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Policy Paper

Low Carbon Emission Shrimp Farming Development Model

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ABSTRACT

Shrimp is a vastly strategic aquaculture commodity in Indonesia, most of which is produced for the export market; hence, competitiveness is the main key in the industry. With the increasing productivity of a shrimp farming area, the regulation for establishing a shrimp culture area needs to be strictly managed, including reducing carbon emissions. The management of aquaculture areas needs to pay attention to the principle of sustainability and consider carbon dynamics. This paper contains a descriptive analysis of the literature related to the substance of the study. The carbon dynamics in aquaculture areas consist of potential sources of carbon emitted and potential sinks or carbon that can be absorbed and stored. By structuring the shrimp pond area, aquaculture engineering, the application of good aquaculture practices and use of alternative energy sources, during the shrimp farming process in ponds, the carbon emission can be minimized, and the carbon sink can be increased. Our recommendation suggests that analysis of land suitability, environmental carrying capacity and carbon dynamics in each shrimp pond area are exceptionally required to be conducted to assess land suitability as a low carbon emission shrimp farming area. Furthermore, to increase farmers' understanding and awareness of the sustainability of the practices, pilot areas for low-emission shrimp ponds need to be developed.

Keywords: Green Production; Mitigation; Greenhouse Gases

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1. Introduction

The development of aquaculture, including shrimp farming, is part of the national development of the marine and fisheries sector. Indonesia's long-term development goal stated in Law no. 17 of 2007 is to realize a beautiful and sustainable Indonesia. This is in line with the global development goals as stated in the Sustainable Development Goals (SDGs) that have been agreed upon by the nations. The integration of the SDGs into the national development plan is expected to realize economic growth and social welfare along with minimizing environmental impacts and reducing Green House Gas (GHG) emissions. Most of the SDG's targets are relevant to the development of aquaculture. In its implementation, the Ecological Aquaculture Approach (EAA) contributes significantly to the achievement of the 17 SDGs goals (Hambrey, 2017).

Shrimp farming in aquaculture development centers has developed into the main livelihood of coastal communities and supports regional and national economies. The huge profits from the shrimp farming business have attracted the public interest, business actors and the private sector. However, not all aquaculture areas have a structuring concept, and not all spatial uses are followed by effective supervision and control. For example, the utilization of the coastal area of Karawang Regency for aquaculture areas has exceeded the allocation for land use in spatial planning, some of which have even converted mangroves (Komarudin, 2013). The shrimp production in Karawang District in 2018 was 11,374.08 tons, which was still 81.22% of the environmental carrying capacity (14,003.83 tons a year^{-1}) (Rifqi, Widigdo, ashar, Nazar, & Wardianto, 2020), so that the Karawang Regency shrimp production target could still be increased (Rifqi, 2020). To date, the target increase has not been officially set; however, achieving such a target cannot be done by increasing the total area of aquaculture but by increasing productivity and cultivation technology on land designated for cultivation areas (Rifqi et al., 2022).

The development of aquaculture areas in order to achieve production targets, needs to pay attention to the principles of sustainability, including considering the dynamics of carbon. Sustainability of shrimp farming in an aquaculture area includes aspects of structuring and utilizing land according to its designation and considering the carrying capacity of the environment (Rifqi, Widigdo, Mashar, Nazar, & Wardiatno, 2020); considering carbon dynamics (Rifqi et al., 2022); mitigation of negative impacts on the environment (Páez-Osuna, 2001), adaptability to climate change (Ahmed et al., 2019; Food and Agriculture Organization of the United Nations [FAO], 2020), and effective communication and education of stakeholders (Xuan et al., 2021).

