43*	-0.1	0.28	0.27	0.3	1

Note: * – significant at 5% level.

2021]. A negative correlation was observed between pH and DO, most likely caused by nitrification [Murray et al., 1975].

Meanwhile, salinity was closely correlated with transparency. Since the study site is located in a coastal area, it is highly influenced by the dynamics of marine and freshwater ecosystems. Thus, the salinity fluctuates [Chand et al., 2015]. The salinity of the sea as well as the estuary causes suspended particles to accumulate or combine. The solid particles continue to sink and solve on the sea bottom as the accumulated load increases. This process improves the transparency of the water. Research has shown that these effects increase along with salinity [Czuba et al., 2011].

PCA results

The sample adequacy (KMO) test that was conducted prior to performing PCA indicated that the water quality of the eco-green aquaculture whiteleg shrimp pond was sufficient for the purposes of this study; the KMO coefficient was 0.70 or greater than 0.50 (). In addition, the results of Bartlett's data homogeneity test also supported PCA analysis ($p < 4.56E-09$). As shown in Figure 2, the results of the analysis suggested that the number of dimensions of water quality should be reduced to five PCs. This is because the first five dimensions or components contributed to 83.5% of the total variation.

According to Table 3, the first PC (PC1) represents pH and DO, as their loading factors in PC1 were the highest among other PCs. Further, PC2 indicates transparency, ammonia, and salinity, while PC3 characterises nitrate. In addition, temperature as well as orthophosphate and TOM, were represented by PC4 and PC5, respectively.

The contribution of each water quality factor to the overall variation in the dataset is depicted in Figure 3. It is evident that salinity, ammonia, and pH have the highest contributions. Therefore,

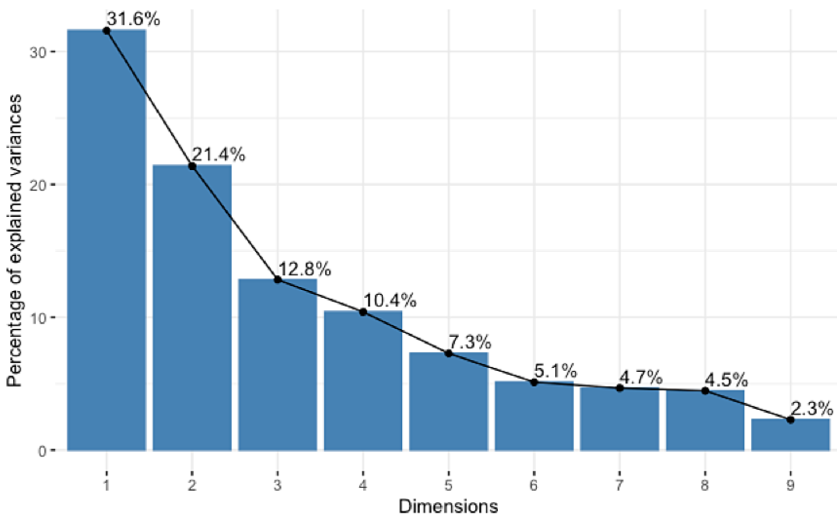

Figure 2. Scree plot of PCA

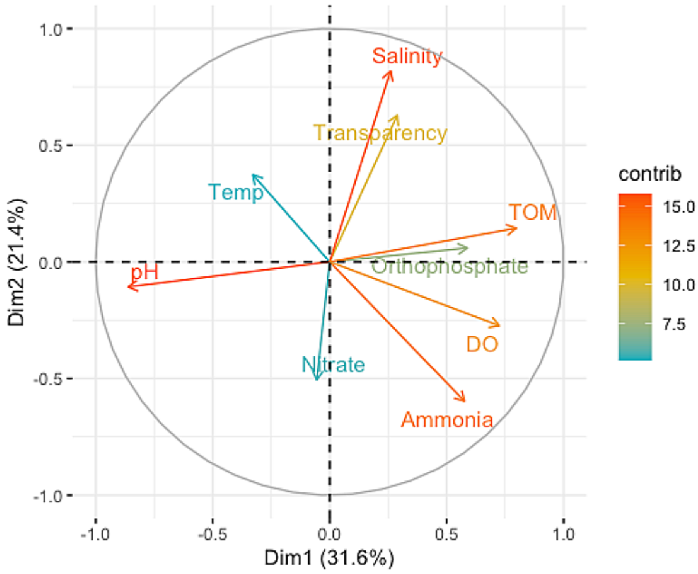

Figure 3. Biplot ordination of PCA

they can be regarded as the determinants of the changes in water quality dynamics in the whiteleg shrimp pond. Moreover, these variables are represented by the first two PCs in this study.

