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Leveraging Aquaculture and Mariculture for Sustainable Economic Growth in Sri Lanka: Challenges and Opportunities

Galdolage B. S[1], Ekanayake E.A[2], Khaleel Ibrahim Al- Daoud[3], Vasudevan A[4], Chen Wenchang[5], Mohammad Faleh Ahmmad Hunitie[6], Suleiman Ibrahim Shelash Mohammad[7]

Abstract

Sri Lanka's strategic location in the Indian Ocean, combined with its rich cultural legacy, has made it a hub for international trade. Recognizing the value of its marine resources, the country has begun to focus on building a blue economy to promote economic advancement, livelihood enhancement, and job creation while safeguarding the ocean ecosystem. The aquaculture and mariculture industries are critical to this endeavor, and understanding their prospects and difficulties is critical to ensuring long-term and equitable development. The qualitative research approach was used, with 20 key-person interviews performed to provide insight into stakeholders' viewpoints, and the data processed using thematic analysis. Findings highlighted a number of prospects, including the worldwide trend toward aquaculture and mariculture, favorable geographical areas in Sri Lanka for aquaculture and mariculture, a diverse range of species to breed, and shrimp culture. It also identified challenges such as capital, technical, disease, and transportation issues, as well as solutions to those challenges, such as increasing investment in aquaculture and mariculture, improving technology and management practices, encouraging foreign collaboration, developing a regulatory framework, and adding value to production. The sustainable and healthy development of Sri Lanka's aquaculture and mariculture sectors is critical to economic growth, resource protection, and biodiversity conservation. With the appropriate approach, the blue economy may greatly contribute to the country's economic prosperity while also protecting its natural resources and cultural heritage.

Keywords: *Blue Economy, Aquaculture, Mariculture, Fisheries, Economic Growth, Sustainable Economic.*

Introduction

Sri Lanka's potential for developing a thriving blue economy is becoming increasingly recognized, given its strategic location on an island in the Indian Ocean with a coastline of 1,585 kilometers (Gunatilleke, Pethiyagoda, & Gunatilleke, 2008). This sector encompasses a range of economic activities that rely on the sustainable use of ocean resources, including aquaculture and mariculture, fisheries, tourism, renewable energy, and marine biotechnology (World Bank Group, 2016).The aquaculture and mariculture sectors are of particular importance in Sri Lanka's blue economy, and their sustainable development presents opportunities for economic progress, employment creation, and community livelihood enhancement while protecting the ocean's ecological balance.

The Exclusive Economic Zone (EEZ) of Sri Lanka, extending up to 200 nautical miles from the coastline and covering approximately 5 million square kilometers, provides access to valuable resources such as fisheries and mineral deposits (Gayashan, Jayakody, Rich , & Andreas, 2017). Developing a sustainable and thriving aquaculture and mariculture industry is vital to the country's economic growth while preserving its aquatic resources and biodiversity.

Sri Lanka is an island country with an expansive coastline that boasts rich marine and coastal resources (Ranasignhe, 2017). The aquaculture and mariculture sectors play a critical role in the country's blue

[1] University of Sri Jayewardenepura, Email: sandamali@sjp.ac.lk.
[2] Ministry of Trade, Commerce and Food Security, Email: eraaryanz@gmail.com
[3] Department of accounting, business school Faculties, Al Ahilya Amman University, Amman-Jordan, Email: K.aldaoud@ammanu.edu.jo
[4] INTI International University, Wekerle Business School, Budapest, Jázmin u. 10, 1083 Hungary, Email: asokan.vasudevan@newinti.edu.my
[5] Guizhou Qiannan College of Science and Technology, China, Email: chenwenchang11@outlook.com
[6] Department of Public Administration, School of Business, University of Jordan, Jordan, Email: Mhunitie57@gmail.com
[7] Department of Business Administration, Business School, Al al-Bayt University, Jordan, Research follower, INTI International University, 71800 Negeri Sembilan, Malaysia, Email: dr_sliman73@aabu.edu.jo

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economy, which has the potential to contribute significantly to its economic growth (Kutty, 2019). However, there is a research gap in examining the opportunities and challenges associated with expanding the blue economy, particularly in the aquaculture and mariculture sectors. Comprehensive research is needed to provide insights into the current state of the blue economy and the potential for sustainable growth in the aforementioned sectors. This research will be beneficial for policymakers, investors, and stakeholders who are interested in sustainable development and the growth of the blue economy. Moreover, an analysis of the opportunities and challenges of the aquaculture and mariculture sectors can guide decision-making for the development of a sustainable blue economy. The expansion of these sectors can contribute to economic progress, employment opportunities, and food security in Sri Lanka while protecting the ocean ecosystem. Therefore, this research aims to analyze the opportunities and challenges in expanding Sri Lanka's blue economy, with a specific focus on the aquaculture and mariculture sector, to facilitate informed decision-making toward sustainable and inclusive development.

Thus, this research aims to analyze the opportunities and challenges in expanding the blue economy in Sri Lanka, with a focus on the aquaculture and mariculture sectors. It further explores the potential solutions in these sectors to achieve sustainable and inclusive development of the blue economy.

Literature Review

Charting a Sustainable Economic Future

The utilization of non-renewable resources such as coal, which are often associated with environmentally detrimental practices, to foster economic growth has resulted in significant climate change, including the emission of greenhouse gases, water pollution, and the loss of biodiversity. Given the aforementioned environmental issues, the long-term viability of economic growth predicated on non-renewable resources, commonly referred to as the "brown economy," is subject to significant questioning and criticism (Mohammad et al., 2024a;Sakhuja, 2015; Mohammad et al., 2024b; Roslan et al., 2024). In response to these challenges, the "green economy" concept was introduced during the Rio+20 conference in June 2012 in Rio de Janeiro, Brazil. The green economy is envisioned as a low-carbon, socially inclusive, and resource-efficient alternative to the brown economy (Babb, 2015). According to various organizations, including IUCN (International Union for Conservation of Nature), UNCTAD (United Nations Conference on Trade and Development), and UNEP (United Nations Environmental Program), the green economy is built on the principles of sustainable development. Sustainable development encompasses economic, social, and environmental development and involves the responsible use of natural resources, including recycling and reducing environmental risks and costs (Golden, Virdin, J., Nowacek, D., Halpin, P., Bennear, L., & Patil, P.G., 2017). Given land-based agriculture's limitations, researchers face significant challenges in achieving global food production targets. This has prompted them to look beyond the green economy concept and recognize the vast potential of another repository of natural resources: the world's oceans (Bari, 2017). In 2012, UNEP published a synthesis report introducing the concept of the "green economy in a blue world." This report emphasized the crucial role of the marine environment as an integral component in the urgently needed paradigm shift towards a new bio-economy, known as the "blue economy," a term coined by the Pacific Small Island Developing States (UNEP, et al., 2012).

Sea or marine and its related economic activities contributions to the global economy are highly significant. According to estimates, the gross value of marine products and related activities, including direct outputs such as aquaculture and fishing, as well as services such as tourism and education, transportation such as coastal and oceanic shipping, and other benefits such as carbon sequestration and biotechnology, could reach as high as USD 2.5 trillion (Guldberg, Poloczanska, Skirving, & Dove, 2017).