Karawang Regency is one of the centres of shrimp farming area in Indonesia. The total area of aquaculture in the coastal area of Karawang Regency is currently 14,411.30 ha consisting of 1,440.00 ha of intensive and semi-intensive ponds and 12,971.30 ha of extensive ponds (District Fisheries Services [DFS], 2018). The number of shrimp farmers in Karawang Regency is 3,391.00 fisheries households (RTP), consisting of: 97.05% extensive technology farmers, 1.47% semi-intensive, 1.47% intensive (processed from DFS, 2018). The average production of traditional ponds is 0.26 tons Ha^{-1}, semi-intensive ponds 5.79 tons Ha^{-1} and intensive ponds 15.62 tons Ha^{-1} (Processed from DFS, 2018). The ideal land productivity for shrimp farming is 0.5-1 ton ha^{-1} in extensive ponds (SNI 7310:2009), 9 tons ha^{-1} for semi-intensive ponds (SNI 8007:2014), 20 tons ha^{-1} for intensive ponds (SNI 01-7246.1-2006). The aquaculture areas are spread over 9 (nine) sub-districts on the coastal area of Karawang Regency, namely: Pakisjaya, Batujaya, Tirtajaya, Cibuaya, Pedes, Cilebar, Tempuran, Cilamaya Kulon and Cilamaya Wetan.

Based on the current level of land use and the performance of shrimp farming on the coast of Karawang Regency as well as the dynamics of carbon related to shrimp farming in ponds, the potential for carbon emissions, carbon sequestration, and stocking potential in the area can be estimated (Rifqi, 2020). Structuring aquaculture areas is an integral part of integrated coastal management because the coastal ecosystem consists of natural and artificial components, dynamic and complex, as well as diverse and interacting habitats (Dahuri et al., 1996). Integrated coastal management can be harmonized between activities and users in utilizing resources in the region.

Arrangement of aquaculture areas that is carried out on land in accordance with the designation of spatial planning and supported by improved aquaculture technology can optimize carbon management. Moreover, the land designated as a mangrove protected area also needs to be restored to its function. Although its utilization for shrimp farming is limited, the land utilization must be in accordance with the recommended technology. Restoration of the mangrove ecosystem on the coast of Karawang Regency will positively impact the continuity and sustainability of shrimp farming in ponds while restoring environmental services (including carbon sinks and stocks).

2. Methodology

This study used a descriptive analysis of data and information from published research and studies to develop a conceptual framework for structuring a low-carbon shrimp pond area. The research location is a shrimp pond area on the coast of Karawang Regency, as shown in Figure 1. We synthesized 46 articles from ScienceDirect and Google Scholar journal databases as well as 11 books and reports in this literature review paper. The search strategy was carried out using keywords: the impact of climate change on shrimp farming, blue carbon emissions in shrimp areas, and blue carbon sequestration stored in shrimp areas. Meta-aggregation could be used for the systematic review of qualitative approach to present comprehensive and balanced facts to policymakers (Siswanto, 2010).