Numerous aquatic animals, including whiteleg shrimp, depend on salinity as one of the major environmental characteristics that affect their existence, growth, and dispersion [Kumlu et al., 2000]. This is because the whiteleg shrimp goes through various phases of living in the ocean as well as in estuaries as part of its natural life cycle [Walker et al., 2009]. Salinity variations are especially noticeable in tropical areas, where the climate consists of both dry and wet seasons [Chand et al., 2015]. However, in recent decades, climatic change has resulted in rising sea levels, a higher likelihood of coastal flooding, and tropical cyclones, all of which are responsible for salinity-mediated environmental stress in freshwater fisheries worldwide [Badjeck et al., 2010]. As one of the most dynamic and unique coastal habitats in the tropics, mangrove forests provide a variety of ecological services, including nutrients and shelter for aquatic organisms. A recent study by Ahmed et al. [2022] suggested that the high levels of nutrients and leaves provided by mangrove forests are likely to mitigate the effects of salinity.

The massive amount of feed consumed by shrimp in intensive cultivation systems is degraded, thus releasing harmful nitrogenous compounds into the culture water [Iber and Kasan, 2021]. Such materials cause a chain reaction, which produces the components that contribute to contamination and degradation of water quality. Ammonia, urea, and carbon dioxide are the most common metabolic waste materials found in shrimp aquaculture sewage [Patil et al., 2021].

According to previous reports, the levels of nitrogen ammonia increase directly with the length of the culture period and could potentially rise to 46 mg/L in intensive ponds [Lin and Chen, 2001]. It has been found that high levels of total ammonia in the water have a negative impact on the quality of the water, which in turn reduces the amount of shrimp that can be produced [Iber and Kasan, 2021]. These issues can be addressed by continuous water exchange. Besides the effort required for water exchange, how and where to dispose of old water may pose a challenge. As a result, lowering the ammonia concentration in sewage water before releasing it into the environment is a better way of dealing with contaminated water [Lyles et al., 2008]. A noticeable decrease in ammonia content was observed in the silvofishery aquaculture system [Musa et al., 2020]. However, although the existence of mangrove trees has been proven to enhance the quality of aquaculture effluents, the pollution index might still fall short of the ‘ideal’ category [Mahmudi et al., 2022].

Furthermore, the emergence of carbon dioxide as a shrimp culture sewage material has had an impact on pH regulation in water [Boyd, 2015]. Numerous biological and chemical processes occurring in the pond could cause shifts in the pH [Kathyayani et al., 2019]. For instance, plants take in carbon dioxide during the day for photosynthesis, while plants and animals let out carbon dioxide at night [Boyd, 2017]. Unsuitable pH values in aquaculture ponds may elevate ammonia toxicity, which causes aquatic species to experience stress. This could reduce their growth, increase their susceptibility to disease, and ultimately lead to their demise [Kathyayani et al., 2019].

CONCLUSIONS

The increasing intensification of whiteleg shrimp farming has raised the questions regarding the sustainability of this industry as well as associated environmental issues. In response to this, eco-green aquaculture has emerged as a system that integrates aquaculture and mangrove forests to preserve coastal ecosystems. Moreover, proper aquaculture management is critical to ensure the success of the fisheries culture industry, especially in terms of water quality monitoring and evaluation. To achieve this, complex data are required to detect changes in water quality characteristics in such whiteleg shrimp ponds. Furthermore, identifying the major factors that are responsible for the dynamics of water quality in aquaculture ponds is critical for effective and efficient farming management. Therefore, a multivariate approach, like PCA, is implemented. The result of this study revealed that salinity, ammonia, and pH are the key factors that determine water quality in the studied pond. Hence, these factors are suggested as the focal point in water quality management in whiteleg shrimp ponds that are a part of tropical eco-green aquaculture systems.

