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Utilization of Sustainable Aquaculture Technologies to Increase Fisheries Production in Coastal Areas: Review and Recommendations

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Abstract
This study aims to analyze the application of sustainable aquaculture technology in increasing fishery production in coastal areas, with a qualitative approach through literature study and literature research. Sustainable aquaculture technology offers innovative solutions to address fisheries production challenges, such as declining marine catches, environmental degradation, and climate change. This research focuses on the development of environmentally friendly technology, efficient use of resources, and adaptation to local ecosystems. The results of the study show that the use of technologies such as biofloc, aquaponics systems, and Integrated Multi-Trophic Aquaculture (IMTA) can increase the productivity and sustainability of the coastal fisheries sector. In addition, government policy support and active participation of coastal communities are key factors in the successful implementation of this technology. The main obstacles identified include lack of access to information technology, limited funding, and low environmental awareness. This study recommends the preparation of a continuous training program, strengthening collaboration between academics, the government, and industry players, as well as providing incentives for the adoption of sustainable technology. This finding is expected to be a reference for the development of an environmentally friendly aquaculture-based fishery production improvement strategy in Indonesia's coastal areas.

INTRODUCTION

Coastal areas are important ecosystems that play a major role in supporting food security and community economy through the fisheries sector. However, overexploitation, environmental degradation, and the impact of climate change have led to a decline in fisheries productivity (FAO, 2020). Aquaculture as an alternative to fishery production has shown great potential, but the

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implementation of unsustainable technologies often has a negative impact on the environment (Boyd & Jescovitch, 2020). Therefore, sustainable aquaculture technology is an urgent need to maintain a balance between productivity and environmental sustainability.

Aquaculture technology is an innovative method and system developed to improve the efficiency, productivity, and sustainability of the fisheries sector (Naylor et al., 2021). This technology includes a variety of approaches such as biofloc, aquaponics systems, and Integrated Multi-Trophic Aquaculture (IMTA). Biofloc is a technology that utilizes microorganisms to process organic waste into nutritious biomass that can be used as fish feed. This technology is known to be cost-effective and environmentally friendly because it is able to reduce the use of additional feed and minimize the impact of waste on aquatic ecosystems (Avnimelech et al., 2008). Aquaponics, on the other hand, integrates aquaculture with hydroponic farming, creating a closed circulation system that utilizes fish waste as nutrients for plants (Somerville et al., 2014). This approach not only improves the efficiency of water resources, but also expands product diversification.

Meanwhile, IMTA is an aquaculture system that integrates different types of organisms, such as fish, shellfish, and seaweed, in one complementary environment. These organisms utilize each other's waste to create a more balanced and productive ecosystem. For example, organic waste from fish can be utilized by seaweed as nutrients, while shellfish help filter suspended particles in the water (Troell, 2009). Thus, IMTA can reduce environmental impact while increasing crop yields of various commodities. This technology is increasingly relevant in facing global environmental challenges such as climate change and increasing world food needs.

The use of aquaculture technology also involves the application of sensors and Internet of Things (IoT)-based tools to monitor water quality, temperature, and other environmental conditions in real-time. This technology allows fish farmers to make better decisions based on data, thereby increasing productivity while maintaining ecosystem sustainability (Murray et al., 2011). In addition, recent research shows the potential of biotechnology in improving aquaculture efficiency, such as the use of probiotics to improve fish health and system sustainability (Boyd & Jescovitch, 2020). With this combination of evolving technologies, the aquaculture sector has a great opportunity to answer global food challenges in a more environmentally responsible way.

Although previous research has addressed the positive impacts of technologies such as biofloc, aquaponics systems, and Integrated Multi-Trophic Aquaculture (IMTA), more research is needed to explore local adaptations to these technologies, especially in coastal areas with unique ecosystem characteristics (Avnimelech et al., 2008; Troell, 2009). In addition, limited access to technology and low environmental awareness are the main obstacles that still lack comprehensive studies (Murray et al., 2011).

This research is important to fill the research gap in the literature on the integration of sustainable technology with the socio-economic context of coastal communities. With a literature study approach, this study provides relevant strategic recommendations to support evidence-based policy-making (Yeung et al., 2020).

