UiT The Arctic University of Norway

FACULTY OF BIOSCIENCES, FISHERIES AND ECONOMICS

Aquaculture market, diversity, and economic development of Bangladesh for the millennium 1995-2019

[Correlation between aquaculture and economic development in Bangladesh]

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Master's Thesis in International Fisheries Management

FSK -3910

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Abstract

Bangladesh is regarded as one of the most favorable regions in the world for aquaculture and fisheries attributed to its largest flooded wetland and third-largest aquatic biodiversity in Asia, behind China and India. The aquaculture in Bangladesh is crucial to the economy and diet of the world population. The purpose of this thesis is to review on aquaculture market, diversity, and their contribution in the economy in Bangladesh. Data for the period 1995-2020 were collected from Food and Agricultural Organization (FAO) and other information was sourced from literature. The author also discusses a variety of natural and manmade challenges that the aquaculture sector is facing including environmental pollution, overfishing, imbalanced urban and industrial development, natural disasters, and climate change. These factors work together to create a serious threat to income, food security, and biodiversity. The findings show that freshwater aquaculture has more potential to contribute to the development of Bangladesh.

1. Introduction

Aquaculture in Bangladesh plays a vital role in addressing protein deficiency and malnutrition, as well as creating jobs and earning foreign currency. On the one hand, it directly improves food security by producing fish for household consumption as well as by increasing supply and lowering the market price of fish. On the other hand, it indirectly assists in the diversification of farms and the construct new sources of revenue and employment streams. Bangladesh and in many other Asian countries, aquaculture is frequently considered to have the ability to boost food security because to its rapid expansion (E-Jahan *et al.*, 2010). For future growth aquaculture sector is one of Bangladesh's most productive and dynamic industries.

Bangladesh has enormous aquaculture potential because to its abundant inland lakes and river systems. Bangladesh is blessed with numerous rivers, including the Haor[0], Baor[1], and Beel[2], as well as numerous wetlands. With the world's largest flooded wetland and Asia's third largest aquatic diversity after China and India, Bangladesh is regarded one of the most favorable places for aquatic fishing and farming in the world (Shamsuzzaman *et al.*, 2017, Ghose, 2014). Bangladesh has a total inland water area of 6.7 million hectares, 94% of which is used for open water capture fishing and 6% for closed water culture fishing. Inland open water fisheries resources have played an important role in Bangladesh's economy, culture, tradition, and eating habits. In total, rivers and their ramified branches cover about 479,735 hectares of land. From inland and marine waterbodies, Bangladesh produced 3.26 million tons of fish in 2011–2012, with aquaculture making up more than half of the total (Dey, 2008). Fish exports are a substantial source of foreign currency earnings for the nation, with both macroeconomic and microeconomic advantages. Fish is the third highest-earning export from Bangladesh and is rising by 5-8 percent annually. Fish is presently Bangladesh's most significant primary export commodity as earnings from non-fish agricultural exports is increasingly being surpassed by sales of fish products (Dey, 2008, Dey *et al.*, 2008b).

[0] Haor is flooded basin
[1] Baor is Oxbow lake
[2] Beel is a wetland that resembles a lake

Fish is the best protein source on the planet, rich in vital macro- and micronutrients, vitamins, and minerals (Oyakhilomen & Zibah, 2013). Fish contributes more than 60% of the protein consumed globally, primarily in developing nations, according to FAO (2007).

Fish is Bangladesh's second most important subsector of agricultural produce, and its production supports millions of people's livelihoods and employment. The total fishing sector directly and indirectly supports the livelihoods of about 18 million people in the country (FRSS, 2017). Approximately 1.4 million women rely on the fishing, farming, and fish handling and processing industries for their livelihoods (BFTI, 2016, Shamsuzzaman *et al.*, 2020).

Bangladesh earns a substantial amount of foreign money from the fish trade, which benefits the country on both macroeconomic and microeconomic levels (Dey *et al.*, 2005). Bangladesh's third-largest export earner is fish, which is expanding at a rate of 5–8% each year. Bangladesh exports 10 types of fishery goods to more than 55 countries (frozen freshwater fish, frozen marine water fish, frozen shrimp, chilled fish, live fish, dry fish, salted dehydrate, live Eel fish, live crab, and fish scale/shrimp scull). Traditional non-fish agricultural exports are gradually being surpassed by fishery exports, to the point where fish has overtaken non-fish agricultural exports as Bangladesh's most important main commodity (Dey et al., 2005, Dey, 2008). Given Bangladesh's persistently huge trade deficit and recent food shortfall, fish exports have become increasingly essential as a source of foreign money. Fish output from aquaculture is progressively contributing to Bangladesh's fisheries sector's foreign exchange revenues, as it is in other Asian countries (Dey, 2000, Mohan Dey *et al.*, 2005).

Francis Hamilton's work is the foundation for understanding Bangladesh's freshwater fish biodiversity (Hamilton, 1822, Humtsoe *et al.*, 2007, Bangladesh, 18 June 2021) and in 1878, Francis Day published descriptions of the subcontinent's marine and freshwater fish species. After that much research has been conducted on the status of aquaculture in Bangladesh, it’s challenges and prospective. However, a comparison among the fish species is still missing. Some studies have been conducted on sustainable aquaculture, marketing and consumption in Bangladesh, socio-economic status of farmers, climate change effect on aquaculture. Though, the number of studies on this topic is still limited (Dey et al., 2008b). Azad et al. (2009) discussed the main difficulties, restrictions, and potential of sustainable shrimp farming. They found shrimp farming has decreased

economic risks and offered employment opportunities for small and marginal farmers in integrated gher[3] systems as a cash crop. Several studies have been conducted on domestic marketing system but research on foreign marketing system is very little. BM Shahriar *et. al*. (2013) found in their research that it is possible to improve their socioeconomic status by using improved technologies to manage the baor (Abdullah-Bin-Farid *et al.*, 2013). Ghose (Ghose, 2014) found that climate change and water pollution are growing threat for the future of aquaculture sector in Bangladesh and mentioned as challenges for Bangladesh. The light of fishermen must be considered, and a special task group should be established to analyze their vulnerability and devise methods to address it. Policymakers must make every effort to ensure that this sector operates at maximum capacity by improving investment and research infrastructure, enacting more stringent environmental rules, and establishing better storage and marketing facilities.

1.1 Research objectives

The aims of this thesis are: Firstly, to assess aquaculture market, diversity, and economic development of Bangladesh for the millennium 1995-2020; Secondly, investigate how aquaculture market and diversity help to economic development in Bangladesh and at the same time how economic development of Bangladesh help to grow aquaculture market and diversity; Finally, in the discussion part which species is more resilient in all aspects for Bangladesh will be discussed. The study uses FAO data on aquaculture production and its value for the period 1995-2019 together with the data on economic development in Bangladesh collected from other sources for analysis.

1.2 Thesis structure

In the first chapter the importance of aquaculture in Bangladesh is presented, research objective and knowledge gaps related to the topic studied to serve as the significance of the research performed are identified. Aims and structure of the thesis are also introduced in chapter 1.

[3] Gher is an aquatic place, where shrimps are raised

The second chapter contains an overview of the aquaculture industry of Bangladesh, aquaculture production system and management system of Bangladesh.

The third chapter presents the method that was developed to study production, diversity, and the economic development of Bangladesh, followed by the fourth chapter presenting the results based on the data analyzed.

Finally, the interconnections between aquaculture production, diversity and economic development are presented in the fifth chapter, before the conclusion chapter.

2. Overview of aquaculture industry in Bangladesh

Bangladesh is rich of water resources and soil where a broad variety of crops and flora grow. The country has an agriculture-based economy, utilizing the country's fertile soil and tropical environment. Fisheries have been hailed as a key sector of Bangladesh's economy due to the country's diverse water resources. Bangladesh features hundreds of crisscrossed rivers and canals, oxbow lakes, lakes, reservoirs, and seasonal floodplains encompassing about 16187.425692 kilometer of interior freshwater resources. Numerous wild fish and shellfish species find acceptable natural homes in these open, semi-closed, or seasonal freshwater resources. It possesses extensive marine and brackish water resources, including coastal plains, tidal flats, estuaries, inshore and offshore waterways, and an Exclusive Economic Zone (EEZ) of 164,000^2 km that has yet to be fully explored (DoF, 2006). Several natural mangrove forest ecosystems (such as the world-famous Sundarbans mangrove) abound in the coastal zone, sustaining rich aquatic life.

There are 67000^2 km of inland water in Bangladesh, 94% of which are used for open water capture fishing and 6% for closed water culture fishing. Resources from inland open water fisheries have been crucial to Bangladesh's economy, culture, heritage, and eating habits. The area covered by rivers and their ramified branches is approximately 4797.35 km^2. From inland and marine waterbodies, Bangladesh produced 3260,00,0000 kg of fish in 2011–12, with aquaculture making up more than half of the total. The vast majority of Bangladesh's poor people depend on the aquaculture industry for their means of subsistence and income. Most of them live in rural areas with little employment opportunities. According to the Poverty Reduction Strategy Paper and the National Fisheries Strategy, rural households have the most alternatives for producing money in the fishing sector (DoF, 2006, PC, 2005).

Aquaculture's output contribution to overall fish production increased from a little over 18% in fiscal year (FY) 1986 to 38% in fiscal year (FY) 2006 (DoF, 1987, DoF, 2015), and aquaculture is now recognized as a separate industry. Bangladesh's fishing industry accounts for 4.4% of GDP, 22.8% of agriculture, and 2.5% of overall export earnings. The export of fish to other countries is a significant source of foreign currency revenues for the country, with macroeconomic and microeconomic benefits. Bangladesh's third-largest export earner is fish, which is increasing by 5-8% per year. Fish products are gradually outpacing revenue from agricultural exports to the point

that fish is now Bangladesh's most important primary export commodity (Dey et al., 2008b). Through fishing, farming, fish handling, and processing, more than 17 million people, including about 1.4 million women, rely on the fisheries sector for a living (BFTI, 2016). Women made up over 80% of workers in the fish processing industry, according to several surveys (DoF, 2015).