Aquaculture and Mariculture as Vital Components of Sri Lanka's Seafood Production and Food Security

Aquaculture is related to freshwater, the branch involving the whole spectrum of fish products. Mariculture is identified with seawater which pertains to a branch of aquaculture. Aquaculture refers to farming aquatic organisms in saltwater and freshwater, including finfish, crustaceans, mollusks, and aquatic plants. In contrast, mariculture is a specific type of aquaculture focused on cultivating marine organisms in their

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natural habitats, such as inshore and offshore waters. It can include species such as oysters and clams, shrimp, and seaweed (Kutty, 2019).

Meaning of aquaculture is the farming of aquatic organisms that belong to four groups such as fish, mollusks, crustaceans, and aquatic vegetation (FAO, 2020). The aquatic plant that can be cultured is seaweed, and humans do farming to enhance fish production (Max, Kautsky, Beveridge, & Henriksson, 2017). There are some factors to be a concern with aquaculture, such as regular feeding, protection from predators, stocking, etc. (Segner, Reiser, Ruane, Roland, Steinhagen, & Vehanen, 2019). According to Segner et al (2019), ownership of the stock being cultivated is typically associated with farming, whether by individuals or corporations. Fish, mollusks, and crustaceans belong to the aquatic animal group, and seaweed belongs to the aquatic plant group.

The waters surrounding Sri Lanka have diverse marine biological resources, with 620 species from 137 families. Most of these resources comprise teleost fish, with fewer elasmobranchs, cephalopods, crustaceans, decapods, echinoderms, gastropods, and reptiles (Athukoorala, Bhujel, Krakstad , & Fri, 2021).

Global fishery production from capturing fisheries has reached its peak level of exploitation in the last two decades, while the demand for fish and fishery products has continued to increase. As a result, aquaculture and mariculture have become the only viable means to meet this growing demand (FAO, 2020). FAO (2020) reports that Sri Lanka, an island country surrounded by the ocean, relies on fish and fisheries products as their primary food source. The per capita fish consumption in Sri Lanka is 18 kg per year, slightly lower than the world average of 20.5 kg per year. Inland aquaculture and mariculture are two crucial areas that can play a significant role in meeting the increasing demand for food. mariculture refers to cultivating marine flora and fauna in a controlled or semi-controlled marine environment. In mariculture systems, fish, shellfish, and aquatic plants are cultured using wholly or partially artificial structures in the sea (Kapetsky, Aguilar-Manjarrez, & Jenness, 2013).

Sri Lanka has a coastline of approximately 1620 km and a sea area of around 517,000 km2 extending up to 370 km (200 nautical miles) from the coastline, nearly eight times the country's land area, which is about 65,610 km2 (Wijayaratne, 2001). Sri Lanka has an enormous potential to develop mariculture on the island since diverse environments, such as lagoons, estuaries and coastal bays, and 1600Km coastline, provide excellent opportunities for mariculture (Cooray, Premarathne, Atapaththu, & Priyad, 2022). The National Aquaculture Development Authority, in collaboration with other research institutes in Sri Lanka, conducted research on various possible species for coastal aquaculture, including finfish, shellfish, and seaweeds. Further investigations revealed that two commercially important seaweeds, *Gracilaria edulis*, and *Gracilariavweucosa*, as well as several other commercially essential algae, are viable options for aquaculture (Deepananda, 2011). There exists significant potential for the development of sea cucumber farming in the coastal waters of Sri Lanka.

The Growth of Sri Lanka's Aquaculture Sector

Figure 1 shows the inland and aquaculture fish production in Sri Lanka from 1999 to 2022. The production shows an increasing trend over the years with a few exceptions. The production in 1999 was 31,450 Mt and increased to 116,890 Mt in 2022. From 1999 to 2001, there was a decline in production from 31,450 Mt to 29,870 Mt. The production increased in the following year and continued to increase until 2009. In 2010, there was a significant increase in production, and the trend continued until 2022. The production in 2020 and 2021 showed a slight increase compared to the previous year. However, there was a significant increase in 2022 compared to 2021, with the production reaching 116,890 Mt.This data indicates that the aquaculture sector in Sri Lanka has been expanding over the years, contributing to the overall fish production of the country. It is also an indication of the potential for further development of the aquaculture industry in the country.

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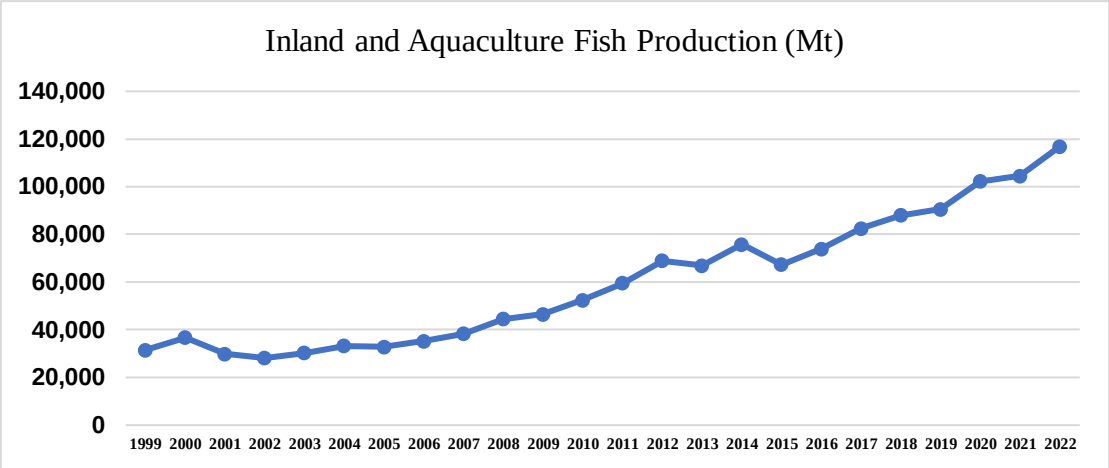
Figure 1- Inland and Aquaculture Fish Production (Mt)



Source: NAQDA, Annual Report 2020

As per Figure 2 data represents the export value of ornamental fish and the export quantity and value of shrimp in Sri Lanka from 1999 to 2022. The export value of ornamental fish has increased steadily from 560 Rs. Mn in 1999 to 7143 Rs.Mn in 2022, with some fluctuations in between. The highest growth was observed between 2014 and 2015, where the value increased by 756 Rs.Mn. The increase in the export value of ornamental fish could be due to a growing demand for exotic aquarium fish in international markets, especially in developed countries.

On the other hand, the quantity and value of shrimp exported also saw some fluctuations over the years. The export quantity of shrimp increased from 2716 Mt in 1999 to 5486 Mt in 2022, with some noticeable declines in 2004, 2008, and 2015. The export value of shrimp increased from 2275 Rs. Mn in 1999 to Rs.13174 Mn in 2022, with some notable declines in 2008 and 2010.The substantial growth in shrimp export quantity and value in recent years (especially in 2021 and 2022) could be attributed to improved production methods and increased international demand for shrimp.

Overall, the data suggest that the Sri Lankan Aquaculture sector has potential for growth and development, particularly in the shrimp industry. However, it is crucial to ensure that the sector's development is sustainable to avoid any negative impact on the environment and the communities that depend on it.

