EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(4), 323–333
https://doi.org/10.12912/27197050/201144
ISSN 2719–7050, License CC-BY 4.0

Received: 2024.01.27
Accepted: 2025.02.24
Published: 2025.03.01

The waste load and carrying capacity on intensive shrimp farming: A mini review

Heri Ariadi[1,2*], Muhammad Musa[3], Mohammad Mahmudi[3], Asus Maizar Suryanto Hertika[3]

[1] Doctoral Student at Faculty of Fisheries and Marine Sciences, University of Brawijaya, Malang, Indonesia
[2] Department of Aquaculture, Faculty of Fisheries, Pekalongan University, Pekalongan, Indonesia
[3] Department of Water Resources Management, Faculty of Fisheries and Marine Sciences, University of Brawijaya, Malang, Indonesia
* Corresponding author's e-mail: ariadi_heri@student.ub.ac.id

ABSTRACT

Intensive shrimp farming activities have had a massive impact on the increase in waste load in aquatic ecosystems. In this review, we attempt to summarize shrimp farming activities along with the waste pollution mechanisms generated from the operational cycle of intensive shrimp ponds to understand their effect on the pond's carrying capacity. The method used for this review is a literature review to gain an in-depth understanding of the research topic being studied. The intensification of shrimp farming, which began in the mid-2000s, has resulted in increased shrimp farming activities in coastal areas. The negative impact of intensive shrimp farming is a decline in environmental quality due to aquaculture waste pollution. The sources of shrimp farming waste include uneaten feed, feces, suspended materials, organic matter, ecdysis, and runoff waste. One of the consequences of waste pollution in shrimp farming is the increase in disease prevalence, a decline in the biophysical status of the farming land, and carrying capacity. The carrying capacity of the pond ecosystem will decrease due to the consumption of dissolved oxygen for waste decomposition. This condition will lead to hypoxia, which is dangerous for shrimp, and a decline in water quality in the pond. Therefore, proper waste management in shrimp farming, based on empirical research findings and providing practical solutions, is needed. This study provides important information regarding the carrying capacity of intensive shrimp pond ecosystems and potential management options for the future.

Keywords: ponds, pollutants, carrying capacity, land, environment.

INTRODUCTION

Shrimp farming is an agribusiness activity that plays a crucial role in maintaining the balance of global food availability (Pazmino et al., 2024). Shrimp farming activities are widely developed in tropical countries such as Indonesia, Thailand, Vietnam, Ecuador, Brazil, and the Philippines (Hong et al., 2020; Muthu et al., 2024). In Indonesia, shrimp farming has been practiced since the 1970s, with the main commodities being Penaeus monodon and *Litopenaeus vannamei* (Goss et al., 2000; Primavera, 2000). In 2023, shrimp production in Indonesia reached 1.079 million tons, representing an 18% increase from the previous period (IFA, 2024). The increase in shrimp production intensity in Indonesia is closely linked to the rising global demand for shrimp and the stable selling prices compared to other fishery commodities (Supono, 2021). Additionally, Indonesia's warm aquatic conditions are considered highly supportive of intensive shrimp farming (Asmild et al., 2024).

In Indonesia, shrimp farming not only impacts the economic income of communities but also results in various other consequences. Massive shrimp farming activities have had effects on labor absorption, foreign exchange earnings, food safety stability, and the creation of new job opportunities (Hukom et al., 2020; Delphino et al., 2022; Indrotristanto et al., 2023; Asmild et al., 2024). *Litopenaeus vannamei* is the most widely farmed shrimp species in Indonesia's aquatic areas (Ariadi et al., 2023). *L. vannamei* is a type of crustacean native to the western coastal waters of the Americas (Khanjani et al., 2023). *L. vannamei* was officially introduced to Indonesia in 2001 as a substitute for Penaeus monodon, which suffered from massive harvest failures (Ariadi et al., 2019). *L. vannamei* has several advantages over *P. monodon*, such as higher disease resistance, faster growth rates, better feed conversion rates, and the ability to adapt to fluctuating environmental conditions (Madusari et al., 2022; Yang et al., 2024; Huang and Li, 2024).

The progress of shrimp farming in Indonesia has continued to see an increase in farming activities. This condition is highly ideal when referring to the food security vision declared by the Government of the Republic of Indonesia in the agrocomplex sector (Kusumastanto et al., 1998). The increase in shrimp farming activities in Indonesia correlates positively with the rising pollution from aquaculture waste in coastal areas (Ariadi et al., 2019). One of the impacts of this waste pollution is the reduction in the carrying capacity of aquatic environments for shrimp farming (Gharibzadeh et al., 2023). Many areas that were initially suitable for farming have become polluted and no longer support shrimp farming (Mardiana et al., 2024). This is due to improper management practices in shrimp farming (Kaewtrakulchai et al, 2024). The lack of waste management facilities and operational activities outside the designated aquaculture zones significantly contributes to the high levels of water pollution and the decline in carrying capacity for shrimp farming (Mardiana et al., 2024).

The high intensity of shrimp farming activities and the waste load generated have prompted many stakeholders to consider appropriate solutions to address this issue (Linayati et al., 2024; Madusari et al., 2024). Some of the efforts that can be made include developing more sustainable farming systems and developing more suitable farming management models (Cruz-Suarez et al., 2010; Viera-Romero et al., 2024; Ghosh et al., 2024). These initiatives are intended to ensure the sustainable development of shrimp farming by farmers. In this review, we attempt to summarize shrimp farming activities along with the waste pollution mechanisms generated from the operational cycle of intensive shrimp ponds to understand their impact on the carrying capacity of the ponds. The results of this review are expected to provide important insights into the efforts that can be undertaken to minimize excessive waste accumulation in the ecosystem of intensive shrimp ponds.

This study is a review analysis of case studies on waste pollution from intensive shrimp farming in Indonesia. Based on the findings from these case studies, a qualitative descriptive analysis was conducted by comparing various related research findings from different locations.

SHRIMP FARMING AND WASTE LOAD

Shrimp farming is widely conducted in coastal areas with warm aquatic conditions (Delphino et al., 2022). The shrimp species commonly farmed are *L. vannamei* and *P. monodon*, with various farming models (Gusmawati et al., 2018; Sahabuddin et al., 2024). Generally, shrimp farming models are divided into three categories: traditional, semi-intensive, and intensive farming. The difference among these models lies in the use of technology and the stocking density of shrimp (Dorber et al., 2020; Dhar et al., 2020). Currently, supra-intensive shrimp farming models are also being developed (Taufiqurrohman et al., 2023).