Up to 1990, it was common for the estimated fish production targets to not be met. The goal for fish output in the first plan (1973–1988) was set at for its final year, 1978, 10,40,000 thousand kg were produced (PC,1973). Actual fish production was 6,40,000 thousand kg or only 61.5% of the goal was accomplished (PC, 1978). The aim was reduced to 8,20,000 thousand kg in the Two-Year Plan (1978–198). However, actual production was unchanged at 6,40,000 thousand kg, which was 22% deficit compared to the updated objective (PC, 1985). Both programs' shortcomings were mostly attributable to institutional bottlenecks, a lack of research and extension connections, the multiple government agencies that control water bodies, inadequate project design and development, and a lack of well-educated or well-trained staff (Bhuiyan and Rahman, 1991). Performance of fisheries sector planning in Bangladesh. Due to implementation of various activities by Bangladeshi government, fisheries sector started to grow. Freshwater and brackish water aquaculture have grown dramatically in Bangladesh over the last two decades. In the fiscal year 2020–2021, an estimated 8,6,21,000 thousand kg of fish was produced, an increase of 11,80,000 thousand kg over the previous year. Brackish water aquaculture has grown in popularity along Bangladesh's coasts, contributing to foreign exchange revenues. Freshwater aquaculture, on the other hand, has gained traction and flourished in other parts of Bangladesh, particularly in the country's north and west. Farmers (particularly rice farmers) have been converting land to pond aquaculture for the past fifteen years (Khan, 2012).

Inland capture, inland culture, and marine fisheries make up Bangladesh's fisheries sector (DoF, 2006). Inland fishing is organized into two sub-sectors: inland catch and inland culture. The inland capture fishery has five types of habitats: 1777 km^2 of Sundarbans, 8538.63 km^2 of river and estuary, 688 km^2 of Kaptai lake, 1141.61 km^2 of beel, and 26955.29 km^2 of floodplain (haor); and the inland culture fishery has six types of habitats: 3713.09 km^2 of pond, seasonal 1304.88 km^2 of cultured water body, 54.88 km^2 of baor (FRSS, 2017). In 2014–2015, Bangladesh produced 36,84,245 thousand kg of fish, with 1023991 thousand kg (27.79%) coming from inland open waters, 2060408 thousand kg (55.93%) coming from inland confined waters, and 599846 thousand

kg (16.28%) coming from maritime fisheries. In Bangladesh's freshwaters, 260 fish and 24 prawn species have been reported, together with 12 exotic fish species (Khan *et al.*, 2000). Bangladesh's inland water resources have huge prospective for freshwater capture and culture fisheries growth (Hossain, 2014).

Among the various fisheries sub-segments, inland aquaculture has had the fastest growth due to the introduction of new technology, species, and intensification and improvement of farming, particularly in pond aquaculture, across the nation (Planning Commission, 2016). 1468.9 km^2 are designated as ponds in Bangladesh, with 54.88 km^2 designated as oxbow lakes (DoF, 2015). Over half of the fish consumed directly by humans in Bangladesh are now produced through aquaculture, and this percentage is likely to climb. Over the past 10 years, aquaculture has expanded at a rate of 8.2 percent annually while fishing has grown at a rate of 5.4 percent. Bangladesh's recent and rapid expansion has allowed it to move up to sixth in the world's aquaculture production (DoF, 2015).

2.1 Aquaculture production system in Bangladesh

Two types of aquacultures are practiced in Bangladesh: Freshwater aquaculture and brackish water aquaculture. 1500 km^2 of ponds and lakes, 1400 km^2 of traditional shrimp farms in coastal areas, and minor areas of baors, drains and ditches, and semi-intensive shrimp farms make up the 3000 km^2 of inland closed water areas (Alam & Thomson, 2001). A satellite study of tiny water bodies undertaken in 1989 yielded a baseline estimate of 1.95 million small ponds at the time (Huda *et al.*, 2010). This is supported by the findings of a pond census done as part of the Mymensingh Aquaculture Extension Project in six northern districts between 1993 and 1996, which discovered 182 percent more ponds with an area of 78 percent larger than that recorded by FRSS. Furthermore, extensive commercial aquaculture is thought to have grown dramatically in the last decade, with the amount of this expansion yet to be properly reflected in official statistics, though DOF is taking attempts to remedy this (Belton & Azad, 2012). Pond culture is dominated by production of Indian major carps (Rohu, *Labeo rohita*; catla, *Catla catla*; mrigal, *Cirrhinus cirrhosus*) and Chinese carps, (silver carp; *Hypophthalmichthys molitrix*; grass carp, *Ctenopharyngodon idella*; common carp, *Cyprinus carpio*). Many rural Bangladeshi households have a small pond near their dwelling

(Little *et al.*, 2016, Huda et al., 2010). According to an analysis of the HIES 2005 dataset, which includes information on landholdings, around 20% of rural families own a pond. This means that a homestead pond is owned by around 4.27 million families.

Around 40 percent of the country's aquaculture production comes from the greater Mymensingh area (International, 2004, Ahmed, 2009). Because of the abundance of fingerlings, fertile land, plentiful labor, and a pleasant environment, Mymensingh is the largest district for pond aquaculture (Alam, 2018). Satkhira, Khulna, Cox's Bazar, and Bagerhat Districts are well known for shellfish culture include tiger shrimp (*p. monodon)* and giant prawn (*M. rosenbergii)*. *M. rosenbergii* is primarily cultivated in the countries southwest. In 2019-2020, overall shrimp and prawn production was estimated to be at 2,70,000 thousand kg. Figure 1 presents the most aquaculture production area of Bangladesh.

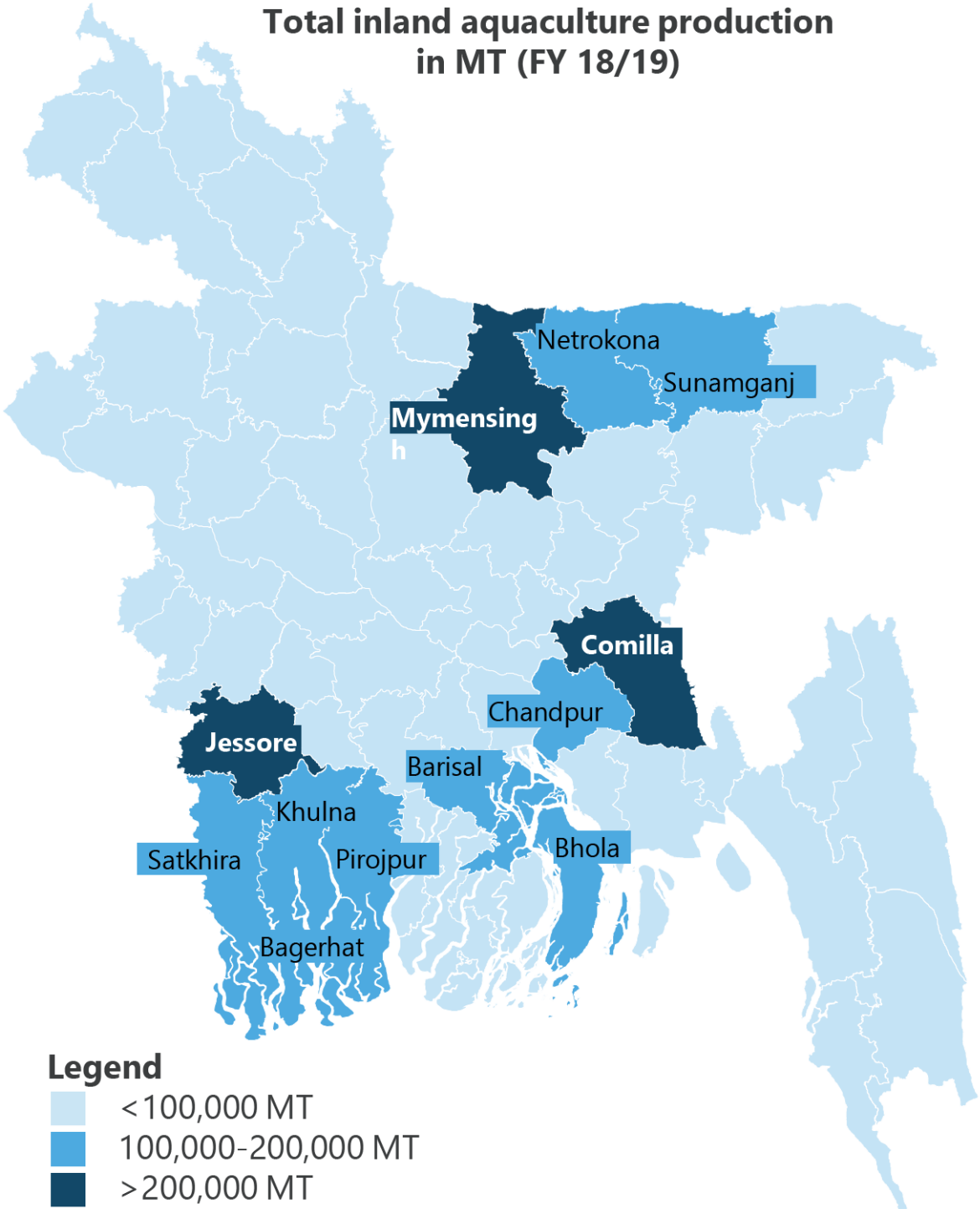


Figure 1: Main aquaculture production areas in Bangladesh (Partners, 2021)

In Bangladesh, extensive and semi-intensive pond polycultures are the primary production techniques for freshwater aquaculture and for coastal waters, extensive shrimp farming

predominates; only 10% of production comes from semi-intensive farms. Performance of fisheries sector planning in Bangladesh Since 1995, the number of owner-operated small businesses with intensive fishponds has expanded dramatically along the Dhaka-Mymensingh corridor and throughout the country. In certain small regions, a more intense fish farming system has arisen, in which rice fields in low-lying areas have been transformed into ponds, and existing ponds have been made more productive with the use of commercial feeds. In Bangladesh, low-cost small cage fish farming was piloted and promoted mostly to landless poor having access to lakes, rivers, water canals, and seasonal water bodies. Many fish species can be farmed in low-cost cages utilizing feeds acquired from the environment by household members, vegetable wastes, and additional feeds like rice bran and oilcake. Because of the cheap investment requirements, small-scale fish cages allow the landless poor to benefit from aquaculture-as long as they have access to water bodies. Fish farming in rice fields has been encouraged by development projects as a strategy to gain incremental benefits with little additional expenditure, however, rice-fish farming has made a minor contribution to total fish production. However, when consumed by the farmers themselves, the captured fish can considerably increase the nutritional level of the household's investment requirements-provided there is access to water bodies. Bangladesh also has a lot of fish pens and water body enclosures for fish farming. Fish pens in canals, small rivers, and lakes can yield appealing labor, land, and financial returns, but they come with major dangers of theft, poaching, natural predation, floods, and other weather hazards.