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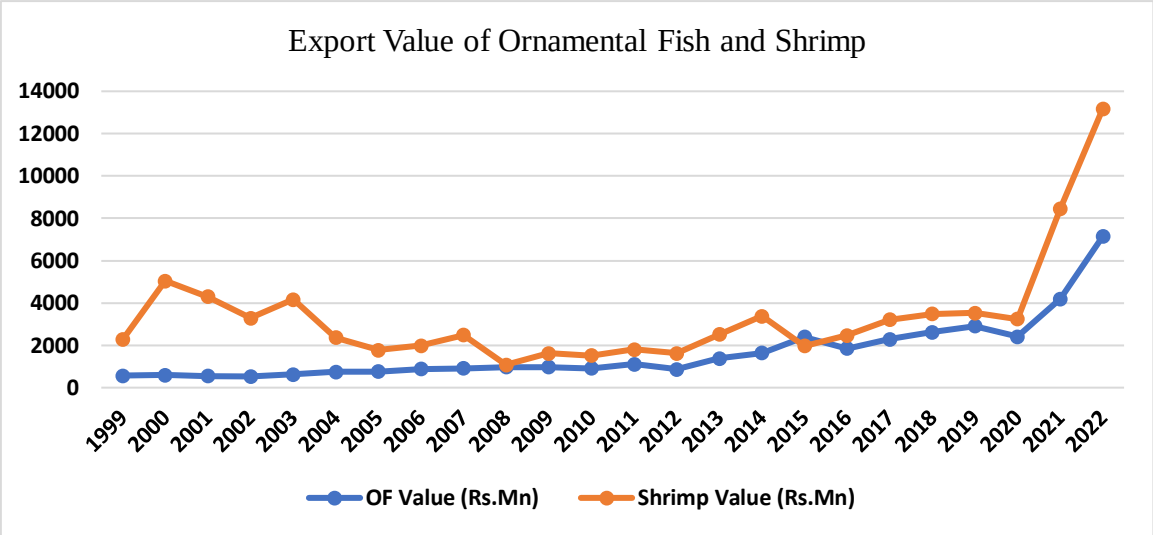
Figure 2-Export Value of Ornamental Fish and Shrimp



Source: NAQDA, Annual Report 2020

The potential impact of environmental degradation and climate change on the global fish population is difficult to accurately predict, but it is expected to be significant (Rumley, Chaturvedi, & Sakhuja, 2009). According to the researchers in the fisheries case, the current status of the Indian Ocean fish stocks further expansion is impossible, as some of the species are over-oppressed (Chang, Sang , Jung, & Kim, 2020).

Challenges and Opportunities in Sri Lanka's Aquaculture and Mariculture Sectors

Each country in the Indian Ocean Rim has its own laws, regulations, and policies to manage marine and ocean resources, particularly fish stocks. However, these measures have often proven to be ineffective in cases of illegal, unreported, and unregulated fishing (Gunnlaugsson & Agnarsson, 2019). There are some key issues related to the fisheries sector such asDecrement of available fish resources, species composition of catches has been shifted, a decrement of the marine biodiversity, Increase the proportion of juvenile fish in the harvested catch and the catching of vulnerable and endangered species leads to their loss.

The overuse of marine resources has been driven by the rapid growth of the human population over the past few decades, resulting in a need to meet the increasing demand for food. However, to provide enough fish to meet this demand, a two to three-fold increase in fishing fleets worldwide would be required, and it is uncertain whether our oceans can sustainably support this. In the Indian Ocean, several indicators suggest a depleted state of fisheries resources (Nisar, Ali, Mu, & Sun, 2021; Polacheck, 2006).Many Indian Ocean countries have experienced a decline in fishery production, the species composition of catches has been changing, there has been an increase in the proportion of juvenile fish being caught, major fish stocks in the Indian Ocean have been assessed by the Asia Pacific Fishery Commission (AFC) and Indian Ocean Tuna Commission (IOTC), over a long time period a decrease in catch-rates in trawler surveys happened and from fisherman's Circumstantial evidence.

Choosing the sector of Aquaculture and mariculture is a sound decision when analyzing the blue economy in Sri Lanka for several reasons.Aquaculture and maricultureis a rapidly growing industry in Sri Lanka that has the potential to provide significant economic benefits while also addressing food security and nutrition challenges (Drengstig, 2020). By focusing on aquaculture, we can examine the different types of aquaculture systems, species cultured, and value chain development. We can also consider the socio-economic and environmental impacts of aquaculture in Sri Lanka and identify potential strategies for sustainable growth.

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Therefore, examining thissector will provide a comprehensive analysis of the blue economy in Sri Lanka and identify opportunities and challenges in key areas that can guide policymakers, investors, and other stakeholders in making informed decisions towards sustainable growth of the blue economy.

Methodology

The study was based on interpretivism; a paradigm that emphasizes the subjective interpretation of social phenomena and human experience. The research approach was inductive, which involves drawing conclusions based on the data collected and available evidence. The research is qualitative in nature and focuses on exploring the perceptions and experiences of the participants regarding the opportunities and challenges in expanding the blue economy in Sri Lanka, specifically in the aquaculture and mariculture sectors.

The primary data collection method was key informant interviews.The populationconsistsofpersonnel from various organizations, including government agencies, industry associations, research institutions, and private sector companies involved in fisheries, aquaculture, tourism, and shipping.It is important to ensure that the sample is diverse and representative of the population, to ensure that findings are applicable to the broader population. The sampling technique for the study involves purposive sampling, ensuring that participants have relevant knowledge and experience in the industry.The sample size depends on the data saturation, which comprised20 interviews in this study.

The interviews conducted face-to-face or through virtual platforms such as zoom, MS Teams or Google Meet.The interview procedure for this study follows a standard protocol to ensure the consistency and quality of the data collection. Field notes were taken using a standard template that includes components such asdate, time, and location of the interview; participant's name, role, and organization, brief description of the participant's background and experience related to the blue economy in Sri Lanka; summary of the key points discussed during the interview; noteworthy observations or reflections related to the participant or the interview process and follow-up questions or comments for future interviews (if applicable). Voice recordings were used to capture the interviews with participants. Researcherstranscribed the recordings to create a verbatim text document of the interview. The use of voice recordings ensures that the data collected is accurate and comprehensive, capturing all of the nuances of the conversation, including tone, emphasis, and pauses.The language used in the interviews is Sinhala or English, depending on the participant's preference.

The data were presented as a narrative, using direct quotes from the participants to support the findings and illustrate the participants' perspectives. The analysis involves organizing data into themes and patterns to understand the topic comprehensively.Thematic analysis was used to analyze the data. The following steps were taken to analyze the data:transcription, familiarization, coding, collating codes, developing themes, reviewing themes, defining and naming themes, andreporting.

The rigor of the study was ensured through the use of multiple data sources and the triangulation of findings from different sources to ensure the credibility and transferability of the research.

Data Analysis and Presentation

Interviews provide a unique perspective on the challenges and opportunities facing the Aquaculture and mariculture sector in Sri Lanka and offer insights into the experiences and perspectives of those working within the sector. The analysis focuses on key themes and issues identified through the interviews, including the current state of the aquaculture and mariculture sector, opportunities of the sector, challenges facing the sector, and potential strategies for addressing these challenges.