Traditional farming is a method where shrimp are raised at low stocking densities without the use of supporting technology (Das et al., 2022). Traditional farming is often developed as a supplementary farming activity, such as intercropping or using biofilter ponds. Semi-intensive shrimp farming is a slightly more modern approach, with the application of some technology within the farming system (Ariadi et al., 2019). Intensive shrimp farming is the most modern model and is widely developed by shrimp farmers to achieve optimal production results in every operational cycle (Davis et al., 2021; Muthu et al., 2024).

The development of shrimp farming models is driven by innovations in technology and scientific advancements applied in aquaculture. *L. vannamei* and *P. monodon* are shrimp species highly sensitive to fluctuations in their habitat's environmental conditions (Gusmawati et al., 2018; Ariadi et al., 2023). These fluctuations in pond ecosystems are addressed through scientific methods to prevent disruption to the performance of farmed shrimp (Sun et al., 2023; Satanwat et al., 2023). In terms of farming techniques, shrimp can be farmed in various pond models, such as HDPE ponds, permanent ponds, circular ponds, earthen ponds, and floating net cages (Li et al., 2021; Wu et al., 2022; That and Hoang, 2024; Dong et al., 2024).

Intensive shrimp farming activities provide significant socio-economic benefits to coastal communities (Asmild et al., 2024; Wafi and Ariadi, 2024). However, the intensity of these activities also leads to an increase in the waste load generated, which needs to be properly managed (Satanwat et al., 2023). Shrimp farming waste can come from leftover feed, shrimp excretion, suspended particles, organic matter, molting shells, and other water runoff waste (Coward-Kelly et al., 2006; Dong et al., 2024). The main source of waste in shrimp pond ecosystems comes from uneaten feed (Madusari et al., 2022). Of the 100% of feed provided to shrimp, about 15% becomes waste (Primavera, 2020). Additionally, high inputs such as fertilizers, lime, probiotics, and other materials into the pond ecosystem significantly contribute to waste accumulation (Li and Boyd, 2016).

The shrimp farming system for *L. vannamei* in Indonesia, which predominantly uses intensive farming methods, requires high feed inputs (Ariadi et al., 2023). The intensive use of artificial feed has a major impact on the risk of ecosystem pollution due to the high nutrient content in the feed (Wang et al., 2023). Feed waste, which contains high levels of nutrients, impacts the release of nitrogen (N) elements into the pond water over time (Vinasyiam et al., 2023). High nitrogen levels released into the water also affect the nitrification cycle and the trophic status of the pond ecosystem, leading to plankton blooms (Yuan et al., 2021). Feed waste also contributes to the accumulation of organic material due to the release of dissolved compounds and suspended solids (Silva et al., 2010). The accumulation of waste that settles at the bottom of the pond can become toxic and pollute the environment if not managed properly (Chatvijitkul et al., 2017).

In addition to the waste from feeding activities, shrimp also produce waste in the form of metabolic byproducts, such as ammonium and phosphate, which, if in excess, can affect water quality dynamics in the pond (Ruangwicha et al., 2024). The high organic matter resulting from the accumulation of solid waste in the pond ecosystem also contributes to the depletion of dissolved oxygen and increases the risk of diseases due to hypoxic environmental conditions (Geng et al., 2022). Therefore, proper waste management is crucial as it directly impacts both shrimp health and the surrounding environmental conditions.

Managing shrimp farming waste presents an important challenge for modern shrimp farmers. Many techniques have been developed to address this issue, such as the use of biofiltration systems to reduce harmful substances in the water, environmentally friendly feed, waste treatment technologies that convert organic waste into fuel or fertilizers, and proper timing for farming seasons (Cahill et al., 2010; Akber et al., 2017; Widiasa et al., 2024). In addition to developing technical systems for shrimp waste management, holistic and sustainable waste management approaches are also being developed (Varga et al., 2016; Kamali et al., 2022). These holistic and sustainable waste management systems aim to develop concepts of resource conservation and environmental protection to ensure shrimp farming remains sustainable (Madusari et al., 2024). The integration of technical farming methods and resource conservation efforts will be key to developing a sustainable shrimp farming model in coastal ecosystems.

Once we understand effective shrimp farming waste management techniques, it is expected that there will be a reduction in waste discharge in the surrounding aquatic environment, an increase in farming productivity, and support for the overall sustainability of the aquaculture industry (Wik et al., 2009). Waste management in shrimp farming is a global challenge that requires collaboration between science, technology, and policy to achieve sustainable goals in the future shrimp farming industry (Goss et al., 2000; Varga et al., 2016). This means that significant efforts and a comprehensive problem-solving approach are needed to provide concrete solutions related to shrimp farming waste management.

POLLUTANT WASTE IN SHRIMP POND ECOSYSTEM

Pollution in shrimp farming ecosystems is a major issue that leads to a decrease in farming productivity. Pollution in the pond ecosystem causes fluctuations in water quality parameters (Qiu et al., 2024). Shrimp living in the pond will experience stress (Shirly-Lim et al., 2024). These fluctuations in water quality are caused by anomalies in certain parameters that lead to causal relationships with other water quality parameters (Li et al., 2021). Pollution in shrimp ponds is a complex phenomenon involving various mechanisms and factors that potentially disrupt environmental balance. In the context of shrimp farming, there are several key mechanisms causing ecosystem pollution, both directly and indirectly (Samsuri et al., 2024). The impacts of waste pollution mechanisms are very complex.

The primary cause of pollution in shrimp pond ecosystems is excess feed waste, suspended particles from plankton lysis, shrimp excrement, byproducts from farming practices, and organic matter aggregation (Li et al., 2021; Khanthong et al., 2021). Leftover feed and shrimp excrement, which are rich in nitrogen, will increase the accumulation of NH_4^+ compounds and Total Ammonia Nitrogen (TAN) in the water. These compounds will decompose through the nitrification cycle into nitrite (NO_2^-) and then nitrate (NO_3^-) (Widiasa et al., 2024). This nitrogen assimilation process triggers ecosystem eutrophication in the pond and threatens plankton *blooming* in suitable conditions (Ariadi et al., 2019) (Figure 1).

The first mechanism is the intensive use of commercial feed during the shrimp farming cycle. The intensive use of feed in farming practices is one of the main mechanisms of environmental pollution in shrimp pond ecosystems (Madusari et al., 2022). Feed waste pollution is the primary source of environmental pollution in shrimp ponds (Kamal et al., 2022). In addition to the pollution caused by toxic compounds due to abnormal environmental conditions, pollution in the pond ecosystem is also caused by the accumulation of organic matter (Aschenbroich et al, 2015). High organic matter causes turbidity and increased oxygen consumption by detritus during decomposition (Martinez-Durazo et al., 2019). Moreover, improperly managed organic waste can trigger the growth of anaerobic bacteria at the pond's bottom (Ariadi et al., 2019; Martinez-Durazo et al., 2019; Li et al., 2021).