a) Extensive system

b) Semi-intensive system

Figure 2: Aquaculture system in Bangladesh: a) Extensive aquaculture (Systems, 2022), b) Semi-intensive aquaculture (Aquaculture, Jan. 20, 2018, Ahmed *et al.*, 2007)

2.2 Management and legal arrangement for aquaculture industry of Bangladesh

Fisheries and aquaculture development, management, and conservation are the responsibilities of the Ministry of Fisheries and Livestock (MoFL) in Bangladesh. In addition, DoF is assisted in the growth of the fishing industry by the Bangladesh Fisheries Development Corporation (BFDC), which was established in accordance with the Bangladesh Fisheries Development Corporation Act (Organization, 1973). The BFDC is responsible for creating fishing equipment and for the preservation, processing, distribution, and marketing of fish and fisheries products. The State Acquisition and Tenancy Act mandates that the Ministry of Land (MoL) be in charge of managing all government-owned lands and bodies of water (Bangladesh, 1951). The Ministry of Land must provide land or water to any ministry or government organization that requires it for a project. As a result, as part of its Community Based Fisheries Management Program, MoL has given MoFL permission to lease various water bodies across the country. The management of land and water bodies, on the other hand, is usually handled by the local government. There are two types of government-owned water bodies: open-access waters and limited access waters. All water bodies with a year-round flow of water are managed as open-access resources. These generate no money for the government, and anyone may utilize them. Closed access waters are any water bodies that are only seasonally connected to rivers or canals and are available for lease. Leases for aquaculture are typically issued for three years. After an auction, the lease is offered to the highest bidder (Nations, 2021). Aquaculture facilities do not need to be authorized or registered in Bangladesh. Aquaculture is performed on government owned land through a leasing system. The government, leaseholders, and farmers share the majority of the profits via a leasing arrangement. For leased water bodies, the government has either accepted the highest bid or set a fixed annual revenue increase.

3. Materials and Method

3.1 Data materials

The data for this study came from a variety of secondary sources. First, the nominal data on production and its market value was collected from FAO and for the period 1995-2019 (Aquaculture, 2020). The data were comprised of 30 fish species of Bangladesh. Both freshwater inland and marine aquaculture were included in the data. Second, the data for GDP growth rate of Bangladesh for the associated period were collected from the World Bank website. The data is described in details in the following sections.

3.1.1 Data on fish production

Aquaculture has grown in importance over the last 15 years as one of Bangladesh's three most diverse fisheries resources (inland open, culture, and marine). In specific, the total fish production was 3,50,99,570 thousand kg and its value were 6,95,8,397 million USD (United states dollar) during the period 1950-2019. Figure 3 from FAO data shows the fish production of different years in Bangladesh. The total production trend of the species-specific capture fisheries exhibited a progressive increase and production was dominated by carp, Pangas and Tilapia and carp production is dominated by Rohu and silver carp. Prior to 1990, the majority of carp seed was obtained by collecting natural spawn from rivers. Beginning in 1990, a considerable number of hatcheries were created in various sections of the country, changing the situation (Begum & Alam, 2002). In terms of productivity growth for both Pangas and Tilapia was high from 2010 until 2015. According to Rahman *et al.* (2020), technical innovation and efficiency have contributed to this advantageous evolution (Rahman *et al.*, 2022). As seen from figure 3, the production has been increased over time but during 1992-1994 and 2008-2010 production fell steeply. Various reasons behind these situations will be discussed in the result section.

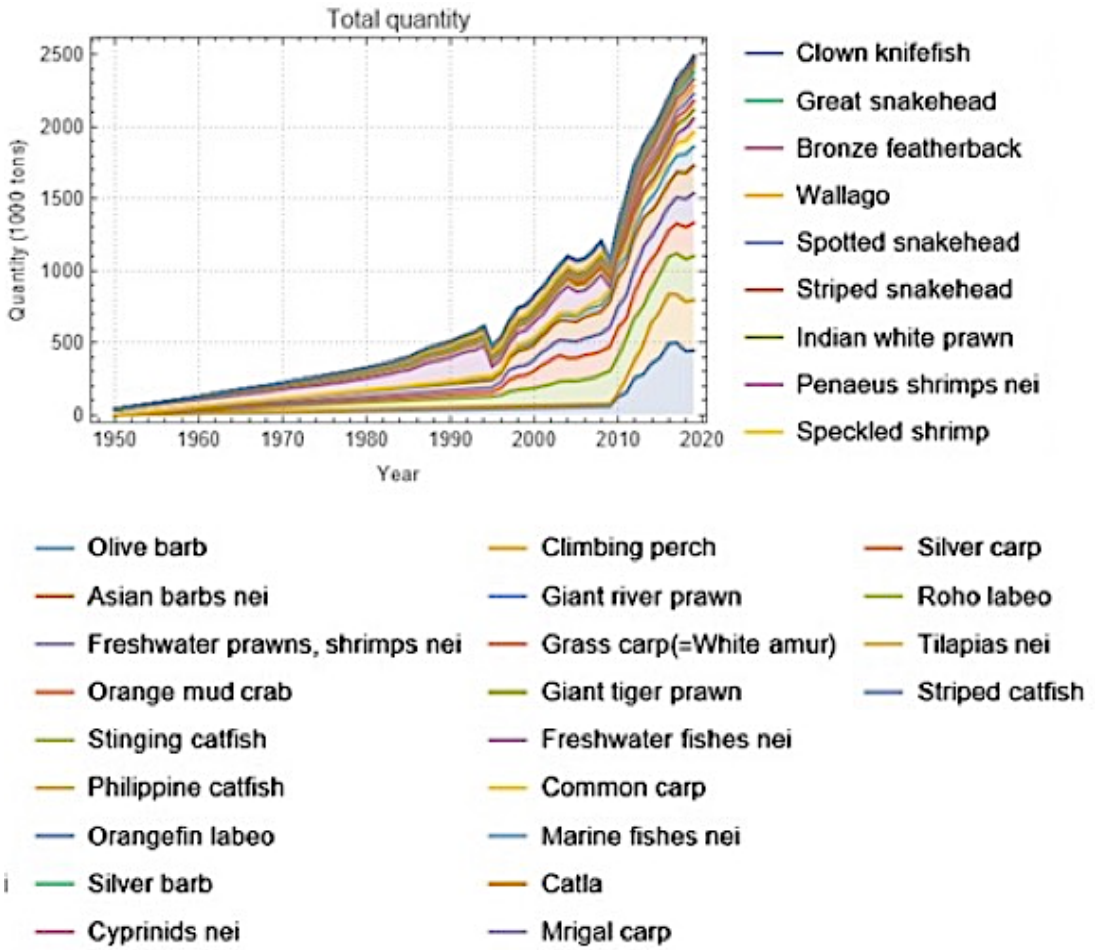


Figure 3: Fish production in Bangladesh from 1950 -2019 (FAO, 2019)

3.1.2 Data on fish value

The data on fish value is also collected from FAO.

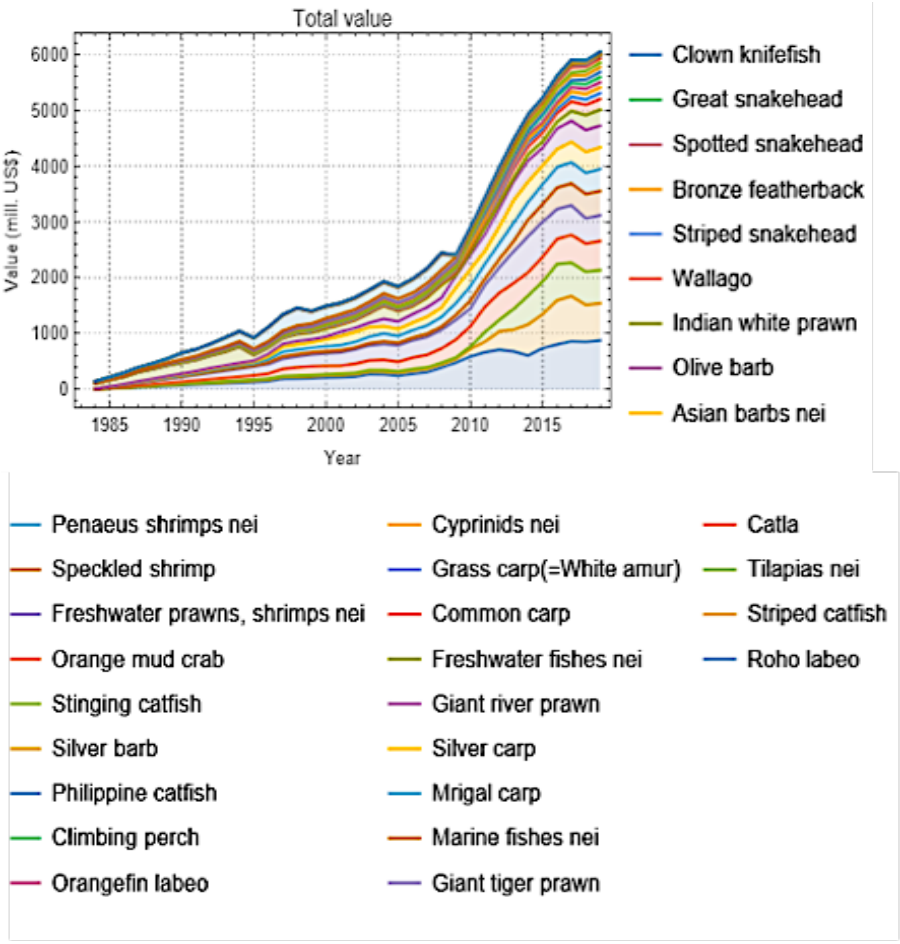


Figure 4: Value of aquaculture species from 1995-2019 (FAO, 2019)

As can be seen in figure 4, value of some species has risen through time, although it has dropped precipitously for some species. The value of striped catfish and carp was high during the period 1995-2019. Shrimp exports generate significant foreign currency income for Bangladesh. According to FAO data, the years 2000 to 2001 through 2009–10 were quite profitable for shrimp and prawn exports and brought in a lot of money. The ups and down in value of shrimp indicates the trend of export was not remained straight to upward. In the result section, many reasons for these occurrences and comparison of values among the species will be examined.