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Opportunities of the Aquaculture and Mariculture Sector

There are opportunities to expand the aquaculture and mariculture sector in Sri Lanka, such as the global trend towards aquaculture and mariculture andsuitable geographical locations in Sri Lanka for aquaculture and mariculture. Further, Sri Lanka has a variety of Species to breed and Shrimp Culture.

The Global Trend Toward Aquaculture and Mariculture

It is clear that the global trend of fish production is moving away from wild catch towards aquaculture and mariculture.

"Countries like Canada are producing around 70% of their fish production by aquaculture. Now global trend goes towards aquaculture and mariculture rather than wild catch." (Director General/DFAR)

Developed countries are leading the way, with Canada producing 70% of their fish production from aquaculture.

"Ornamental fish and ornamental aquatic plants have huge demand in the world market. Only around 3% of the global ornamental fish market has been covered by Sri Lanka." (Principal Scientist/Aquaculture/NARA)

This shift is likely to continue as aquaculture, and mariculture becomes more efficient and accessible, providing the world with a more sustainable and abundant source of fish.

"In Sri Lanka, Per capita, fish consumption is 17 kg per person per year. It should increase up to 21kg. Fish produce more than 60% of human protein as animal protein. So, we need to increase 17 kg to 21 kg as the natural protein requirement of a human. Our annual fish production is around 574000. Since we cannot fulfill the protein need from that amount, we need to go to alternative sources to fulfill our protein requirement. We need to focus more on marine aquaculture." (Principal Scientist/Ocean Resource/NARA)

Sri Lanka's per capita fish consumption is 17 kg per person per year, which falls short of the natural protein requirement of a human. To meet the protein requirement, Sri Lanka needs to increase its fish production and focus more on marine aquaculture. Currently, Sri Lanka's annual fish production is around 574,000 tons, which is not enough to fulfill the protein needs of the population. Therefore, increasing the focus on marine aquaculture can help meet the demand for protein and provide an opportunity for growth in the sector.

"Marine 50% Aquaculture 50% in developed countries. our around 15% to 20%" (Director/Research/DFAR)

This is a significant shift, with estimates that aquaculture and mariculture account for around 15-20% of total fish production in developing countries, compared to 50% in developed countries.

Suitable Geographical Locations for Aquaculture and Mariculture

It is evident that the country has great potential for developing these industries, particularly in terms of shrimp and crab farming.

"For shrimp farming, crab farming. Mannar Wedithalathivezones is ideal for developing aquaculture." (Director/Research/DFAR)

Mannar Wedithalathivezones are ideal for shrimp and crab farming, while the eastern area is suitable for sea cucumber and seaweed cultivation, as well as sea bass culture.

"We have big potential to develop mariculture. NAQDA has zonal plan. But we are not expanding to that areas. Seaweed sea cucumber growing potential is there." (Assistant Director/Fisheries/ MoF)

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"We have more than 10000 reservoirs in our country." (Director/Research/DFAR)

Sri Lanka has over 10,000 reservoirs that can be utilized for aquaculture, and the country's calm sea environment is conducive to the development of the mariculture industry.

"Our aquaculture is very much limited compared to the land." (Director General/DFAR)

"When we considering the opportunities, we have sea around the country. For mariculture, we need a very calm sea environment. If the wave is too much heavy, the cage may go into the deep sea. The eastern area is best for sea cucumber and seaweeds. Also, we can cultivate the sea bass culture there. We have identified some areas in north and Eastern" (Principal Scientist/Aquaculture/NARA)

In addition, the development of the aquaculture and mariculture sector can lead to the growth of other related industries, such as feed production, equipment technology, and seed production. Finally, the lack of deep sea in northern and Eastern areas of Sri Lanka makes them ideal for aquaculture and mariculture.

"Only the Indian Ocean has seen some kind of increase in fish production. All four other oceans are over-exploited. Even though Indian Ocean fish production has increased when we consider that Sri Lankan coastal fishery production is somewhat over-exploited. Coastal fishery produces 60% of the fish production of Sri Lanka, while offshore fishery contributes 40%. So, this 60% is over-exploited."

However, avoiding overexploitation of coastal fishery is essential, which currently contributes to 60% of fish production in Sri Lanka.

"Sri Lanka has the least continental shift. It's not a deep sea since it is not a continental shell. In northern and Eastern area has no deep sea. Less shallow that's ideal for aquaculture and mariculture" (Principal Scientist/Ocean Resource/NARA)

A Variety of Species to Breed

In addition to oysters, Sri Lanka has a variety of other species that can be bred and cultivated for commercial purposes. As mentioned by the Principal Scientist from NARA, there are 252 different species in the Sri Lankan fisheries sector, providing a wide range of opportunities for aquaculture and mariculture.

"oyster- there are two oyster types. One is an edible oyster, and another is a pearl oyster. With the help of private companies and foreign experts, we are mechanically developing pearl oysters. Now we are artificially developing pearls inside the oyster. We have identified the areas Pearl is located. Then we do insertion, the necessary technology to grow the pearl inside the oyster. We can insert some chemicals to get the real color of the pearl" (Principal scientist/Aquaculture/NARA)

Yellowfin tuna, for example, is a high-value species that can be grown through aquaculture and has a strong demand in the world market. Currently, Sri Lanka only produces barramundi, but there is potential to expand into yellowfin tuna production.

"The main opportunity we have in this sector is we have GSP + we can enter the Europe market with that concession. We can supply more. Even though Sri Lanka is not doing in the world, tuna is also growing in aquaculture. Sri Lanka is only doing barramundi. We can do yellowfin tuna. They have a high price in the world market. We have that kind of opportunity. In the Sri Lankan fisheries sector, they are 252 feature species. There we have selection preferences. there in the Pacific Ocean only headache polos we can create a niche market in the world market." (Principal Scientist/Ocean Resource/NARA).

In addition to fish, Sri Lanka also has the potential to cultivate other marine species, such as seaweed and sea cucumber. Seaweed has a growing demand in international markets due to its use in food, cosmetics, and pharmaceuticals, while sea cucumbers are highly priced in Asian markets for their medicinal properties.Overall, Sri Lanka's diverse range of marine species provides numerous opportunities for the development of aquaculture and mariculture industries, providing economic benefits and contributing to food security and sustainability.

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Shrimp Culture in Sri Lanka

According to the Director NAQDA, shrimp culture in Sri Lanka has a cycle of four months, and two and a half cycles can be produced per year. Suitable land for shrimp farming can be identified within a short period.

"Shrimp culture cycle is four months. We can make two and a half cycles per year. In the short term, we can identify suitable land for Shrimp farm and cultivate within a short period" (Director/NAQDA)

There are two significant types of shrimp in Sri Lanka, *Penaeus mondon* and *litopenaesvannamei*. In 2012, shrimp production was around 7,000 metric tons, but after the introduction of *vannamei*, the production doubled to 14,415 metric tons in 2019. Shrimp is cultivated using brackish water and seawater. In Hambantota, seawater is used, and freshwater can also be added. The sector earned around 37 million USD in exports last year.