The second mechanism involves the accumulation of dissolved particle waste that causes environmental conditions changes in the pond ecosystem. Dissolved particle waste from byproducts of farming materials and shrimp excretion leads to nutrient enrichment and water quality degradation in the pond (Li et al., 2021; Kaewtrakulchai et al., 2024). Additionally, dissolved particle waste residues that accumulate in water and soil around the pond are considered to pollute the water and even affect the sanitation of the surrounding environment (Sabu et al., 2022).

Another factor to consider is the management of solid waste in ponds. Solid waste consists of sediment and other organic materials at the bottom of the pond (Khanthong et al., 2021). If this solid waste is not regularly removed, it can produce toxic gases, such as hydrogen sulfide (H_2S), which can poison shrimp or disrupt the pond ecosystem (Iber and Kasan, 2021). To ensure the sustainability of shrimp farming, it is crucial to apply environmentally friendly farming practices (Ariadi et al., 2023). These practices include using technology to improve pond water management, reducing the use of harmful chemicals, implementing efficient waste management, and educating farmers about the importance of maintaining long-term ecosystem balance in the ponds (Liu et al., 2021).

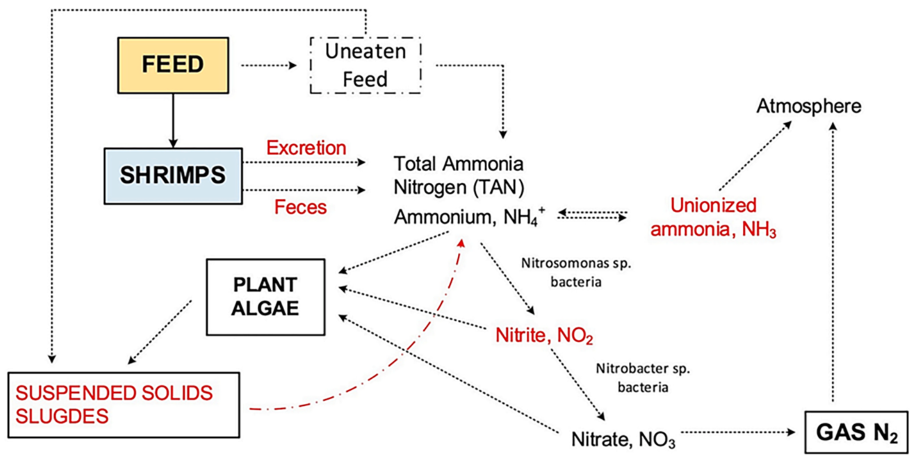

Figure 1. The dynamic of waste and nutrients in the intensive shrimp pond, modified from Widiasa et al., 2024

Waste pollution in shrimp pond ecosystems is caused by the accumulation of feed waste and other organic materials at the bottom of the pond waters (Dong et al., 2024). In intensive shrimp farming, the use of commercial feed plays a crucial role in supporting optimal shrimp growth (Yuan et al., 2021). However, the intensive use of commercial feed poses a risk of pollution to the shrimp farming ecosystem (Primavera, 2000). Feed waste includes uneaten feed remnants and dissolved substances such as phosphorus and nitrogen (Zhou et al., 2021; Su et al., 2023). The increased concentration of these nutrients can trigger excessive algal growth, leading to eutrophication and disrupting the local ecosystem (Mata et al., 2010; Soeprapto et al., 2023). Excessive plankton growth can reduce oxygen levels in the water at night, potentially causing stress to shrimp and resulting in mass mortality (Ariadi et al., 2023; Kamali et al., 2022; Gharibzadeh et al., 2023).

Feed waste contaminating pond water can also pose problems for soil quality around the pond (Rahman et al., 2013). Increased nutrient levels in the water can lead to the movement of excess nutrients into the soil, which may reduce soil fertility or even contaminate groundwater in the surrounding area (Ariadi et al., 2019; Li et al., 2021). Another impact of shrimp pond ecosystem pollution due to aquaculture waste is the potential spread of diseases (Linayati et al., 2024). Decomposing aquaculture waste at the pond bottom can become a breeding ground for bacteria and other pathogens that threaten shrimp health (Ariadi et al., 2019). Such conditions can lead to decreased harvest production and lower shrimp quality.

The solution for this issue, an integrated approach involving shrimp farmers, scientific research, and policy implementation needs to be adopted. Using properly digestible feed, closely monitoring the amount of feed given, and implementing technologies to reduce feed waste can be effective initial steps (Cahill et al., 2010; Hukom et al., 2020). Additionally, educating and training shrimp farmers on environmentally friendly and sustainable farming practices is essential for maintaining the sustainability of shrimp pond ecosystems (Jiménez-Montealegre et al., 2002). Through proactive measures like these, shrimp pond pollution caused by feed waste can be better managed, ultimately supporting the sustainability of the shrimp farming industry and preserving the balance of aquatic environments (Dong et al., 2024).

The high intensity of waste discharge from shrimp farming activities in pond ecosystems can be very dangerous if not properly managed. One of the risks is the reduction in the pond's carrying capacity to accommodate waste from farming activities. Carrying capacity refers to the maximum environmental capacity of a pond ecosystem to support a healthy and productive shrimp population (Mardiana et al., 2023). Carrying capacity is a key concept for maintaining the balance of the pond ecosystem and for developing sustainable aquaculture management practices (Ariadi et al., 2022). In intensive shrimp farming areas, detailed environmental management and carrying capacity assessment are essential. This is necessary to provide scientific information on how well the farming area's environment can neutralize the waste load generated by intensive shrimp farming activities. Furthermore, carrying capacity assessment is also an important way to determine whether the water area is still suitable for shrimp farming activities.

POND CARRYING CAPACITY

Carrying capacity refers to the maximum environmental capacity of a shrimp pond to support the shrimp population so that they can live healthily and productively (Mardiana et al., 2023). It is a crucial concept for maintaining the balance of pond ecosystems and developing sustainable aquaculture management strategies (Ariadi et al., 2022). The carrying capacity concept is designed to ensure that shrimp farming activities remain sustainable without causing adverse effects on the surrounding aquatic environment (Yang et al., 2017). The carrying capacity level varies across different ponds and aquaculture sites, depending on biophysical conditions and the surrounding environmental profile (Wafi et al., 2021; Ahmed et al., 2023).

The carrying capacity concept has been developed as an adaptive approach to shrimp farming patterns that can be integrated with the status of an aquaculture site (Ariadi et al., 2022; Mardiana et al., 2024). In the initial phase of cultivation, shrimp farmers carefully and thoroughly prepare the farming environment. During this phase, they measure water quality parameters, record temperature, salinity levels, and oxygen content (Ni et al., 2021; Colette et al., 2022). These steps are essential to ensure an optimal environment for shrimp growth (Ariadi et al., 2019). Once these conditions are met, farmers proceed with the stocking of shrimp post-larvae in alignment with the pond's carrying capacity.