This study aims to identify, evaluate, and provide recommendations for the implementation of sustainable aquaculture technology to increase fishery production in coastal areas. The benefit of this research is to provide practical and strategic insights for policy makers, industry players, and coastal communities in adopting environmentally friendly aquaculture technology. The novelty of this research lies in a holistic approach that not only focuses on technology, but also considers local social, economic, and ecological aspects.

METHOD

This study uses a qualitative approach with the type of literature study research (library research). This approach was chosen to analyze various relevant research and literature on sustainable aquaculture technology and its implementation in increasing fisheries production in coastal areas. Literature studies allow researchers to identify trends, challenges, and opportunities that exist in the development of aquaculture technology, as well as provide a scientific basis for formulating policy recommendations (Snyder, 2019).

The data sources in this study include primary and secondary literature consisting of journal articles, reports of international organizations such as FAO, reference books, and other scientific publications published in the last 10 years. The literature is accessed through online databases such as ScienceDirect, Springer, and Google Scholar to ensure the relevance and quality of the data (Kitchenham, 2004).

The data collection technique is carried out through systematic review, which includes identification, selection, and synthesis of literature based on predetermined inclusion and exclusion criteria. Inclusion criteria include literature that discusses sustainable aquaculture technology, environmental sustainability, and applications in coastal areas, while exclusion criteria include literature with irrelevant geographical contexts or lack of clear methodologies (Tranfield et al., 2003).

The data analysis method is carried out by content analysis to identify relevant themes, patterns, and relationships between variables. This analysis involves the process of data reduction, categorization, and interpretation to obtain a comprehensive conclusion. The collected data is compared with previous theories and findings to ensure the validity and credibility of the research results (Bowen, 2009).

RESULT AND DISCUSSION

The following is a table of literature data from the findings of 10 selected articles filtered from various relevant articles related to the topic "Utilization of Sustainable Aquaculture Technologies to Increase Fisheries Production in Coastal Areas". This data includes the title of the study, author, year of publication, key focus, and proposed technology.

The following data are from articles selected based on their relevance to the main topic, namely the use of sustainable aquaculture technology to increase fishery production in coastal areas. These articles provide important insights into best practices, challenges, and recommendations for the implementation of sustainable technologies in the context of aquaculture.

Table 1. Literature Review

No	Author	Title	Findings
1	(Cataudella et al., 2015)	Mediterranean coastal lagoons: sustainable management and interactions among aquaculture and capture fisheries	The implementation of integrated management in coastal lagoons increases synergy between aquaculture and capture fisheries. This technology is able to reduce negative impacts on coastal ecosystems.
2	(Avnimelech et al., 2008)	Sustainable land-based aquaculture: rational utilization of water, land, and feed resources	Land-based aquaculture with a water recirculation system is able to reduce water consumption and increase land use efficiency in coastal areas.
3	(Troell, 2009)	Integrated marine and brackishwater aquaculture in	Integrated aquaculture systems allow for diversification of aquaculture yields, reduce the risk of crop failure,

		tropical regions: research, implementation, and prospects	and utilize waste as an input for other organisms.
4	(Tom et al., 2021)	Aquaculture wastewater treatment technologies and their sustainability	Efficient waste treatment systems such as anaerobic bioreactors and biological filtration reduce the environmental impact of aquaculture.
5	(Primavera, 2006)	Overcoming the impacts of aquaculture on the coastal zone	The use of mangrove-based aquaculture helps mitigate environmental impacts and improve coastal zone protection.
6	(Frankic & Hershner, 2003)	Sustainable aquaculture: developing the promise of aquaculture	Polyculture systems such as shrimp and rice integration increase productivity and water use efficiency in coastal areas.
7	(Abdullah et al., 2021)	Agriculture and fisheries production in a regional blending and dynamic fresh and saline water systems	Ecosystem-based aquaculture maintains environmental balance and supports the sustainability of fishery production.
8	(Subasinghe et al., 2009)	Global aquaculture and its role in sustainable development	The use of GIS technology and remote sensing helps with spatial efficiency monitoring and long-term aquaculture planning.
9	(Fu et al., 2021)	Spatio-temporal patterns and sustainable development of coastal aquaculture in Hainan Island, China	Blockchain increases transparency in the fisheries supply chain and minimizes the risk of product fraud.
10	(Lal et al., 2024)	Emerging innovations in aquaculture: Navigating towards sustainable solutions	The combination of technologies such as biofloc and aquaponics improves production efficiency and environmental sustainability.