3.1.3 Data on fish diversity

Bangladesh has a diverse fish fauna, with over 250 different species, the majority of which are endemic to the country (Alam *et al.*, 2012). In pond fish farming, farmers are increasingly using a polyculture of Rohu, Catla, Silver carp, and common carp. Because of rich fish productivity and increasing demand, the production of high-yield, fast-growing species including Pangas, Tilapia, and Thai koi fish has exploded in the last fifteen years. Bangladesh, with its diverse marine and aquatic bio diversities, is one of the most resourceful countries. The data from FAO presents the production of 30 species in total, (see Figure 3). In Bangladesh, 91% of fish come from freshwater, 8% from marine water, and 1 % from brackish water which are shown in figure 5. According to Ghose (2014), there are around 1093 marine aquatic creatures, with finfish accounting for 44.35 percent, shellfish for 32.23 percent, seaweeds for 15.10 percent, and other organisms such as shrimp accounting for just 8.32 percent.

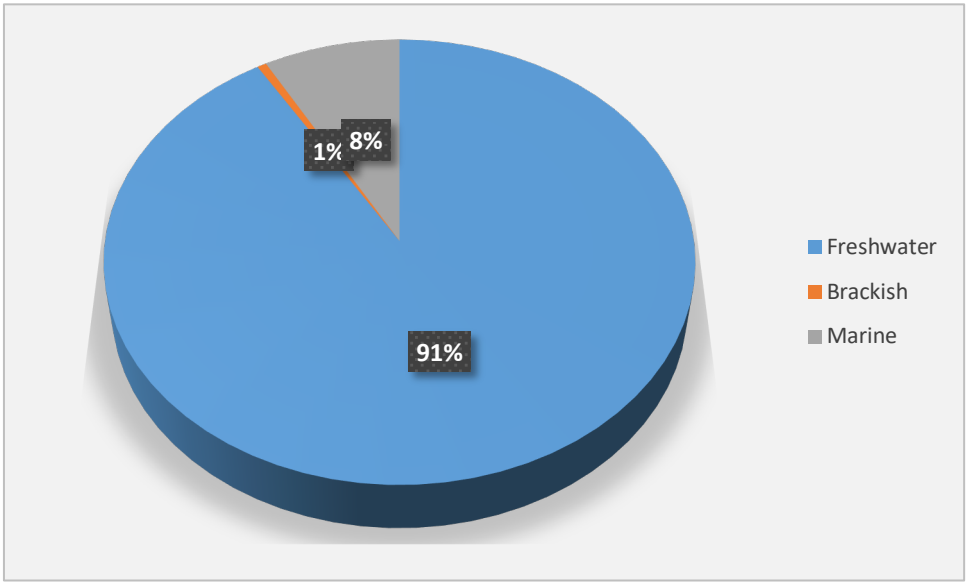


Figure 5: Species diversity of fisheries and aquaculture 1995-2019

Figure 5 visualizes the fish and aquaculture diversity of Bangladesh from 1995-2019 and table 1 presents all species collected from FAO and used for analysis.

Table 1: Species used for analysis from FAO data

Carp:
1. Mrigal carp
2. Catla
3. Grass carp
4. Common carp
5. Rohu labeo
6. Silver carp
Catfish:
7. Striped catfish
8. Stinging catfish
9. Philippine catfish (*Pangasianodon hypophthalmus*)
10. Wallago
Shrimp and prawn:
11. Giant tiger prawn
12. Speckled shrimp
13. Penaeus shrimps nei
14. Indian white prawn
15. Giant river prawn
Others:
16. Spotted snakehead
17. Asian barbs nei
18. Cyprinids nei
19. Climbing perch
20. Freshwater fishes nei
21. Striped snakehead
22. Great snakehead

23. Orangefin labeo
24. Marine fishes nei
25. Clown knifefish
26. Bronze featherback
27. Silver barb
28. Olive barb
29. Tilapia
30. Orange mud crab

2.1.4 Data on economic development in Bangladesh

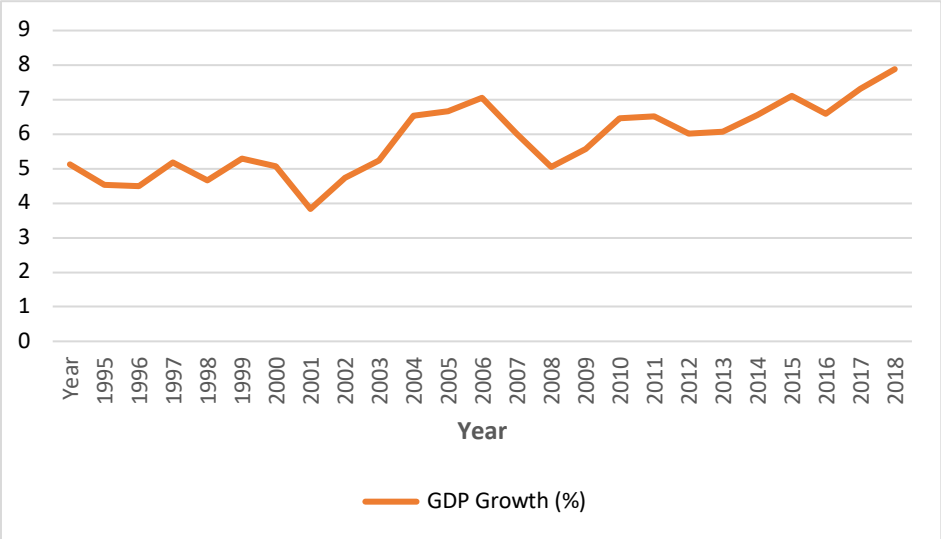
Economic development is measured by several indicators. Economists usually measure economic growth in terms of gross domestic product (GDP) or related indicators. Here I use indicators of GDP growth, population growth for analysis. Bangladesh's economy has grown rapidly since the end of the 1980s after suffering significant setbacks in levels during the Liberation War and a halt in growth in its aftermath.

The fisheries sector is important to the national economy of Bangladesh. Fisheries accounted for 3.61 percent of GDP of Bangladesh. The contribution of fisheries has greatly expanded, rising from 7% in FY1973–75 to 15% in FY1993–95 and 22% in FY2003–05 (Dey et al., 2008a). The Bangladeshi economy has grown by 4% or more on average yearly throughout the 1990s. The average GDP growth rate throughout the 1990s (FY1991-2000) was 4.78%, which was 0.1% greater than the growth rate during the decade before that (i.e., FY1981-90, which was 3.74%). In compared to the first half of the 1990s (4.49% for FY1991-95), the second half of the decade showed a more spectacular growth performance (5.29%, FY1996-2000) (Ahmed et al., 2007).

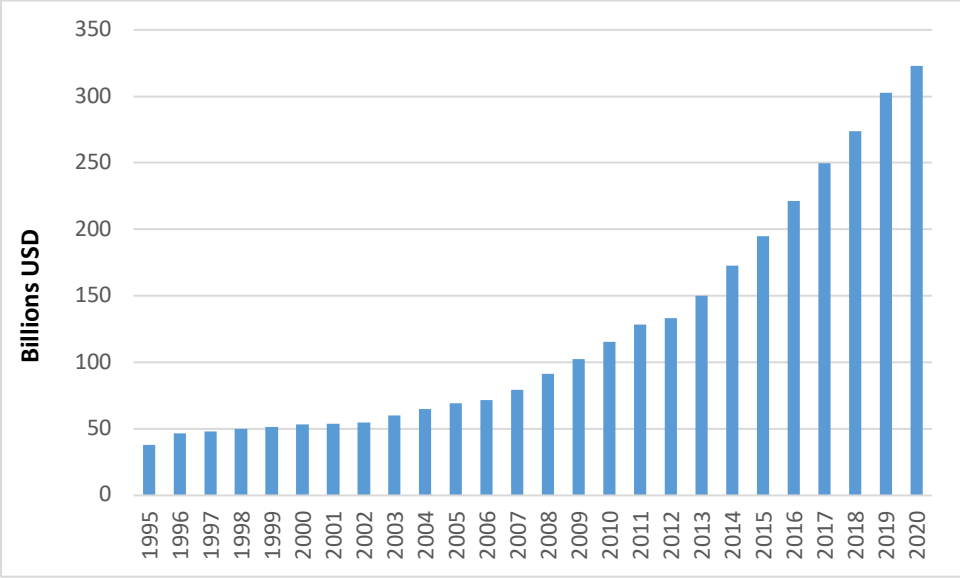
From 2007–08 to 2016–17, the sub-sector of fisheries contributed 3.79 percent to 3.61 percent of GDP (Shamsuzzaman et al., 2020). Bangladesh's yearly GDP growth rate increased to 8.1 percent in 2019 compared to 7.9% in 2018. GDP was EUR 292.6 billion in 2019. Domestic demand for fish has risen in Bangladesh with population growth, which averaged 1.8 percent per year in the 1990s and peaked at 128.1 million people in 1999. Bangladesh has had exceptional economic

growth during the previous few decades, which is shown in figure 6 fueled by robust private sector consumption, consistent export market expansion, and growing remittance flows.

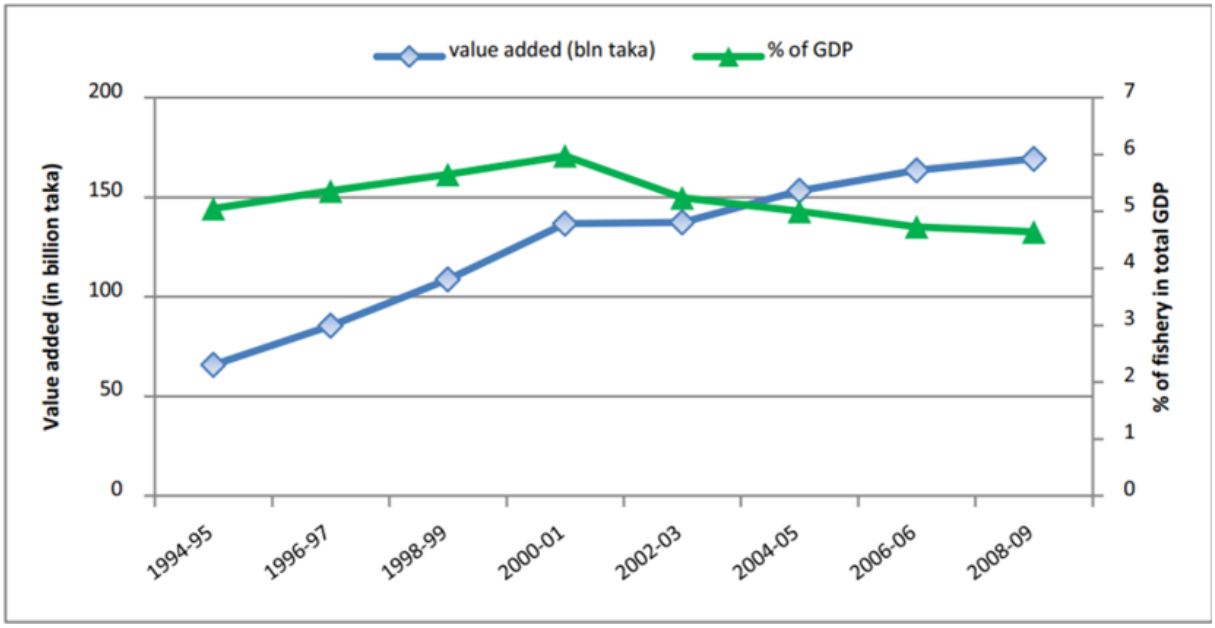
According to Khan (2012) up to 2000/2001, the contribution of the fishing sector to the national GDP was on the rise (Khan, 2012). Despite a drop in the proportion of fisheries' contribution to the national GDP, the sector's overall value addition has rapidly increased from BDT 65.83 billion in 1994 to BDT 114.55 billion in 2016 (Figure 6)



a) GDP growth of Bangladesh



b) Economic growth in Bangladesh (World-Bank, Oct 14, 2021)



c) Fisheries including aquaculture contribution in GDP growth of Bangladesh (Khan, 2012)