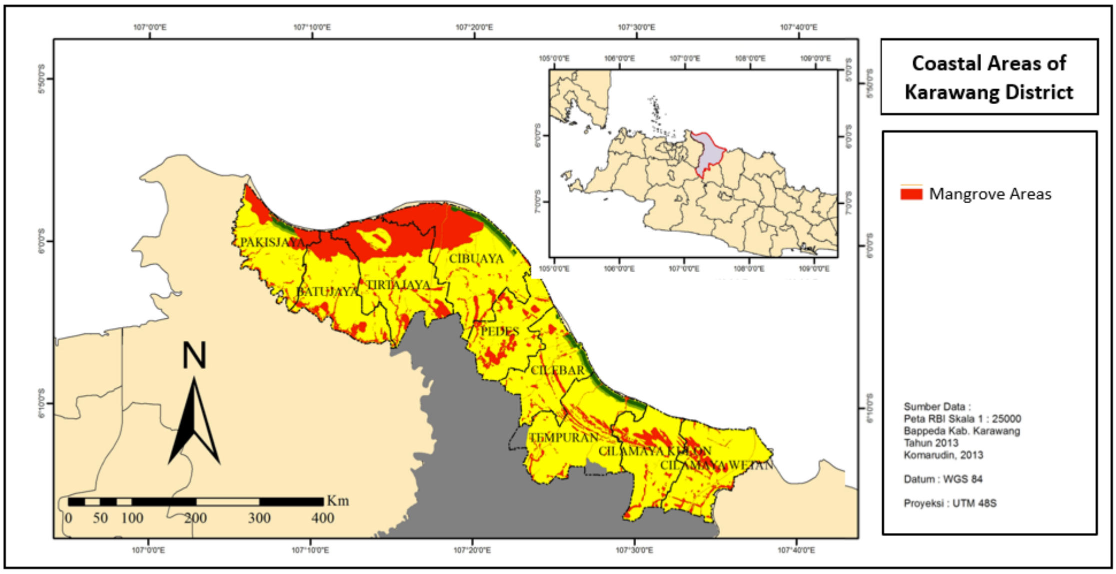

Figure 1. Coastal areas of Karawang District

The meta-aggregation synthesis process, as stated by Siswanto (2010), which was also carried out in this study, includes (i) extracted themes and concepts from relevant studies, (ii) organizing the results of this extraction into important (main) findings, (iii) grouped the findings into categories, (iv) synthesized the categories into themes or adapted to the conceptual framework. The approach and methods used in this paper are believed to be able to make this policy brief actionable.

The desk research results in this study were supported by experience and field observations. Field observations were carried out to examine the problems studied (Sugiyono, 2008). Documents used as desk study materials include research results, reports, planning documents, Indonesian National Standards (SNI) and regulations/laws.

3. Results and Discussions

Environmental aspects determine the success of the production and business continuity of aquaculture activities and, on the other hand, determine the acceptability and competitiveness of products in the global market. Increasing aquaculture production must be carried out in an environmentally friendly manner to minimize environmental costs (Hall et al., 2011). To minimize the impact on ecosystems in an area, sustainable pond management with mangrove conservation is needed (Fawzi & Husna, 2021). The main challenge of aquaculture governance is determining effective measures to ensure environmental sustainability along with building entrepreneurship and social harmony. The emphasis on spatial planning developed as part of the Ecosystem Approach to Aquaculture (EAA) will bring EAA closer to blue growth (Brugère et al., 2019). Ecosystem approaches to aquaculture, climate change, habitat restoration, protected areas and passive species regulation and control are part of the blue growth initiative (Moffitt & Cajas-Cano, 2014).

The agreement of the nations on the Sustainable Development Goals (SDGs) sets Climate Action as the 13th agenda. The approach taken is low-carbon and climate-resilient development to mitigate climate change and minimize the risk of other environmental damage impacts, as stated in the National Medium-Term Development Plan (RPJMN) of 2020-2024. Carbon trading mechanisms have been widely developed in the form of the regulated market (cap and market scheme) and voluntary carbon market (Ullman et al., 2013). Presidential Regulation Number 98 of 2021 indicates that Indonesia's carbon policy is carried out using market-based instruments.

The majority of papers available today only addressed the emission of carbon and other greenhouse gases in the aquaculture industry due to the shrimp farming process. Yang, Bastviken, et al. (2017) and Tong et al. (2021) concluded that shrimp farming activities in ponds contribute to greenhouse gas emissions, especially in ponds that convert mangrove land (Kauffman et al., 2017). The accumulation of carbon and other greenhouse gas (GHG) emissions, especially CO_2, CH_4, and N_2O, has triggered global climate change (Griggs & Noguer, 2002). The linkages between shrimp farms area, carbon emissions and climate change are shown in Figure 1.