Acknowledgements

The research was funded by Hibah Professor Faculty of Fisheries and Marine Science, Universitas Brawijaya 2022 with contract number 13/UN10.F06/PP/2022.

REFERENCES

1. Adnan, K.N.A.K., Yusuf, N., Maamor, H.N., Rashid, F.N.A., Ismail, S.W.M., Thriumani, R., Zakaria, A., Kamarudin, L.M., Shakaff, A.Y.M., Jaafar, M.N., Ahmad, M.N. 2014. Water quality classification and monitoring using e-nose and e-tongue in aquaculture farming. In: 2014 2nd International Conference on Electronic Design (ICED), 343–346.
2. Ahmed, S., Sarker, S.K., Friess, D.A., Kamruzzaman, Md., Jacobs, M., Islam, M.A., Alam, Md.A., Suvo, M.J., Sani, Md.N.H., Dey, T., Naabeh, C.S.S., Pretzsch, H. 2022. Salinity reduces site quality and mangrove forest functions. From monitoring to understanding. Science of The Total Environment, 853, 158662.
3. Asche, F. 2011. Green Growth in Fisheries and Aquaculture Production and Trade.
4. Badjeck, M.-C., Allison, E.H., Halls, A.S., Dulvy, N.K. 2010. Impacts of climate variability and change on fishery-based livelihoods. Marine Policy, 34(3), 375–383.
5. Boyd, C.E. 2015. pH, Carbon Dioxide, and Alkalinity. In: Boyd, C.E. (Ed.), Water Quality: An Introduction. Springer International Publishing, Cham, 153–178.
6. Boyd, C.E. 2017. Chapter 6 - General Relationship Between Water Quality and Aquaculture Performance in Ponds. In: Jeney, G.B.T.-F.D. (Ed.), Academic Press, 147–166.
7. Bush, S.R., van Zwieten, P.A.M., Visser, L., van Dijk, H., Bosma, R., de Boer, W.F., Verdegem, M. 2010. Scenarios for Resilient Shrimp Aquaculture in Tropical Coastal Areas. Ecology and Society, 15(2).
8. Carbajal, J.J., Sánchez, L.P. 2008. Classification Based on Fuzzy Inference Systems for Artificial Habitat Quality in Shrimp Farming. In: 2008 Seventh Mexican International Conference on Artificial Intelligence, 388–392.
9. Chand, B.K., Trivedi, R.K., Dubey, S.K., Rout, S.K., Beg, M.M., Das, U.K. 2015. Effect of salinity on survival and growth of giant freshwater prawn Macrobrachium rosenbergii (de Man). Aquaculture Reports, 2, 26–33.
10. Czuba, J.A., Magirl, C.S., Czuba, C.R., Grossman, E.E., Curran, C.A., Gendaszek, A.S., Dinicola, R.D. 2011. Comparability of Suspended-Sediment Concentration and Total Suspended-Solids Data for Two Sites on the L'Anguille River, Arkansas, 2001 to 2003 Scientific Investigations Report 2005-5193.
11. De-León-Herrera, R., Flores-Verdugo, F., Flores-de-Santiago, F., González-Farías, F. 2015. Nutrient removal in a closed silvofishery system using three mangrove species (Avicennia germinans, Laguncularia racemosa, and Rhizophora mangle). Marine Pollution Bulletin, 91(1), 243–248.
12. Emerenciano, M.G.C., Rombenso, A.N., Vieira, F. d. N., Martins, M.A., Coman, G.J., Truong, H.H., Noble, T.H., Simon, C.J.y 2022. Intensification of Penaeid Shrimp Culture: An Applied Review of Advances in Production Systems, Nutrition and Breeding. Animals, 12(3).
13. Esparza-Leal, H.M., Ponce-Palafox, J.T., Aragón-Noriega, E.A., Arredondo-Figueroa, J.L., García-Ulloa Gómez, M., Valenzuela-Quiñonez, W. 2010. Growth and performance of the whiteleg shrimp Penaeus vannamei (Boone) cultured in low-salinity

water with different stocking densities and acclimation times. Aquaculture Research, 41(6), 878–883.