Figure 6: a) GDP growth of Bangladesh b) Economic growth in Bangladesh c) Fisheries contribution in GDP growth

Bangladesh is one of the world's most populated nations. The 147,500 km^2 country is populated by more than 150 million people, who eat rice and fish as their main sources of nutrition. Figure 7 shows the population growth in Bangladesh. Fish consumption has increased during the past ten years (2000–2010) and average monthly household spending on fish has climbed by more than 60%. About 97 percent of the nation's entire fish production is sold domestically for consumption, with the remaining 2.84 percent going to export (EPB 2013). According to DoF (2013), around 46,800 tons of fish are imported, or 1.6% of the nation's entire current fish demand. Despite Bangladesh's relatively small volume of fish exports, this has a major impact on the country's economy, social situation, and employment market.

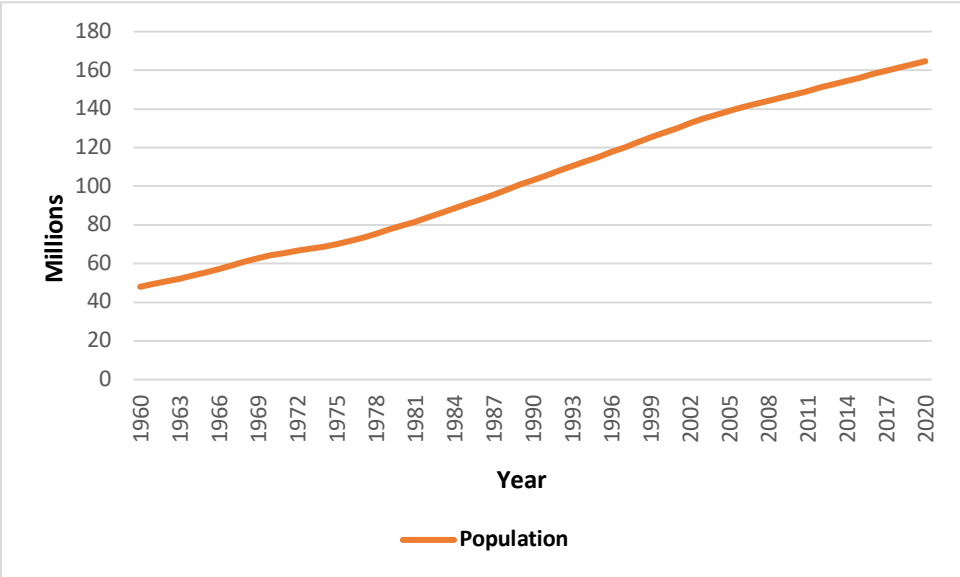


Figure 7: Population growth in Bangladesh during the years 1960-2020 (World-Bank, Oct 14, 2021)

According to Kibria (2012) 8.5% people dependent only on fishing industry which is the 3rd largest industry in Bangladesh by profession (Kibria, 2012). Direct and indirect employment is one significant way that the fisheries sector contributes to national economies in Bangladesh. This number should include jobs for fishermen, fish processors, fish traders, and other related occupations. Many occupations are available for women in the post-harvest industry, which is crucial to the growth of the economy and society. The welfare of the home, especially the children's health and education, is greatly impacted by this.

The fishing sector's value addition significantly boosts the country's wealth. According to World Fish report, the exports of fish aid countries' economies in entering global markets, particularly in high added value categories (Apu, 2014 July). Fish processing has currently limited potential because Bangladeshi people often prefer to buy entire, unprocessed fish.

3.2 Method

Quantity and market value of all species have been analyzed to see how market aquaculture diversity and economic development have been changed in Bangladesh during last millennium. The analytical framework is presented in Figure 8, focusing on three dimensions of aquaculture of Bangladesh: Production, fisheries diversity, and economic development

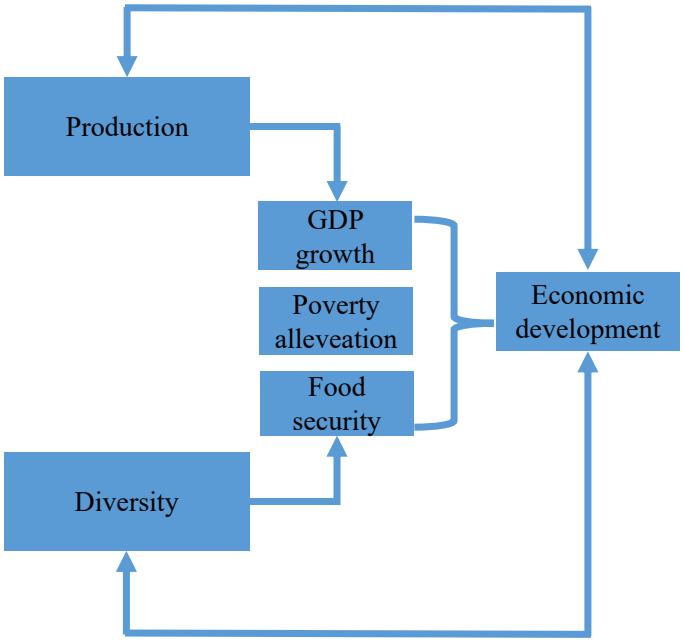


Figure 8: Conceptual framework

To describe species richness, species diversity indexes are commonly used. Shannon diversity index is used to find out how diverse Bangladesh's fish species. Information on the composition and richness of an area is obtainable through the Shannon equability index.

$H = -\sum_{i=1}^{S} p_i ln p_i,$

where H = Shannon diversity index, p_i = Proportion of total abundance of species

By calculating the Shannon diversity index H =2.5340548 was found.

Shannon Winner Diversity index (H)	Population level	Values found (Range)
3.0-4.5	Slight	
2.0-3.0	Light	2.54
1.0-2.0	Moderate	
0.0-1.0	Heavy	

$E_H = {}^{H}/_{\ln(s)}$,

Where H: The Shannon Diversity Index, S: The total number of species

$E_H = 0.745$

This value is between 0 and 1, with 1 denoting absolute evenness.

Bangladesh has a low species diversity richness and perfect evenness.

4. Results

4.1 Analysis of fish production in Bangladesh

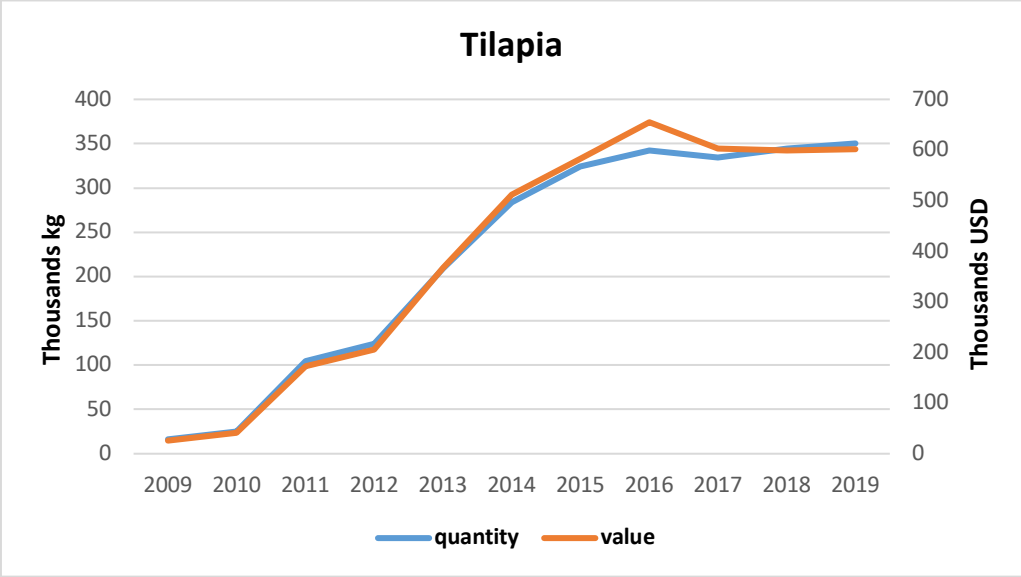
As seen from figure 3, the total production of aquaculture in Bangladesh has been increasing over the year. Particularly, the production has slightly increased from 1950-1990, but then increased tremendously from 2010-2020. In 2016–17, aquaculture production increased by more than three times compared to 2000–2001 (7,87,000 thousand kg versus 2,318,000 thousand kg) (Shamsuzzaman et al., 2020). This can be explained by many reasons. One reason is that the proliferation of many established technologies helps aquaculture has been progressing with reasonable success. Pen and cage culture is becoming increasingly popular, and it is now the most extensively practiced culture system in Bangladesh. Coastal aquaculture, including shrimp, prawn, and finfish farming, is growing, with total shrimp and prawn production up to 18% in the last 18 years (Shamsuzzaman et al., 2020). Through the introduction of new technology, supportive extension services at the farmer level, and improved pond aquaculture farming, the overall growth performance of inland aquaculture shows a modestly increasing trend.