Carrying capacity is influenced by various technical and non-technical factors throughout the operational cycle of shrimp farming, as illustrated in the causal loop diagram in Figure 2. During the shrimp farming cycle, farmers regularly monitor shrimp growth (Reis et al., 2022). They ensure that there are no signs of overpopulation, which could negatively impact water quality and shrimp health. This monitoring is conducted through responsible management practices, such as the appropriate use of feed and disease control, to maintain the pond environment in optimal condition (Madusari et al., 2024). During total harvest, farmers collect all remaining shrimp for analysis regarding harvest tonnage and feed consumption (Fonseca and Navedo, 2020). A well-planned harvesting process helps sustain the environment and ensures the availability of natural resources for the future (Lourenco et al., 2017). Experienced farmers recognize the importance of maintaining carrying capacity to keep the ponds productive over time by implementing partial harvesting, adding aerators, and determining appropriate shrimp stocking densities (Mardiana et al., 2023; Ariadi et al., 2023).

Additionally, natural factors such as climate change and pollution can affect the carrying capacity of an aquaculture site (Do and Ho, 2022). Therefore, continuous research and innovation in aquaculture technology are crucial to assist farmers in managing shrimp farming operations effectively. In shrimp farming, the application of proper and responsible farming practices significantly determines sustainability while preserving the aquatic ecosystem (Lien et al., 2023).

Based on this study, several findings have emerged. First, waste load in shrimp ponds

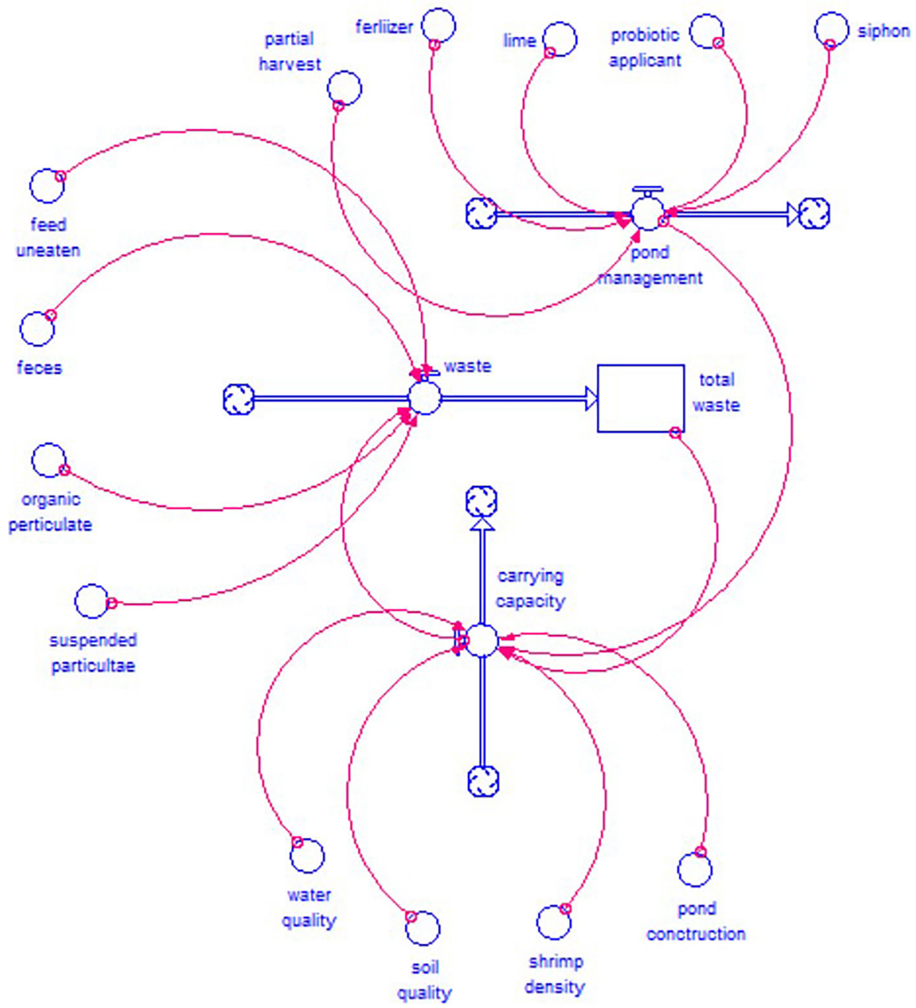

Figure 2. Causal loop model of carrying capacity effect correlation in intensive shrimp farming

continues to increase due to the diverse dynamics of operational activities. Pond management patterns significantly impact the level of waste pollution. Excessive waste loads lead to a decline in carrying capacity. In intensive shrimp ponds, carrying capacity is influenced not only by biotic and abiotic parameters but also by farm management practices. Currently, waste management methods in intensive shrimp farming remain limited and tend to be uniform across different farming locations.

Given these findings, there is a research gap that needs to be addressed to resolve waste pollution issues in intensive shrimp pond ecosystems. First, effective shrimp pond waste management solutions should be explored through more technical approaches. Second, an ideal standard for waste load carrying capacity should be developed to optimize shrimp farming operations. Third, studies on waste treatment using natural biofilters should be conducted as a cost-effective and mitigative approach to intensive shrimp pond waste management. Finally, an effective shrimp farming strategy should be developed, considering ecological status and surrounding environmental conditions.

CONCLUSIONS

Intensive shrimp farming activities contribute to environmental pollution due to the continuous accumulation of aquaculture waste. This condition leads to a decline in environmental quality and increases the intensity of disease outbreaks. One of the efforts to prevent excessive waste accumulation is to implement proper waste management strategies. This issue directly affects the carrying capacity of shrimp ponds in their operational activities. The high waste load in intensive shrimp farming requires a significant amount of dissolved oxygen for the decomposition process. The retention of dissolved oxygen influences the oxygen carrying capacity, which is essential for both shrimp respiration and the survival of aquatic microorganisms within the pond ecosystem. If this situation persists, it will negatively impact shrimp farming productivity, leading to a decline due to mass shrimp mortality caused by hypoxia and the degradation of the pond ecosystem.

