

DEVELOPING MARICULTURE IN PAKISTAN



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ACRONYMS

ANF	Anti-nutritional Factors
AQD	Animal Quarantine Department
BAAC	Bank for Agriculture and Agricultural Cooperatives
BKD	Bacterial Kidney Disease
BRI	Belt and Road Initiative
CCP	Critical Control Point
CCFAM	Canadian Council of Fisheries and Aquaculture Ministers
CPEC	China Pakistan Economic Corridor
DNA	Deoxyribonucleic Acid
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization of the United Nations
FDB	Fisheries Development Board
GDP	Gross Domestic Product
GIS	Geographic Information System
HACCP	Hazard Analysis and Critical Control Point
KHV	Koi Herpes Virus
LPG	Liquid Petroleum Gas
MFF	Mangroves for the Future
NACA	Network of Aquaculture Centers in Asia-Pacific
NASAPI	National Aquaculture Strategic Action Plans Initiative
NGO	Non-Governmental Organization
NIMA	National Institute of Maritime Affairs
NPMF	National Policy on Marine Fisheries
OSH	Occupational and Safety Hazards
PBM	Poultry Byproduct Meal
SAR	Special Administrative Region
SPC	Soy Protein Concentrate
SPF	Specific Pathogen Free

SPG	Seafarm Pulse Guard
SPS	Sanitary and Phytosanitary
SUPARCO	Space and Upper Atmosphere Research Comission
UAE	United Arab Emirates
USD	United States Dollars
WSSV	White Spot Syndrome Virus
WTO	World Trade Organization
WWF	World Wide Fund for Nature
YHV	Yellow Head Virus

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EXECUTIVE SUMMARY

1. Pakistan has vast potential for mariculture with a coastline of over 1000 km; however, it lags far behind neighboring countries in this area. Developing mariculture in the country could serve as an effective means to enhance the production of marine organisms, which, given results of the stock assessments along the country's coast, is no longer possible through wild capture fisheries. Furthermore, the development of mariculture in the country could have vast benefits for the socioeconomic status of communities living along Pakistan's coast.
2. The purpose of this study was to investigate the reasons for fall-outs in the past, analyzing the challenges in developing mariculture in Pakistan and putting forward policy recommendations based on the best-practices for mariculture around the world. The report examined various avenues for Pakistan to develop mariculture in a way that aligns with its social, economic and environmental objectives.
3. The concept of mariculture is not new to Pakistan. Mariculture was introduced to Pakistan somewhere between 1910 and 1930. Although experiments have been conducted by various research institutes, Fisheries Department and other private organizations but Pakistan has no remarkable commercial history for production of sea food/marine species through mariculture. In the past, crab fattening and the farming of oyster, shrimps and fish has taken place in the country. Currently, no mariculture related practices are taking place in the country, except for crab fattening on the community level.
4. Pakistan has ideal marine environmental conditions to support mariculture, however, due to the lack of a proper value chain in the country, many mariculture projects have not been able to meet their potential. While policies are being put into place for the development of mariculture in the country, it is crucial to ensure the development of this industry without being damage to other goods or resources. The challenges while developing mariculture in Pakistan include additional pressure on resources, threats to public health, destruction of natural resources, increase in marine pollution, the transfer of disease to wild populations, and other concerns regarding fish welfare.
5. Major recommendations of the report are as under:
 - a. This study recommends that mariculture in Pakistan requires extensive planning. Spatiotemporal planning is a vital pre-requisite to develop mariculture in Pakistan.
 - b. Thorough risk assessment is also necessary before developing mariculture on selected sites. Species that are in demand in local and export markets should be stressed upon and the culture of economically important species such as the Specific Pathogen Free (SPF) White Leg Shrimp (*Litopenaeus vannamei*) should be focused upon.

c. At potential mariculture sites, basic infrastructure, access roads, electric supply, and allied services be developed. Federal and Provincial governments should invest on infrastructure and other services.

d. The development of a local value chain is vital to ensure profitable mariculture. It is crucial to build and develop fish hatcheries near sites, improve the feed processing plants' production quality.

e. Coastal communities be engaged in mariculture activities for their socioeconomic welfare.

f. Awareness about the benefits of mariculture and the best-practices in its development are also necessary at both, the consumer and developer level, this includes awareness regarding potential employment, related to alternatives to fishmeal such as insect meal, soy protein concentrate, poultry-by product meal, blood meal, etc.

g. Flexible training workshops and short courses for hatchery, nursery and aquatic farm workers are critical to growing a workforce with the skills necessary for a competitive industry.

h. Government should promote good management and legal institutional arrangements for sustainable mariculture.

i. As facilities on boats are not suitable enough for the preservation and transportation of fish, it is also important that consumers know about the faster farm-to-table distribution channels.

j. To ensure the welfare of organisms and efficiency and safety of mariculture practices, it is necessary to form supervisory bodies that would visit mariculture sites regularly and suggest better mariculture practices.

k. The study identifies the need for a local value chain to support mariculture, the importance of risk assessments at different levels while planning for mariculture and the necessity of monitoring technologies while developing mariculture in the country.

l. Development of an interactive GIS mapping tool which layers relevant existing oceanographic, satellite, and social data and allows users to analyze new sites for productivity, conflicting uses, and efficiency would help reduce risks for new businesses to enter mariculture.

Further research is needed regarding consumer preference for mariculture products in Pakistan and in foreign countries, when the producer is Pakistan.

CHAPTER 1

INTRODUCTION TO MARICULTURE

The problem of fishing in excess throughout the world has led to various environmental and socioeconomic issues in marine waters; it has been responsible for decreases in biodiversity and has altered the functioning of ecosystems (Jackson et al., 2001; Lotze et al., 2006; Worm et al., 2006). The trend in global capture fisheries, including freshwater fisheries, since the 1980s has generally been stable, varying between 86 million tonnes and 93 million tonnes annually, however, it peaked at its highest recorded level at 96.4 million tonnes in 2018, this was mostly the result of excessive capture fisheries from the marine environment. The number of marine fish stocks extracted within biologically sustainable levels had decreased from 90% in 1974 to 65.8% in 2017, out of which, 59.6% were fished to their sustainable limit and only 6.2% were under fished (FAO, 2020a).

In some parts of the world, well-managed fisheries have led to an increase in biomass of the stock, causing depleted stocks to replenish while poor fisheries management systems have resulted in an unfortunate state for the fisheries. Well-managed stocks in some regions of the world have not been enough to compensate for lost stocks throughout the globe. There is a dire need for countries struggling to manage their coastal fisheries to learn by example and for new policies and regulations to be formulated (FAO, 2020).

Mariculture has been defined as the cultivation, management, and harvesting of marine organisms in their natural environment or close reservoirs such as tanks, or channels. The range of organisms cultured includes seaweeds, mollusks, crustaceans, fish, and, a more recent development, echinoderms. As with all forms of aquaculture, operations range from extensive to highly intensive. At one extreme, extensive mariculture is simply based on the protection of the stock to improve survival rates of wild juveniles, with few or no nutrients supplied; at the other extreme, intensive mariculture may take place in an enclosed system where all nutrients are provided by the farmer. Other forms of mariculture include ranching, in which juveniles produced in a hatchery are released into the marine environment where they feed and grow in the same way as their wild equivalents (Laird, 2001).

Mariculture is one of the fastest-growing techniques for food-producing industries in the world. Globally, the scale and production of mariculture have expanded rapidly to fulfill the protein demand for an ever-increasing population to achieve the United Nations' sustainable development goals. Geographically, mariculture is distributed worldwide, with production concentrated in specific countries including China, Indonesia, India, Norway, Chile, Japan, and Scotland,

amongst which China is by far the largest producer (20.65 million tons in 2019) (xinyan wang et al., 2020).

During the last three decades, global wild-caught fish roughly increased from 69 million to 93 million tons. But 85% of the world's fisheries are either being fished at full capacity or already overexploited, depleted, or recovering. The world's human population is expected to reach 9.7 billion by 2050 according to the 2015 UN revision of world population prospects. Despite substantial efforts to improve fishery management, global fisheries will continue to experience pressure to meet future demand. In the meantime, aquaculture has grown at an impressive rate. Global aquaculture production rates increased from 5 million to 63 million tons and are expected to grow further over the period 2014-2024. Since 2014, it has been contributing more to the supply of seafood for human consumption than capture fisheries. Furthermore, the number of hunger-stricken people worldwide has gradually been rising since 2014; if things are to continue as they were, it is expected that this number will go above 840 million by 2030. Food insecurity can lead to a lower-quality diet and can cause people to become malnourished, undernourished, overweight, or obese (FAO, 2020b).

Mariculture has been gaining momentum during the past few years in the world as well as in the South Asian region. The overall aquaculture market value as per production was estimated at \$38 billion as of 2010. At present over 80% of amenities for mariculture are located just within 1-7 km from the coast, where their environment impact is on the land as well as the marine environment (FAO 2020a). In Pakistan, aquaculture contributes 1% to Gross Domestic Product (GDP). Due to limited culture, majority of contribution is from capture fisheries. Fisheries contribute significantly to employment, income, and food production and are considered important for the national economy of Pakistan. The government imports fish from China, Myanmar, Viet Nam, Singapore, Thailand, and Burma. In general, aquaculture is practiced on a small scale in areas where the land is not suitable for agricultural purposes.

Pakistan has a great potential for aquaculture for economic development that offers numerous opportunities including livelihood to local communities, contribution to food production, training and management staff, conservators, researchers, ecologists, and business and other jobs through offering different types of aquaculture systems such as integrated aquaculture, cage culture, bait culture, ornamental fish culture, export and import of fisheries product, integrated aquaculture, intensive aquaculture, and culture-based fisheries. However, Mariculture in Pakistan has been limited to a few experiments and quasi-commercial scale operations leaving Pakistan far behind not only the rest of the world but also its neighboring countries. Recently, the government has paid serious attention to mariculture development through the Department of Fisheries and Donor funded projects. At the same time, Fisheries Development Board is also established to promote aquaculture and fisheries in Pakistan (Laghari, 2018).

CHAPTER 2

IMPORTANCE OF DEVELOPING MARICULTURE IN PAKISTAN

2.1. Mariculture as a Solution for the Conservation of Organisms along Pakistan's Coast

Pakistan's wild fish stocks have been noted to decrease over time. The most commercially valuable demersal groups including snappers, groupers, grunters, croakers, soles, and shrimp have all reduced, in some cases by 90% or more. Furthermore, many small organisms are caught and sold as fishmeal (Fanning et al., 2016).

Various indicators of fishing pressure and ecosystem degradation have been seen in Pakistani waters, including the increased abundance of opportunistic, fast-growing, and small species such as threadfin bream and lizard fish, which demonstrates the lack of top predators. Ecosystem disturbances may also be indicated by the abundant and diverse catches of cephalopods including squids, cuttlefish, and jellyfish. These cephalopods could later be a threat to juvenile fish and shrimp, interfering with the rebuilding of stocks of commercially valuable species.

Mariculture may serve as an effective means of preserving Pakistan's biological resources not only by enhancing production but also by reducing harms such as by-catch and habitat destruction that occurs as a result of capturing fish from the wild; however, some conservationists today do not consider mariculture to be a means of conservation. They may hold this point of view due to several reasons. In order to build shrimp farms, local mangrove areas must be cleared (Silva, 2012). Organisms that escape from mariculture structures could harm the local species by introducing new genes in the offspring after mating with the local population (Naylor and Burke, 2005; Naylor et al., 2009), carnivore fish species require forage fish to be extracted from the sea for feed adding food for the fish and fish waste may cause the local marine environment to become contaminated (Islam, 2005; Sara, 2007). However, with time, technology and practices for mariculture have improved and the environmental harms and risks have been mitigated (Edwards, 2015).

Two different types of scales for conservation via aquaculture exist including species-level conservation and ecosystem-level conservation. Species-level conservation can be practiced by minimizing pressure on wild stocks, enhancing at-risk populations, and/or restoring critical habitats (Froehlich et al., 2017a). Some stocks of wild populations such as oyster and carp species have increased as a result of aquaculture practices (Diana, 2009; Jiang, 2010). Whether conservation through aquaculture for consumptive species will be successful or not depends on

other factors including consumer preference, market dynamics, and management approaches (Froehlich et al., 2017b).

The other type of aquaculture practiced for conservation is ecosystem-level conservation. Cultivated oysters, seaweeds, seagrass, and mangroves have the capability of improving water quality (Humphries et al., 2016), coastal defense, carbon sequestration (Greiner et al., 2013), and essential habitat for wild species. In open-systems, farms can serve as a means of habitat and energy for endangered organisms in the surrounding environment (Akyol and Ertosluk, 2010; Dempster et al., 2009; Fernandez-Jover et al., 2011; Hehre and Meeuwig, 2016; Pitta et al., 2009). However, this may also depend on the environment and could have a positive effect on some wild organisms while it could harm other organisms (Hehre and Meeuwig, 2016).

To utilize mariculture as a means for conservation in Pakistan, initially, highly threatened and over-exploited species need to be identified; other than this factor, consumer preference, market dynamics, and management strategies also need to be taken into account.

Although mariculture may not be the solution to all of Pakistan's marine conservation problems, if planned properly, it could be included in the fight to save the depletion of Pakistan's valuable marine species.

2.2. Mariculture as a Solution for Food Security in Pakistan

Generally, any person needs satisfactory health, a good environment, and food for a sustainable life and better survival, but this greatly depends on the economic and social health of the nation and society that the individual belongs.

Fish plays an important role in the diets of people. It is a rich source of vitamins, minerals, essential fatty acids, and high-quality proteins. Billions of consumers belonging to low and middle-income countries depend on fish for their dietary needs. While fish is not a solution to food security in Pakistan, by producing affordable fish locally, mariculture could potentially reduce hunger in Pakistan.

In developing countries, with the development of mariculture, the consumption of farmed fish rapidly increased in poorer households, which were sensitive to food prices, hence this resulted in a decline in the quantity of wild fish eaten across the world. Consequently, an increase in the quantity of farmed fish has been observed, the real price of farmed fish adjusted for inflation in these states, and the quantity of fish consumed by poorer consumers has increased.

2.3. Socioeconomic Importance of Mariculture in Pakistan

The development and growth of aquaculture in the future could have significant social and economic impacts on Pakistan.

The development of mariculture will significantly benefit coastal communities. If the aquaculture industry is promoted and developed, it will be a major form of alternative earnings and will be a major income opportunity for coastal communities as well as unskilled workers living in coastal and hinterland towns. Between 1998 and 2014, 50 unskilled fishermen were engaged in crab fattening. Aquaculture at the community level will help in disaster risk reduction for communities living in isolated islands and villages in the Indus delta and other vulnerable areas. In Bangladesh, around 70% of the income from aquaculture is generated from estuarine areas. The Indus estuary, Miani Hor and Kalamat Khor have almost similar habitats (NIMA, 2020).

Developing mariculture in Pakistan will also result in the development of new ancillary industries and ultimately lead to the creation of many jobs for tasks such as building cages, ready-to-install nets, rafts, feed barges installing cages, cleaning nets, husbandry maintenance, fish feeding, transportation, seed collection, etc. A significant social impact of improved aquaculture will be achieving healthy dietary patterns; this will come about with the help of large transformative changes in the food systems at all levels.

CHAPTER 3

MARICULTURE IN PAKISTAN

3.1. Organisms used in Mariculture in Pakistan

The last mariculture activity in Pakistan was the pen culture of seabreams in the Hub Estuary, however, due to heavy rain and the opening of the spillway of the Hub Dam, all of the stocked seabreams were wiped out. Currently, crab fattening on the community level is the only type of mariculture being conducted, however, it is on a very small scale (NIMA, 2020). In the past, shellfish, marine fish, and crustaceans have been cultured in the country, details of which are given below.

3.1.1. Mariculture of Molluscs

Oyster culture where Pakistan stands now began somewhere between 1910 and 1930.

During this time, the British government appointed a one-man Commission to look into the causes of decline of oysters in Karachi and Sindh. The commission recommended that the production of oysters should be enhanced via spat collection and subsequent growth in natural water bodies; therefore, tiles made of adobe were utilized for the collection and growth of spat in some creeks in Karachi. Some of these tiles are still present at Younas Abad, opposite of Pakistan Navy Hovercraft base.

As fisheries were under the customs department at the time, this activity of sea ranching was also undertaken under the customs department. After the creation of Pakistan, this activity almost came to a standstill since the consumption of oysters is not prevalent in Pakistan, however, an oyster park was inherited by the Central Fisheries Department (now known as the Marine Fisheries Department) and was in operation till 1984. Oysters used to be collected from various creeks' beds, placed in the oyster park to grow and were subsequently sold to hotels in Karachi. The major purchaser of these oysters was the Palace hotel (Killarney hotel at the time), a hotel inhabited by individuals from the United States. With the closing of this hotel in the early 1970s, the sale of oysters declined, halting the oyster park's activities in 1984.

Attempts to culture oysters on rafts were also conducted by the Center of Excellence in Marine Biology from 1975 to 1980 without any major success.