Also observed from figure 3, the fish production fluctuated from 1990-2010 with remarkable declining around 1992-1993 and 2007-2010. Many reasons may explain as indicated in the literature review. Firstly, there is a disease outbreak during1992-1994. In Bangladesh, WSSV was initially discovered in a semi-intensive farm in Cox's Bazar in 1994, and the illness expanded to the Khulna region and other southwest parts of the country in 1996, infecting almost 90% of substantial shrimp farms and causing a 20% decline in national shrimp production. Most investors suffered significant losses over several years, and outsiders lost interest in the industry. As a result, Bangladesh's shrimp exports fell from 25742000 kg to 18630000 kg in 1997–1998 (Bir *et al.*, 2017). Secondly, the increasing number of flood control measures was threatening open-water fish which affected on total fish production in Bangladesh. The water regulated area had risen to 3.36 million ha in 1990, the final year of the third five-year plan (1985-1990). It was quickly discovered that floodplain management can have negative consequences for fisheries. Moreover, Bangladesh experienced the lowest rainfall in over a decade (since 1994), with scientists blaming global climate change for the unpredictability. Rainfall totaled 47,447 mm from June to September 2009, compared to 56,163 mm at the same time of 2008, 66,520 mm in 2007, and 60,551 mm in 2008.

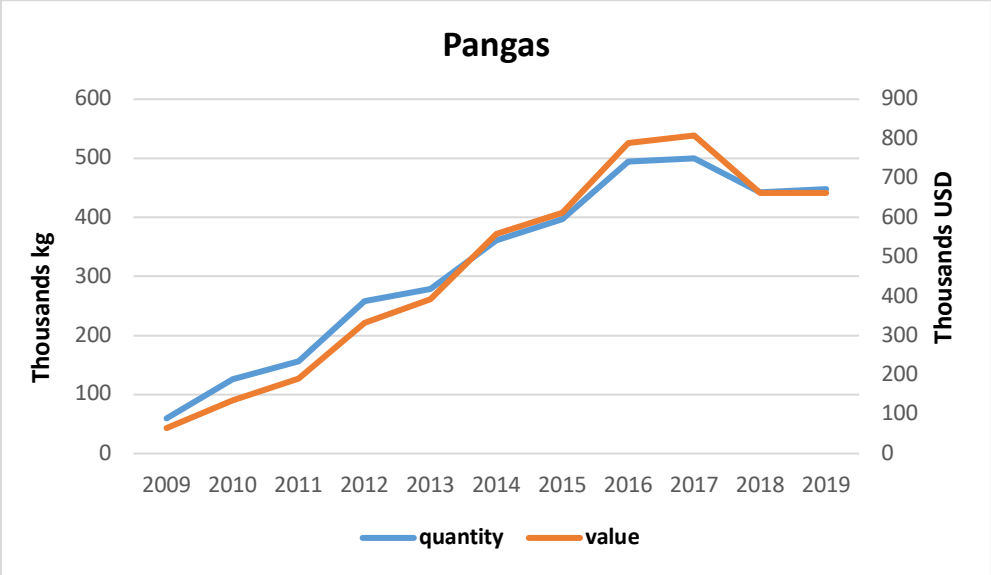
Drought during the dry season, from November to February, is one of the most significant environmental constraints to pond-fish culture, according to a field survey.

Especially, the catastrophic storm Aila struck Bangladesh's southwestern coastal region and India's eastern coast on 25th May, 2009, made a tremendously decrease in production during the period of 2009-2010. Although it was a tropical cyclone with few fatalities, the devastation lasted for up to two weeks following the storm. According to DoF and FAO, shrimp production in Aila-affected areas was 80 percent lower than in a normal year (Nation, 2010). Because Aila devastated the embankments along the rivers, shrimp farmers were unable to harvest shrimp for one or two seasons, depending on the placement of ghers, as the entire farming region was submerged. Furthermore, flooded storm surge water frequently causes variations in pond water salinity, which impacts shrimp growth (Kais & Islam, 2018). Shrimp commerce was slow for two years after Aila due to a substantial drop in shrimp productivity in the area.

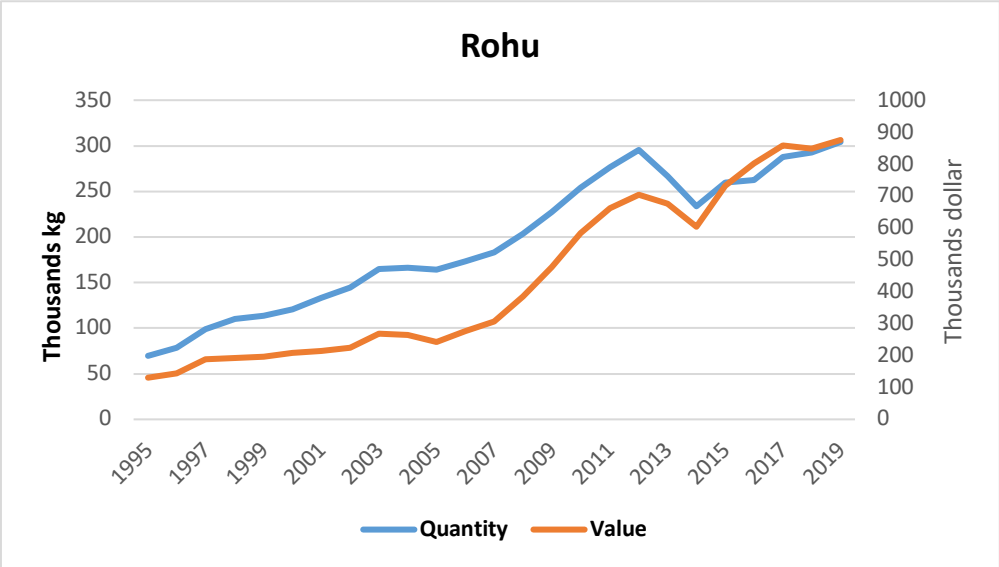
However, whereas most of the other species were affected by environmental conditions, Tilapias, Pangas and Rohu carp production were not hampered and still managed to rise during these years. Figure 9 shows the production and value trend of these three species.



a) Production and value trend of Tilapia



b) Production and value trend of Pangas



Fc) Production and value trend of Rohu

Figure 9: Production and value trend of a) Tilapia b) Pangas, and c) Rohu

Figure 9 shows that apart from a modest decrease in value fluctuation in some years, there has been no significant change in Rohu's volatility pattern over the last decade. Between 2014 and 2016, there was a large price shock in the Dhaka market for Rohu (from 250 to 200 thousand dollars), possibly due to a deficit in carp production at the time. For all other species and markets,

there was lesser price variation in the recent 5 years compared to earlier years (see figure 4). As a result, Bangladesh's pricing volatility has decreased dramatically since 2013. According to Deb et al. (2022) lower fish price fluctuation is likely the result of higher aquaculture production (Deb *et al.*, 2022).

Table 2 shows the total production of all carp species from 1995-2019 and figure 10 visualize the production trend of all carp species in Bangladesh. As seen from figure10, production of major and exotic carp's production has been increasing gradually over the years. The three major carps and the exotic species, dominate freshwater aquaculture production in terms of quantity. Figure 10 shows that the quantity of Silver carp being produced is steadily growing and Rohu production continues to outnumber other carp species which was found in other studies (Parven & Ahmed, 2010).

Table 2: Total carp production in Bangladesh from 1995-2019

Major carp	Total production (Thousand kg)	Exotic carp	Total production (Thousand kg)
Roho	4883920	Silver carp	3940908
Catla	3685603	Common Carp	1045704
Mrigal	3115512	Grass carp	567065

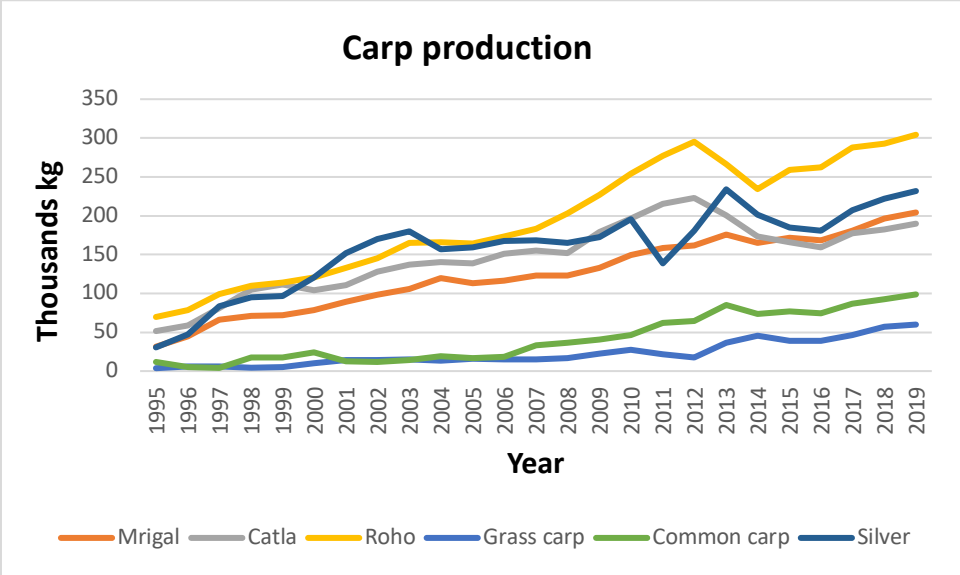
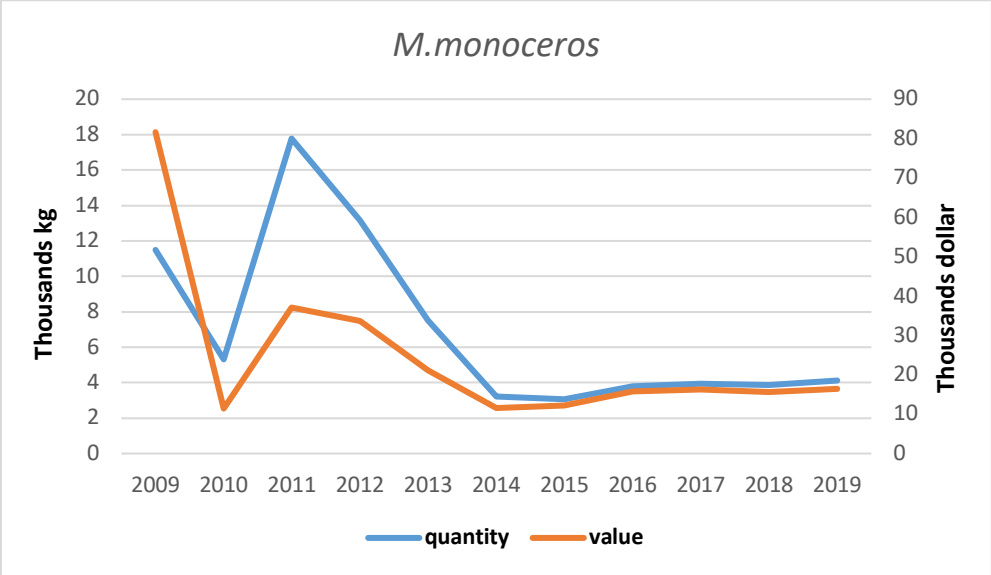
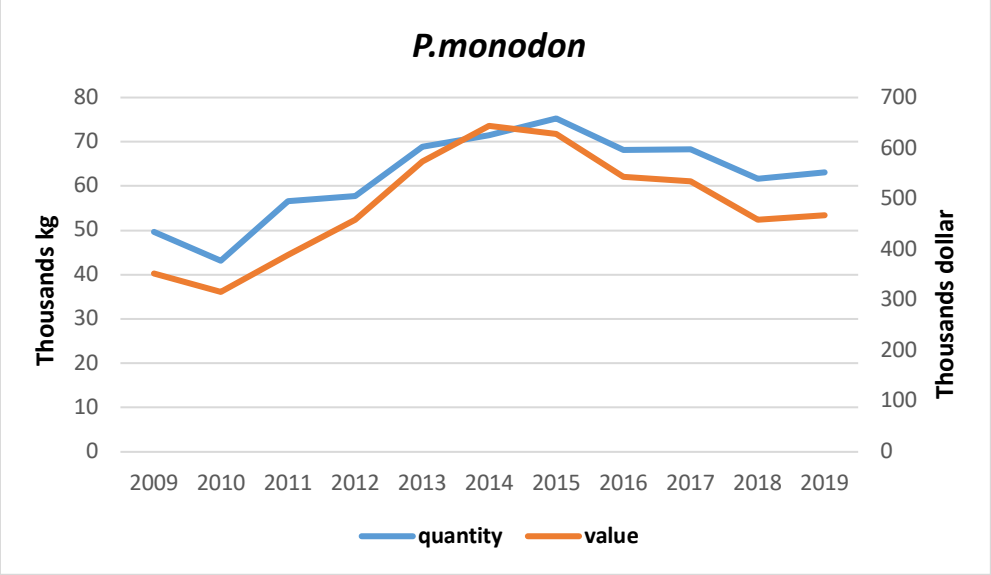