"We have five years plan to develop shrimp farms, but there are problems in land clearance. We are now identifying suitable Lands for shrimp farming in Hambantota. We can produce around 20000 metric tons of shrimp. From shrimp farming, we are earning around 9.9 USD million from sea cucumber. We are exporting 100% of the sea cucumber since we are not consuming" (Director/NAQDA)

This plan has the potential to significantly boost the economy and create employment opportunities in the region. However, it is crucial to ensure that the development of shrimp farms is done sustainably to minimize adverse environmental impacts.

Challenges of The Aquaculture and Mariculture Sector

As per the discussion held with officials, 04 challenges were identified as barriers to expanding the Aquaculture and mariculture sector in Sri Lanka, such as Capital Issues, Technical Issues, and Disease and Transportation issues.

Capital Issues

Some of the main challenges facing the aquaculture and mariculture sector in Sri Lanka include capital issues.

"Fingerlings are developed in NAQDA laboratories, so supply is not sufficient as demand." (Director/RESEARCH/ MoF)

"We have big potential to develop mariculture, NAQDA has Zonal Plan. But we are not expanding to that areas. Seaweed sea cucumber growing potential is there. Investment is high." (Assistant Director/Fisheries/ MoF)

This is particularly relevant in developing fingerlings in NAQDA laboratories, where supply is insufficient to meet demand.

"Only Ocean Pick company (Located in Trincomalee) is doing mariculture in the deep sea in Sri Lanka." (Director General/DFAR)

"mariculture in lagoons and sheltered coastal areas requires investment in infrastructure, technical inputs, and significant private capital." (Sectorial Officer, MoF)

Additionally, investment is high for expanding into potential areas for mariculture, including seaweed and sea cucumber growing. The high investment required is related to the infrastructure, technical inputs, and significant private capital needed for mariculture in lagoons and sheltered coastal areas, as well as the need for cages, feeding, and other necessary chemicals and medicines.

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"Still, we are around 1% of sea cucumber breeding success rate due to lack of technology in mariculture. We need to invest more for cages and feeding, so we need a huge investment." (Principal Scientist/Aquaculture/NARA)

Another challenge is the low success rate for sea cucumber breeding due to a lack of technology and investment in cages and feeding.

"From now, they are diving into the sea and collecting seeds and then exporting. Not like freshwater aquaculture, coastal aquaculture should have very pure water. Sea water is always pure since there is always an oxygen supply, and it is high. To maintain that much Oxygen needs High investment" (Principal Scientist/Aquaculture/NARA)

this shift towards sea-based aquaculture could significantly benefit the industry. However, it is essential to ensure that the collection of seeds and farming practices are done sustainably to minimize adverse environmental impacts. Additionally, the high cost of maintaining water purity should be considered when planning for investment in coastal aquaculture.

"the whole world is doing promotion toward aquaculture and mariculture. Norway and Ireland are doing aquaculture in a big way. They have aquaculture zones. Unfortunately, the recurrent cost is high in aquaculture. We need to feed the fish, provide cages for fish, provide necessary chemicals and other medicines for them whenever necessary, quality control, and raw material. Even though the market has high demand, it is difficult to capture the market since the investment is high" (Principal Scientist/Ocean Resource/NARA)

Finally, while there is high demand for aquaculture and mariculture products in the global market, the high investment required for these activities can make it challenging to capture that market.

Technical Issues

The technical issues associated with aquaculture and mariculture in Sri Lanka can be broadly categorized into three main areas: insufficient seed supply for sea cucumber aquaculture, lack of hatchery facilities and lab facilities, and the use of obsolete technology.

"insufficient seed supply for sea cucumber aquaculture. Hatchery operations are also technically complicated. Adults are captured from the wild and induced to spawn with a temperature shock." (Sectorial Officer, MoF)

The insufficient seed supply is a significant challenge, as hatchery operations are technically complicated, requiring the capture of adults from the Wild and inducing them to spawn with temperature shock.

"Establishing more hatchery facilities. It can save equivalent foreign currency for import of fish seed, earn foreign exchange by exporting fish, keep the seed cost at a minimum, and disseminate breeding technology." (Director/Research/ MoF)

Establishing more hatchery facilities could help to save foreign currency for the import of fish seed, export fish for foreign exchange, and keep the cost of seed at a minimum.

"Lack of lab facilities and quarantine facilities and Use of obsolete technology is a barrier." (Sectorial Officer, MoF)

The lack of lab and quarantine facilities, as well as the use of obsolete technology, is also a significant barrier to the development of the sector.

"Still, we are around 1% of sea cucumber breeding success rate due to lack of technology in mariculture. We need to invest more for cages and feeding, so we need a huge investment." (Principal Scientist/Aquaculture/NARA)

"Sri Lanka has huge potential to grow crab, but for that, also we do not have enough technology. So, people are catching some small species and growing them inside their farms. We call it patterning sometimes." (Principal Scientist/Aquaculture/NARA)

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Investing in advanced technology and research to improve breeding and farming practices could increase the success rate of sea cucumber breeding and crab farming, resulting in greater productivity and profitability for the aquaculture industry in Sri Lanka.

"We lack modern technology such as cage materials and the equipment we are using. The feeding machine is there in other countries, not in our countries. So, we may need to import that kind of technology into our country. In aquaculture, we must focus on the export market. To go to the international market, we need hygiene certificates. There are stewardship councils and eco-labeling. In Japan, fish has a tag. when we use our phone and scan the barcode, we can get the complete history of the fish, but Sri Lanka does not have such kind of technology." (Principal Scientist/Ocean Resource/NARA)

Investing in modern technology and developing sustainable practices that meet international standards are crucial for the growth of the aquaculture industry in Sri Lanka. By adopting such practices and investing in new technology, Sri Lanka can tap into the lucrative export market and ensure the long-term sustainability of the industry.

"Apart from the lack of technology and investment, another huge challenge is the lack of seeds. Even though we have established huge farms, we do not have seeds. We do not have enough hatchery facilities for the seeds. People are catching the seeds from the sea by diving, and they are taking that to their farms and cultivating them. Sri Lanka has huge potential to grow crab, but for that, also we do not have enough technology. So people are catching some small species and growing them inside their farms. We call it patterning sometimes." (Principal Scientist/Aquaculture/NARA)

Addressing the lack of technology, investment, and hatchery facilities is crucial for the sustainable growth of the aquaculture industry in Sri Lanka. Additionally, efforts should be made to develop sustainable practices for seed collection and farming that minimize negative environmental impacts.

"We have enough in post-larvae for Shrimp farming, but we do not have enough fingerings. On the other hand, we do not have enough fingerings to put the tanks in the middle of the country." (Director/NAQDA)

"We have only three hatcheries. private sector owns two hatcheries, NAQDA owns one hatchery" (Director/NAQDA)

This shortage of hatcheries and fingerlings could hinder the growth of the aquaculture industry in Sri Lanka, particularly for inland shrimp farming. Addressing this issue would require investment in hatchery facilities and increased collaboration between the private sector and government agencies like NAQDA.

Diseases

White spot disease is an increasingly prevalent disease affecting fish, and new breeds of fish have been developed in order to combat it.