The Department of Fisheries, Government of Sindh with the assistance of the Sindh Coastal Development Authority established the raft farming of oysters in Keti Bundar and Ambra Creek, however, despite successful farming, this product could not be marketed, resulting in the project's failure.

With a very high production, the oysters produced could not be sold in the local market due to no domestic demand or in the international market as oysters are a very cheap product with very low meat content (NIMA, 2020).



Figure 3.1. Raft culture of oysters at Ketu Bundar by Sindh Fisheries Department (NIMA, 2020)



Figure 3.2. Raft culture of oysters at Ambra Creek by Sindh Fisheries Department (NIMA, 2020)



Figure 3.3. Raft culture of oysters at Ambra Creek by Sindh Fisheries Department (NIMA, 2020)

3.1.2. Mariculture of Marine Finfish

A pilot scale cage culture of fish was experimented upon in the coastal areas of Pakistan. It was successfully practiced in the Sonmiani area. Cage culture was piloted at Damb in collaboration with the Coastal Association for Research and Development (a local CBO). Pilot scale farming was initiated in two HDP cages at Miani Hor and Ketī Bundar under FAO/Telefood which was based on locally available species including groupers, barramundi and snappers. Due to the theft of the construction material, these initiatives could not be successful (NIMA, 2020).

Attempts for pen culture have been made by the Sindh Fisheries Department, the local community and the Fisheries Development Board, however, none of these have been successful. An attempt for pen culture was also conducted in Damb (Sonmiani) by one local entrepreneur Haji Ali, who established two 10-acre pens in November 2000; the first harvesting was done in October 2006. The harvesting yielded approximately 11 metric tons of large groupers, snappers, trevallies, mullets, seabreams and other fish. Since the production was much lower than the expectations of the operator, he decided to abandon the operation. These pens are now used as parking for fishing boats (NIMA, 2020).

A fish pen farm was established by FDB in the Hub River Estuary (NIMA, 2020). One pen farm was established here with multiple net happa. Seabass and milkfish were cultured. In the first year, the crop was lost as a result of a cyclone. The next year, due to the rain, the Hub River's spillways opened, carrying trees and bushes into the estuary, again resulting in the loss of the crop.



Figure 3.4 Cage culture at Miani Hor (NIMA, 2020)



Figure 3.5. Cage culture under FAO/Telefood (NIMA, 2020)



Figure 3.6. Cage Culture under FAO/Telefood-Keti Bundar (NIMA, 2020)

3.1.3. Mariculture of Crustaceans

In 1980, the Sindh Government began the pond culture of shrimp in Pakistan under the First Aquaculture Development Project, funded by Asian Development Bank. Demonstration shrimp farms at Garho on Ambra Creek were to be established. The Government of Sindh allocated land to approximately 82 potential shrimp farmers to start shrimp farming. Only a few were able to acquire land for farming. Of these, 4 parties established their farms but halted their operations after harvesting one or two crops (NIMA, 2020).



Figure 3.7. Shrimp Farms in Sindh (NIMA, 2020)



Figure 3.8. Alam Baloch Shrimp Farm (NIMA, 2020)



Figure 3.9. Lipton, Sharif and Government of Sindh farms (NIMA, 2020)



Figure 3.10. Shrimp Farming at Garho (NIMA, 2020)

The closure of one of the private enterprises, Lipton's Farms caused the other 82 farmers who had been given land to become skeptical about the success of

shrimp farming in Pakistan. Lipton was quite successful in its farming operations; their farming was based on tiger prawn and they were importing feed, despite this they managed to produce a significant amount of 24m tonnes. Lipton closed down its operation throughout Asia due to a glut in the international shrimp market. Later, attempts to culture shrimp at Garho were conducted again under a pilot-scale operation. Less than 200 kg of shrimp were produced as a result (NIMA, 2020).

In 1993, the National Institute of Oceanography (NIO) cultured approximately 100 kg of shrimp at Mirpur Sakro in a pilot-scaled attempt. M/S Habib Arkady (Pvt.) Ltd produced 6 metric tonnes of shrimp in Hub Chowki, earning 16,000 USD in export (NIMA, 2020).

The Balochistan Government also established a Shrimp Farming Promotion Committee and approved the Shrimp Farming Policy. The Shrimp Farming Policy aimed to enhance economic development, create employment, replenish depleting stocks, develop and disseminate low-cost technology for shrimp culture, promote shrimp farming and trade in the Province, and utilize wasteland along the coast. This policy is applicable both for state and private lands. The policy also addresses the importance of sustainable ecosystems while developing mariculture by means such as not allotting or utilizing the inter-tidal area for shrimp farming. It sets the scope of the lease and restrictions. Furthermore, it offers mechanisms for technical assistance to potential fish farmers.

A project entitled 'Aquaculture and Shrimp Farming' at a total cost of Rs. 2.0 billion was implemented in 2008 (NIMA, 2020). The Fisheries Development Board was established under this project and was led by the private sector. The establishment of 13 shrimp demonstration facilities, with 8 in Balochistan and 5 in Sindh was planned. A detailed survey for the first demonstration facility at Jiwani (Panwan and shrimp Okar) was conducted. The survey revealed that only a small area was suitable for farming, therefore, the site was not considered optimal. A shrimp hatchery building was established at Okar, Jiwani under the project. Due to the 18th Amendments to the Constitution of Pakistan, the Aquaculture and Shrimp Farming project was abruptly closed; this was a serious blow to shrimp farming in Pakistan (NIMA, 2020).

The Fisheries Development Board started another project amounting to 178 million, funded by the Export Development Fund, Ministry of Commerce in 2014. The project started with the construction/improvement of 12 shrimp ponds of 2.5 acres each, lined with a geo-membrane. During the project's period, four private companies participated in shrimp farming operations. The first crop of 70 tons was produced in 2015, for which imported shrimp seed and feed were utilized. In 2016, another crop of 55 metric tons was harvested for which feed was procured locally. The shrimp was sold to a processor in Karachi, who further exported these shrimp to the UAE. In subsequent years, only 2 metric tons of shrimp were produced. Attempts were made to farm the shrimp, *Penaeus vannamei*, in highly saline waters

in Muzaffargarh, but due to the mortality in imported seed and the high cost of the feed, operations were halted (NIMA, 2020).



Figure 3.11. Fisheries Development Board aquaculture facility in Dariya Pir (NIMA,2020)

The five shrimp hatcheries of Pakistan are mentioned below:

1. Government of Sindh Hatchery at Hawksbay
2. Marine Fisheries Department Hatchery at Hawksbay
3. National Institute of Oceanography Hatchery at Sonmiani
4. Center of Excellence Hatchery at Sonmiani
5. Government of Balochistan Hatchery at Okar, Jiwani



Figure 3.12. Marine Fisheries Department's Shrimp Hatchery (NIMA, 2020)



Figure 3.13. Spawning Tanks of Shrimp (NIMA, 2020)

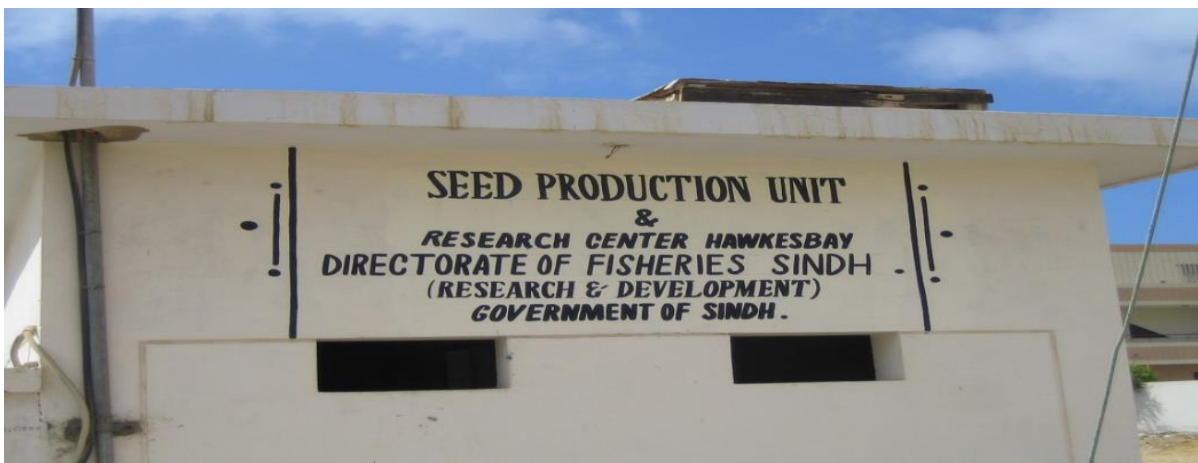


Figure 3.14. Sindh Fisheries Department's Shrimp Hatchery (NIMA, 2020)



Figure 3.15. Larval Rearing Tanks of Shrimp (NIMA, 2020)



Figure 3.16. Seawater Storage and Filtration Tank (NIMA, 2020)



Figure 3.17. National Institute of Oceanography's Shrimp Hatchery (NIMA, 2020)

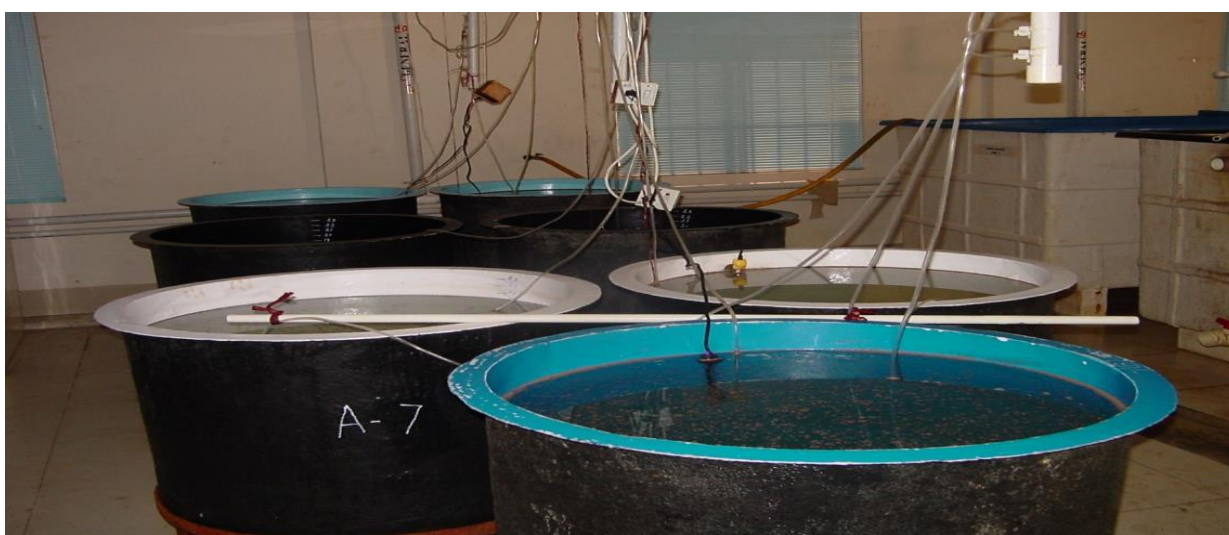


Figure 3.18. Live Food Culture Tank (NIMA, 2020)

All of these hatcheries were operational except for the Okar hatchery and produced seeds of local shrimp species. None of these hatcheries are currently working, however, are still available and able to support the aquaculture industry (NIMA, 2020).

Shrimp farming operations in Pakistan have been successful as a result of favorable land, environment and water. However, Pakistan cannot still conduct shrimp farming on a commercial scale. This is due to various reasons including the lack of proper infrastructure, electricity, and a proper value chain.

Salinity increases in creeks and reservoirs as water evaporates in the summer. This also results in an increase in the salinity of the ponds as water moves from the reservoirs to the ponds. Selecting a site where freshwater supply is available can mitigate this issue. Furthermore, compensating for the lack of electricity through a generator is not cost-effective. Moreover, seed and feed are not available in Pakistan and must be imported from Thailand or elsewhere. Although the production of fishmeal has been attempted in Lahore, the quality was not up to the mark. People have, however, been investing in their feed mills to produce quality shrimp feed in large quantities, indicating that Pakistan may have local feed soon. The availability of sites where suitable land, electricity, and roads are available are very few in the country (NIMA, 2020).

With the introduction of Pacific shrimp in Pakistan, production can be increased tenfold. If all goes well, Pakistan has the potential of producing up to 120,000 metric tonnes by the year 2030 (Table 3.1).

Table 3.1. Potential of Shrimp Farming in Pakistan (NIMA, 2020).

Year	QUANTITY (m.tons)	Value (m. US \$)
2020-2021	Nil	Nil
2021-2022	1,500	6.750
2022-2023	5,000	25.00
2023-2024	11,000	55.00
2024-2025	27,000	148.00
2025-2026	44,000	242.00
2026-2027	57,000	313.50
2027-2028	69,000	379.50
2028-2029	80,000	440.00
2029-2030	120,000	660.00

The potential shrimp/fish farming areas are as shown on the map below:

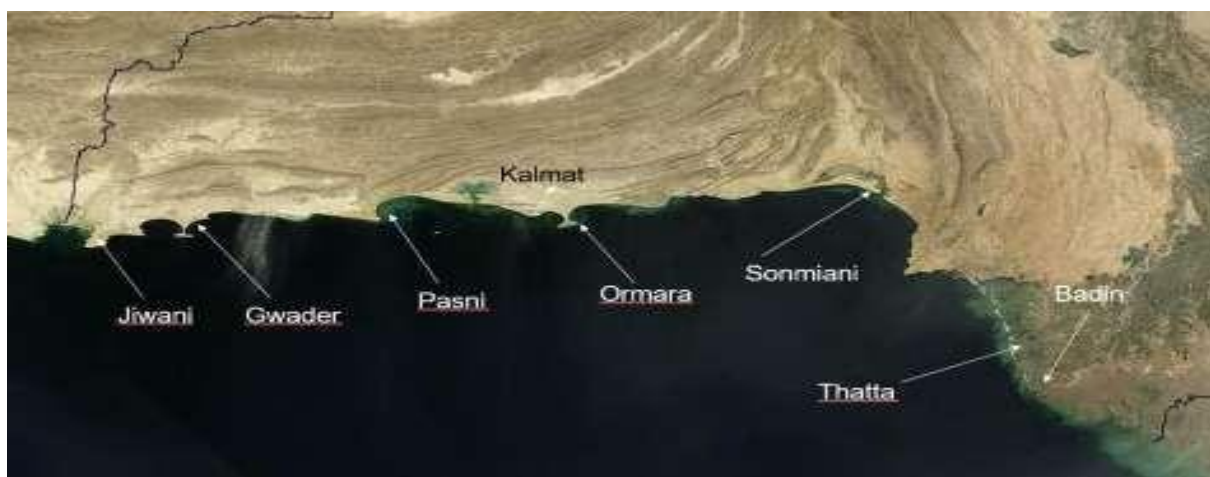


Figure 3.19. Potential Shrimp/Fish Farming Areas in Pakistan (NIMA, 2020)

Crab fattening was introduced in Pakistan in 1997, with farms established in Garho. Juvenile crabs were collected from mudflats and placed in ponds to fatten. These crabs consumed fish and shellfish. In the summer, fattening required 15 days and in the winter, it required 3 months. Previously, it was a large- scale operation. There was a time when approximately 8 tonnes of crabs were exported every day (NIMA, 2020). In addition, community-level crab fattening started at Ketu Bundar and other areas of the creeks as well.



Figure 3.20. Crab fattening in Pakistan (NIMA, 2020)



Figure 3.21. Crab fattening in Pakistan (NIMA, 2020)

3.2. Types of Mariculture Production Systems used in Pakistan

As mentioned above, Pakistan has 5 hatcheries, which are currently non-functional. Past mariculture attempts in Pakistan have mainly consisted of cage culture systems, a few pen culture systems and mudflat cultures for crab fattening (pictures shown above).

3.3. Development of Sustainable Resources

3.3.1 Sustaining Land and Water Resources

The land and water resources of Pakistan include mangrove forests. Mangroves are salt tolerant plants including trees and shrubs, found in tropical areas. They naturally occur in sheltered, coastal areas, such as river mouths, creeks, backwaters, lagoons, bays and estuaries, where freshwater meets seawater. Mangroves forests are included in one of the world's most productive ecosystems. In Pakistan, mangroves are abundant in the Indus Delta, constituting 97% of the total mangrove cover in Pakistan; the remaining mangroves are found along Balochistan's coast, Miani Hor, Kalamat Hor and Jiwani (MFF, 2016).

8 species of mangroves were initially found in the Indus Delta; 4 of these species have, however, become extinct due to increasing levels of salinity. *Avicennia marina* is the most dominant specie out of these, accounting for 90% of all the mangrove species found within Pakistan (MFF, 2016).