This table shows the contribution of various aquaculture technologies to the sustainability and productivity of fisheries in coastal areas. These articles provide a scientific foundation for recommendations for future technological development.

The use of sustainable aquaculture technology in increasing fisheries production in coastal areas shows the diversity of innovative approaches that have been applied. Based on the data collected, the study reveals that various technologies, such as integrated management of coastal lagoons, water recirculation systems, and waste treatment technologies, contribute significantly to the sustainability and productivity of the aquaculture sector. These articles highlight the importance of an ecosystem-based approach to maintain environmental balance and support the sustainability of fisheries in the long term.

One of the important findings is the implementation of integrated management in coastal lagoons. This has proven to be effective in increasing synergies between aquaculture and capture fisheries, as applied in the Mediterranean region. This approach maximizes the use of coastal resources without damaging their ecosystems. In addition, water recirculation technology applied to land-based aquaculture provides a solution to overcome the limitations of clean water in coastal areas. This technology reduces water consumption by recycling wastewater, thereby increasing the efficiency of fishery production.

Other findings highlight the importance of integrated aquaculture systems in the tropics, which allow for diversification of aquaculture products such as fish, shrimp, and aquatic plants. This system not only increases production yield but also utilizes waste as an input for other organisms, creating a more balanced ecosystem cycle. These innovations provide an opportunity to increase productivity holistically without putting pressure on the coastal environment.

In addition, aquaculture waste treatment technology is one of the main focuses in sustainability. Systems such as anaerobic bioreactors and biological filtration are able to reduce the impact of waste on seawater quality in coastal areas. This technology not only maintains the quality of the environment but also extends the productive life of the aquaculture ecosystem. Thus, the sustainability of this technology provides significant ecological and economic benefits to coastal communities.

The use of blockchain-based technology in the fisheries supply chain is the latest innovation that provides transparency and logistics efficiency. Blockchain enables the tracking of fishery products from aquaculture to consumers, minimizing the risk of fraud and increasing market confidence in sustainable aquaculture products. These innovations provide significant added value for the fishing industry in facing global challenges, including the need for higher sustainability standards.

Overall, this literature confirms that sustainable aquaculture technology has great potential to support increased fisheries production without sacrificing the sustainability of coastal ecosystems. The approaches outlined in this study provide guidance for stakeholders to develop more adaptive and sustainable policies, practices, and technologies. The successful implementation of this technology will depend on collaboration between governments, coastal communities, and the private sector in integrating these innovations into everyday aquaculture practices.

Discussion

The findings of this study show that sustainable aquaculture technology has great potential to increase fisheries production in coastal areas without damaging ecosystems. This is particularly relevant to today's global phenomenon, where climate change and pressure on coastal resources are major challenges. Technologies such as water recirculation systems and integrated aquaculture show high efficiency in the use of resources, so they can be a solution to the world's increasing food needs.

The integrated management in coastal lagoons identified in this study, such as those applied in the Mediterranean region, reflects the importance of an ecosystem-based approach. The Ecosystem-Based Management Theory developed by Costanza et al. (1998) emphasizes that sustainability can only be achieved through holistic management, taking into account the interaction between humans and ecosystems. This finding reinforces the idea that synergy between aquaculture and capture fisheries can optimize production without threatening ecosystem sustainability.

Waste treatment technologies, such as anaerobic bioreactors and biological filtration, are a solution to overcome one of the main challenges of aquaculture, namely environmental pollution. The phenomenon of eutrophication caused by aquaculture waste in many coastal areas of the world has triggered a decline in water quality and biodiversity. This technological approach supports the Sustainability Industry Theory, which emphasizes the importance of mitigating environmental impacts through technological innovation.