14. Ferreira, N.C., Bonetti, C., Seiffert, W.Q. 2011. Hydrological and Water Quality Indices as management tools in marine shrimp culture. Aquaculture, 318(3), 425–433.
15. Gao, W., Tian, L., Huang, T., Yao, M., Hu, W., Xu, Q. 2016. Effect of salinity on the growth performance, osmolarity and metabolism-related gene expression in white shrimp Litopenaeus vannamei. Aquaculture Reports, 4, 125–129.
16. Hasibuan, S., Syafriadiman, S., Aryani, N., Fadhli, M., Hasibuan, M. 2021. The age and quality of pond bottom soil affect water quality and production of Pangasius hypophthalmus in the tropical environment. Aquaculture and Fisheries.
17. Iber, B.T., Kasan, N.A. 2021. Recent advances in Shrimp aquaculture wastewater management. Heliyon, 7(11), e08283.
18. Jaffer, Y.D., Saraswathy, R., Ishfaq, M., Antony, J., Bundela, D.S., Sharma, P.C. 2020. Effect of low salinity on the growth and survival of juvenile pacific white shrimp, Penaeus vannamei: A revival. Aquaculture, 515, 734561.
19. Jolliffe, I.T., Cadima, J. 2016. Principal component analysis: a review and recent developments. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences, 374(2065), 20150202.
20. Kathyayani, S.A., Poornima, M., Sukumaran, S., Nagavel, A., Muralidhar, M. 2019. Effect of ammonia stress on immune variables of Pacific white shrimp Penaeus vannamei under varying levels of pH and susceptibility to white spot syndrome virus. Ecotoxicology and Environmental Safety, 184, 109626.
21. Koyama, M., Nagao, N., Syukri, F., Rahim, A.A., Toda, T., Tran, Q.N.M., Nakasaki, K. 2020. Ammonia recovery and microbial community succession during thermophilic composting of shrimp pond sludge at different sludge properties. Journal of Cleaner Production, 251, 119718.
22. Kumlu, M., Eroldogan, O.T., Aktas, M. 2000. Effects of temperature and salinity on larval growth, survival and development of Penaeus semisulcatus. Aquaculture, 188(1), 167–173.
23. Lin, Y.C., Chen, J.C. 2001. Acute toxicity of ammonia on Litopenaeus vannamei Boone juveniles at different salinity levels. Journal of Experimental Marine Biology and Ecology, 259(1), 109–119.
24. Lusiana, E., Mahmudi, M., Hutahaean, S., Darmawan, A., Buwono, N., Arsad, S., Musa, M. 2022. A Multivariate Technique to Develop Hybrid Water Quality Index of the Bengawan Solo River, Indonesia. Journal of Ecological Engineering, 23(2), 123–131.
25. Lusiana, E.D., Mahmudi, M. 2020. Teori dan Praktik Analisis Data Univariat dengan PAST. UB Press, Malang.
26. Lusiana, E.D., Musa, M., Ramadhan, S. 2019. The estimation of nutrient limit for predicting eutrophication using quantile regression model (case study: Aquaculture pond at IBAT Punten, Batu). In: IOP Conference Series: Earth and Environmental Science.
27. Lyles, C., Boopathy, R., Fontenot, Q., Kilgen, M. 2008. Biological Treatment of Shrimp Aquaculture Wastewater Using a Sequencing Batch Reactor. Applied Biochemistry and Biotechnology, 151(2), 474.
28. Mahmudi, M., Musa, M., Arsad, S., Lusiana, E.D., Bunga, A., Wati, N.A. 2021. Use of Phytoplankton to Assess Water Quality of Eco-Aquaculture System in Super-Intensive Whiteleg Shrimp (Litopenaeus vannamei) Pond. Advances in Animal and Veterinary Sciences, 10(5), 971–979.
29. Mahmudi, M., Musa, M., Bunga, A., Wati, N.A., Arsad, S., Lusiana, E.D. 2022. A Water Quality Evaluation of Integrated Mangrove Aquaculture System for Water Treatment in Super-Intensive White Leg Shrimp Pond. Journal of Ecological Engineering, 23(4), 287–296.
30. McQuatters-Gollop, A., Gilbert, A.J., Mee, L.D., Vermaat, J.E., Artioli, Y., Humborg, C., Wulff, F. 2009. How well do ecosystem indicators communicate the effects of anthropogenic eutrophication? Estuarine, Coastal and Shelf Science, 82(4), 583–596.
31. Murray, I., Parsons, J.W., Robinson, K. 1975. Inter-relationships between nitrogen balance, pH and dissolved oxygen in an oxidation ditch treating farm animal waste. Water Research, 9(1), 25–30.
32. Musa, M., Lusiana, E.D., Buwono, N.R., Arsad, S., Mahmudi, M. 2020. The effectiveness of silvofishery system in water treatment in intensive whiteleg shrimp (Litopenaeus vannamei) ponds, probolinggo district, East Java, Indonesia. Biodiversitas, 21(10), 4695–4701.
33. Musa, M., Mahmudi, M., Arsad, S., Buwono, N.R. 2019. Feasibility study and potential of pond as silvofishery in coastal area: Local case study in Situbondo Indonesia. Regional Studies in Marine Science, 100971.
34. Nirmal, N.P., Santivarangkna, C., Rajput, M.S., Benjakul, S. 2020. Trends in shrimp processing waste utilization: An industrial prospective. Trends in Food Science & Technology, 103, 20–35.
35. Orozco-Lugo, A.G., McLernon, D.C., Lara, M., Zaidi, S.A.R., González, B.J., Illescas, O., Pérez-Macías, C.I., Nájera-Bello, V., Balderas, J.A., Pizano-Escalante, J.L., Perera, C.M., Rodríguez-Vázquez, R. 2022. Monitoring of water quality in a shrimp farm using a FANET. Internet of Things, 18, 100170.
36. Patil, P.K., Antony, L., Avunje, S., Viswanathan, B., Lalitha, N., Jangam, A.K., Kumar, D., Solanki,