There are three mangrove species along the Makran coast. Miani Hor is the only area where three mangrove species occur naturally. These species include *Avicennia marina*, *Rhizophora mucronata* and *Ceriops tagal*. Only *Avicennia marina* grows in Kalamat Hor (Pasni) and Gwatar (Jiwani) Bay (MFF, 2016).

Mangroves have historically occupied most parts of the Indus Delta. During 1958, an area of 344, 846 ha with mangroves, mudflats and water channels were placed under the control of the Sindh Forest Department.

The Sindh Forest Department carried out an assessment in 1985 using Landsat Data and ecological surveys; this survey demonstrated the mangrove area reduced to 280, 470 ha. In 2003, SUPARCO further revealed that the total mangrove area reduced to 86,728 ha (MFF, 2016).

In 2008-2009, WWF estimated an area of approximately 98,128 ha, out of which 92,412 ha (94%) were present in the Indus Delta; 1,056 ha in the Sandspit area along the Karachi coast and the remaining 4, 660 ha of mangroves were present along the Makran coast. In 2009, an assessment by the Sindh Forest Department revealed an area of approximately 107, 000 ha in the Indus Delta, demonstrating a slight increase in the mangrove cover (MFF, 2016).

Several agencies manage mangroves in Pakistan including the Sindh Forest Department, Port Qasim Authority, Karachi Port Trust and Defence Housing Authority. Mangroves along Balochistan's coast do not have any legal status, other than 294 hectares of mangroves in Miani Hor, which was declared as a "Protected Forests" in 1958 and is under the administrative control of the Balochistan Forest Department. The remaining areas are either under communal property or with the Balochistan Board of Revenue (MFF, 2016).

Until recently, mangrove systems were considered to be wastelands, however, since their social, economic and environmental significance has been realized, efforts to conserve these natural ecosystems have enhanced. Efforts are taking place at both regional and local levels for the protection and restoration of mangroves. Efforts for the rehabilitation of mangroves have been conducted by Government Agencies, International Organizations, local NGOs and Coastal Communities (MFF, 2016).

Mangrove ecosystems within Pakistan are already under threat due to a number of reasons including the reduction in the inflow from the river Indus, the construction of barges and reservoirs, pollution, cutting for wood for fuel and livestock grazing, especially for camels (MFF, 2016).

The loss of mangrove forests as a result of the development of mariculture on these sites may have detrimental environmental and socio-economic consequences. These include reduced reproduction and availability of commercially important fish; loss of a nutritious food source for communities dependent on fish and fish-based products; increased coastal erosion, causing damage to coastal villages and agricultural land through saltwater intrusion and contamination of groundwater; reduced availability of wood for local communities; loss of faunal and floral biodiversity; silting up navigational channels, ports and harbours.

In order to protect the precious mangrove environments found within Pakistan, it should be ensured that mariculture structures are made after the intertidal zone and sufficient spatiotemporal planning is done in advance in order to mitigate the risks mariculture could potentially have on the environment.

It is also vital to ensure the health of the marine environment by limiting marine pollution caused by external additions such as antibiotics, drugs, chemicals, etc. into open water mariculture systems.

In Pakistan, coastal pollution is already caused due to factors such as untreated industrial effluents, municipal sewage and oil spills. Chemical additions into mariculture systems may further add to the chemicals found in these effluents, causing eutrophication, deposition within the sediment and accumulation in organisms residing within these waters, potentially also affecting humans through the food chain.

3.3.2. Post-Harvest Practices

Although the waters of Pakistan produce fish of good innate quality, much fish is lost due to unsatisfactory post-harvest practices during storage, processing and packaging. Fishing vessels in Pakistan often stay out in sea for long periods at a time with poor facilities for storage on board. Fish are placed on unhygienic ice on board vessels that usually stay at sea for up to 2 weeks. After landing, fish are placed on the floor, causing the fish to rot in the sun and put up for auction and transported without adhering to proper Hazard Analysis and Critical Control Point (HACCP) procedures. Advancements in processing as well as refrigeration, ice-making and transportation throughout the world have led to a variety of product forms and have made the distribution of fish over long distances possible. The nutritional attributes of fish can also vary according to the way fish are processed and prepared. Capital investment is needed for value addition, particularly to enhance the quality of aquaculture products (Patil et al., 2018).

3.4. Spatiotemporal Analysis

3.4.1. Spatial Analysis

Although spatial planning is vital to ensure the successful development of mariculture in Pakistan, it is not being practiced in the country. Spatial planning is crucial in order to protect the natural environment and to mitigate harms such as the destruction of mangroves. Furthermore, spatial planning could also assist in identifying areas with the most suitable infrastructure; this is vital in order to maintain the quality of the products obtained through mariculture. The Fisheries Development Board has planned to conduct this study (NIMA, 2020).

3.4.2. Temporal Analysis

Proper attention is also not being paid to temporal analysis while setting up mariculture in Pakistan. Temporal analysis is necessary to study the external factors which change over time such as population growth, development, global trade and climate change, which could affect mariculture practices at the site it is developed in in the long run.

3.5. Capacity Building for Mariculture

3.5.1. Human Capacity Building

Skilled manpower for mariculture is not available in Pakistan. There is a shortage of mariculture engineers and skilled workers who can install and clean mariculture structures, maintain husbandries, acclimatize seeds, nurse seeds, transport live fish, plan for resources, monitor practices and resolve conflicts.

The successful development of mariculture in Pakistan requires strong links with academia. This will ensure that potential farmers are able to receive adequate hands-on training and to be well-versed with the best mariculture practices before

entering into the field; furthermore, education in the field will enable the labor force to be more aware about the needs of the specific species being cultured, thus enhancing production and ensuring species' welfare.

There is a need to hire experts in the fisheries departments with special education in and training in mariculture.

3.5.2. Institutional Capacity Building

Countries including Pakistan usually develop and support their mariculture sectors from their fishery institutions and organizations. Although this may be useful from biological, marketing and food quality perspectives, linkages should also be strengthened with institutions dealing with agriculture, rural development, irrigation, engineering, etc.

Banks also need to offer special funds for financing for the private sector's mariculture projects with matching grant and markup loans

3.5.3. Technological Capacity Building

Government officials in collaboration with aquaculture development experts need to assess the possible advantages and disadvantages of new or different mariculture products, methods or technologies in order to determine if they are likely to contribute to an increase in food supply, rural development, the economy and the welfare of the citizens generally or if it may result in a significant public burden such as abandoned capital investment, requirements for subsidy or excessive demands on scarce or critical resources including land, water, feedstuffs and electricity.

Hatcheries also need to be developed and maintained in the country as catching seed from the wild is very sensitive work and importing the seed is not feasible for sustainable mariculture.

Mariculture structures need to be made and sold in the local market after technical expertise for their manufacturing is developed.

The training and tools required for spatiotemporal planning are also necessary.

A local industry needs to be established for the production of equipment, machinery and ready to use cage nets. Furthermore, a value chain with fish hatcheries, commercial fish feed and live fish transport vehicles needs to be developed; a common facility for mariculturists where services such as transport boats for live fish and feed, seed nursing facilities, extension services and collective bargain services for the purchase and sale of inputs and crops needs to be established.

3.6. Stakeholder Involvement

3.6.1. Stakeholder Involvement at National, Regional and Inter-Regional Levels

To make the industry stable and sustainable there is a strong need for all major and minor stakeholders to be onboard and realize that the development of one sector would complement the development of other sectors and not vice-versa. A strong connection needs to be developed between academia, industry, and governmental bodies which would assure that the cycle of innovation is continuous.

At regional and extra regional levels there is no synergy amongst countries, there are countries of East-Asia like China, Thailand, and Vietnam, Philippines which have developed expertise in mariculture and have a big share in the exporting of seafood products across various countries on the map.

3.6.2. Cooperation amongst Stakeholders

Relevant people need to be engaged for investment in the creation of sustainable mariculture inputs, e.g., local supply of good quality fingerlings produced in a hatchery and ensuring constant availability of fish feed, is key to sustainable development and the mariculture industry can benefit from collaboration with the private sector.

3.7. Food Safety and Public Health

3.7.1. Consumer demand for safe, traceable and healthy fish

The use of fertilizers, disinfectants, pesticides and other feed additives is very common in mariculture in order to prevent the spread of organisms such as insects, water weeds and plant diseases (Sabra and Mehana, 2015). Cultured species and subsequently consumers and wild biota are susceptible to harm due to these toxic substances (Holmstrom et al., 2003; Primavera, 2006). Furthermore, cultured organisms may also be affected due to heavy metals, residues from domestic wastes and untreated industrial effluents. Mariculture products may also be affected in post-harvest processing.

Farmed fish are generally fresher than fish caught from the wild due to the faster farm-to-table distribution channels. It is vital that producers are well aware of how their animal husbandry practices affect the meat's quality and consequently the consumers and their opinions.

Research regarding consumer awareness about safe, traceable and healthy fish in Pakistan is non-existent. Therefore, thorough research is needed to determine consumer demand and requirements for mariculture products before developing mariculture in Pakistan.

3.7.2. Disease Control Methods

Patil *et al.* (2018) suggest that the quarantine and certification system within Pakistan needs to be strengthened in order to reduce biosecurity hazards. Aquatic animal health laboratories need to be upgraded and stronger certification measures should be employed. They also suggest that a Federal level bio-security institution should be established and that international organizations dealing with biosecurity in mariculture should be involved.

3.7.3. Post-Harvest Practices and Trade

Post-harvesting practices in Pakistan are generally outdated. Fishing periods are long, the cold-chain is not maintained and fish are not handled hygienically. This leads to a degradation in the quality of the raw materials and a shortage of raw materials for processing. Furthermore, this has resulted in an increase in the amount of fish meal and fish meal processing, leading to a lack of fishery resources along with economic losses.

In order to ensure that cultured products are able to compete internationally, it is vital that infrastructure and services are invested in. Patil *et al.* (2018) suggest that competitive clusters consisting of sites of co-related fisheries related firms should be grouped together in order to encourage healthy competition and growth. This co-location may also be essential for growth via the sharing of facilities and export services and being able to learn from each other's experiences.

Currently, Pakistan is exporting fish to 10 countries. Export to these markets is also, however, limited due to SPS and Technical Barriers to Trade. Demand for whole fish in Southeast Asian markets limits the requirement for SPS measures to an extent, especially since the product could also undergo secondary processing in the importing country (Patil *et al.*, 2018).

3 Federal authorities are responsible for the safety of imported and exported fishery products. The safety of the exported fishery products is controlled by certification at the point of export by the Marine Fisheries Department with authority granted by the Pakistan Fish Inspection and Quality Control Act of 1997. Imported and unprocessed fishery products are managed by the Animal Quarantine Department (AQD) of the Ministry of National Food Security and Research. Quality assurance of processed fishery products such as canned goods is done through the Pakistan Standards and Quality Control Authority.

3.8. Social and Legal Frameworks

3.8.1. Worker Safety

While developing mariculture policies in Pakistan, it is important to address the safety and security of the farmers working on the mariculture farms to avoid any

kinds of accidents on the field. The government needs to address health and safety hazards and risks, and related data on injuries and occupational ill health, regulations, social welfare conditions, and labour and industry activity in the sector before formulating policy. Good practice as well as mariculture Occupational and Safety Hazards (OSH) need to be taken as a model framework using the experience from other countries, inclusion of health and training programme would play an essential role in assuring that the work force part of the industry is not at any health or safety risk and are provided with a healthy working environment.

3.8.2. Fair Distribution of Income amongst Workers

Developing the mariculture industry in Pakistan has the potential to serve as a catalyst for improving employment and social equality within society. It would assist in securing workers' rights, endorsing social protection schemes and reducing social inequalities overall. It will perform an effective role in improving conditions and equality along the value chain and will have wide-ranging benefits for society as a whole and will help to ensure that the benefits of development are felt by all, it is however, also vital to ensure that income is fairly distributed amongst workers and no person is over-exploited while another gets an un-deserved share of his income.

3.8.3. Livelihood of Coastal Communities and Mariculture

Most of the population in coastal areas is engaged in fishing and ancillary industries. If the mariculture industry is promoted and developed, it has the potential to be a major form of alternative earnings, both directly through fish farming and through other attached markets such as processing, transport, research, extension services, etc.

3.8.4. Incentives

Since the mariculture industry is at its initial stages, there should be multiple incentives offered to the investors to invest in the growing industry. The incentives should include no import tax for aquaculture equipment and products and good practices which are inculcated in mariculture farming globally. Cultured products such as pink and brown shrimp could be exported to countries of the European Union, Japan, and the US, leading to the earning of foreign exchange. China Pakistan Economic Corridor (CPEC) and Belt and Road Initiative (BRI) have opened new ways and means for capacity building and training, which is being offered to farmers as well as other relevant individuals.

3.8.5. Deterrents

It is vital to have consequences for not complying to the best practices when it comes to practicing mariculture in Pakistan. This will prevent the further degradation of the marine environment, will ensure the welfare of cultured organisms and will

prevent physical, financial and other harms to people working in the mariculture industry.

3.9. Current Mariculture Strategies, Policies and Regulations in Pakistan and Examples from other Countries

Currently, there is no comprehensive policy framework for aquaculture and mariculture in both Sindh and Balochistan. A mutually acceptable and common policy framework needs to be implemented in Federal and Provincial bodies.

Norway has 2 strategic documents; one is the 2008 Strategy for a Competitive Norwegian Aquaculture Industry and the other is the 2009 Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry.

The Strategy for a Competitive Norwegian Aquaculture Industry ensures that Norway:

1. Maintains its position as a leading international producer and exporter
2. Meets global market challenges and takes into account environmental sustainability
3. Has a coordinated and efficient licensing application process
4. Undertakes research and development

The Strategy for an Environmentally Sustainable Aquaculture Industry is focused on the mitigation of environmental impacts of aquaculture. These areas include:

1. Genetic Interaction and Species
2. Pollution and affluent
3. Sustainable usage and utilization of coastal areas
4. To curb sea lice and diseases
5. Take proper steps for feed and feed measures.

The National Aquaculture Strategic Action Plans Initiative (NASAPI), 2011-2015 was established to bring together all the stakeholders for Canadian Aquaculture. The activities identified in the plan focused on the fine details of mariculture in Canada; mainly, East and West Coast shellfish, and freshwater; these activities were across three thematic areas including governance, social licenses and reporting, and productivity and competitiveness.

The jurisdiction in accordance with NASAPI completed a significant portion of the planned and proposed activities utilizing multiple regimes, adopting special initiations, or including those activities in daily operations.

The defined priority areas were:

- Improving site and stocking approval processes and service standards;

- Developing highest-level operating standards (regionally or nationally) for areas such as, but not limited to siting, containment and environmental impacts;
- Harmonizing environmental monitoring standards;
- Harmonizing and improving risk assessment methodologies and processes; and
- Improving information collection and sharing in support of improved program delivery and transparency through public reporting (Government of Canada, 2016)

The new Aquaculture Act in Canada has set clean and consistent standards for aquaculture farming across the country. The Act further allows greater federal-provincial coordination to manage the industry. The act has also simplified cross-provincial actions and operations and has focused on the implementation of sound scientific rules.

The new Federal Act states:

1. Foster a healthy, responsible and sustainable farmed seafood sector in Canada.
2. Ensure a science-based, accountable and transparent management approach.
3. Revitalize hard hit coastal communities including First Nations communities with sustainable, high value jobs.
4. Enable greater federal/provincial cooperation and collaboration.
5. Meet future demand with global best practices and international competitiveness.
6. According to new aquaculture act, it would modernize and enable growth of aquaculture industry in Canada.
7. It will increase the supply of safe and healthy seafood for the people. The act will further pave the way in increasing Canada's contributions in the global seafood market.
8. The act will also ensure promotions related to wildlife and seafood.

The Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) agree on and support the following commitment:

"Jurisdictions commit to work together – as a Council of Ministers and through bilateral arrangements between individual jurisdictions, as well as collaborating with Indigenous nations, industry, stakeholders and the public – to foster sustainable aquaculture development that is enabled by innovation

and regulated by an effective and efficient regime supported by world-class science (Government of Canada, 2016)."

The CCFAM Strategic Management Committee on Aquaculture (SMC) has vowed to develop annual work plans that will clearly align activities against the three desired strategic outcomes and objectives. As the Strategy's action items are implemented, governments will consult with Indigenous nations, industry, and other stakeholders, where appropriate and according to jurisdictions' mandates and responsibilities. Annually, the Committee will report to CCFAM Ministers on what actions were taken during that year and what was achieved or accomplished by those actions. Implementation of this Strategy will build on existing programs and resources; however, new resources may be added depending on each jurisdiction's priorities and overall capacity. The Strategy will reflect the unique circumstances of jurisdictions and the diversity of the aquaculture industry throughout Canada; not every action item or strategic objective will be possible for every federal, provincial or territorial partner (Government of Canada, 2016).