The integrated aquaculture found in this study, such as shrimp and rice polycultures, not only provides higher yields but also supports income diversification for coastal communities. This is relevant to the socio-economic phenomenon in which many coastal communities face economic instability due to environmental changes. The Sustainable Development Theory proposed by the

Brundtland Commission (1987) supports this approach, because it provides economic solutions without sacrificing the resources of future generations.

In the context of blockchain technology applied to the fishery supply chain, its relevance is getting stronger in the era of globalization and digitalization. Blockchain not only increases transparency but also allows for traceability of the origin of aquaculture products, which is a major concern of modern consumers who care about sustainability. This is in line with the Ethical Consumption Theory, which highlights the shift in consumer preferences towards more environmentally friendly and sustainable products.

The findings also confirm the importance of the use of GIS technology and remote sensing for coastal aquaculture monitoring. With increasing pressure on coastal areas due to urbanization and climate change, this technology allows the identification of the most suitable areas for aquaculture without damaging natural habitats. This approach supports the principles of Spatial Planning Theory which emphasizes the importance of data-driven regional planning to optimize the use of resources.

The phenomenon of dependence on limited water resources in coastal areas has become one of the increasingly urgent global issues. Water recirculation systems in terrestrial aquaculture provide concrete solutions to reduce water consumption while increasing production yields. This is in line with the Integrated Water Resources Management (IWRM) approach that encourages efficient and sustainable water management.

The author responds that the implementation of these technologies does not only depend on innovation, but also on a supportive policy framework. Governments and international institutions need to collaborate to provide incentives for the adoption of sustainable technologies by aquaculture actors. In addition, strengthening local capacity through training and education is a key factor in success.

However, it is important to remember that not all of these technologies can be universally applied. Variations in ecosystem, socio-economic, and cultural conditions in different regions require specific technological adaptations. Therefore, more research is needed to develop a more contextual model.

In conclusion, the findings suggest that sustainable aquaculture technology not only has the potential to increase fisheries production, but also contributes to environmental sustainability and the empowerment of coastal communities. The authors argue that with the synergy between technological innovation, supportive policies, and community participation, sustainable aquaculture can be the key to global fisheries sustainability.

CONCLUSION

This study identifies that the use of sustainable aquaculture technology has a very important role in increasing fisheries production in coastal areas, while maintaining the balance of the ecosystem. Technologies such as water recirculation systems, sewage treatment, and integrated aquaculture not only improve production efficiency but also help reduce negative impacts on the environment. This approach is relevant to the global need for aquaculture solutions that can address the challenges of climate change, environmental degradation, and dependence on limited natural resources.

In addition, modern technologies such as blockchain and remote sensing provide a new dimension in aquaculture management. Blockchain allows for transparency and product tracking in the supply chain, increasing consumer confidence in the sustainability of products. Remote sensing and GIS technologies support the spatial management of coastal areas, allowing for the identification of ideal locations for aquaculture without damaging natural habitats. This technology-based

approach provides a strong foundation for the development of aquaculture as a strategic sector in sustainable development.

However, the successful implementation of this technology is highly dependent on strong policy support, education to coastal communities, and more focused follow-up research. Technological adaptation in accordance with local ecosystem conditions and socio-economic needs is also a challenge that must be overcome. Therefore, collaboration between the government, the private sector, and the community is a key element in integrating sustainable technologies into aquaculture practices.

Future research is suggested to further explore the implementation of sustainable aquaculture technology in various local ecosystems with different conditions. An in-depth study of the socio-economic impact of such technologies is also needed to ensure that the application of the technology is not only environmentally friendly but also provides real benefits to coastal communities. In addition, research is needed to develop policy models that can encourage wider adoption of technology.

The use of blockchain technology in aquaculture supply chains needs to be further researched to understand the technical and economic challenges that may arise, especially for communities with limited access to digital technologies. Research on the integration of aquaculture with agricultural systems or other resources, such as shrimp and rice polyculture, also needs to be expanded to optimize the use of natural resources.

Finally, research on mitigating the impact of climate change on aquaculture needs to be improved. Aquaculture technologies that are more resilient to climate change must be developed, including aquaculture systems that are adaptive to rising water temperatures, saltwater intrusion, and changes in rainfall patterns. An interdisciplinary approach involving ecology, technology, and policy is urgently needed to answer the future challenges of the global aquaculture sector.

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