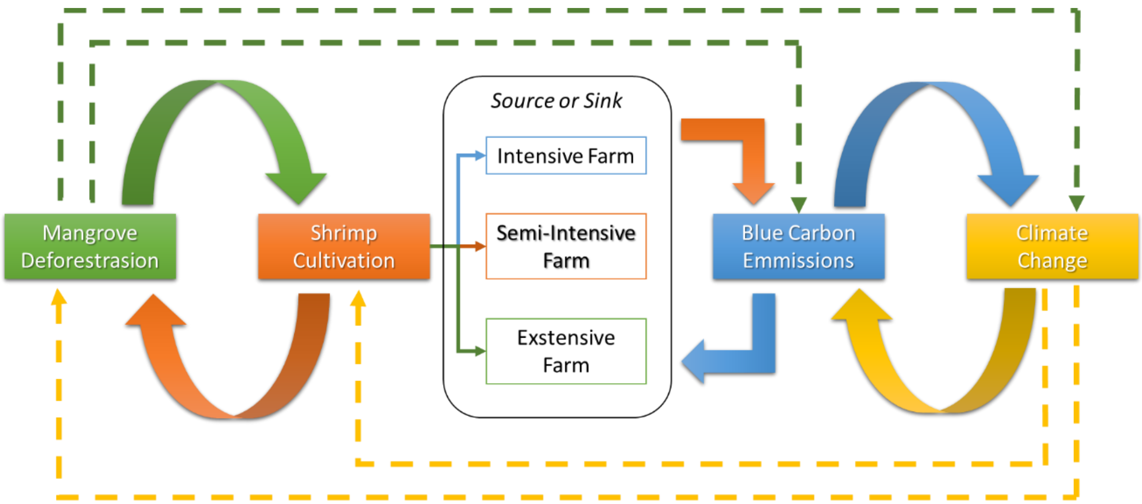

Figure 1. Backward and forward linkage of shrimp farming area and climate change (modified from Ahmed et al., 2017)

The carbon stock of mangrove ecosystems converted to aquaculture areas decreased to 81.9 Mg C ha^{-1} or 50% of the natural mangrove carbon stock (Merecí-Guamán et al., 2021). Kauffman et al. (2017) concluded that shrimp farming by converting mangroves and extensive technology (productivity of about 250 kg ha^{-1}) in the Mahakam Delta caused emissions of 1,603 kg CO_2-equivalent for every 1 kg of shrimp produced. There are potential emissions and releases of carbon elements by shrimp ponds that convert mangroves, i.e. from the basic substrate of mangrove ecosystems (Alongi et al., 2016; Kauffman et al., 2014; Liu et al., 2014; Siikamäki et al., 2013); the loss of the ability of mangroves to absorb CO_2 (Chen et al., 2016; Heriyanto & Subiandono, 2012; Rahman et al., 2017; Sondak, 2015)(and the loss of carbon stocks in the form of biomass (Alongi et al., 2016; Hilmi et al., 2017; Liu et al., 2014; Murdiyarso et al., 2015; Rachmawati et al., 2014; Rahman et al., 2017; Siikamäki et al., 2013). And also, there are potential emissions of CO_2 (Rifqi, Widigdo, Mashar, & Wardiatno, 2020; Rifqi, Widigdo, Wardiatno et al., 2020; Arifanti et al., 2021), CH_4 (Rifqi, Widigdo, Mashar, & Wardiatno, 2020; Rifqi, Widigdo, Wardiatno et al., 2020) and N_2O (Yogev et al., 2018) during the shrimp farming process in ponds.

The amount of emission per kg of shrimp produced will probably certainly be much lower on land that does not convert mangroves and have better land productivity, such as in semi-intensive and intensive ponds. However, there are still limited studies that explain the potential for carbon uptake and storage during the shrimp farming process in aquaculture. Furthermore, there is a potential for carbon absorption by phytoplankton and carbon stocks in the form of phytoplankton and shrimp/fish biomass (Widigdo et al., 2020).

Table 1: List of potential dynamics of blue carbon in shrimp farming area

No.	Items	Sources
a.	**Potential of Sources or carbon emitted**	
1.	Land conversion	
	- Loss of mangrove biomass	Hilmi et al., 2017
	- Loss of mangrove absorption capability	Chen et al., 2016; Rahman et al., 2017
2.	Emissions during shrimp farming)	Dewata, 2013; Rifqi, Widigdo, Mashar, & Wardiatno, 2020; Rifqi, Widigdo, Wardiatno et al., 2020
3.	Emissions when ponds are drained	Sidik & Lovelock, 2013; Yang, Lai et al., 2017
4.	Increased emissions of coastal natural ecosystems that exposure to the pond's effluent	Queiroz et al., 2019; Pérez et al., 2020
b.	**Potential of Sinks or carbon that can be absorbed and stored**	
1.	Carbon absorption by phytoplankton	Chen et al., 2017; Reeder, 2017; Vallina et al., 2017; Widigdo et al., 2020
2.	Carbon storage in the form of phytoplankton biomass and aquatic organisms	Hill et al., 2015; Mitra & Zaman, 2015; Widigdo et al., 2020

Estimation of GHG emissions during shrimp farming in ponds is the key to predicting the impact of shrimp farming on global warming (Vasanth et al., 2016). Efforts to reduce GHG emissions are related to the continuity and sustainability of aquaculture, including shrimp farming in the pond itself (Ahmed & Diana, 2015). Because climate change decreases survival and growth rates and reduces the production of shrimp reared in ponds (Ahmed & Diana, 2015; Ahmed et al., 2019). Efforts to mitigate greenhouse gas emissions in aquaculture areas include controlling emission sources through structuring the area, aquaculture engineering technology, using alternative energy sources, and increasing carbon sequestration and storage.