"White spot diseases. Now new breeds are cultured for this kind of disease." (Director/Research/ MoF)

"Since the old shrimp culture has been affected by the white spot diseases, regulation institutions introduce venomy to the shrimp culture" (Principal Scientist/Ocean Resources/NARA)

This has been done in order to protect our aquatic ecosystems and to ensure that the fish population remains healthy. This effort is essential for maintaining a balanced, healthy aquatic environment and for preserving aquatic species.

Transportation Issue

Transportation is a significant issue for sea cucumber farms in rural areas of Sri Lanka. These farms are located in remote locations such as Thewanpitti, Mannar south bay, Ambupuram, Valaipaduaand, and Nachchikuda, which makes it difficult for farmers to access resources and markets.

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"Since Sea cucumber farms are located in the rural areas such as Thewanpitti, Mannar south bay, Ambupuram, Valaipaduaand, and Nachchikuda, Transportation has become an issue." (Sectorial Officer, MoF)

Without access to efficient transportation, farmers are unable to transport their products to markets and are unable to make a profit. This lack of transportation has resulted in a decrease in profits for sea cucumber farmers and has led to a decreased production of the product.

"There are transportation issues at the northern and eastern region." (Director/Research/ MoF)

By creating better transportation options, sea cucumber farmers could increase their productivity and profits, and the industry could grow.

Proposing Solutions to Overcome the Above Problems

Officials provide some possible solutions to overcome the current issues and challenges of the aquaculture and mariculture sector, such as investing more in aquaculture and mariculture, Enhancetechnology and best management practices, foreign collaboration to create a regulatory framework and value addition to the production.

Invest More in Aquaculture and Mariculture and Develop an Investor-Friendly Environment

The statement made by the sectorial officer MoF highlights the seaweed industry's potential in terms of exports and wages for individual farmers.

"In 2013, Hayleys Agriculture Holdings Ltd., with support from Vietnam, began a pilot project in the Mannar District to help fishing communities rebuild their livelihoods and generate steady incomes through seaweed farming. By 2015, the project had expanded to Analaitivu, Eluvaitivu, and Nainaitivu islands in Jaffna District, with 3,500 seaweed racks, each measuring 12m x 12m. This endeavor benefitted over 1,000 farmers, intending to reach 5,000 by the end of 2016. Hayleys provided technical support to the farmers and facilitated marketing by offering buy-back arrangements. In 2015, the company exported 180 tons of dried seaweed, worth Rs 9.4 million, and individual farmers earned an average of US$1,100 a year for their raw product. With proper cultivation and harvesting techniques, these numbers could be higher." (Sectorial Officer, MoF)

The Heyleys company has already successfully exported 180 tons of seaweed and generated revenue of Rs 9.4 million, showing the industry's potential. Furthermore, individual farmers earned an average of US$1,100 a year for their raw products, indicating that seaweed harvesting and cultivation can provide a sustainable income.

"The procedure for implementing shrimp farm is complicated. We need to develop a project proposal and get clearance from an institution such as the irrigation department, Forest Department, coastal convention department, and environmental authority. Then we can apply for the aquatic management growing certificates from the NAQDA. NAQDA has a technical committee to evaluate the proposal after need to get the annual license, and we can get this management license and do the farming."

"When Investors come, we need to clear the land within quick time. If we can do so, 90% of the problems are solved" (Director/NAQDA)

However, with improved techniques, these numbers could increase further, benefiting both business owners and farmers alike.

Enhance Technology and Best Management Practices

The use of modern technology should be encouraged in order to increase production and efficiency.

"Establishing more hatchery facilities. It can save equivalent foreign currency for import of fish seed, earn foreign exchange by exporting fish, keep the seed cost at a minimum, and disseminate breeding technology." (Sectorial Officer, MoF)

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"We Need to impose buffer zones and introduce biosecurity measures and implement best management practices. Abuffer zone is the area between two shrimp forms around 100 meters, then the water is not mixed within the farms, and diseases are not spread. We need to implement that kind of BMP advice, and that advice must be followed" (Director/NAQDA)

This could include automated systems, sophisticated monitoring systems, and other advanced technologies.

Foreign Collaboration

Foreign collaboration could bring significant benefits to the aquaculture industry in Sri Lanka, particularly regarding technology transfer, knowledge sharing, and market access.

"If we can apply some mechanism to attract investors here like PPP, not only local but also foreign technology. It would be better if we could do some foreign collaboration as we can get some training from the people outside. We can send our people to other countries and give them the necessary knowledge. We can invite the sound technical people here and get the technical knowledge from them." (Principal Scientist/Aquaculture/NARA)

Implementing public-private partnerships (PPP) could be a practical approach to attract both local and foreign investors, as well as encourage the development of the aquaculture industry in Sri Lanka.

"we can engage in bilateral agreements with other countries for our aquaculture exports and development. In the urban area, we must develop infrastructure to provide necessary training skill labor training" (Principal Scientist/Ocean Resources/NARA)

Furthermore, collaboration could help to establish better infrastructure and training programs, particularly in rural areas where access to resources is limited. It is also essential for the government to provide the necessary support to facilitate such collaborations and ensure their success.

"We have Sound Technology in shrimp farming, but we do not have sufficient technology in the hatchery, so we are focusing on technology sharing with other countries."

"We have to find the technology from other countries and expert knowledge should be transmitted and should get training from highly developed countries there are bottlenecks. Sometimes Government support should needed." (Director/NAQDA)

Developing partnerships with other countries could help to improve the skills and knowledge of local farmers and businesses, which would, in turn, increase production, efficiency, and profitability.

Create a Regulatory Framework

Creating a regulatory framework is an essential step toward ensuring sustainable aquaculture and mariculture operations. The framework should include laws and regulations that govern the types of species that are allowed to be cultured, the size and scale of operations, and the methods used. Additionally, there should be provisions for monitoring and enforcement to ensure compliance with the regulations.

"Regulatory functions (Prohibited Fisheries methods), Societies empowerment should be done." (Director/Research/ MoF)

"It is better if we can provide some concessions for exporters to export this kind of products and also we can import netting materials. Government intervention is very much needed for the Ornamental fish and plant industry to create the market within the country and outside the country" (Principal Scientist/Aquaculture/NARA)

Monitoring and enforcement of the regulations are crucial for the success of the regulatory framework. The government should ensure that there is a system in place for monitoring and enforcing compliance with the regulations to ensure that sustainable practices are followed.

"When we consider farmers, we introduced regulations for them. They lack knowledge. We informed them to do not to release dirty water into the Lagoons again, but they are doing so.

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It is essential to empower societies and farmers with knowledge and training to comply with the regulations. The government should also provide concessions for exporters and importers of aquaculture products to encourage growth in the industry.

"NAQDA has introduced a new act. Now brood stock cannot be taken from the sea. We have to take that from hatcheries. Earlier, people caught the mother fish from their lagoons and grew them. Now it is prohibited from only hatchery they can get the brood stock" (Principal Scientist/Ocean Resources/NARA)

"We have five years plan to develop shrimp farms, but there are problems in land clearance. We are now identifying suitable Lands for shrimp farming in Hambantota. We can produce around 20000 metric tons of shrimp. From shrimp farming, we are earning around 9.9 USD million. From sea cucumber we are exporting 100% of the sea cucumber since we are not consuming" (Director/NAQDA)

The introduction of new acts and regulations, such as prohibiting the capture of brood stock from the sea, is a positive step towards sustainable practices. The government should continue to identify suitable lands for shrimp farming and other aquaculture operations and provide support for land clearance.