Bangladesh has a Policy for Coastal Shrimp and Finfish Culture. Committees have been formed to take appropriate measures for the development of shrimp production, implement laws related to shrimp culture and mitigate other related problems. Appropriate scientific measures shall be taken and proper training shall be given to fry catchers to ensure that other organisms are not affected during the collection of shrimp post-larvae from the wild and to reduce mortality during transportation. In light of this, adequate infrastructure facilities will also be created. The harvesting of shrimp will be banned during the peak breeding season to ensure natural breeding in the sea. Private entrepreneurs shall be encouraged to establish shrimp and prawn hatcheries and shrimp feed will be produced using local ingredients.

In order to obtain a good foreign market, marketing sectors will be strengthened. To ensure high-quality exports of fish and shrimp products, laboratory facilities for Quality Control will be expanded and modernized. The Central Shrimp Cell will be extended up to the field level in order to provide services for shrimp culture management.

Coastal areas will be demarcated for shrimp farming. Consultation will be made with the Ministry for Environment and Forests to ensure increased shrimp production while maintaining the ecological balance. Joint ventures with foreign countries and their institutions with improved shrimp culture technology shall be encouraged to promote environmentally friendly semi-intensive shrimp farming and insurance systems will be adopted in fish and shrimp culture.

A non-institutional credit programme is also being established to alleviate poverty and generate employment in Bangladesh. Aquaculture and natural resource

exploitation in Bangladesh are mainly undertaken by rural people, farmers and fishers. To improve this situation, the following policies will be followed:

- Fisheries sector will be given priority for institutional loans.
- Supervised credit without collateral instead of compulsory property mortgage will be provided from starting of production to marketing for small-scale fisheries sector.
- The culture of shrimp and other exportable fish will be considered an exportable industry. Facilities such as credit with low rates of interest, tax rebate, and tax holiday might be offered.
- Fisheries Bank may be established for extension of credit on easy terms.

India has a National Marine Fisheries Policy 2017, which was notified by the Central Government in April 2017, a draft of the National Inland Fisheries and Aquaculture Policy 2019 which was released in February 2019, and a draft of National Mariculture Policy 2019 which was also released in 2019. In light of the National Fisheries Policy 2020 draft, it is unclear what will become of the rest.

The National Fishery Policy, 2020 states that besides conventional mariculture, Culture Based Fisheries, Capture Based Aquaculture, conservation mariculture and farming of non-food species need to be promoted using the same type of facilities and skill sets. These activities include the following:

1. Culture Based Fisheries which is the practice to enhance fish stocks in waters that do not have enough natural recruitment to sustain a fishery
2. Capture-Based Aquaculture, which is the practice of collecting - seed material from the wild, and growing to marketable size in captivity, using aquaculture techniques
3. Conservation Mariculture which is the practice of stock enhancement of endangered, threatened and protected (ETP) species and depleted marine fish stocks for replenishment and
4. Farming of non-food species such as microbes, micro algae and seaweeds for extraction of bioactive compounds, bio-fuels, bio-chemicals, nutraceuticals and natural growth promoters and
5. Farming of marine ornamental fishes and invertebrates; pearl oysters and seaweeds.

For the future, India plans to increase the production of fish up to 20 million tonnes as compared to the 13.4 million tonnes being produced today through wild harvest and aquaculture. This additional fish production will have to come exclusively through aquaculture. The National Policy on Marine Fisheries, 2017

(NPMF, 2017), gives a detailed assessment of the exploited fish stocks in the Indian Exclusive Economic Zone (EEZ) and also highlights their overcapacity in the territorial waters with respect to different categories of mechanized fishing vessels in all maritime states/Union Territories and indicated that further increase in production from capture fisheries has limited scope (Vohra, 2020).

In the NPMF, 2017, it is stated that the Indian Government will encourage schemes to set up mariculture farms / parks and setting up of hatcheries for supply of seeds for the development of the sector.

CHAPTER 4

MARICULTURE PRACTICES GLOBALLY

4.1. Organisms used in Mariculture

4.1.1. Species of Flora and Fauna Cultured

Due to the great variability in climatic and environmental conditions across the world, a wide variety of species are being produced throughout the world via mariculture. The main types of species produced through mariculture include molluscs, aquatic algae, marine finfish and crustaceans.

4.1.2. Molluscs

Despite the technological developments in marine finfish aquaculture, marine and coastal aquaculture results in a far greater number of molluscs than finfish and crustaceans. Stats from 2018 show that shelled molluscs represented 17.3 million tonnes or 56.3% of the total production of marine and coastal aquaculture; while finfish at 7.3 million tonnes and crustaceans at 5.7 million tonnes represented 42.5% collectively (FAO, 2020a).

Table 4.1: Mariculture production of main species groups by continent in 2018 (FAO, 2020a)

Year	Africa	Americas	Asia (-Cyprus)	Europe (+Cyprus)	Oceania	World
Finfish	291	1059	3995	1892	92	7328
Crustaceans	6	888	4834	0	6	5734
Molluscs	6	640	15,876	680	102	17304
Other Aquatic Animals	0	...	387	3	0	390
Subtotal	302	2587	25093	2575	200	

Various species of bivalve and gastropod molluscs are farmed throughout the globe. Most bivalves are usually introduced into the market as fresh products, however, some products may be introduced as processed, frozen, canned and pickled products.

On the other hand, the culture and subsequent consumption of bivalves can also be a hazard to human health, causing shellfish poisoning, as they are filter

feeders who can accumulate heavy metals, toxins, bacteria and viruses. Depuration can help in improving the quality of the final product. (Phillips, 2018).

4.1.3. Aquatic Algae

Aquatic plants also greatly contribute towards mariculture, this is especially true for the Asia-Pacific region.

Seaweed farming is gaining attention as an environmentally friendly means to develop the economy. Farmed seaweeds accounted for 97.1% of the 32.4 million tonnes of wild-collected and cultivated aquatic algae produced globally (FAO, 2020a). The practice of seaweed farming is most prevalent in East and Southeast Asia, China is the largest producer of aquatic algae globally, while it is rarely practiced in the rest of the world (FAO, 2020a). From 2000 to 2018 the amount of seaweed produced has increased from 10.6 million to 32.4 million tonnes (FAO, 2020a). The production of seaweed in Indonesia increased from less than 4 million tonnes in 2010 to over 11 million tonnes in 2015 and 2016, with an analogous amount of production in 2017 and 2018.

There is a limited amount of data on small-scale seaweed farming in Europe and North America due to confidentiality (FAO, 2020a). Out of the 32.4 million tonnes of seaweed farmed, only some, for example *Ulva lactuca*, *Undaria pinnatifida*, *Porphyra* spp. and *Caulerpa* spp. are fit for human consumption, the low grade products and scraps from processing factories are used for other purposes including feed for abalone culture (FAO, 2020a). Seaweed production is dependent on simple technology and can therefore be conducted in developing areas. On the other hand, seaweed is also vulnerable to physiological and pathological problems such as 'green rot' and 'white rot' as the result of environmental conditions, 'ice-ice' disease, and epiphyte growth. Additionally, cultured seaweeds are the victim of consumption by organisms such as sea urchins and herbivorous fish (Phillips, 2018). While the culturing of seaweed is suitable for small-scale village operations and provides employment opportunities to many farmers in remote coastal areas, the culture of seaweed has also developed into an export level industry.

Microalgae is also farmed, however, it is regulated at the national or local level separately from aquaculture (FAO, 2020a). In 2018, out of the 87,000 tonnes of microalgae produced by 11 countries, 86, 600 tonnes were from China (FAO, 2020a). Microalgae such as *Spirulina* spp., *Chlorella* spp., *Haematococcus pluvialis* and *Nannochloropsis* spp. is used in nutrition supplements for humans as well as in other uses. The amount of microalgae production is understated due to the unavailability of data from countries such as Australia, Czechia, France, Iceland, India, Israel, Italy, Japan, Malaysia, United States of America and Myanmar (FAO, 2020a).

4.1.4. Marine Finfish

In 2018, finfish accounted for 7.3 million tonnes of the production of marine and coastal aquaculture (FAO, 2020a). The culture of marine finfish is well-established on a global scale and is growing at a rapid pace. Currently, various species of finfish are being cultivated, with many more coming up in the pipeline (Phillips, 2018).

The main species cultured in the Americas and in Northern Europe consist of the Atlantic salmon (*Salmo salar*). The production of Atlantic salmon, coho salmon and rainbow trout in Chile is now a multibillion dollar industry, and is second in number after Norway in production (FAO, 2020a). Warm water species such as seabass and seabream are cultured in the Mediterranean. Groupers have become overfished commodities, therefore their culture has become highly profitable, this is especially true in the live fish markets of Hong Kong SAR and China (Phillips, 2018). In Australia, Southern Bluefin tuna (*Thunnus maccoyii*) is cultured using juvenile fish caught from the wild (Phillips, 2018). Bluefin tuna is a valuable product in the Japanese market and thus is very beneficial to South Australia's economy, even though the output from this species is comparatively little (3500-4000 t per annum in 2001-2003) (Phillips, 2018). In 2003, 3500 tonnes of this species generated 65 million US dollars (Phillips, 2018).

4.1.5. Crustaceans

Important economic crustaceans include shrimp, crabs and lobsters. Shrimp are important animals in worldwide aquaculture, and their total output accounts for 10% of the total aquatic production. For a long period, *Penaeus monodon* and *Litopenaeus vannamei* have been the two most important species among the farmed shrimp in the world.

In Southeast Asia, especially in the Philippines and Vietnam, tropical spiny rock lobsters in particular the ornate lobster, *Panulirus ornatus* are cultured. The culture of lobsters in Vietnam results in approximately 1,500 tonnes, generating an income of about 40 million US dollars per annum.

4.1.6. Other Invertebrates

Various other invertebrates are also cultured at sea including organisms such as sea cucumbers, sea urchins, sponges, corals, sea horses, etc. Some species have been farmed for quite some time now and are well established such as sea cucumber farming in Northern China while the culture of other organisms is still under development (Phillips, 2018). The commercial production of farmed sponges is low, although occurring in areas such as the Pacific islands. Recently, sponge production has been gaining a considerable amount of interest from researchers. Like seaweed farming, sponge farming requires relatively simple equipment and

infrastructure needed for farm development. Also like seaweed, sponge farming is ideal for remote communities. The product may be dried and used as bath sponges (Phillips, 2018) and insulation material.

4.2. Most Efficient Species Cultured

Bivalve molluscs form the majority of the production from mariculture, as many of these species such as oysters, which produce valuable products for example pearls, can be cultured in large volumes at a low cost (FAO, 2020a). Molluscs can be produced at a very rapid pace, going up to 1800 tonnes per hectare annually (Phillips, 2018). They can produce a cooked meat yield of approximately 20%, leading to a very large quantity from a very small area (Phillips, 2018).

Aquatic plants also greatly contribute towards mariculture, this is especially true for the Asia-Pacific region. The culture of seaweed can serve various purposes; it can be used for food and medicine, polysaccharides alginate and carrageenan can be extracted from it, it can be used as a fertilizer and finally it can be utilized to feed other cultured organisms for example abalone (FAO 2020a; Phillips, 2018).

4.3. High Demand Farmed Species

Various species of fish, whether live or processed and several types of fish products are traded throughout the globe. In 2018, finfish were the most valuable commodities to be traded, contributing towards 66% of the total value of traded species. Salmons, trouts and smelts have been known to produce the greatest value through trade contributing towards 19% of the internationally traded fish products' value in 2018 (FAO, 2020a). This is especially true for farmed Atlantic salmon. Although the markets for farmed coho salmon, rainbow trout and wild salmon species have all grown, the farmed Atlantic salmon is in demand in both developed as well as developing markets and has contributed the most towards export revenue (FAO, 2020a).

Norway and Chile are in the lead when it comes to the culture of Atlantic salmon especially with regards to innovative products and marketing strategies (FAO, 2020a).

Secondly, shrimp and prawns contributed towards approximately 15% of the total value of traded fish products (FAO, 2020a). Historically, shrimp and prawns have been one of the most traded commodities. Most of the shrimp and prawn production takes place in Asia and Latin America and the major markets are located in the United States of America, the European Union and Japan. Recently, the total trade of shrimp has been declining, with salmon taking the lead (FAO, 2020a).

Ground fish and other white fish such as hake, cod, haddock, Alaska Pollock, etc. contributed towards 10% of the market. Cod and Alaskan Pollock contributed towards the majority of this segment. The amount of wild-caught marine groundfish

shrunk from 2018 to 2019, resulting in a price increase for some species such as cod (FAO, 2020a).

Tunas, bonitos and billfishes accounted for 9% (FAO, 2020a). Canned tuna is mostly received by the United States of America and the European Union, and fresh and frozen tuna in whole or loin form is mostly received by Japan (FAO, 2020a). Bluefin and bigeye tuna are utilized for sashimi and sushi, while skipjack, albacore and yellow fin tuna are utilized in canned as well as prepared and preserved products (FAO, 2020a).

In total, mollusks and other aquatic invertebrates account for 12%, with squids, cuttlefishes and octopuses accounting for 7% and other molluscs/aquatic invertebrates accounting for 5%. The wild catch of cephalopods, especially octopus has been decreasing in recent years, thus increasing their demand and subsequently their prices.

The demand for bivalve molluscs has increased greatly over time, mostly as a result of incomes increasing on a global scale. Bivalves such as scallops, clams and oysters are an excellent source of micronutrients.

Furthermore, fishmeal contributed towards 3%, while fish oil contributed towards 1% (FAO, 2020a). The most heavily traded small pelagic species include mackerel, herring, sardine and anchovy (FAO, 2020a). The small organisms are used to make fishmeal and fish oil while the larger ones are consumed by humans, however smaller organisms such as Peruvian anchoveta are being used for human consumption and in nutritional supplements (FAO, 2020a). The supply and price of these products is fluid. Prices for fishmeal have generally been decreasing since mid-2018, while the price for fish oil has been increasing (FAO, 2020a).

4.4. Use of Genetically Modified Organisms in Mariculture

Genetic manipulation is much more advanced for aquacultured species such as fish and bivalves than any other species. The genetic engineering of aquaculture products increases their productivity, increases survival rate, increases turnover rate, ensures resources are utilized more efficiently, reduces production costs and increases environmental protection. Transgenic fish convert food into weight more efficiently than non-transgenic fish. Fish are genetically modified to produce growth hormones for optimal growth and feed conversion, produce antifreeze proteins in order to withstand cold temperatures, produce antimicrobial peptides for protection against disease, incorporate metabolic genes in organisms so that they are able to digest cheap land-based diets and to make organisms sterile to prevent them from affecting the local gene pool in case they escape (Joseph & Augustine, 2020).

4.5. Types of Mariculture Production Systems and Technologies

A variety of techniques and technologies can be used to culture marine species in multiple settings

4.5.1 Hatcheries

Hatcheries are the place where most maricultured fish begin their lives.



Figure 4.1. A fish hatchery

4.5.2. Pond culture

Pond culture is a system of earthen ponds which are used to culture some marine species.



Figure 4.2. Pond culture

4.5.3. Floating Raft Culture

The floating raft culture's cage is made from nets supported by a buoyant collar or a stable frame. This is the most widely used method of cage mariculture because the cages can be made in any size or shape.



Figure 4.3. Floating raft culture

4.5.4. Mud Flat Culture

Mudflat culture consists primarily of infaunal and epifaunal bivalve species.



Figure 4.4. Mud flat culture of mussels

4.5.5. Pen Culture

Pen culture involves the raising of fish in a volume of water that is enclosed on all sides except for the bottom. This system can be considered a hybrid between pond culture and cage culture.



Figure 4.5. Pen culture

4.5.6. Cage Culture

Cage culture takes place in cages submerged in aquatic surroundings. Careful procedures, practices and monitoring are required to help to minimize potential interfaces with the environment. It is an intensive method of mariculture. It is practiced in areas with sufficient movement of water.



Figure 4.6. Cage Culture

There are two types of cage cultures:

1. Inshore Cage Culture
2. Off-shore Cage Culture

4.5.6.1. Submerged Cage Culture

The submerged Cage Culture is the least common of culturing techniques and the submerged cages are perpetually kept under water.