REFERENCES

1. Ahmed, M.U., Alam, M.I., Debnath, S., Debrot, A.O., Rahman, M.M., Ahsan, M.N., Verdegem, M.C.J. (2023). The impact of mangroves in smallholder shrimp ponds in south-west Bangladesh on productivity and economic and environmental resilience. *Aquaculture 571,* 739464. https://doi.org/10.1016/j.aquaculture.2023.739464
2. Akber, M.A., Islam, M.A., Ahmed, M., Rahman, M.M., Rahman, M.R. (2017). Changes of shrimp farming in southwest coastal Bangladesh. *Aquaculture International,* 1–120. https://doi.org/10.1007/s10499-017-0159-5
3. Ariadi, H., Mahmudi, M., Fadjar, M. (2019). Correlation between density of vibrio bacteria with Oscillatoria sp. abundance on intensive *Litopenaeus vannamei* shrimp ponds. *Research Journal of Life Science, 6(2),* 114–129. https://doi.org/10.21776/ub.rjls.2019.006.02.5
4. Ariadi, H., Fadjar, M., Mahmudi, M. (2019). The relationships between water quality parameters and the growth rate of white shrimp (*Litopenaeus vannamei*) in intensive ponds. *Aquaculture, Aquarium, Conservation & Legislation, 12(6),* 2103–2116.
5. Ariadi, H., Khristanto, A., Soeprapto, H., Kumalasari, D., Sihombing, J.L. (2022). Plankton and its potential utilization for climate resilient fish culture. *AACL Bioflux, 15(4),* 2041–2051.
6. Ariadi, H., Mujtahidah, T., Wafi, A. (2023). Implications of good aquaculture practice (GAP) application on intensive shrimp ponds and the effect on water quality parameter compatibility. *Journal of Aquaculture & Fish Health, 12(2)*, 259–268. https://doi.org/10.20473/jafh.v12i2.32371
7. Ariadi, H., Azril, M., Mujtahidah, T. (2023). Water quality fluctuations in shrimp ponds during dry and rainy seasons. *Croatian Journal of Fisheries, 81(3)*, 127–137. https://doi.org/10.2478/cjf-2023-0014
8. Aschenbroich, A., Marchand, C., Molnar, N., Deborde, J., Hubas, C., Rybarczyk, H., Mezinae, T. (2015). Spatio-temporal variations in the composition of organic matter in surface sediments of a mangrove receiving shrimp farm effluents (New Caledonia). *Science of The Total Environment, 512–513*, 296–307. https://doi.org/10.1016/j.scitotenv.2014.12.082
9. Asmild, M., Hukom, V., Nielsen, R., Nielsen, M. (2024). Is economies of scale driving the development in shrimp farming from Penaeus monodon to *Litopenaeus vannamei*? The case of Indonesia. Aquaculture*, 579*, 740178. https://doi.org/10.1016/j.aquaculture.2023.740178
10. Cahill, P.L., Hurd, C.L., Lokman, M. (2010). Keeping the water clean – Seaweed biofiltration outperforms traditional bacterial biofilms in recirculating

aquaculture. *Aquaculture, 306*, 153–159. https://doi.org/10.1016/j.aquaculture.2010.05.032

11. Chatvijitkul, S., Boyd, C.E., Davis, D.A., McNevin, A.A. (2017). Pollution potential indicators for feed-based fish and shrimp culture. *Aquaculture, 477*, 43–49. https://doi.org/10.1016/j.aquaculture.2017.04.034
12. Colette, M., Guentas, L., Gunkel-Grillon, P., Callac, N., Patrona, L.D. (2022). Is halophyte species growing in the vicinity of the shrimp ponds a promising agri-aquaculture system for shrimp ponds remediation in New Caledonia? *Marine Pollution Bulletin 177,* 113563. https://doi.org/10.1016/j.marpolbul.2022.113563
13. Coward-Kelly, G., Agbogbo, F.K., Holtzapple, M.T. (2006). Lime treatment of shrimp head waste for the generation of highly digestible animal feed. *Bioresource Technology, 97(3)*, 1515–1520. https://doi.org/10.1016/j.biortech.2005.06.014
14. Cruz-Suarez, L.E., Leon, A., Pena-Rodriguez, A., Rodriguez-Pena, G., Moll, B., Ricque-Marie, D. (2010). Shrimp/Ulva co-culture: A sustainable alternative to diminish the need for artificial feed and improve shrimp quality. *Aquaculture, 301*, 64–68. https://doi.org/10.1016/j.aquaculture.2010.01.021
15. Das, S., Saha, P., Adhurya, S., Ray, A., Ray, S. (2022). Present and future scenarios of changing land use patterns from the perspective of agroecosystem under the shadow of ever-expanding shrimp culture. *Environmental Development, 44*, 100772. https://doi.org/10.1016/j.envdev.2022.100772
16. Davis, R., Abebe, A., Boyd, C.E., McNevin, A. (2021). Exploring the relationship between production intensity and land use: A meta-analytic approach with shrimp aquaculture. *Journal of Environmental Management, 300*, 113719. https://doi.org/10.1016/j.jenvman.2021.113719
17. Delphino, M.K.V.C., Laurin, E., Patanasatienkul, T., Rahardjo, R.B., Hakim, L., Zulfikar, W.G., Burnley, H., Hammell, K.L., Thakur, K. (2022). Description of biosecurity practices on shrimp farms in Java, Lampung, and Banyuwangi, Indonesia. *Aquaculture, 556*, 738277. https://doi.org/10.1016/j.aquaculture.2022.738277
18. Dhar, A.R., Uddin, M.T., Roy, M.K. (2020). Assessment of organic shrimp farming sustainability from economic and environmental viewpoints in Bangladesh. *Environmental Research, 180*, 108879. https://doi.org/10.1016/j.envres.2019.108879
19. Do, H.L., and Ho, T.Q. (2022). Climate change adaptation strategies and shrimp aquaculture: Empirical evidence from the Mekong Delta of Vietnam. *Ecological Economics 196,* 107411. https://doi.org/10.1016/j.ecolecon.2022.107411
20. Dong, S., Liu, X., Zhu, B., Liu, D., Shan, H., Wang, F. (2024). Bioremediation potential of the hard clam Mercenaria mercenaria as an intensive shrimp aquaculture pond polyculture condidate. *Water Research, 255*, 121552. https://doi.org/10.1016/j.watres.2024.121552
21. Dorber, M., Verones, F., Nakaoka, M., Sudo, K. (2020). Can we locate shrimp aquaculture areas from space? – A case study for Thailand. Remote Sensing Applications: *Society and Environment, 20*, 100416. https://doi.org/10.1016/j.rsase.2020.100416
22. Fonseca, J., and Navedo, J.G. (2020). Shorebird predation on benthic invertebrates after shrimp-pond harvesting: Implications for semi-intensive aquaculture management. *Journal of Environmental Management 262,* 110290. https://doi.org/10.1016/j.jenvman.2020.110290
23. Geng, X., Chen, Y., Chen, Z., Wei, X., Dai, Y., Yuan, Z. (2022). Oxygen-carrying biomimetic nanoplatform for sonodynamic killing of bacteria and treatment of infection diseases. *Ultrasonics Sonochemistry, 84*, 105972. https://doi.org/10.1016/j.ultsonch.2022.105972
24. Gharibzadeh, M., Osfouri, S., Jamekhorshid, A., Jafari, S.A. (2023). Microbial chitin extraction and characterization from green tiger shrimp waste: A comparative study of culture mediums along with bioprocess optimization. *International Journal of Biological Macromolecules, 242(4)*, 125213. https://doi.org/10.1016/j.ijbiomac.2023.125213
25. Ghosh, A.K., Hasanuzzaman, A.F.M., Sarower, M.G., Islam, M.R., Huq, K.A. (2024). Unveiling the biofloc culture potential: Harnessing immune functions for resilience of shrimp and resistance against AHPND-causing *Vibrio parahaemolyticus* infection. *Fish & Shellfish Immunology, 151*, 109710. https://doi.org/10.1016/j.fsi.2024.109710
26. Goss, J., Burch, D., Rickson, R.E. (2000). Agri-Food Restructuring and Third World Transnationals: Thailand, the CP Group and the Global Shrimp Industry. *World Development, 28(3)*, 513-530. https://doi.org/10.1016/S0305-750X(99)00140-0
27. Gusmawati, N., Soulard, B., Selmaoui-Folcher, N., Proisy, C., Mustafa, A., Le Gendre, R., Laugier, T., Lemonnier, H. (2018). Surveying shrimp aquaculture pond activity using multitemporal VHSR satellite images – case study from the Perancak estuary, Bali, Indonesia. *Marine Pollution Bulletin*, *131*, 49–60. https://doi.org/10.1016/j.marpolbul.2017.03.059
28. Hong, A.H., Hargan, K.E., Williams, B., Nuangsaeng, B., Siriwong, S., Tassawad, P., Chaiharn, C., Huertos, M.L. (2020). Examining molluscs as bioindicators of shrimp aquaculture effluent contamination in a southeast Asian mangrove. *Ecological Indicators, 115*, 106365. https://doi.org/10.1016/j.ecolind.2020.106365
29. Huang, H.H., and Li, C.Y. (2024). Adaptability of