Table 2: Dynamics of blue carbon on three differences of shrimp farming technology

No.	Items	Extensive	Semi-Intensive	Intensive
a.	***Source*** **(ton Ha^{-1})**			
1.	Gas emission from substrate[1)]	673.00	673.00	673.00
2.	Loss of CO_2 absorption capacity [2)]	150.19	150.19	150.19
3.	Loss of carbon stock[3)]	160.70	160.70	160.70
4.	CO_2 emission during shrimp culture[4)]	0.97	66.39	91.59
5.	CH_4 emission during shrimp culture [4)]	0.0017	0.0007	0.0006
b.	***Sink*** **(ton Ha^{-1})**			
1.	Carbon absorption[5)]	0.71	7.81	9.08
2.	Carbon stock[5)]	0.0071	0.16	0.27

Source:
[1)] = modified from Kauffman et al., 2014; Liu et al., 2014; Siikamäki et al., 2013.
[2)] = modified from Chen et al., 2016; Rahman et al., 2017.
[3)] = modified from Hilmi et al., 2017.
[4)] = Rifqi, Widigdo, Mashar, and Wardiatno, 2020.
[5)] = Widigdo et al., 2020.

Utilization of aquaculture areas on the coast of Karawang Regency as aquaculture areas with low carbon emissions can be formulated by considering: (1) the carbon dynamics of each cultivation technology (extensive, semi-intensive and intensive), (2) socio-economic conditions such as the income of shrimp farmer, and (3) the area of ponds that meets with the designation and does not exceed the carrying capacity. The results of the study on the carbon dynamics in existing aquaculture areas can scientifically explain the mitigation efforts that can be done. Kauffman et al. (2014), Liu et al. (2014), Siikamäki et al. (2013), and Rifqi, Widigdo, Mashar, and Wardiatno (2020) described the potential for emissions, while Widigdo et al. (2020) explained the potential for carbon sequestration and storage at various levels of aquaculture technology, namely: extensive, semi-intensive and intensive.

Scenario analysis was used by Rifqi (2020) to design blue growth and low carbon emissions in the Karawang Regency shrimp farming area. The main principle of blue carbon management is to reduce and minimize emissions and increase the carbon sink. Rationalization of shrimp farming area on the coast of Karawang Regency can reduce carbon emissions and increase the ability to absorb CO_2 and carbon stocks Rifqi et al. (2022). This study suggested that the existence of mangrove protected areas in a spatial pattern will provide environmental services, including absorbing and storing carbon, filtering and absorbing organic matter from pond effluent, and also will increase the carrying capacity of the environment to support the continuity and sustainability of shrimp farming activities in the area. Moreover, aquaculture activities' productivity in coastal regions with mangrove protected areas can also be increased. Achieving the target of pond production can be done by increasing the area and productivity of semi-intensive and intensive ponds. As for traditional ponds, production targets can be optimized by producing commodities other than shrimp such as seaweed and fish.

Carbon dynamics are integrated with the results of land suitability analysis, environmental carrying capacity and socio-economic studies of the community to develop a representative, applicable and science-based management plan. The principle of blue carbon is to reduce emissions and increase the sinks. Based on potential emissions, climate change mitigation efforts in aquaculture areas can be carried out through (1) efficiency of energy use and use of alternative energy sources during the aquaculture process; (2) optimization of water quality management during the aquaculture process, including optimizing the population and composition of phytoplankton; (3) effluent management; (4) keeping the ponds inundated during the non-production phase; (5) enforcement of spatial utilization regulations, and (6) waste management in aquaculture areas.

a. Efficient use of energy and use of alternative energy

In addition to emissions from land conversion, the greatest potential for carbon emissions during the shrimp farming process is the conversion from energy consumption Rifqi (2020). This study learned that the highest energy consumption in shrimp farming in ponds is for paddlewheels, water pumps and lighting. Energy consumption efficiency can be done by assessing the ideal number of paddlewheels that need to be operated at certain hours by considering dissolved oxygen saturation and efficient water replacement frequency and volume. Efficient use of energy can also have an impact on reducing operating costs and increasing production efficiency.