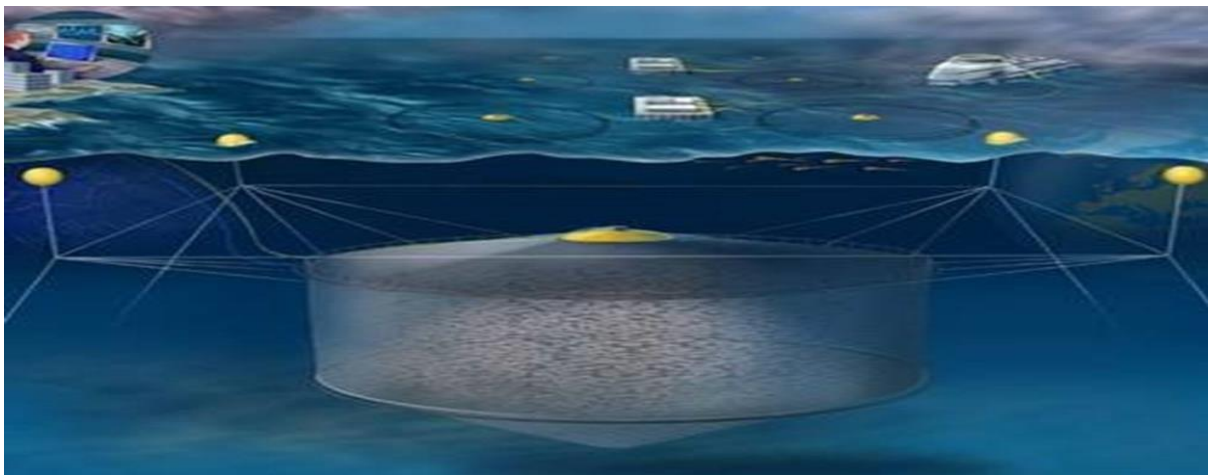


Figure 4.7. Submerged Cage Culture

4.5.7. Indoor Tank Culture with Water Recirculation

The recirculating system caters to fish, shellfish, and or plant-life raised in "closed-loop" production systems that constantly filter and recycle water and waste from the tanks.



Figure 4.8. Indoor tank with water recirculation (Xu, 2019)

4.5.8. Integrated Multitrophic Mariculture

Integrated multitrophic mariculture is a system in which several species are raised together in a way that permits one species' residue and waste to be recycled as feed for another, therefore reducing the impact mariculture has on the surrounding environment.

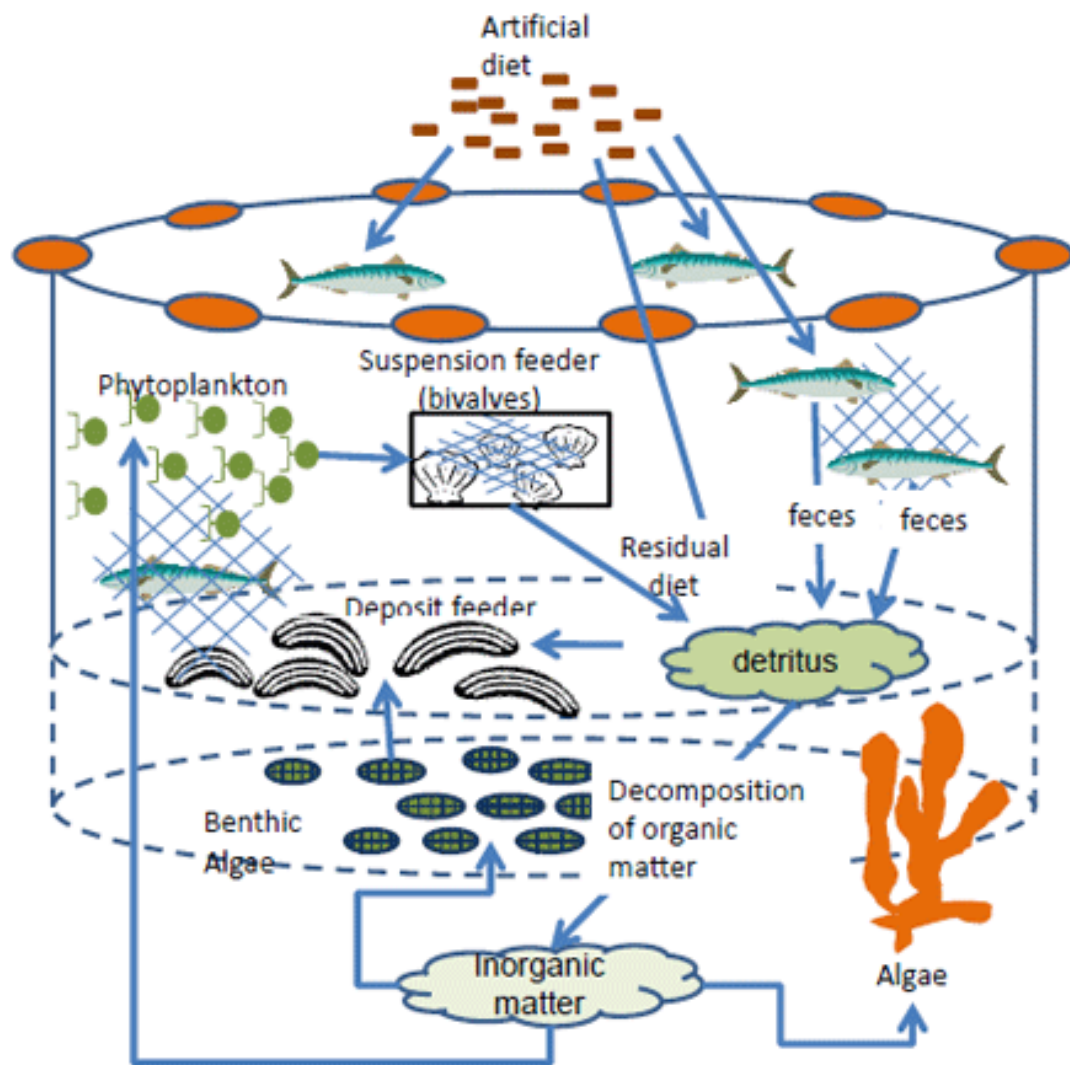


Figure 4.9. Integrated Multitrophic Mariculture

4.6. New Technologies

Ocean Farm 1, the World's largest offshore fish farm has been constructed off the coast of Norway by SalMar. Environmental Vision Norway (EVN), they have also come up with the Autonomous Offshore Fish Farming Vessel. This vessel's fish pens contain current deflectors, shielding smaller fish from potentially deadly ocean currents and allowing larger fish to swim to greater depths. Mariculture in open waters reduces the risk of environmental contamination as stronger currents and deeper waters are able to dilute the effects of the wastes and contaminants.



Figure 4.10. Norway's Ocean Farm 1

Norway has also been developing the 'Marine Donut' made by OPD, a submerged or semi-enclosed fish farm which prevents fish and waste from entering the marine environment, while also reducing the risk of sea lice outbreaks.

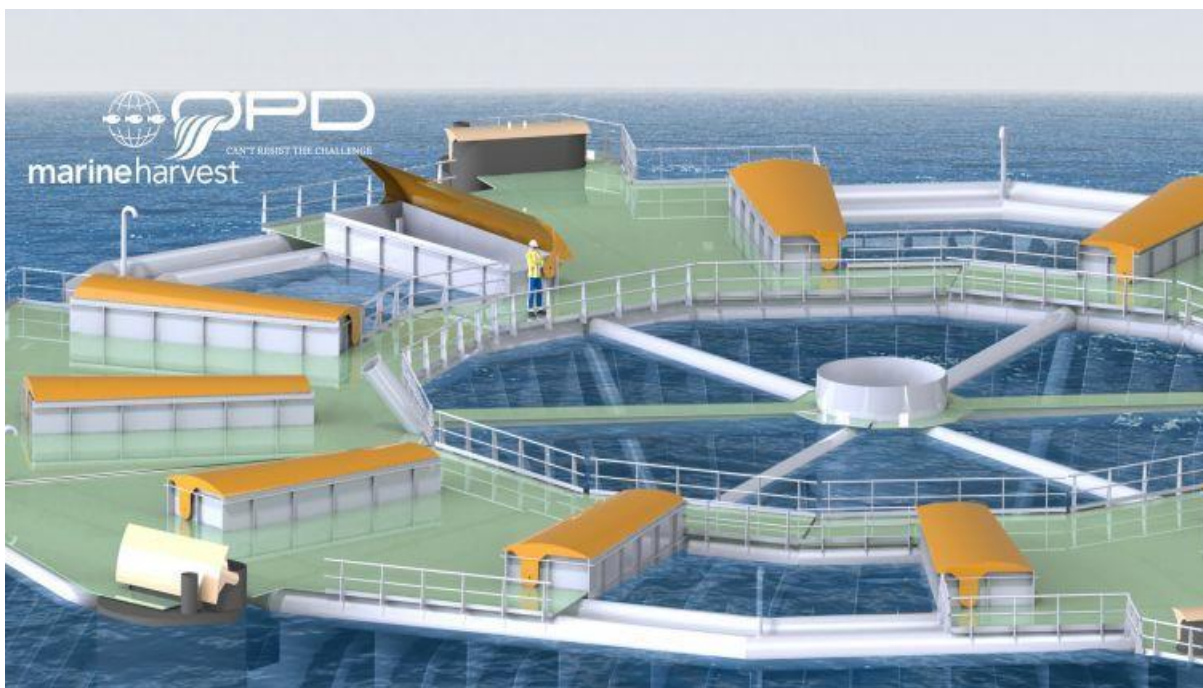


Figure 4.11. Marine Donut by OPD

Furthermore, Fish Globe has developed a fully enclosed, mobile fish farming unit. This is available in various sizes with the largest tank being able to withhold 30,000 m³ of seawater. The water in the tank is automatically replaced twice within an hour. It is pumped from depths of 15 m or more where sea lice and other pathogens are comparatively few. This structure also prevents organisms, disease, waste and excess feed from entering into the marine environment. Furthermore, the

tank collects organic waste which can later be used for other bio-based products such as biogas and fertilizer.



Figure 4.12. A fully enclosed fish farm by Fish Globe

4.7. Development of Sustainable Resources

4.7.1. Alternatives to Fishmeal

With the spread of aquaculture, an increase in the demand for fishmeal has also been seen. Finfish and in particular carnivorous fish have higher protein demands than their terrestrial counterparts. However, exploiting forage fish such as sardine, anchovy and menhaden to produce fishmeal put additional pressure on these already scarce resources. According to Naylor et al. (2009), the amount of fish protein or high nutrient pellets used to feed farmed species is 2-5 times greater than the output obtained from the cultured product.

In order to maintain sustainable mariculture, it is important to shift the culture of organisms to lower trophic levels. During the 1980s, majority of the feed for carnivorous and omnivorous fish consisted of pelagic fish, this has now changed by incorporating agricultural resources (Gatlin et al., 2007; Naylor et al., 2009). Scientists and manufacturers of aquafeeds have aimed at developing alternative sources of protein which are inexpensive, readily available, and have a high nutritional value (Jobling, 2016). Today, fishmeal has been replaced to some extent or completely by processed animal and plant protein sources and also with new proteins including microalgae and yeasts (Bandara, 2018). According to FAO (2020), the share of capture fisheries production reduced into fishmeal should decline from 19% in 2018 to 18% in 2030.

Insect meals have been studied, as insects are a part of the diet for carnivorous fish (Henry et al., 2015). The chemical composition and nutritional value of insect larvae meals depend on what treatment they undergo for example the drying methodologies, the defatting procedures and the substrate used to rear them (Henry et al., 2015). However, the issue with insect meals lies with their high fat content, this can, however, be

PC) is one of the most frequent protein alternatives used in fishmeal (Salze et al., 2010; Colburn et al., 2012; Trejo-Escamilla et al., 2017). Although the cost of soy protein concentrate is higher than the cost of regular soybean meal, it contains lower levels of anti-nutritional factors (ANFs) such as protease inhibitors and oligosaccharides (Buentello et al., 2015).

Poultry byproduct meal (PBM) is commonly used in domestic animal feeds; it is a high protein source. The PBM's quality and nutritional value, changes from one batch to another, depending on the included materials and the processing time (Cruz-Surarez et al, 2007).

Blood meal has also been tested in aquaculture. Blood meal has a high amount of crude protein and has successfully been used to replace fish meal in the diets of carnivorous fish species such as Atlantic salmon (*Salmo salar*), gilthead seabream (*Sparus aurata*) and rainbow trout (*Oncorhynchus mykiss*) (Nogueira et al., 2012; Hatlen et al., 2013; Lu et al., 2015).

The microalgae *Athrospira* sp., also known as *Spirulina* commercially, is a blue-green filamentous cyanobacteria, with high nutritional value, which can be used as a replacement for fish meal. *Spirulina* contains 60-65% of crude protein and essential AA, β -carotenes, antioxidants and vitamins (Guedes et al., 2015). This microalgae has proven to be useful for growth and a strong immune system.

Alternative feedstuffs should, however, not completely replace fish meal since imbalances such as high levels of ANFs, essential AA deficiencies, variable quality or reduced digestibility may occur. In a study conducted on *Totoaba macdonaldi*, by Villanueva-Gutierrez et al. (2020), 100% fishmeal replacement diets led to mass mortality, while a replacement of fishmeal by 33% led to a survival rate of 91.55% and a replacement by 66% led to a survival rate of 89.11%. The researchers also found that fish fed with a replacement feed of 33% had a greater growth rate than those fed with a replacement of fishfeed of 66%. Fish on the *Arthrospira* meal blend and the SPC blend did better than fish fed with blood meal.

4.7.2 Sustaining Land and Water Resources

An important concern in the development of mariculture arises with the change in land. Mangrove forests and salt marshes have extensively been cleared for this use. Unsatisfactory environmental regulations and deficiencies in planning

and management strategies on national and international levels have led to the uncontrolled and uncoordinated development of mariculture and has resulted in much environmental degradation over the past decades (Smith et al., 2010). Much of mariculture is already being conducted in off-shore areas, such as off-shore cage culture (Troell et al., 2014).

Coastal ecosystems are highly productive environments, being home to various organisms comprising several species of fish, shellfish and shrimp and are vital breeding and nursery areas (Afroz and Alam, 2013; Dewalt et al., 1996; Spalding et al., 2014).

The destruction of mangroves and other coastal wetlands alters the natural tidal system, decreases sedimentation rates and affects the fisheries in the environment (Kuenzer et al., 2011). The expansion of aquaculture has been a major source for the decline of mangroves worldwide (Wolanski et al., 2000); shrimp farming has particularly been responsible for this decline (Ottinger, 2016).

As aquaculture is often more profitable than agriculture, many farmers have converted their land to incorporate aquaculture systems. Aquaculture has developed extensively along the South China Sea's coast and has resulted in great amount of loss in wetland habitats and fragmentation due to land reclamation and conversion (Peng et al., 2013; Spalding et al., 2014). Wetlands are threatened due to the lack of environmental protection and uncontrolled mariculture development (Peng et al., 2013).

Mariculture requires regular water replacement in order to replace lost oxygen, to make up for the water loss that occurs through evaporation and to replace the water that has been contaminated due to fish waste (Bosma et al., 2009; Paez-Osuna et al., 2003; Verdegem and Bosma, 2009).

One way of mitigating pollution through mariculture is through aquaponics. Aquaponics is the integration of hydroponics with aquaculture in a recirculating system. In this process, wastes and metabolites produced by cultured fish are removed by nitrification and are taken up by plants. The bacteria that live in the gravel and that are associated with plant roots play a vital role in the removal of nutrients. Through aquaponics, higher quantities of protein and produce may be generated while a smaller amount of labour, land, water and chemicals are required. Aquaponics works well in areas where the soil is poor and water is scarce, for example in urban areas, arid climates and low-lying islands.

4.8. Spatiotemporal Analysis

4.8.1. Spatial Analysis

Spatial management is now known to be a crucial part of sustainable mariculture around the world. Spatial planning in marine waters is far behind terrestrial planning, however, the spatial complexity and dynamics of the ocean environment allot quite an important role to spatial planning. Spatial planning needs to maintain a balance between ecological, economic, social and cultural objectives and is typically tackled via a political process (Katsanevakis et al., 2011; Jay et al., 2012; Carneiro 2013; Foley et al., 2013). Additionally, the social and cultural values of coastline communities need to be taken under consideration (Gee and Burkhard, 2010).

4.8.2. Temporal Analysis

External factors which change over time such as population growth, development, global trade and climate change deem temporal analysis a vital component in planning for mariculture.

4.9. Capacity Building

4.9.1. Training/Research Institutions

Global practices include building a strong bond between academia and the mariculture industry. This enables farmers and students to receive hands-on training. With proper training, both become well versed with the field setting, and this as a result provides the relevant learning to understand the minute details of specific species.

The academia is tasked with bringing forward new research leading to a better GDP output and developing further linkages which consolidate the academia-industry-government relationship.

A good example of this is Norway, who is amongst the countries leading the way in operations, technology and research and development in mariculture. The country is one of the leading seafood exporters in the world. Norway's government played a very vital part in the early success of mariculture by providing substantial resources and support such as research and development and educational programs.

4.9.2. Public and Private Investment in Mariculture

Worldwide, cooperation between the public sector and the private sector has been vital to ensure sustainable and profitable mariculture. Private investments have aided developments in infrastructure such as hatcheries and incentives for private investors would further aid the development of the sector.

Governments and international organizations along with the private sector need to develop criteria and methodologies for the assessment of environmental impacts and resource requirements during mariculture production and processing. These need to be transformed into clear indicators in order to inform consumers and decision makers.

4.9.3. Microfinance and Micro-Enterprise Development

In recent years, the attention and concentration of policymakers in the developed, as well as the developing world, have moved to the endowment of credit and financial services to entrepreneurs in the realization of their importance to the economies of a country and the necessity to assist them to work towards the economic development of their countries (Tafida and Ayanda, 2007). The United Nations General Assembly 1997 onwards acknowledged the important contribution that microfinance programs have made to poverty extermination and empowerment of the underprivileged which led to the call of the United Nations System to include a microfinance approach in their programs. Allotment of micro-financing comparatively does not require huge guarantees and securities to take loans.