commercial probiotics to biofloc system: Influences on autochthonal bacterial community, water quality and growth performance of shrimp (*Litopenaeus vannamei*). *Aquaculture, 590*, 740992. https://doi.org/10.1016/j.aquaculture.2024.740992

30. Hukom, V., Nielsen, R., Asmild, M., Nielsen, M. (2020). Do aquaculture farmers have an incentive to maintain good water quality? The case of small-scale shrimp farming in Indonesia. *Ecological Economics*, *176*, 106717. https://doi.org/10.1016/j.ecolecon.2020.106717
31. Iber, B.T., and Kasan, N.A. (2021). Recent advances in Shrimp aquaculture wastewater management. *Heliyon*, *7*, e08283. https://doi.org/10.1016/j.heliyon.2021.e08283
32. Indonesian Fisheries Association (IFA). (2024). Production and Economic Value of Shrimp in 2021–2023. Jakarta: Indonesian Fisheries Association.
33. Indrotristanto, N., Andarwulan, N., Dewanti-Hariyadi, R., Fardiaz, D. (2023). Estimating the rejection risk of Indonesian shrimp exports from Salmonella spp. contamination using the food safety objective approach. *Food Control, 153*, 109932. https://doi.org/10.1016/j.foodcont.2023.109932
34. Jimenez-Montealegre, R., Verdegem, M.C.J., van Dam, A., Verreth, J.A.J. (2002). Conceptualization and validation of a dynamic model for the simulation of nitrogen transformations and fluxes in fish ponds. *Ecological Modelling 147*, 123-152. https://doi.org/10.1016/S0304-3800(01)00403-3
35. Kaewtrakulchai, N., Samattakarn, N., Chanpee, S., Assawasaengrat, P., Manatura, K., Wongrerkdee, S., Eiad-Ua, A (2024). Solid shrimp waste derived nanoporous carbon as an alternative bio-sorbent for oxytetracycline removal from aquaculture wastewater. *Heliyon, 10*, e32427. https://doi.org/10.1016/j.heliyon.2024.e32427
36. Kamal, S.Z., Koyama, M., Syukri, F., Toda, T., Tran, Q.N.M., Nakasaki, K. (2022). Effect of enzymatic pre-treatment on thermophilic composting of shrimp pond sludge to improve ammonia recovery. *Environmental Research*, *204*, 112299. https://doi.org/10.1016/j.envres.2021.112299
37. Kamali, S., Ward, V.C.A., Ricardez-Sandoval, L. (2022). Dynamic modeling of recirculating aquaculture systems: Effect of management strategies and water quality parameters on fish performance. *Aquacultural Engineering*, *99*, 102294. https://doi.org/10.1016/j.aquaeng.2022.102294
38. Khanjani, M.H., da Silva, L.O.B., Foes, G.K., Vieira, F.N., Poli, M.A., Santos, M., Emerenciano, M.G.C. (2023). Synbiotics and aquamimicry as alternative microbial-based approaches in intensive shrimp farming and biofloc: Novel disruptive techniques or complementary management tools? A scientific-based overview. *Aquaculture, 567*, 739273. https://doi.org/10.1016/j.aquaculture.2023.739273
39. Khanthong, K., Purnomo, C.W., Daosud, W., Thai, Y.L.U. (2021). Microbial diversity of marine shrimp pond sediment and its variability due to the effect of immobilized media in biohydrogen and biohythane production. *Journal of Environmental Chemical Engineering, 9*, 106166. https://doi.org/10.1016/j.jece.2021.106166
40. Kusumastanto, T., Jolly, C.M., Bailey, C. (1998). A multiperiod programming evaluation of brackish-water shrimp aquaculture development in Indonesia 1989/1990–1998/1999. *Aquaculture, 159,* 317–331. https://doi.org/10.1016/S0044-8486(97)00191-9
41. Li, Y., and Boyd, C.E. (2016). Laboratory tests of bacterial amendments for accelerating oxidation rates of ammonia, nitrite and organic matter in aquaculture pond water. *Aquaculture, 460*, 45–58. https://doi.org/10.1016/j.aquaculture.2016.03.050
42. Li, T., Zhang, B., Zhu, C., Su, J., Li, J., Chen, S., Qin, J. (2021). Effects of an ex situ shrimp-rice aquaponic system on the water quality of aquaculture ponds in the Pearl River estuary, China. *Aquaculture, 545*, 737179. https://doi.org/10.1016/j.aquaculture.2021.737179
43. Lien, H.H., de Mey, Y., Meuwissen, M.P.M., Bush, S.R. (2023). Information practices for improved sustainability assurance in Vietnamese shrimp aquaculture. *Journal of Rural Studies 100,* 103015. https://doi.org/10.1016/j.jrurstud.2023.103015
44. Linayati., Nhi, N.H.Y., Ariadi, H., Mardiana, T.Y., Fahrurrozi, A., Syakirin, M.B. (2024). Relationship Between Abundance of *Clamydomonas* spp and *Chlorella* spp on Clinical Performance of Red Tilapia *Oreochromis niloticus* in Silvofishery Ponds. *Croatian Journal of Fisheries, 82(1),* 33-42. DOI: https://doi.org/10.2478/cjf-2024-0004
45. Liu, X., He, X., Huang, G., Zhou, Y., Lai, J. (2021). Bioremediation by the mullet *Mugil cephalus* feeding on organic deposits produced by intensive shrimp mariculture. *Aquaculture, 541*, 736674. https://doi.org/10.1016/j.aquaculture.2021.736674
46. Lourenco, P.M., Catry, T., Granadeiro, J.P. (2017). Diet and feeding ecology of the wintering shorebird assemblage in the Bijagós archipelago, Guinea-Bissau. *Journal of Sea Research 128,* 52–60. https://doi.org/10.1016/j.seares.2017.08.004
47. Madusari, B.D., Ariadi, H., Mardhiyana, D. (2022). Effect of the feeding rate practice on the white shrimp (*Litopenaeus vannamei*) cultivation activities. *AACL Bioflux, 15(1),* 473-479.
48. Madusari, B.D., Ariadi, H., Mardhiyana, D. (2024). Dynamic modelling analysis on the effectiveness of coastal land resources for aquaculture activities utilization. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan, 14(1)*, 174–180. https://doi.org/10.29244/jpsl.14.1.174