Efficiency in energy use and the use of alternative energy sources during the shrimp farming process, among others, through the conversion of the use of electrical energy and fuel to alternative renewable energy sources such as wind power and solar cells. The current condition of investment and maintenance costs for solar cell facilities and wind power drives is still relatively high, so it is not feasible to analyze it with direct economic value. In the future, business analysis calculations need to use the total economic value that takes into account the carbon price. Along with the increasing use of alternative energy sources in various sectors, it is expected that the investment and maintenance costs will decrease.

b. Optimization of water quality management

Optimal water quality parameters during rearing will support the survival and growth of shrimp. At the same time, water quality affects the population and composition of phytoplankton as well as potential carbon emissions. The population and composition of phytoplankton in shrimp ponds contribute to carbon sequestration and storage (Widigdo et al., 2020). Water quality parameters are also related to potential carbon emissions (Rifqi, Widigdo, Mashar, & Wardiatno, 2020; Rifqi, Widigdo, Wardiatno et al., 2020) through biological processes (Setyanto, 2008).

There is a relationship between the accuracy of the development and management of shrimp ponds and GHG emissions, especially CO_2 and CH_4 (Yang et al., 2019). The rate of release of these two GHGs into the atmosphere is influenced by photosynthetic activity and organic matter decomposer microorganisms in the water column (Dariah et al., 2011), so the water quality parameters that influence these two factors determine the potential for emissions.

GHG released into the air partly depends on the physical structure of the water body, which is influenced by physical factors such as temperature, oxygen content, microbial population and metabolic pathways (Laurion et al., 2010). An increase in water temperature causes an increase in the mobility of gas molecules that makes the gas escape from the water (Segers, 1998). Water quality parameters that significantly affect surface water CO_2 emissions are concentrations CO_2 in the air, water temperature, chlorophyll-a, NO_2- and PO_4. Variables that significantly affect the surface CH_4 of semi-intensive pond water are pH and NO_2- (Rifqi, Widigdo, Mashar, & Wardiatno, 2020)

c. Pond effluent management

The management of shrimp pond effluent at the waste treatment installation is important, because it can minimize the potential for carbon emissions from waters and coastal ecosystems around the pond area. Emissions of ecosystems exposed to effluent runoff are higher than the natural emissions of these ecosystems (Queiroz et al., 2019; Pérez et al., 2020).

The management of pond effluent is included in one of the implementations of the Integrated Multi Trophic Aquaculture (IMTA) model. Pond effluent contains high organic matter, so it needs to be treated first before being discharged into coastal waters to avoid eutrophication. Effluent management is carried out in a waste treatment unit or installation which can be in the form of a reservoir and a mechanical method of zigzag ponds in the sewer. The application of IMTA in aquaculture areas allows for two advantages, utilizing organic waste as biomass for low-level trophic organisms and having an economic value such as seaweed, shellfish and fish.

d. Inundation of earthen ponds during the non-production phase

Embankments and pond bottoms that are exposed to air and sunlight during the tillage process have the potential to generate CO_2 emissions (Sidik & Lovelock, 2013). Non-flooded earthen ponds between cycles or are not producing have the potential for higher CO_2, CH_4 and N_2O emissions than ponds that are inundated (Yang, Lai et al., 2017).

To reduce potential GHG emissions from aquaculture areas, especially in earthen pond areas, one way that can be done is to inundate the idle ponds between periods/production cycles. Until now, no information has been obtained about the potential for GHG emissions in plastic lining ponds as long as they are not in production and are not inundated.

e. Law enforcement

The greatest potential for GHG emissions in aquaculture areas is from land conversion, especially those that convert mangroves. Thus, the enforcement of laws and regulations related to land use is very strategic in an effort to mitigate GHG emissions from aquaculture areas. Shrimp farming activities in ponds are carried out on according to the designation in the spatial plan.