Capacity building and training of the farmer would further facilitate the farmers in acquiring the finance and backing and would help to create a productive workforce. The money invested in mariculture farming would benefit the entire household's operations. In Bangladesh, approximately more than 1,200 microfinancing institutions are now in operation. These institutions provide the basic (seed money)/capital for farmer's fish culture projects. They also allow credit support to cover assimilated mariculture and aquaculture. It is believed that if mariculture farmers continue their fish culture for a period of two to three years, backed up by proper monitoring and required microcredit support, they become sustainable both technologically and financially. (FAO, 2003).

In the Philippines, there is a combined project with a microcredit component to fund the national population plan to improve the living condition of small-scale fishers Land Bank of the Philippines (LBP). The effort made is devoted to agriculture and rural development \$553.000 had been disbursed. Around 80% of the microenterprises financed by the LBP were fishery-based.

In Thailand, the credit for fisheries is directed through commercial banks, the regional rural development banks, and the compliant and the complaisant banking system. BAAC, a specialized financial institution in Thailand expanded from an agricultural bank to a full-fledged rural development bank. This microfinance institution in Thailand fills the rural financial gap through lending in support of rural entrepreneurs / community enterprises/village funds and local government and also establishes autonomous institutions for farming and rural development to arrange for its farmer clients with technical support and community capital. These institutions

also help to increase the income of farmers through the advancement of assimilated mariculture.

4.9.4. Strengthening of Fisher Organizations, Cooperatives and Self-Help Groups

Corporations usually have fish farmers' organizations and other platforms that bring together all the stakeholders in the marine fishery and aquaculture industry. In the West, they carry out a participatory strategy of local development, in which fishing communities and aquaculturists are included, to promote the aquaculture industry under the goal of innovation, which comes from the new European perspective based on the knowledge economy (Valderrama & Anderson, 2010).

In the fishery and aquaculture sector, community-led local development boosted innovative methods, created growth and jobs, in particular by adding value to fishery products and expanding the local economy towards new economic activities and initiatives, including those offered under the blue growth and the broader maritime segments there is a constant development of understanding that there would be issues about competing and conflicting of interests. Very often, in the oceanic areas where fishers and aquaculture farmers function, there is a contentious relationship where both the farmer and fisher compete for space, resources, and finally for customers in the market (Mikkelsen, 2007).

4.10. Stakeholder Involvement

The validations of government involvements are used to overcome the barriers involved with dealing with the stakeholders. The establishment of a regulatory framework in the mariculture practicing countries established has different approaches to drive the activities of the stakeholders (Valderrama & Anderson, 2010).

4.10.1. Cooperation amongst Stakeholders

For sustainable mariculture, it is important that all stakeholders including Government, industry, academia, the general public and environmental NGOs work together. For the benefit of local communities, it is important that Government authorities should facilitate collaboration and constructive dialogues between farmers and other stakeholders in the local community. It is important to guarantee access to fishing grounds and where necessary, they should be regulated for the mutual benefit of fisheries and mariculture. There is also a necessity for agreements between mariculture farmers and fisherfolk to avoid disagreements over access to shared resources such as water, space and living resources.

4.11. Food Safety and Public Health

4.11.1. Consumer Demand for Safe, Traceable and Healthy Fish

Studies have found that consumers prefer domestic products (Bannister and Saunders, 1978; Ettenson et al., 1998; Orth and Firbasova, 2003). This phenomenon is known as ethnocentrism (Bannister & Saunders, 1978; Ettenson et al., 1988; Orth and Firbasova, 2003) and may be due to the benefit purchasing local products has on the economy, mistrust in the exporter's safety conditions, environmental concerns, or due to the freshness of the product.

Fresh sea fish is preferred compared to its frozen counterpart. The greater the amount of handling and processing during the production and retailing of the product, the greater the uncertainty about the original characteristics of the product and its safety. Even though freezing kinetics technology has played a vital part in the improvement of the quality of the frozen fish, changes in the characteristics of the fish such as flavor, odor, texture and color can still occur as a result of freezing and thawing (Barroso et al., 1998; Sveinsdottir et al., 2009). Consumers are willing to pay a higher price for fish as long as they are sure that the fish is fresh and safe (Claret et al., 2012). However, in recent years, studies have found that the amount of frozen fish being consumed has been increasing due to its convenience for consumers (Claret et al., 2012).

In a study conducted by Lopez-Mas et al (2020), researchers found that consumers are aware that fish in the wild are exposed to a greater amount of pollutants, heavy metals and parasites. They also found that many participants had beliefs that contradicted scientific knowledge.

4.11.2. Disease Control Methods

A consequence of the increased demand of mariculture products produced around the world includes a higher probability of the transfer of disease and the spread of non-endemic pathogens across various regions. The outbreaks of infectious bacterial and viral pathogens can result in a great amount of loss in the cultured products and can restrict the development of mariculture.

A production loss of 44.4 % in Bangladesh was seen as a result of the White Spot Syndrome Virus in 1996 (Hossain et al., 2013; Mazid and Banu, 2002). Salmon lice outbreaks in Chile in 2007 have led to losses of 2 billion USD and a loss of over 25,000 jobs while disrupting international supply chains (Alvial et al., 2012; Buschmann et al., 2009). Other than these examples, disease outbreaks have also been experienced in Thailand (Verdegem and Bosma, 2009), Vietnam (Joffre and Bosma, 2009), Peru (Mialhe et al., 2013), Nicaragua (Benessaiah and Sengupta, 2014) and Taiwan (Chen and Qiu, 2014).

Once a disease or pathogen enters the wild, controlling its spread becomes very difficult if not impossible, for example the Koi Herpesvirus (KHV) incursion which was transmitted from koi carp to cultured common carp before being transferred to wild populations of carp (Reantaso, 2005).

The potential hazards that a pathogen could have on an organism must be determined. Initially, all the types of pathogens that are capable of infecting the organism will be determined; subsequently, the pathogens which are expected to pose a risk to the country importing it will be determined.

A number of global instruments are available for minimizing the risks and diseases that aquatic animals may spread; These include OIE's Aquatic Animal Health Code (OIE, 2019), the Codes of Practice on the Introductions and Transfers of Marine Organisms of the International Council for the Exploration of the Seas (ICES, 2005) and the Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms of the European Inland Fisheries Advisory Commission (EIFAC) (Turner, 1988).

Relevant articles are also present in the Code of Conduct for Responsible Fisheries (CCRF) of the Food and Agricultural Organization of the United Nations (FAO, 1995), the Convention on Biological Diversity (CBD, 1992) and the Sanitary and Phyto-sanitary Agreement of the World Trade Organization (WTO, 1994). Countries have been persistent in their efforts to implement the provisions of these international codes even though they may be limited in their capacities and resources, however, some of the provisions in the current international protocols do not always apply to the diseases present in the Asian region. The Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and the Beijing Consensus and Implementation Strategy or the Technical Guidelines was based on a set of guiding principles developed via a regional project of FAO and put into practice by the Network of Aquaculture Centers in Asia-Pacific (NACA); this process was put into practice by using a consultative process with representatives from 21 participating governments and technical assistance from regional and international experts on aquatic health. The technical guidelines were based upon the different socio-economic and environmental conditions of the participating countries in the Asia-Pacific region.

National strategies are also very vital for the action plans of governments for the short, medium and long-term. The National Strategy Framework consists of national coordination, legislation and policy, list of pathogens, institutional resources, diagnostics, health certification and quarantine, surveillance and reporting, disease zoning, contingency planning, risk analysis of imported products, capacity building, awareness building and communication, farmer/private sector involvement, financial resources, monitoring and evaluation and regional cooperation.

FAO/NACA (2000) recommends 3 levels of diagnostics. The first level consists of observations of the animal's habitat and clinical examination. The second consists of laboratory observations using parasitology, bacteriology, mycology and histopathology. Finally, the third level consists of laboratory observations utilizing virology, electron microscopy, molecular biology and immunology. Furthermore, Vaccines are also an effective means of controlling diseases in cultured organisms. Depending on the availability of resources and development, countries are advised to move from one step to the other.

Biosecurity, risk analysis and epidemiology techniques are used for scientific research in order to prevent, control and manage diseases. It is also very important to characterize the diseases that could potentially affect mariculture. The risk of a pathogen should be labelled high if information such as modes of transmission, host susceptibility tolerance to abiotic factors such as temperature and salinity and immune response is lacking. It is also vital to develop morphological and molecular diagnostic tools in order to recognize a pathogen and their variants.

For developing countries, risk analysis faces many hurdles such as reliable information, trained manpower, disease surveillance and legislation and decisions for determining acceptable risks (Arthur et al., 2004).

Research is also a vital control method. Via research, release assessment, exposure assessment and consequence assessment must all be determined. Topics necessary for mariculture research including the pathways of pathogen spread, methods for pathogen inactivation and vaccinations may be developed. Research must be utilized to identify biological factors (at-risk populations, hazards, pathways, means of spread, incubation period and characteristics of the pathogen); risk factors; interventions; methodologies including surveillance techniques, disease outbreak modelling, use of GIS; studies on host- susceptibility; modes of transmission; infectivity, virulence and stability; intermediate hosts and vectors; effects of processing, storage and transport. The surveillance of wild fish is also essential in order to track disease spread at an early stage (Reantaso, 2005)

The White Spot Syndrome Virus (WSSV) and the Yellow Head Virus (YHV) in Asia are amongst the most hazardous diseases for aquaculture in Asia and have led to losses of shrimp amounting to millions of dollars (Primavera, 2006). Fish diseases including vibriosis "winter ulcer", photobacteriosis, furunculosis, flexibacteriosis, "winter disease", streptococcus, BKD, mycobacteriosis and piscirickettsiosis have also been responsible for substantial losses.

A greater focus should be placed upon prevention, better management practices and on maintaining healthy fish.

Norwegian companies have been working on instruments such as Seafarm Pulse Guard (SPG) to inactivate sea lice by using electrical pulses before the lice

attach to the fish, preventing its spread both within the cage and the surrounding environment. Stingray Marine Solutions scans fish, identifies parasites and then destroys them using lasers. To detect fish at an early stage, Norway utilizes Fishency Innovation's technology as an alternative to the manual counting of sea lice. This technology takes a 360 degree photograph to identify lice on the fish's surface. Another approach being used by Norway to control sea lice is blue lice, which prevents sea lice from entering the cage, and acts like a mosquito trap through various attractors. This system uses the sea lice's instincts to make the trap look more attractive than the salmon.

4.11.3. Post-Harvest Practices and Trade

Most of the post-harvest and trade practices used for fisheries in open waters are also applied to the mariculture practices of a country. Fish is a highly perishable item, meaning that it requires great care while harvesting as well as along the supply chain in order to preserve the fish's quality, its nutritional benefits and to prevent contamination, loss and waste. Major improvements in processing, refrigeration, ice-making and transportation have made the transportation of fish in different product forms over long distances possible. Developed countries have been able to process fish into high value products such as ready to eat meals. China, for example, is aiming to process cultured products by using state of the art technology to maintain freshness and to test for fish quality quickly. Technologies include ultra-high pressure technology, microencapsulation technology, high-efficiency concentrated fermentation technology, membrane separation technology, microwave technology, ultra-fine comminution technology, expansion and extrusion technology, biological engineering, supercritical CO₂ fluid extraction, ultra-micro pulverization, nano-technology, ohmic heating, microwave technology and freeze-drying in a vacuum.

In developing countries, fish is mostly utilized in live or fresh form (51%) or in the frozen form (31%) (FAO, 2020a).

Member countries of the World Trade Organization (WTO) have signed the Sanitary and Phytosanitary (SPS) Agreement in order to protect public health and to facilitate international trade.

It is also vital to incorporate Hazard Analysis and Critical Control Point (HACCP) measures to ensure the food safety of products produced from mariculture. HACCP is an internationally recognized system for reducing the risk of safety hazards in food. HACCP is designed for use in the entire food industry from production, manufacturing, distribution and retailing food for consumption. HACCP is not only important in order to prevent food borne illness but also to prevent recalls and help companies save money. HACCP controls biological, chemical and physical hazards. HACCP is based on 7 principles – List processes and identify hazards,

identify Critical Control Points (CCPs), establish critical limits, monitor CCPs, establish corrective actions, verification and documentation.

4.12. Social and Legal Frameworks

4.12.1. Worker Safety

Especially in the mariculture industry, there are diverse workplaces with workers being exposed to different physical, chemical and biological perils such as noise, hot / cold working environment, working in isolation, cuts, sprains, fractures, occupational asthma and rhinitis, burns, skin irritation and allergies, parasitic infestation and pathogenic infections. Events that furthermore need to be taken in account could include the provision of personal protective gear and clothing (heat, water, etc), measures to avert/minimalize slips and trips accidents (right footwear, usage of right cleaning methods, electrical and machinery safety, sound management of chemicals). In the long term, occupational accidents can result in frequent changes in employers, and reduced job satisfaction, efficiency, morale and employee loyalty. The issues of health and safety at work should properly be implemented to safeguard the mental and physical wellbeing of organizations' human resources, taking all necessary precautions and proactive policies that prevent and deter accidents and occupational diseases.

4.12.2. Fair Distribution of Income amongst Workers

Mariculture has created jobs for coastal communities, around the world. Small fish and no-value fish are supplied and used as fish feed, which has further created an opportunity for fair distribution of income for all and strengthens the farmers economically and has increased their earnings manifolds than an average agriculture farmer (J. Ramos, et al., 2015). However, in order to ensure that income is fairly distributed amongst the workers, it is vital to have sound legal instruments in place to protect the rights of the lower class.

4.12.3. Communities' Livelihoods and Access to Fishing Grounds

Coastal communities are often dependent on wild fish resources for their livelihoods. It is vital to ensure that mariculture structures are not located in areas where fishermen access the open sea from.

4.12.4. Incentives

Using economic instruments to influence mariculture holds considerable promise., Institutions could provide education, training, research and extension services to support the implementation of legislation, policy and regulatory frameworks. Economic and other incentives may help in the planning and management of aquaculture development.

Although some positive incentives may be expensive, it may be possible to pay for them through taxes on undesirable locations, activities and technologies.

4.12.5. Deterrents

Deterrents are also legal instruments, which punish either *ex ante* (by requiring a payment returnable upon compliance) or *ex post* (by being charged for a fine when non-compliance occurs).

CHAPTER 5

POTENTIAL RISKS FOR DEVELOPING MARICULTURE IN PAKISTAN

5.1. Additional Pressure on Resources

5.1.1. Fish for Fishmeal

Approximately 60% of the captured fisheries production in Pakistan is used in fishmeal (Fanning *et al.*, 2016). Various companies export fishmeal to China. Fishmeal is utilized for the poultry industry within Pakistan, however, the increasing development of mariculture or aquaculture as a whole will increase demand for fishmeal, thus putting additional pressure on already scarce wild stocks.

Due to the decrease in fish stocks, the price for feed with fishmeal as an ingredient has increased; as a consequence, the demand for alternatives to fishmeal is on the rise. Soybean meal has been an alternative tested in Pakistan (Patil *et al.*, 2018).

5.1.2. Water

Water replacement is frequent in mariculture practices in order to make up for the loss of water through evaporation, to replace contaminated water and to make up for the loss of oxygen (Paez-Osuna *et al.*, 2003; Verdegem and Bosma, 2009)

Water is needed for the production of plant-based diets as the use of fishmeal and fish oil for mariculture decreases. This dependency puts additional pressure on fresh water resources in order to water the plants. Soybean is an important crop for feed in that it produces a higher yield per unit of water consumed (Pahlow *et al.*, 2015). This crop has been tried in Pakistan (Patil *et al.*, 2018). Water resources may also be conserved by utilizing the by-products of terrestrial animals for feed (Naylor *et al.*, 2009).

5.1.3. Land

As elaborated earlier in this section, shrimp farming has been a significant contributor to the loss of mangroves throughout the globe.

As agricultural lands found along the coast, such as rice farms, are often the victim of saline intrusion during the dry season and due to the potential of earning a greater amount via shrimp farms, farmers have converted their agricultural land into shrimp farms. Shrimp-rice production systems in the brackish-water zone after removing mangroves may also cause saline intrusion into homestead land. As in the

case of Bangladesh, this could lead to a loss in the amount of fruit trees and plant species and could shrink homestead areas along with land for grazing (Gowing et al., 2006) in Pakistan. Furthermore, hydrological changes along the coast of Pakistan may also occur due to the construction of canals and roads, thus causing coastal erosion.