49. Mardiana, T.Y., Ariadi, H., Linayati., Wijianto., Fahrurrozi, A., Maghfiroh. (2023). Estimation of Water Carrying Capacity for Floating Net Cage Cultivation Activities in Pekalongan Coastal Waters. *Jurnal Perikanan Universitas Gadjah Mada, 25(1),* 19-24. https://doi.org/10.22146/jfs.80968
50. Mardiana, T.Y., Ariadi, H., Al Ramadhani, F.M., Syakirin, M.B., Linayati. (2024). Dynamic Modeling System of Cholorophyceae Abundance in Pen-Culture Ponds During the Dry Season. *Ecological Engineering & Environmental Technology, 25(8),* 47–56. https://doi.org/10.12912/27197050/189238
51. Mardiana, T.Y., Ariadi, H., Rattanavichai, W., Soedibya, P.H.T., Linayati. (2024). Feasibility Study Area and Dissolved Oxygen Carrying Capacity of Silvofishery Pond on the Coastal Area. ILMU KELAUTAN: *Indonesian Journal of Marine Sciences, 29(2),* 1–10. https://doi.org/10.14710/ik.ijms.29.2.201-210
52. Martinez-Durazo, A., Garcia-Hernandez, J., Paez-Osuna, F., Soto-Jimenez, M.F., Jara-Marini, M.E. (2019). The influence of anthropogenic organic matter and nutrient inputs on the food web structure in a coastal lagoon receiving agriculture and shrimp farming effluents. *Science of The Total Environment, 664*, 635-646. https://doi.org/10.1016/j.scitotenv.2019.01.343
53. Mata, T.M., Martins, A.A., Caetano, N.S. (2010). Microalgae for biodiesel production and other applications: A review. *Renewable and Sustainable Energy Reviews 14*, 217–232. https://doi.org/10.1016/j.rser.2009.07.020
54. Muthu, C.M.M., Vickram, A.S., Sowndharya, B.B., Saravanan, A., Kamalesh, R., Dinakarkumar, Y. (2024). A comprehensive review on the utilization of probiotics in aquaculture towards sustainable shrimp farming. *Fish & Shellfish Immunology, 147*, 109459. https://doi.org/10.1016/j.fsi.2024.109459
55. Ni, M., Yuan, J., Zhang, L., Hua, J., Rong, H., Gu, Z. (2021). In- situ and ex- situ purification effect of ecological ponds of *Euryale ferox* Salisb on shrimp aquaculture. *Aquaculture 540,* 736678. https://doi.org/10.1016/j.aquaculture.2021.736678
56. Pazmino, M.L., Chico-Santamarta, L., Boero, A., Ramirez, A.D. (2024). Environmental life cycle assessment and potential improvement measures in the shrimp and prawn aquaculture sector: A literature review. *Aquaculture and Fisheries,* 1–19. https://doi.org/10.1016/j.aaf.2024.06.003
57. Primavera, J.H. (2000). Development and conservation of Philippine mangroves: institutional issues. *Ecological Economics, 35(1)*, 91–106. https://doi.org/10.1016/S0921-8009(00)00170-1
58. Qiu, J., Zhang, C., Zhaojun., Zhang, Z., Chu, Y., Shang, D., Chen, Y., Chen, C. (2024). Analysis of changes in nutrient salts and other water quality indexes in the pond water for largemouth bass (*micropterus salmoides*) farming. Heliyon *10*, e24996. https://doi.org/10.1016/j.heliyon.2024.e24996
59. Reis, J., Peixoto, S., Soares, R., Rhodes, M., Ching, C., Davis, D.A. (2022). Passive acoustic monitoring as a tool to assess feed response and growth of shrimp in ponds and research systems. *Aquaculture 546,* 737326. https://doi.org/10.1016/j.aquaculture.2021.737326
60. Ruangwicha, J., Cheirsilp, B., Suyotha, W. (2024). Green biorefinery of shrimp shell waste for α-chitin and high-value co-products through successive fermentation by co-lactic acid bacteria and proteolytic fungus. *Bioresource Technology, 393*, 130106. https://doi.org/10.1016/j.biortech.2023.130106
61. Sabu, E.A., Gonsalves, M.J., Nazareth, D., Sreepada, R.A. (2022). Influence of environmental variables on methane related microbial activities in a tropical bio-secured zero-exchange shrimp culture system. *Aquaculture Reports, 22*, 100950. https://doi.org/10.1016/j.aqrep.2021.100950
62. Sahabuddin, S., Cahyadi, A., Nafisah, N., Suwoyo, H.S., Nawang, A., Septiningsih, E., Hendrajat, E.A., Taukhid, I., Sahrijanna, A., Rosmiati, R., Herlinah, H., Susianingsih, E. (2024). The utilization of brackish water-induced land through a rice-tiger shrimp coculture system. *Aquaculture Reports 34*, 101909. https://doi.org/10.1016/j.aqrep.2023.101909
63. Samsuri, E.R., Ganesan, P., Jauhari, I., Tan, G.Y.A., Hamad, F.A. (2024). Reusing biofloc-culture water and microbubble aeration for culturing the white-leg shrimp *Litopenaeus vannamei.* Aquaculture*, and Fisheries*, 1–9. https://doi.org/10.1016/j.aaf.2024.04.010
64. Satanwat, P., Tapaneeyaworawong, P., Boonprasertsakul, T., Maksee, A., Kotcharoen, W., Adlin, N., Watari, T., Yamaguchi, T., Pungrasmi, W., Powtongsook, S. (2023). Sustainable practice for a zero-discharge outdoor earthen shrimp pond based on biological nitrogen waste carrying capacity. Aquaculture*, 574*, 739734. https://doi.org/10.1016/j.aquaculture.2023.739734
65. Shirly-Lim, Y.L., Rahmah, S., Ghaffar, M.A., Liang, L.Q., Chang, Y.M., Chisti, Y., Lee, M.A., Liew, H.J. (2024). Pacific whiteleg shrimps compromize their physiological needs to cope with environmental stress. Environmental Advances*, 15*, 100492. https://doi.org/10.1016/j.envadv.2024.100492
66. Silva, C.A.R., Davalos, P.B., Sternberg, L.S.L., de Souza, F.E.S., Spyrides, M.H.C., Lucio, P.S. (2010). The influence of shrimp farms organic waste management on chemical water quality. Estuarine, Coastal and Shelf Science*, 90*, 55–60. https://doi.org/10.1016/j.ecss.2010.08.014
67. Soeprapto, H., Ariadi, H., Badrudin, U., Soedibya, P.H.T. (2023). The abundance of Microcystis sp.