Figure 10: Carp production trend in Bangladesh (FAO)

Figure 11 shows the production and value trend of two shrimp species. The value of *P.monodon* is very high compared with the value of *M.monoceros*. Figure11 shows that the value of *P.monodon* increased from around 350 thousand USD to around 600 USD in 2009-2014. After that the value was decreased to around 400 thousand dollars. The value of *M.monoceros* was 80 thousand USD in 2009 and the value decreased to 20 thousand USD in 2019. Although *P. monodon* is the targeted species due to its export value, the brown shrimp *M. monoceros* contributed roughly 56 percent of the overall shrimp capture (Quader, 2010).



a) Production and value trend of shrimp *M. monoceros*

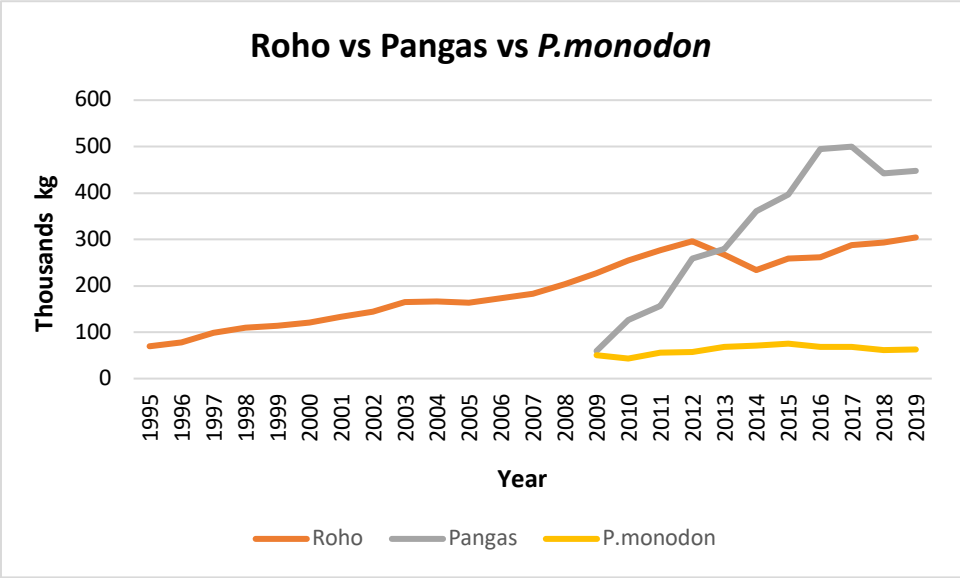


b) Production and value trend of shrimp *P. monodon*

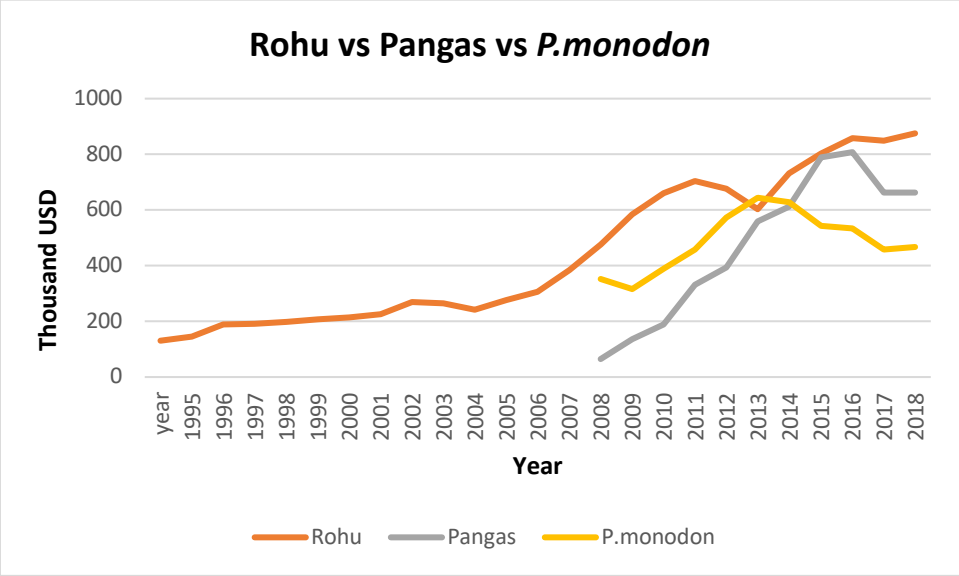
Figure 11: Production and value of the two shrimp species: a) *M. monoceros* and b) *P. monodon* (FAO,1995-2019)

FAO data shows that some indigenous fishes have higher value. For instance, production of Rohu is lower than that of Pangas from 2012-2019; however, its value was high compared to Pangas value. Figure 12 depicts the production and value data of Rohu and Pangas from FAO (1995-2019)

In terms of value and production comparison between freshwater aquaculture and marine aquaculture, the freshwater aquaculture production and its value are always high. Figure12 shows the comparison between freshwater aquaculture and marine aquaculture.



a) Production of Rohu, Pangas and *P.monodon*



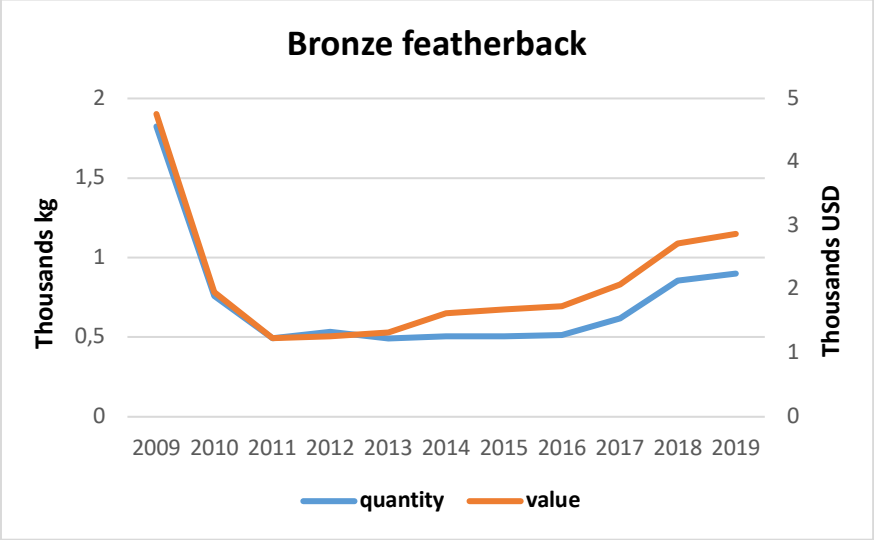
b) Value of Rohu, Pangas and *P.monodon*

Figure 12: Comparison of production between freshwater aquaculture (Rohu and Pangas) and marine aquaculture (*P.monodon*) (FAO,1995-2019)

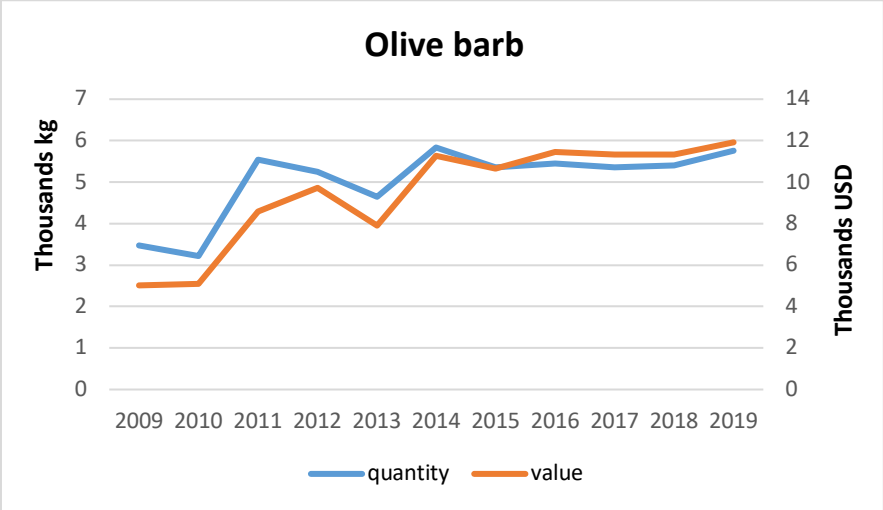
4.2 Analysis of aquaculture diversity in Bangladesh

Figure 3 present 30 species in total are cultured and figure 5 shows the species diversity in Bangladesh. Among the 30 species, 24 species from freshwater, 1 species from brackish water and 5 from salt water. In other words, 22 species are domesticated indigenous, and 8 species are exotic which are shown.