5.1.4. Energy

Pakistan is currently facing an acute energy crisis, particularly in the northern, rural and off-grid areas (Raza et al., 2019). The requirements for Pakistan's energy sector are compensated through petroleum products, electricity, LPG and coal consumption. During 2018, oil consumption increased by 107.6% (Latif et al., 2020), while energy consumption increased by 9.7% from the previous year (HDIP, 2018). The import bill of oil during the year 2017-2018 reached US \$12 billion, putting pressure on Pakistan's financial resources and proving that Pakistan is highly dependent on foreign reserves for oil. Furthermore, the hot temperatures in the summer months lead to an increasing demand for energy during the season; as supply cannot be met with demand, the country often experiences blackouts. Therefore, agriculturalists and industrialists have started looking to other sources of energy such as solar, wind, hydropower and wave. Pakistan particularly has great potential for solar energy (Firoz and Intikhab, 2004) and is particularly useful for supplying energy to remote areas. Balochistan has the most potential for solar energy, with sunlight coming in at an average of 8.5 hours per day. Wind turbines are also good for the coastal areas of Pakistan.

Energy is required for various components of the mariculture processes including the collection and production of juveniles, general system operations and the harvesting, processing and transport of the product. The amount of energy required depends on the intensity of the operation, the degree of mechanization, the type or means of production, and the quality/quantity of feed inputs.

Fishing fleets consume large amounts of fossil fuels while going out to sea to collect fish for the feed and reduction plants consume energy while processing the feed. Furthermore, both direct and indirect energy inputs are required for producing plant-based and live-stock derived inputs for the feed. Energy is also required to produce juveniles in hatcheries and to collect them from the wild.

Most extensive culture systems require low energy inputs as the species used are able to obtain their food from primary producers such as phytoplankton or macrophytes. These systems do not use formulated feeds, but use agricultural products or wastes and chemical fertilizers, resulting in less input of energy. However, although the amount of indirect consumption of energy may be small, the direct amount of energy for harvesting, sorting and cleaning, especially in developed countries, which use industrial means is high; the energy input in developing countries is low as labor is cheap and readily available. Likewise, farming

herbivorous species in industrialized countries would make use of a greater amount of fossil fuels.

Feed used in semi-intensive systems consists of fish that is either partially or completely from local fisheries, this type of feed is unprocessed and is either supplied directly or goes through very minor transformations for example being turned into moist pellets.

The use of local fishery resources results in less fossil fuel consumption; this is especially true if drying and transportation-related energy inputs are limited. Energy is also wasted while storing products susceptible to spoilage, if they are not locally available. Wastes from fish processing may also be utilized for feed, this will result in a reduction of the expenditure of energy while extracting fish and will only leave behind energy consumption in the process of transportation and secondary processing.

In open water systems, water is able to circulate via natural processes, removing wastes and metabolites and also oxygenating the water. On the other hand, tanks and pond systems utilize great amounts of energy for the same processes. It has been suggested that a shrimp pond farm is capable of consuming 5 times more energy than a salmon cage farm.

Feeds which come from fish and livestock generally take up more energy than those derived from plants. Furthermore, the energy consumed while preparing different forms of animal-based feeds and similarly, different forms of plant-based feeds vary, for example, depending on the method of fishing used and the quantity of fish stocks and the types of crops used and the type of agricultural system they are derived from respectively (Troell *et al.*, 2014).

5.2. Food Safety and Public Health

In Pakistan, surveillance of aquatic animal health and mitigation strategies are not as developed as they should be, even though an Animal Quarantine Ordinance is in place. Importers of live aquatic organisms are also required to obtain and display health certification. No requirements or facilities currently exist for quarantine. Furthermore, the diagnostic capacity for fish disease in Pakistan is limited, for instance, Pakistan's fisheries departments and universities do not currently have the means for shrimp viral diagnostics. Often, controls are limited only to checking for fish disease with the naked eye. 60% of the diseases in shrimp culture are caused by viruses; Pakistan is lucky in that it is currently free of viruses which could potentially harm shrimp. Patil *et al* (2018) suggest that a precautionary approach should be used when importing shrimp species such as *Litopenaeus vannamei*. Therefore, the country is not as prepared as it should be to take on the challenges of safe mariculture development, and in mitigating the risks of disease

transmission in the local market and the already reluctant to import, foreign countries.

5.3. Destruction of Natural Ecosystems

Various examples exist throughout the world where mariculture has been developed in areas where mangrove forests are abundant. About 1/3rd of mangrove areas have been destroyed due to anthropogenic activities, a contributor of which is coastal aquaculture development, resulting in 11% of the loss between 1996 and 2010 (Thomas *et al.*, 2017).

The conversion of agricultural fields and natural habitats into coastal aquaculture not only leads to a greater amount of erosion due to the wind or waves (Kuenzer *et al.*, 2011), but also results in the suspension of inorganic particles in fish and shrimp ponds (Burford *et al.*, 2003).

Ironically, according to researchers, the loss of mangroves is a major reason for the unsustainability of shrimp farming as a result of erosion, loss of productivity, water acidity and contamination. It is therefore vital to ensure spatial planning before introducing mariculture into an area, to prevent the further loss of these vital habitats and also to mitigate the decline of fisheries in Pakistan (details given in section 3.3.1 above).

5.4. Marine Pollution

Generally, the effects of aquaculture activities on the surrounding environment occur within 5 km of the culture sites and decrease as the distance increases, however, the effect on benthic communities may persist years later, even if inputs into mariculture systems cease (Kraufvelin *et al.*, 2001).

One of the main concerns for pollution via mariculture arises through the discharge of untreated waste-water into coastal waters (Islam *et al.*, 2004). The large amount of organic water in these effluents results in eutrophication (Carrasquilla-Henao *et al.*, 2013; Wolanski *et al.*, 2000) and algal blooms, resulting in dire consequences for the ecosystem (Cao *et al.*, 2007; Costanzo *et al.*, 2004; Paez-Osuna *et al.*, 2003).

Furthermore, adding feed, fertilizers and chemicals to the water in order to control diseases also result in additional nutrients and pollutants including bacteria, viruses and other toxic compounds (Sohel and Ullah, 2012), which subsequently contaminate the surrounding natural ecosystem when discharged.

Organic waste dispersal from salmon farms has caused alterations in the biodiversity of microflora found within benthic sediments (Buschmann *et al.*, 2009). Strong local eutrophication processes in coastal lagoons of the Gulf of California, Mexico have been noted to occur as a result of effluent discharge after shrimp

farming (Carrasquilla-Henao et al., 2013). As mentioned previously in this report, integrated multitrophic mariculture systems are an effective way of mitigating marine pollution in Pakistan.

In developing countries, the unnecessary and unrestricted use of antibiotics and chemicals including pesticides and fertilizers is generally a problem. In order to prevent bacterial infections and disease outbreaks, and often as an easier alternative to problems that occur as a result of high stocking densities and poor water quality, antibiotics are added to the fish feed. This is of great concern, as these practices may lead to resistance in bacterial populations, ultimately hampering the functioning of an organisms' natural immune system (Cabello, 2006; Primavera, 2006).

Mariculture also leads to an increased amount of salinity in surface waters. Salinization is also occurring as a result of higher evaporation rates, especially in tropical regions. Hyper-saline waters and wastewaters are often discharged into the surrounding environment after harvest, resulting in increased salinity in mangrove and saltmarsh areas. Storing saline water in ponds meant for shrimp production can also cause salts to enter the surrounding soils (Afroz and Alam, 2013), which alters its physical structure and reduces its fertility (Paul and Roskaft, 2013).

5.5. Threats to Cultured Organisms if they Escape

According to previous studies, the rates of survival and reproductive success were lower in farmed organisms than in wild populations, especially in eggs and juveniles (Gross, 1998). The diets of cultured organisms have not been shown to vary much from wild organisms (Fleming et al., 2000). Males present in the wild have been observed to court females more frequently than cultured males (Webb et al., 1991; Fleming et al., 2000). Farmed fish have also displayed a higher level of juvenile aggression and lower levels of predator avoidance (Weir and Grant, 2005).

5.6. Threats to Wild Populations if Cultured Organisms Escape

The artificial selection and genetic engineering of cultured organisms may result in changes in an organisms' phenotype and genotype. These changes may include alterations in body size, fitness, age at sexual maturity, etc. Under poorly managed conditions, if these organisms escape, they could alter the demography of wild populations along Pakistan's coast.

Invasive organisms, however, also have the capability of harming endemic populations without interbreeding. The escape of cultured organisms may result in increased competition for territories, food and mates between the invasive organisms and wild populations.

Wild populations are also susceptible to diseases from cultured organisms. Once a pathogen is introduced into the natural environment, there is little to no possibility of its mitigation.

5.7. Environmental Stress on Organisms

5.7.1. Climate Change

Climate change will have a much greater impact on maricultured organisms than on terrestrial farmed animals; This is because cultured organisms are poikilothermic, meaning that their body temperatures vary with changes in the surrounding environment. Furthermore, climate change could also alter wild fisheries, affecting mariculture practices as they are dependent on wild stocks for fishmeal and fish oil.

In Pakistan, an increase in the temperature has led to a decrease in the flow of rivers. The sea level is also predicted to rise. Furthermore, an increase in cyclonic activity due to higher sea surface temperatures are predicted. Pakistan's coastal area falls under the tropical zones of the world's oceans. This area is expected to experience relatively high extinction rates, a low amount of wild catch and a decrease in the size of fish (Patil et al., 2018). As sea surface temperatures rise, wild fish are able to migrate, however this is not possible when they are enclosed within structures.

5.7.2. Pollution

The excessive use of chemicals and fertilizers in mariculture systems can cause eutrophication in these waters, restricting the amount of oxygen reaching these cultured organisms and ultimately leading to mass mortalities. Furthermore, solid waste, including micro and nano plastics may also gather in cultured organisms and subsequently in human consumers leading to a myriad of adverse health hazards.

In Pakistan, untreated domestic and industrial waste from coastal cities and towns is dumped into the sea. It is estimated that about 430 million gallons/day of untreated sewage is dumped into the sea by Karachi alone through the Lyari and Malir Rivers as well as through a number of small drains (MFF, 2016). Only about 15% of sewage is treated in Karachi (MFF, 2016). The accumulation of solid waste from coastal cities into the environment is also routine in Pakistan.

5.7.3. Changing Currents and Tides

Water exchange through mariculture systems is vital for both the replenishment of oxygen and the removal of wastes. A weak and continuous current stream is preferable, while excessive currents result in additional loads, damage structures, reduce the volume of the structures due to deformations and may

adversely affect fish behavior. Tidal currents form the majority of surface water currents and change according to the pull of the sun and the moon on the earth. For marine cage culture a tidal amplitude of <1 m is preferred. Monsoon season is generally avoided for cultural activities as current velocity during monsoon season is influenced by littoral current, strong winds, wave effects and increased river discharge (Prema. 2013).

5.8. Fish Welfare

Fish welfare is a vital component of mariculture; not only for public perception, marketing and social acceptance, but also for production efficiency, quality and quantity (Broom, 1998; Southgate and Wall 2001; FSBI, 2002). Freedom from hunger and thirst, discomfort, pain, injury, disease, fear and distress as well as the freedom to express normal behavior (FAWC, 1996) all encompass fish welfare; however, for many, fish welfare is not only a matter of physical wellbeing but is also a matter of mental wellbeing. Traditionally, concepts of animal welfare have been applied to animals which experience pain, fear and suffering and have been linked with species with a higher cognitive functioning than fish.

There has been some debate regarding whether fish experience pain and fear. Some researchers claim that fish lack the essential brain regions required to feel pain while others present anatomical, physiological and behavioral evidence for nociception in fish and that they are capable of experiencing pain and fear (Braithwaite and Huntingford, 2004; Chandroo et al., 2004; Portavella et al., 2003; Sneddon et al., 2003).

Fish welfare issues in mariculture include fish health, mariculture procedures, stocking density, aggression and altered behavior. Cultured fish could be the victim of various diseases due to low temperatures. In addition to specific bacterial pathogens, this may also be the result of immunosuppression during the winter months. This could be solved by boosting immunity in fish by a supplementary dosage of vitamins and trace minerals to assist the immune system (Tort et al., 2004) and by changing the feeding regime in order to control the amount of nutrients available to the pathogen (Damsgard et al., 2004; Rorvik et al., 2003). Fins also rot within mariculture structures as a result of abrasions or aggressive interactions with other fish; secondary infections may occur following this (Turnbull et al., 1998; Ellis, 2002). In this respect, more effective vaccines with reduced side effects and oral application may improve welfare. Furthermore, parasites within the environment could result in severe tissue damage (Johnson et al., 2004); these parasites have become resistant to the effects of traditional chemical treatments (Jones et al., 1992; Treasurer et al., 2002; Tully and McFadden, 2000). This may also be controlled via vaccination and selective breeding (Woo, 1997; Jones et al., 2002; Mordue and Pike, 2002; Revie et al., 2002; Stone et al., 2002; Treasurer et al., 2002; Glover et al., 2004). Additionally, if cleaner wrasse is being used as a means of biological control, the welfare of this organism also needs to be taken under

consideration. Examples of viral diseases include infectious pancreatic necrosis (Park and Reno, 2005; Roberts and Pearson, 2005), infectious haematopoietic necrosis (Bergmann et al., 2002), viral haemorrhagic septicaemia (Fichtner et al., 1998), infectious salmon anaemia (Hovland et al., 1994) and sleeping disease (Graham et al., 2003). Traditional vaccines have not been very successful, however, alternative anti-viral treatments such as DNA vaccines exist (Lorenzen and Oleson, 1997; Lorenzen and LaPatra, 2005). Another risk to animal health arises from deformities of the heart (Poppe and Taksdal, 2000; Poppe et al., 2002), swim bladder (Poppe et al., 1997), and spine (Vagsholm and Djupvik, 1998; Silverstone and Hammell, 2002). Fish with deformities of the heart demonstrate a high mortality rate during stress as a result of impaired cardiovascular function, cardiac failure or heart rupture (Brocklebank and Raverty, 2002; Poppe et al., 2002). Spinal deformities could occur as a result of genetic or environmental factors (Vagsholm and Djupvik, 1998; Halver et al., 1969; Choo et al., 1991; Toften and Jobling, 1996). To prevent deformities, high temperatures during the incubation of salmon should be avoided (Poppe and Taksdal, 2000). Spinal deformities could be avoided by increasing the smolt weight before they are put into seawater, vaccinating and by decreasing variations in temperature and salinity (Vagsholm and Djupvik, 1998). Breeding fish from families in which a high rate of deformation occurs should be avoided (Gjerde et al., 2005).

Aquaculture management procedures are also vital for fish welfare. Procedures such as grading, handling and crowding are inherently stressful (Barton et al., 1980; Davis and Schreck, 1997; Sharpe et al., 1998; Conte, 2004). Vitamin C and E supplements and glucan can help to protect against the adverse effects of chronic stress (Merchie et al., 1997; Dabrowska et al., 1991; Montero et al., 2001; Jeney et al., 1997; Volpatti et al., 1998). In order to prevent stress in fish, reduced stocking density, appropriate nets, careful handling, recovery periods and movement using fish pumps and transfer pipes should be used (FAWC, 1996; Scottish Executive, 2002; Conte, 2004).

Transporting fish involves capturing, loading, transporting, unloading and stocking the fish (Specker and Schreck, 1980); these factors can cause fish stress for long periods of time (Davis and Parker, 1986; Iversen et al., 2005). The extent of the stress due to transportation may be mitigated by acclimation and recovery periods (Conte, 2004; Iversen et al., 2005), the use of anaesthesia, depending on the species (Erikson et al., 1997; Sandodden et al., 2001; Finstad et al., 2003) and dilute salt solutions (Carmichael, 1984; Pickering, 1992; Wedemeyer, 1997). Withdrawing food for the fish before slaughter, transportation and other management practices could be good for the welfare of fish as it could reduce metabolism, oxygen demand and waste production. Atlantic salmon undergo long periods of starvation in the wild (Kadri et al., 1995), however, the consequences of withdrawing food from cultured organisms is unknown. Depriving fish of food for short periods of time may not affect their welfare. The slaughter of fish also needs to

be as humane as possible. It is recommended that before slaughtering, fish should be stunned, so that they are unconscious immediately and until death (FAWC, 1996). Stunning may be percussive or electrical and have proven to be a humane means to an end in fish such as salmon, gilt-head sea bream and turbot (Robb et al., 2002, Morzel et al., 2003; Van de Vis et al., 2003). Electric stunning tongues or batches of eel in freshwater combined with nitrogen flushing can lead to instant unconsciousness in fish (Robb et al., 2002; Van de Vis et al., 2003).

Stocking density affects the welfare of fish in a number of ways including through aggression, water quality, and activity/feeding patterns. The effects of stocking density differ on a case to case basis. Seabass, for example, demonstrates high levels of stress at high densities (Vazzana et al., 2002; Gornati et al., 2004). Arctic char grows slower and eats less food at very high densities (Jorgensen et al., 1993; Ellis et al., 2002). The tolerance of halibut for high stocking densities is dependent on its stage (Greaves and Tuene, 2001; Kristiansen et al., 2004). For halibut, high stocking densities could be overcome by altering feeding patterns and increasing floor space (Kristiansen et al., 2004). The swimming depth of salmon and their shoals' density may be manipulated by artificial light levels (Juell et al., 2003; Juell and Fosseidengen, 2004). Changes in feeding patterns can also change aggressive interaction in several species including Atlantic salmon (Andrew et al., 2002).