on intensive shrimp ponds. *Depik Jurnal Ilmu-Ilmu Perairan Pesisir dan Perikanan 12(1)*, 105–110. https://doi.org/10.13170/depik.12.1.30433

68. Su, W., Xu, W., Polyakov, N.E., Dushkin, A.V., Qiao, P., Su, W. (2023). Zero-waste utilization and conversion of shrimp shell by mechanochemical method. *Journal of Cleaner Production 425,* 139028. https://doi.org/10.1016/j.jclepro.2023.139028
69. Sun, Y., Hou, H., Dong, D., Zhang, J., Yang, X., Li, X., Song, X. (2023). Comparative life cycle assessment of whiteleg shrimp (*Penaeus vannamei*) cultured in recirculating aquaculture systems (RAS), biofloc technology (BFT) and higher-place ponds (HPP) farming systems in China. Aquaculture*, 574*, 739625. https://doi.org/10.1016/j.aquaculture.2023.739625
70. Supono. (2021). Current status of technical and economic analysis of inland shrimp culture in Lampung Province, Indonesia. AACL Bioflux*, 14(1)*, 218–226.
71. Taufiqurrohman, A.H.A., Wibowo, D.E., Ariadi, H. (2023). Study of Fisheries Law For The Development of the Aquaculture Sector In Land Based Areas. DE LEGA LATA: *Jurnal Ilmu Hukum, 8 (2)*, 253–259. https://doi.org/10.30596/dll.v8i2.15158
72. That, L.T., and Hoang, H.Y. (2024). Utilizing a settling pond-based constructed wetland for the treatment of shrimp aquaculture wastewater – From laboratory to field scale: A case study in Ben Tre Province, Vietnam. *Ecological Engineering, 199*, 107172. https://doi.org/10.1016/j.ecoleng.2023.107172
73. Varga, M., Balogh, S., Wei, Y., Li, D., Csukas, B. (2016). Dynamic simulation based method for the reduction of complexity in design and control of Recirculating Aquaculture Systems. *Information Processing in Agriculture, 3(3)*, 146–156. https://doi.org/10.1016/j.inpa.2016.06.001
74. Viera-Romero, A.M., Diemont, S.A.W., Selfa, T.L., Luzadis, V.A. (2024). The sustainability of shrimp aquaculture: An emergy-based case study in the Gulf of Guayaquil thirty years later. *Renewable and Sustainable Energy Reviews, 194*, 114326. https://doi.org/10.1016/j.rser.2024.114326
75. Vinasyiam, A., Kokou, F., Ekasari, J., Schrama, J.W., Verdegem, M.C.J. (2023). Effects of high wheat bran input on the performance of a biofloc system for Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture Reports, 33*, 101853. https://doi.org/10.1016/j.aqrep.2023.101853
76. Wafi, A., and Ariadi, H. (2024). The dynamic model analysis of production feasibility and market valuation of intensive shrimp culture business. AACL Bioflux, *17(1)*, 173–179.
77. Wafi, A., Ariadi, H., Muqsith, A., Mahmudi, M., Fadjar, M. (2021). Oxygen consumption of Litopenaeus vannamei in intensive ponds based on the dynamic modeling system. *Journal of Aquaculture and Fish Health 10 (1),* 17–24. https://doi.org/10.20473/jafh.v10i1.18102
78. Wang, T., Tong, C., Wu, F., Jiang, S., Zhang, S. (2023). Distribution characteristics of microplastics and corresponding feeding habits of the dominant shrimps in the rivers of Chongming Island. *Science of The Total Environment, 888*, 164041. https://doi.org/10.1016/j.scitotenv.2023.164041
79. Widiasa, I.N., Susanto, H., Ting, Y.P., Suantika, G., Steven, S., Khoiruddin, K., Wenten, I.G. (2024). Membrane-based recirculating aquaculture system: Opportunities and challenges in shrimp farming. *Aquaculture, 579*, 740224. https://doi.org/10.1016/j.aquaculture.2023.740224
80. Wik, T.E.I., Linden, B.T., Wramner, P.I. (2009). Integrated dynamic aquaculture and wastewater treatment modelling for recirculating aquaculture systems. *Aquaculture, 287*, 361–370. https://doi.org/10.1016/j.aquaculture.2008.10.056
81. Wu, L., Yang, P., Luo, L., Zhu, W., Hong, Y., Tong, C., Penuelas, J. (2022). Conversion of mangrove forests to shrimp ponds in southeastern China destabilizes sediment microbial networks. *Geoderma*, *421*, 115907. https://doi.org/10.1016/j.geoderma.2022.115907
82. Yang, Z., You, W., Huang, Z., Zhang, Z., Wang, G. (2024). Exploiting hybrid vigor to enhance survival and growth for whiteleg shrimp (*Litopenaeus vannamei*): A complete diallel cross experiment. *Aquaculture and Fisheries*, 1–6. https://doi.org/10.1016/j.aaf.2024.04.004
83. Yuan, Y., Lawrence, A.L., Chehade, S.B., Jensen, K.E., Barry, R.J., Fowler, L.A., Makowsky, R., Powell, M.L., Watts, S.A. (2021). Feed intake as an estimation of attractability in Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture, 532*, 736041. https://doi.org/10.1016/j.aquaculture.2020.736041
84. Zhou, Y., Guo, N., Wang, Z., Zhao, T., Sun, J., Mao, X. (2021). Evaluation of a clean fermentation-organic acid method for processing shrimp waste from six major cultivated shrimp species in China. *Journal of Cleaner Production 294,* 126135. https://doi.org/10.1016/j.jclepro.2021.126135