Value Addition to The Production

The director of MoF stresses the importance of value addition to maximize the benefits of harvesting seaweed. This involves stocking, extension services, regulatory functions, and social empowerment.

"We are in basic step. Value addition should do for that. Stocking, Extension services, Regulatory functions (Prohibited Fisheries methods), Societies empowerment should be done." (Director/Research/ MoF)

"There are opportunities for value-added processing to occur at the site of harvest since this would allow much more of the benefits of seaweed harvest to be captured locally, the product extracted from seaweed being carrageenan." (Sectorial Officer, MoF)

"The value addition through local processing to intermediary products such as the Alkaloid Treated Chips (ATC) or semi-refined carrageenan (SRC) could have significant financial benefits." (Director/Research/ MoF)

The officials are discussing the potential for value-added processing of seaweed, specifically carrageenan, at the site of harvest in Sri Lanka. They believe that local processing would allow for more benefits to be captured locally and that value addition through local processing could result in significant financial benefits, such as the production of Alkaloid Treated Chips (ATC) or semi-refined carrageenan (SRC).

"Adding value to seaweeds can be done at the site of harvest, enabling local communities to capture more of the benefits. Processing seaweeds into intermediary products such as Alkaloid Treated Chips (ATC) or semi-refined carrageenan (SRC) can be profitable, as these products are worth more than five times the price of raw seaweed." (Sectorial Officer, MoF)

"China eats a lot of Sea cucumber. We gained more income in the past year, around 10 million US dollars, by exporting sea cucumber, but we are not focusing on value addition. also, shrimp need to process and chill, but we are not developed that as a ready-to-eat product." (Director/NAQDA)

The sectorial officer of the MoF promotes the local processing of seaweeds to capture more of the benefits. This includes processing into intermediary products such as Alkaloid Treated Chips (ATC) or semi-refined carrageenan (SRC) which could have significant financial benefits.

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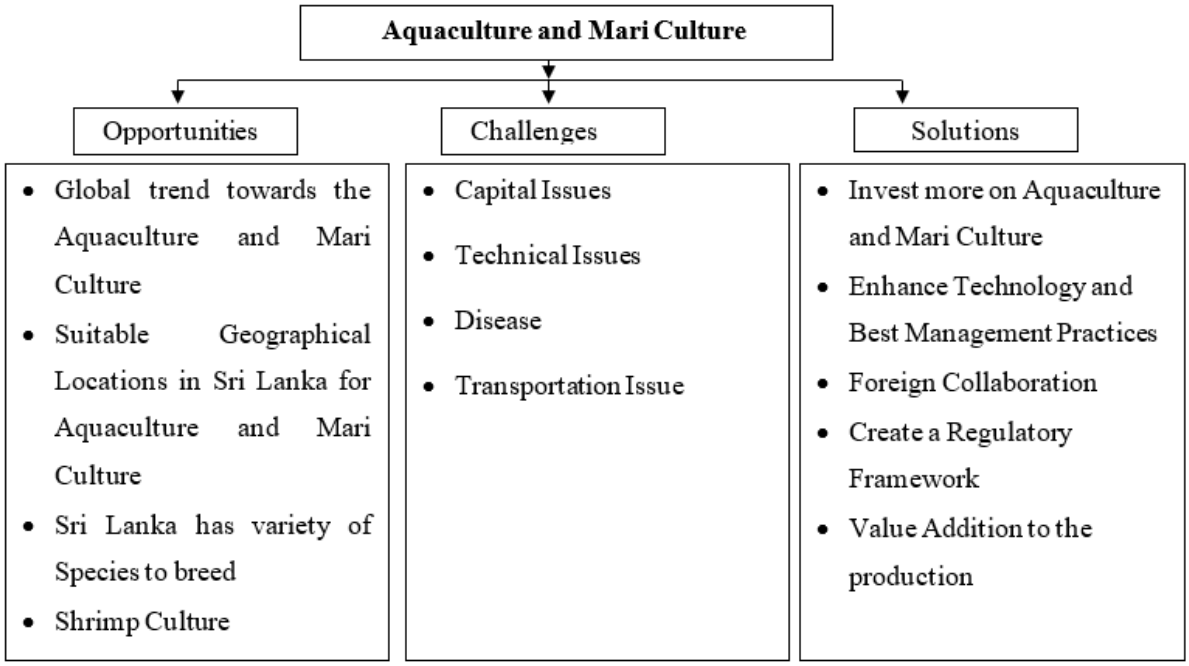
Table 1-Summary Of the Findings



Discussion

The findings from the interviews align with the available literature on the subject of aquaculture and mariculture. Globally, there has been a push towards sustainable aquaculture practices that are environmentally friendly and economically viable. Over the past few decades, mariculture, which is the managed cultivation of aquatic species in coastal waters, has become a growing industry worldwide and an increasingly prominent topic for discussion (Deepananda, 2011). Though a few species of mollusks, crustaceans, fishes, and seaweeds play a significant role in global mariculture, mariculture production has continuously increased during the past few decades, and the industry accounted for 54% of the world aquaculture production in 2004 (Deepananda, 2011). This includes using modern technology, best management practices, and regulatory frameworks to ensure that operations are conducted responsibly (FAO, 2020).

Some areas of the island possess sea depths, temperatures, ocean currents, and economically viable ports, making offshore aquaculture a promising prospect for Sri Lanka. Some private enterprises, with overseas assistance, have already begun to participate in this sector (Naveenan, 2018).

Locally, Sri Lanka has made efforts to develop its aquaculture and mariculture industry, focusing on promoting sustainable practices and increasing production. This includes initiatives such as the development of seaweed farming projects and the implementation of regulations to control the use of brood stock (Drengstig, 2020). However, challenges remain to be addressed, such as land clearance issues and the lack of knowledge among farmers.

In order to overcome these challenges and further develop the aquaculture and mariculture industry in Sri Lanka, the findings suggest the need for more significant investment in these sectors, both domestically and through foreign collaboration. This can promote modern technology and best management practices while creating opportunities for training and knowledge exchange. Naveenan (2018) identified that in order for the mariculture sector to develop and be sustained in the long term, proper management measures must be implemented by governmental bodies, including regulations on the issuing of licenses for aquaculture farms, in order to avoid a repetition of the uncontrolled shrimp farming that took place in the past. Disease,

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the primary cause of economic loss in the mriculture industry, is minimized through Best Management Practices (BMPs) (Deepananda, 2011). Moreover, environmental impacts from the industry have been minimized either at the planning stage or during operations. In addition to the governing directives, a new concept, i.e., creating marine Protected Areas (MPAs) adjacent to the mariculture installations, is being introduced to alleviate the pressure on wild biota (Deepananda, 2011). Additionally, any conflicts concerning the use of ocean space between different stakeholders must be resolved to benefit all involved. International collaboration with countries with a long-standing tradition of offshore aquaculture is essential in establishing a rapidly growing, long-lasting mariculture sector. Aquaculture business is viable in Sri Lanka, including offshore mariculture, albeit with limited production volume. If managed properly, it has the potential to become a significant contributor to the national economy while providing employment opportunities for rural populations (Naveenan, 2018).