Enforcement of regulations and restoration of the function of protected areas such as mangroves can increase carbon sequestration and storage in coastal ecosystems. At the same time, consistent law enforcement can also minimize habitat degradation and environmental damage. Effective law enforcement requires cooperation between the government, shrimp farmer associations, community and religious leaders, as well as business actors and the private sector.

The coastal land area of Karawang Regency, which is physically suitable with the spatial pattern for ponds with extensive technology as well as semi-intensive and intensive technology, is 1,299.99 ha and 1,667.91 Ha for the S1 category (very suitable) and S2 (suitable), (Rifqi, Widigdo, Mashar, Nazar, & Wardiatno, 2020). The coastal waters of this area are able to accommodate production of 14,003.83 tons per year-1 (Rifqi, Widigdo, Mashar, Nazar, & Wardiatno, 2020).

f. Waste management

Waste is one of the sectors targeted for GHG emission reduction, as stated in the National Determination Contribution (NDC). To reduce the potential for GHG emissions from aquaculture areas, waste treatment is one of the efforts that can be done. The higher the technology applied and the more businesses operating in an area, the problems related to waste also increase.

Until now, not all shrimp farming areas have paid attention to waste management. For this reason, in the future, stakeholders need to seek waste management in aquaculture areas. The management concept that can be applied is the 4Rs, namely Replace, Reduce, Reuse, and Recycle. The simplest thing that needs to be implemented is sorting and selecting waste so that it can be separated between organic and inorganic waste.

Optimizing the use of aquaculture in coastal areas can be done by rationalizing the pond area and simultaneously trying to restore mangrove forests or reforestation in protected areas and plant mangroves in possible pond clusters. Coastal management is an effort to optimize and synergize the use of existing resources in a sustainable manner and harmonize activities between users and ecological and economic relationships. Efforts to manage and protect coastal ecosystems from minimizing economic losses by maintaining their sequestration and carbon storage capabilities are urgent and important to do (Alongi, 2018). As part of the coastal ecosystem, future management of aquaculture areas needs to be carried out by considering the dynamics of blue carbon. Especially aquaculture areas that convert mangroves because they are related to carbon sequestration and storage and the resilience and capacity of ecosystem protection against climate-induced disasters (Arifanti, 2020).

Conclusions

Although shrimp farming is very profitable from an economic and business perspective, there is a lot of evidence showing that increased productivity in shrimp farming areas contributes to an increase in carbon emissions and greenhouse gas emissions. Therefore, to develop sustainable shrimp farming, it is necessary to arrange the shrimp farming area according to its designation and consider important factors in its management. Mitigation efforts should also be conducted in order to follow the principle of blue carbon in the aquaculture sector.

In conclusion, to develop a low carbon emission shrimp farm area model, the designated area should be prepared by considering land suitability, environmental carrying capacity and carbon dynamics. The highest emission sources in aquaculture areas include: the conversion of ex-mangrove land into pond plots, energy consumption, and potential emissions during shrimp farming and ponds not operating. Enforcement of spatial use regulations, together with efforts to increase land productivity, can increase aquaculture production in aquaculture areas with low emissions.

The use of low emission alternative energy and aquaculture engineering can minimize sources and increase sinks in aquaculture areas. Restoring the function of the mangrove protected area will provide environmental services, including carbon sequestration and storage as well as support for the continuity and sustainability of the aquaculture area itself.

Recommendations

Based on the results of the analysis, the following recommendations should be considered to address the root issues: (1). It is necessary to analyze land suitability, environmental carrying capacity and carbon dynamics in each shrimp farming area. (2). Achievement of shrimp production targets by increasing shrimp ponds productivity so that the use of land resources becomes efficient. (3). It is necessary to engineer aquaculture technology for efficient use of energy. (4). It requires support for the development of science and knowledge to provide alternative energy sources for shrimp farming. (5). Extension materials and technical guidance related to carbon emissions and their relation to the sustainability of shrimp farming need to be strengthened. (6). Pilot areas of low-emission shrimp farms are needed to increase farmers' understanding and awareness of sustainability. (7). Further study is required, particularly that aims to explain the differences in potential GHG emissions of plastics lining ponds and earthen ponds when they are flooded and not, potential emissions in ponds that use alternative energy and the efficiency of energy use.

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