H.G., Reddy, M.A., Alavandi, S.V., Vijayan, K.K. 2021. Bioaugmentation with nitrifying and denitrifying microbial consortia for mitigation of nitrogenous metabolites in shrimp ponds. Aquaculture, 541, 736819.

37. Peng, Yisheng, Li, X., Wu, K., Peng, Yougui, Chen, G. 2009. Effect of an integrated mangrove-aquaculture system on aquacultural health. Frontiers of Biology in China, 4(4), 579.
38. Rencher, A.C., Christensen, W.F. 2012. Methods of multivariate analysis. Wiley, New Jersey.
39. Rurangwa, E., Baumgartner, U., Nguyen, H.M., van de Vis, J.W. 2017. Aquaculture Innovation in Vietnam. Journal of Environmental Science and Engineering B, 6(4), 236–241.
40. Suwoyo, H.S., Nirmala, K., Djokosetiyanto, Mulyaningrum, S.R.H. 2015. Faktor Dominan yang Berpengaruh Pada TIingkat Konsumsi Oksigen Sedimen Di Tambak Intensif Udang Vaname(Litopenaeus vannamei). Jurnal Ilmu dan Teknologi Kelautan Tropis, 7(2), 639–654.
41. Tumwesigye, Z., Tumwesigye, W., Opio, F., Kemigabo, C., Mujuni, B. 2022. The Effect of Water Quality on Aquaculture Productivity in Ibanda District, Uganda. Aquaculture Journal, 2(1), 23–36.
42. Walker, S.J., Neill, W.H., Lawrence, A.L., Gatlin, D.M. 2009. Effect of salinity and body weight on ecophysiological performance of the Pacific white shrimp (Litopenaeus vannamei). Journal of Experimental Marine Biology and Ecology, 380(1), 119–124.
43. Wickins, J.F. 1984. The effect of reduced pH on carapace calcium, strontium and magnesium levels in rapidly growing prawns (Penaeus monodon fabricius). Aquaculture, 41(1), 49–60.
44. Wu, J., Zhang, K., Cen, C., Wu, X., Mao, R., Zheng, Y. 2021. Role of bulk nanobubbles in removing organic pollutants in wastewater treatment. AMB Express, 11(1), 96.