Organic mariculture is a contemporary phenomenon in worldwide mariculture, and combined mariculture is anticipated to direct the sector toward an enduring future. The practicability of offshore mariculture has already been established, and novel technologies and research developments have become indispensable components in the ongoing proliferation of offshore mariculture (Deepananda, 2011). Innovations are constantly improving, which will lead to more positive mariculture development in the future, consequently helping to meet the ever-increasing global demand; thus, the Sri Lankan mariculture industry is likely to capitalize on the expansion of coastal aquaculture, leveraging the available technologies and innovations (Deepananda, 2011).

European commission (2017) identified the opportunities for the Aquaculture and maricultural sector in developing countries as the interest in aquaculture projects is growing, and there are opportunities for sustainable aquaculture development in developing countries.Challenges are there are no simple, universal solutions to developing sustainable aquaculture in all its different forms, and solutions indicated as national aquaculture extension programs should continue promoting proven aquaculture models and production technologies, and it is crucial to strengthen the nexus between biodiversity restoration, economic benefit, and livelihoods.

Growing demand for seafood presents an opportunity for the aquaculture industry to meet the increasing global protein needs and technological advancements and sustainable practices can lead to increased production and economic growth, also mariculture can contribute to food security and economic development, especially in coastal areas with suitable conditions for farming marine species (Liu, Molina, Wilson, & Peer, 2018; FAO Technical Workshop, 2010).Environmental impact and sustainability of aquaculture practices, Disease management and biosecurity measures to ensure the health of farmed fish. Environmental impact, such as habitat alteration and waste production, and site selection and management to minimize conflicts with other marine activities and protect natural ecosystems are the challenges (Liu, Molina, Wilson, & Peer, 2018; FAO Technical Workshop, 2010). Solutions are implementation of integrated multi-trophic aquaculture (IMTA) systems to minimize environmental impact, research and development of alternative feeds to reduce pressure on wild fish stocks and adoption of best management practices to minimize environmental impact, such as proper site selection and monitoring, collaboration between government, research institutions, and private entrepreneurs to develop effective strategies for sustainable mariculture (FAO Technical Workshop, 2010).

Overall, the findings suggest significant potential for the growth of the aquaculture and mariculture industry in Sri Lanka. However, this will require concerted government and private sector efforts to address the challenges and promote sustainable practices.

Theoretical Contributions

The research has significant theoretical implications across multiple domains of economic development. It sheds light on how developing countries, like Sri Lanka, can harness the potential of aquaculture and mariculture to achieve sustainable economic growth. Firstly, the research underscores the relevance of economic development models, emphasizing the role of diversification in the economy. By investing in aquaculture and mariculture, Sri Lanka can create jobs, boost exports, and bolster GDP growth.Secondly,

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the study aligns with theories of resource-based economic growth. Sri Lanka's coastal and marine resources offer tremendous potential for driving economic expansion. Efficient utilization of these resources through aquaculture and mariculture can significantly contribute to income generation and the strengthening of the country's economic foundation.Sustainability and environmental economics theories come into play as the research highlights the importance of sustainable practices in these sectors. It warns against overexploitation and environmental impacts, emphasizing the necessity of balancing economic growth with environmental well-being. Moreover, innovation and technology transfer theories find resonance in the research, stressing the role of modern technology and international collaboration in achieving growth in aquaculture and mariculture.The need for foreign collaboration and investor-friendly environments underscores the significance of foreign direct investment (FDI) and global economic interconnection, aligning with theories related to globalization trends and the impact of FDI on a country's economic development.

The research bridges traditional agricultural and fisheries economics with emerging aquaculture and mariculture sectors, indicating how these conventional sectors can adapt to changing economic and environmental landscapes.Additionally, the research emphasizes the importance of policy and regulatory frameworks in facilitating sectoral growth, which has implications for public policy theories.The focus on value addition and processing in these sectors contributes to theories of economic diversification, illustrating how enhancing the value of raw materials can promote economic growth and the creation of higher-value products.The research's concentration on rural areas, where aquaculture and mariculture operations are primarily located, has implications for theories related to rural economic development, job creation, and poverty reduction in these regions.Lastly, the research underscores the significance of global trade and market access, relating to theories of international trade and export-led growth, highlighting the pivotal role of market access in a country's economic development.

Practical Implications

Based on the findings and discussions, the following solutions are proposed to address the challenges faced by the aquaculture and mariculture industry in Sri Lanka.In order to expand the blue economy in Sri Lanka, it is recommended that the government improve access to capital, ensure a steady supply of seed and develop a regulatory framework that encourages best practices in the sector. Firstly, there should be a concerted effort to increase investment in these sectors and establish an investor-friendly environment that appeals to both local and foreign investors. This approach can help in securing the necessary capital for growth and innovation.

Secondly, it is crucial to prioritize the adoption of advanced technology and best management practices in aquaculture and mariculture. This can involve the integration of modern technology, the expansion of hatchery facilities, the implementation of buffer zones and biosecurity measures, and the introduction of best management practices. Sri Lanka should particularly concentrate on the development of sustainable aquaculture practices that minimize the environmental impact of these operations. This could encompass the utilization of recirculating aquaculture systems, improved waste management practices, and the incorporation of alternative feeds to ensure long-term ecological sustainability.

Lastly, Sri Lanka should actively promote foreign collaboration by establishing bilateral agreements with other nations, facilitating the sharing of technology, and offering essential training to enhance the knowledge and skills of local experts. This international cooperation can lead to valuable insights and advancements in the aquaculture and mariculture sectors, contributing to their overall success and development.

Future Research Directions

Expanding the blue economy in Sri Lanka involves developing sustainable and profitable fisheries, aquaculture and mariculture and marine and coastal tourism. Future research could focus on the areasof developing new technologies for mariculture, such as offshore aquaculture and seaweed farming, to increase production and reduce environmental impact, identifying new markets for mariculture products, assessing the economic impact of mariculture on the local communities and economy.

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Overall, future research in these areas can help Sri Lanka to develop a sustainable and profitable blue economy that benefits the local communities and protects the marine ecosystem.

Conclusion

The aquaculture and mariculture sector in Sri Lanka has significant potential to contribute to the blue economy. It has a range of opportunities for diversification, value addition, and investment in hatcheries and capture fisheries. The aquaculture and mariculture sector in Sri Lanka has excellent growth potential. However, it faces challenges such as technical issues, disease, transportation issues, lack of investment, limited best management practices, and inadequate regulatory frameworks. However, the stakeholders interviewed during this study provided various solutions to these challenges, such as investing in aquaculture and mariculture, enhancing technology and best management practices, foreign collaboration, creating a regulatory framework, and providing training and support to farmers. To overcome these challenges, the government should focus on investing more in the sector, enhancing technology, creating a regulatory framework, and adding value to production. The government and industry leaders need to consider these solutions and act to improve the sustainability and profitability of the aquaculture and mariculture industry in Sri Lanka. Collaboration among stakeholders and implementing effective policies and regulations can facilitate the growth and success of this industry while also ensuring the preservation of aquatic resources and biodiversity. With suitable investments, Sri Lanka could become a key player in the global aquaculture and mariculture industry, providing a sustainable and abundant source of fish for the world.

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