Aggression may result due to the formation of social hierarchies; this could lead to injuries (Greaves and Tuene, 2001), chronic social stress (Ejike and Schreck, 1980; Schreck et al., 1997; Wedemeyer, 1997; Alanara et al., 1998) and size heterogeneity (Alanara et al., 1998; Dibattista et al., 2005). The levels of social interactions are greatly affected by socio-biology, stocking density and feeding techniques (Alanara and Brannas, 1996; Adams et al., 1998; Andrew et al., 2002; Andrew et al., 2004). To prevent aggression, species should be fed food which is specific to them. A study by Adams et al. (2000) showed that a small number of larger Atlantic salmon could possibly reduce aggression in smaller fish. Increasing levels of L-tryptophan in fish diets has been shown to limit aggression (Winberg et al., 2001; Hoglund et al., 2005; Hseu et al., 2003). Additionally, changing the color of the substrate or background may also prove useful in reducing aggressive behaviors in fish. Another welfare concern has to do with abnormal behavior, including repetitive behavior and abnormal swimming activity or patterns. It is vital to examine the cause of an abnormal behavior and to determine whether a behavior is abnormal due to unacceptable welfare practices or if it is due to an adaptive response with no effect on the well-being of fish (Dawkins, 1998; FSBI, 2002; Dawkins, 2003; Dawkins, 2004). Studies should be conducted for species specific behavioral changes in accordance to compromises on welfare (Ashley, 2006).

In Pakistan, the concept of fish welfare is as good as non-existent. To our knowledge, no published paper concerning this issue, specific to Pakistan exists in

the literature. Fish are left to suffocate in the open air after being extracted from the water and are often still alive when being thrown into the ice meant for preservation on boats. Furthermore, due to a lack of awareness or general apathy concerning the welfare of farmed animals, other farmed-animal industries such as poultry and red meat in the country also do not have the best practices when it comes to animal welfare. It is therefore expected that fish welfare will not be a priority during mariculture and thus it is vital to ensure that strict policies are put into place for fish welfare when developing mariculture in the country.

5.9. Financial Risks

There is less investment available in the market for mariculture enterprises due to the lack of information and knowledge. There is also a constant fear and chance of losing the crop if proper methods and techniques are not followed. If no proper repair or maintenance facility is available, the whole infrastructure deployed would suffer greatly leading to great financial damages. Poor pond, water, crop, and equipment management if not dealt with will cause huge losses.

Furthermore, there is hesitation from the banks and investment agencies to fund the mariculture enterprises. Juvenile and adult mortality due to unknown diseases is a big financial risk for the crop. Sub-standard or incompatible feed, infected feed, fungal growth, or infestation feed can lead to financial loss.

5.10. Social Risks

5.10.1. Worker Safety

Occupational risks and hazards in aquaculture may be due to physical, chemical or biological hazards.

In developing countries, governments do not concern themselves with potential physical risks as much as they should to ensure worker safety. Workers who operate with locally fabricated machines are especially exposed to excessive noise; this noise can result in hearing defects, hearing loss, and mental fatigue. Farmers may also be exposed to diverse injuries. These may include stings and bites from fish, crab clawing, cuts from oyster shells, falls, etc., especially when workers are not using the appropriate protective gear. This is especially prevalent in rural fish farming. Mechanical injuries may also be associated with laboratories and processing plants.

Chemical hazards are also a potential threat to mariculture farmers. This type of hazard may be the result of exposure to chemicals that are added into mariculture systems such as inorganic fertilizers, lime, pesticides, formaldehyde, etc. It may also be the result of severe and prolonged pollution in waterways, through pesticides, oil spills, and other xenobiotics. Some of these compounds may result in severe burns or skin irritation, amounting to severe cases of occupational dermatitis, or from

fumes, smoke and soot, coming out of water pumping and other machines. This can result asthma, cancer and other serious conditions.

Biological hazards include parasites and pathogens. Parasites include leeches which can also attack unprotected humans. As a result of the use of human and animal wastes in mariculture systems in developing countries, nematodes and cestodes are some of the parasites farmers may be exposed to. Pathogens such as fungus and vibrio are also examples of potential biological hazards.

It is therefore vital to develop a health and safety plan for mariculture practices in Pakistan in order to ensure worker safety in mariculture. This should include a method for identifying hazards, safe work procedures, a program for training workers for safe work procedures, a method of monitoring workers for safe work procedures, a progressive disciplinary policy to ensure compliance with safety policies, documentation of the steps of the health and safety plan as proof of due diligence.

When developing a health and safety plan, safety issues of the work place need to be addressed. It is important to conduct informal inspections of the various work areas and tasks, to discuss safety concerns with workers and to obtain information regarding safe industry standards (Erondur, 2005).

5.10.2. Local Communities' Livelihoods and Access to Fishing Grounds

Mariculture structures present on the coastline may cause a hinderance for local communities, who may not be able to access their normal fishing grounds for their livelihoods.

Although this has not created problems for mariculture in Pakistan in the past, it may be a potential issue in the future.

5.10.3. Unfair Distribution of Income amongst Workers

Mariculture in Pakistan is at the basic level, the industry has been recognized as a sub-sector of the agricultural economy that has the potential to play a vital role for becoming a source of income amongst workers.

A potential risk of mariculture practices in Pakistan is that the newly developing industry may not have sufficient resources of income to be fairly distributed among workers. Furthermore, corruption may lead to workers in the mariculture industry getting a smaller proportion of the earnings than they deserve.

CHAPTER 6

DISCUSSION

6.1. Previous Studies on Mariculture in Pakistan

Studies regarding mariculture in Pakistan are very few, and the ones that have been conducted have been a segment of studies conducted on aquaculture as a whole. Although reports such as Revitalizing Pakistan's Fisheries by the World Bank and State of World Fisheries and Aquaculture by the Food and Agriculture Organization of the United Nations do exist, to the authors' knowledge, such in-depth research regarding the development of mariculture in Pakistan has not been published.

6.2. Importance of Research

This research will contribute towards the existing knowledge of developing mariculture in Pakistan by putting forward recommendations for the development of this sector by studying reasons for fall-outs in the past, by analyzing the potential risks of developing mariculture in Pakistan and by implementing the best-practices for mariculture in Pakistan by example of various countries around the world.

6.3. Future Research

Further research is needed in order to determine the demand and consumer preference for mariculture products in Pakistan. There is also a need for detailed spatiotemporal planning as well as thorough risk assessments. Further research should also be conducted by visiting the aquatic diagnostic labs and fish processing units in Pakistan to determine their shortcomings and subsequently for putting forward recommendations to develop the mariculture sector to the best of its ability.

CHAPTER 7

WAY FORWARD

In order to incorporate the best-practices utilized around the world while developing mariculture in Pakistan, the following recommendations are put forward.

7.1. Potential Organisms for Mariculture in Pakistan

1. Species that are in demand in both local and export markets should be focused upon. *L. vannamei* broodstock should be imported from approved sources and quarantined in government-run facilities upon entry into the country. The development of broodstock multiplication centers should be allowed.

2. Profitable organisms such as Cephalopods and groupers, which also desperately need to be conserved in open waters, should be cultivated in the country.

3. Seeds of transgenic organisms should be used in mariculture for favorable traits such as increased survival rate, increased turnover rate, efficient use of resources, reduced production costs, increased environmental protection, production of growth hormones, production of antimicrobial peptides, incorporation of metabolic genes to digest cheap land-based diets.

7.2. Development of Infrastructure and other Facilities

1. The development of a local value chain is vital to ensure profitable mariculture. It is crucial to build and develop local fish hatcheries near mariculture sites when developed and improve the feed processing plants' production quality.

2. Special funds should be made available for financing the private sector's mariculture projects offering matching grants and markup loans. A comprehensive financial policy needs to be structured and focused on this segment of the agricultural industry where the bank should provide easy financing options to the farmers, with no or very low-interest rates.

3. Proper mechanisms to track progress related to mariculture need to be established. Databases that monitor mariculture outcomes such as production, profits, and employment need to be developed and regularly updated. Research concerning mariculture should be spread to ensure that it is not duplicated and maximum research efficiency is achieved. Furthermore, policy implementation should be regularly monitored via the use of pre-established qualitative and quantitative indicators.

4. Incentives should be provided to the coastal communities to take part in the development of mariculture, leading to their better socio-economic status.

Bank and other investment agencies should provide easy and soft loans with a low mark-up on 10 to 15 years payout option, to incentivize investment in this sector of the agricultural economy.

7.3. Capacity Building for Mariculture

1. Experts educated and trained in mariculture should be hired in the country's fisheries' departments. Fisheries experts need to be employed and they should visit mariculture sites on a regular basis, provide advice and conduct in-situ training.

2. Marketing sectors should be strengthened to obtain a good local and foreign market.

3. Scientists, entrepreneurs, innovative businessmen and managers must collaborate for the successful development of mariculture in Pakistan.

7.5. Socioeconomic Development through Mariculture

1. Data for employment through mariculture needs to be collected in order to determine the socio-economic impact of the sector.

2. It is important to develop indigenous population capacity to formulate feed for the cultured species, to ensure that people living in the vicinity can earn their livelihoods.

3. An understanding needs to be developed amongst the fishermen community to embrace the farming of sea organisms to increase the employment opportunities; these would increase not only by opting for mariculture but by developing the ancillary industry that would enable people to earn their livelihoods through local development of gears, aerators, feeding machine, ponds frame/structure lightning, etc. the goods manufactured in the ancillary industry established can also be exported to other mariculture practicing countries enabling Pakistan to earn foreign exchange.

7.5. Spatiotemporal Planning

1. Spatiotemporal planning studies need to be conducted in the country to determine the most suitable areas to practice mariculture in Pakistan and remote sensing should be used for the spatial assessment of aquaculture areas at different scales.

2. Sites such as Miani Hor and Kalamat Bay could be utilized for initial, low impact mariculture projects.

7.6. Mitigation of Environmental Risks

1. In order to mitigate environmental risks, thorough risk assessment should be conducted prior to mariculture implementation and procedures for environmental assessment and monitoring should be established. Integrated multitrophic mariculture systems should be focused upon. Furthermore, therapeutants, hormones and drugs should be used safely, effectively and minimally.

2. Financial planning should be done in advance in order to handle diseases emergencies in cultured organisms at both the national and regional levels.

3. It should be ensured that the disposal of wastes such as offal, sludge, dead or diseased fish, excess veterinary drugs and hazardous chemicals does not cause harm to humans or to the environment. Wastewater should be treated properly.

4. Shrimp farms should not be constructed in intertidal zones to prevent habitat degradation.

5. The extraction of seed from the wild should be minimized and proper training should be given to fry catchers to ensure that other organisms are not affected during the process of catching seeds from the wild.

7. Research should be conducted regarding the number and density of sea cages that can be accommodated by an area without harming the cultured organisms or the environment.

8. Awareness is needed concerning alternatives to fishmeal such as insect meal, soy protein concentrate, poultry by-product meal, blood meal, spirulina.

9. Pakistan can incorporate novel technologies while developing mariculture in the country to prevent disease such as the Seafarm Pulse Guard and blue lice instead of adding antibiotics and chemicals which will ultimately contaminate the marine environment, to the systems. Pakistan may also learn from Ocean Farm 1 to develop offshore mariculture. Furthermore, in order to develop sustainable and environment friendly mariculture Pakistan may adopt technologies such as the marine donut and mobile farming unit by Fish Globe.

7.7. Awareness about Mariculture in Pakistan

Awareness and information should be promoted and disseminated amongst the general public to increase the consumption of farmed fish through education in schools and through the media.

7.8. Food Safety and Post-Harvest Processing

1. National strategies for the short, medium and long term consisting of national coordination, legislation and policy, list of pathogens, institutional resources, diagnostics, health certification and quarantine, surveillance and reporting, disease zoning, contingency planning, risk analysis of imported products, capacity building, awareness building and communication, farmer/private sector involvement, financial resources, monitoring and evaluation and regional cooperation need to be worked upon.

2. To mitigate the spread of disease within and outside mariculture enclosures, national disease reporting systems/databases should be established; Emerging diseases and potential pathogens should be kept in check and aquatic animal health laboratories should be increased in number while existing ones should be upgraded.

3. Awareness is needed concerning the safety and quality of consumable cultured products. The whole mariculture process should be a transparent one with the traceability of a product being easily available to a consumer via product labelling including nutritional values, environmental friendliness and drug use.

7.9. Fish Welfare

1. A supervisory body for the welfare of cultured organisms should be established which would visit mariculture sites regularly to ensure that stocking densities are low, inherently mobile organisms are able to get ample exercise, to monitor altered behavior and aggression and to subsequently make suggestions to the farmers for the welfare of their cultured organisms including supplementary vitamins and trace minerals to prevent disease, effective oral vaccines with reduced side effects and food specific to the species. This body would examine the cause of an abnormal behavior to determine whether a behavior is abnormal due to unacceptable welfare practices or due to an adaptive response with no effect on the well-being of the organisms.

2. Species specific measures should be taken while culturing species. Research should be conducted concerning whether aggression in the species to be cultured in Pakistan can benefit if larger species are added into the system and if changing the color of the substrate or background could help with aggression. To avoid heart and spinal deformities in cultured organisms such as increasing the smolt weight before they are put into seawater, vaccinating, decreasing variations in temperature and salinity and avoiding breeding fish from families in which a high rate of deformation occurs. Species should also be fed with food that is specific to them in order to prevent aggression.

3. The extent of stress due to transportation may be mitigated by acclimation and recovery periods, procedures stressful for fish such as grading,

handling and crowding should be avoided and Vitamin E and C supplements and glucan should be given to prevent chronic stress.

CHAPTER 9

CONCLUSION

This research shows the necessity of mariculture in Pakistan for the conservation of its depleting species, for food security and for the socioeconomic development of the country. Pakistan is far behind not only developed countries, but also regional and economically similar countries such as Bangladesh in terms of mariculture. Although all economically important species and species in demand in the export market cannot be cultured in Pakistan, Pakistan has much potential for cultivating commercially important species such as groupers and has room for the development of domestic markets such as the nutritional supplements market through the development of the culture of microalgae, however, is struggling to maintain mariculture due to the absence of local industries to support mariculture. Much of the work concerning mariculture in Pakistan is rightly so focused on shrimp farming. The development of shrimp farms could potentially result in a greater amount of revenue on an annual basis than that of fish, shellfish and seaweed farming combined. As the world advances in mariculture, and works towards enhancing mariculture output through practices such as genetic engineering, developing alternatives to fishmeal and spatiotemporal planning, Pakistan still lags far behind.

While policies are being put into place for the development of mariculture in the country, it is also crucial to ensure environmental protection and consumer well-being. The protection of various resources which come into play while trying to develop mariculture in the country must all be looked upon in tandem; For example, mariculture should aim towards preserving wild fish stocks rather than extracting more fish from the seas and oceans for feed; on the other hand, in an attempt to conserve wild fish stocks, plant-based diets should consist of plants which take up less water such as soy-bean meal or the by-products of terrestrial animals should be made use of.

Being a developing country, Pakistan does not have all the benefits that countries require for the mariculture industry to flourish such as ample energy and proper fish disease risk management. Furthermore, as in other developing countries, the environment is not on top of the list of Pakistan's priorities. To prevent long-term environmental consequences such as benthic sediment contamination via additions to culture systems such as antibiotics and other chemicals including fertilizers and pesticides, it is vital that policies should not only be presented but also be strictly adhered to as these processes may be very difficult to reverse.

Pakistan can accelerate its growth and economic potential by promoting the application of new technologies in sea products' processing to drive forward

technological transformation and innovation, including promoting the application scope and level of advanced and new technologies in sea products processing, such as microencapsulation technology, high-efficiency concentrated fermentation technology, membrane separation technology, microwave technology, ultra-high pressure technology, ultra-fine communication technology, expansion and extrusion technology and biological engineering. Pakistan needs to upgrade its technology and build resource capacity to guarantee high value processed products to earn foreign exchange. It also needs to develop deep processing technology, efforts to optimize product structure and increase the added value of the cultured species rapidly.

Furthermore, the effect of the practice of mariculture on organisms within mariculture enclosures, on cultured organisms when they escape and on organisms present in the surrounding environment must not be ignored. While developing mariculture, it is the responsibility of everyone involved to ensure the well-being of the cultured organisms by being well-informed and via policies being strictly adhered to. Possible stresses of any sort and their impact on the species being cultured must be studied at the species level.

In conclusion, along with learning from past experiences, it is also pertinent to ensure that the harm caused by developing mariculture in Pakistan does not outweigh the good that can result from it. This can only take place through thorough research, training and by ensuring that policies involving best- practices are adhered to.

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