However, some species are threatening as indicated in figure 13. For instance, the production of bronze feather back started to decrease since 2009 from 18,24,000 to 4,92,000 kg in 2013. After 2013 the production of this fish was slightly increased. Hakaluki *et. al* (2021) claimed that habitat loss as a result of agricultural expansion, urbanization, environmental degradation and pollution, resource overexploitation, and climate change are responsible for inland capture fisheries output (Aziz *et al.*, 2021). According to the IUCN Bangladesh, Bangladesh has 54 threatened freshwater fish species, 12 of which are severely endangered, 28 endangered, and 14 vulnerable (Uddin *et al.*, 2019). Olive barb is critically endangered and Bronze featherback is vulnerable (Pandit *et al.*, 2015). The production of Bronze featherback was decreased tremendously from 2009 to 2011, but then slightly was increased until 2019. Even though the production of Olive barb was increased in general during the period 2009-2019, the amount however was very small.



a) Bronze featherback



b) Olive barb

Figure 13: Production trend of two endangered fish of Bangladesh: a) Bronze featherback and b) Olive barb (FAO, 2019).

Even though the data from FAO shows that Pangas production has started from 2009, this species has been introduced since around 1990s and started to produce commercially in 1994. Hossain at al. (2019) conducted research on Pangas and concluded that 6 percent of Pangas farmers began farming in 1991-95, and 22% began in 1996-2000, according to the farmers polled for this study. Farmers started in 38 percent of cases in 2001-05, 22 percent in 2006-10, and another 12 percent in 2011-2015. So, it can be assumed that as more farmers got involved in Pangas production from 2001-2010, the production of Pangas was remarkable in this period.

Bangladesh's economy is mostly dependent on shrimp. The industry contributes around 6% of national GDP and 5% of national income generating US$ 456 million in 2006. (BFFEA, 2008). Bangladesh is the fourth largest shrimp producer in the world. In terms of shrimp farming area, it ranks sixth in terms of production volume. Shrimp. Earnings from exports shrimp accounts for almost 93 percent of sectoral export earnings. Figures 11 and 14 show the production and value of three major shrimp species of Bangladesh.

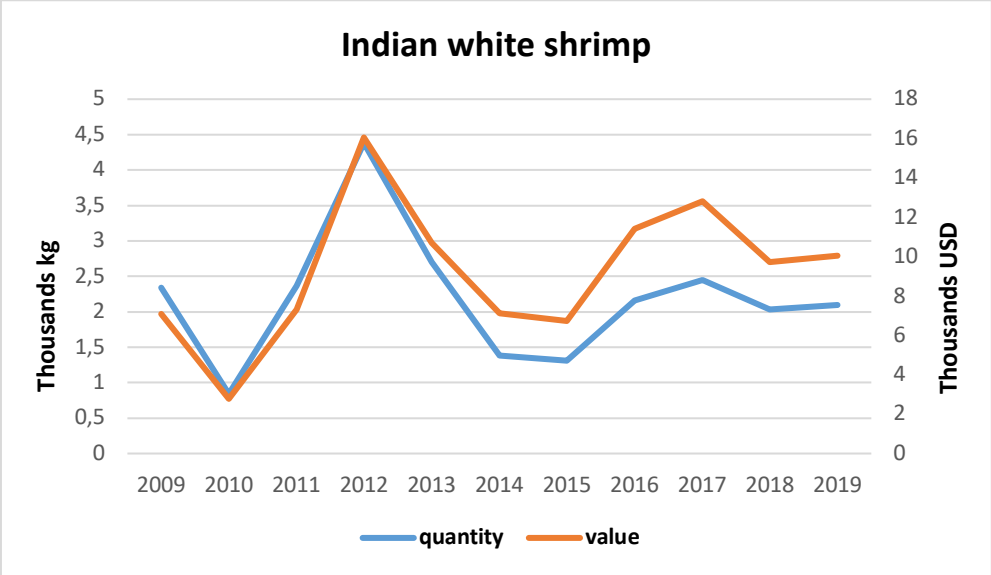


Figure 14: Production and value of Indian white shrimp from 2009-2019 (FAO, 2019)

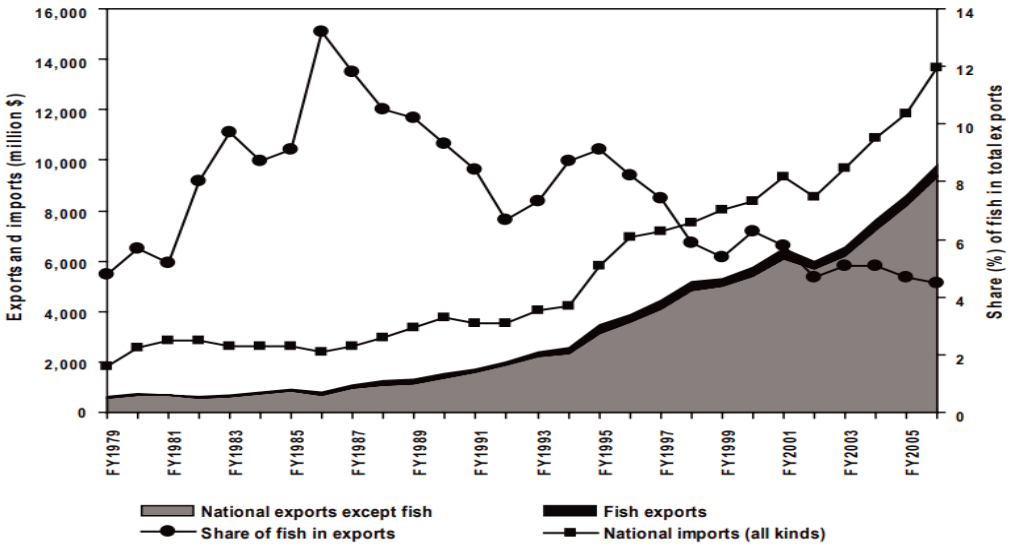
4.3 Aquaculture in Bangladesh and its role in Economic development

The great majority of Bangladesh's poor are supported by the fisheries industry in terms of livelihood and income. It is particularly crucial for underprivileged people as a primary or secondary source of work, a means of subsistence, and income. Even though in the national level, there are no detailed statistics on employment in the fishing sector and according to the labor force survey, employment in the fishing industry expanded by 19.1% annually between FY2000 and FY2003 (BBS 2004b,) Moreover, fish is the main source of nutrition for millions of underprivileged people in Bangladesh, where it is known as "poor people's protein." Actually, fish has long been Bangladesh's primary source of protein. The total value of fish production was 231,957,990 USD on average annually from 1995-2019.

Table 3: GDP of fisheries and share in Bangladeshi economy from 1973– 2005 (Dey et al. 2008a)

Average period (Year)	Fisheries	
	GDP (Million USD)	Share (%)
1973-75	379	7.0
1983-85	378	6.5
1993-95	1217	15.2
2003-05	2435	21.8
(%) increase from 1973-75 to 2003-05	542.4	212.3

Fish exports comprised over 8% of all exports in the second half of the 1980s, peaking at 13% in 1986 (Figure 15). The absolute value of fisheries exports has increased even if the proportion of fish in total export value has decreased in recent years due to expansion in manufacturing (such as clothing) and services. From $30 million in 1979 to $440 million in 2006, the value of fish exports increased by 15 times, representing an annual growth rate of 9.4%.



FY = fiscal year.
Sources: BBS various issues, Statistical Yearbook of Bangladesh, DoF various issues, Fish Catch Statistics and Fishery Statistical Yearbook.

Figure 15: Fish export earnings from 1979-2006 and their economic contribution (Dey *et al.*, 2008a)

Figures 3 and 4 show for both volume and value of all species has increased in general over the period except downfall in some year. Siddiqa *et al*. (2018) conducted research on some aquaculture farm in Bangladesh (Siddiqa *et al.*, 2018). The study's findings show that the average total revenue per hectare for commercial fish culture was BDT (Bangladesh taka, the currency for Bangladesh) 38476700, for commercial shrimp culture was BDT 374662.62, and for homestead aquaculture was BDT 242100.29. All forms of aquaculture are profitable in the research region, but it is important to determine their sustainability. Expanding pricing and increasing the quantity of things sold are two conventional strategies for boosting revenue. The profit margin will consequently rise if costs stay the same.

5. Discussion

As shown in the result section, Bangladesh's aquaculture production has substantially improved during the last decade and potential to increase in the coming years. However, for several reasons, the fish diversity has been decreased. There are several reasons that can be used for explanation as follows.

5.1 Reason of increasing aquaculture production

5.1.1 Increased fish demand in Bangladesh

The Rohu and Pangas are the two most consumed species in terms of quantity. Bangladesh's food consumption trends have evolved in recent years, and from 2005 to 2010, the number of fish consumed per person grew by 17%. (HIES 2010). While much of the production involves species that are not native to Bangladesh, farmed fish production accounts for the majority of the increased supply (Beveridge et al. 2013). The Bangladeshi diet is currently shifting in favor of low-cost, farm-raised foreign species. Fish consumption per person worldwide has increased due to aquaculture output, and in 2014, farmed fish consumption was comparatively higher than that of wild fish (FAO, 2017).According to a review of studies on the price elasticity of demand for fish in Western countries, demand is highly responsive to price (Deb et al., 2022). The price is likely to be a deciding factor in whether impoverished people buy fish in developing countries. When it comes to fish consumption, farmed fish is generally less expensive compared to wild- caught fish, allowing more people to access the market (Juffe-Bignoli & Darwall, 2012). In Bangladesh, farmed fish was more expensive than wild-caught fish ten years ago (Juffe-Bignoli & Darwall, 2012).

The domestic market revolution is a quiet change in the fish value chain: 94 percent of aquaculture production is for domestic consumption (Biswas et al., 2019). Over the last three decades, the farmed fish industry has been increased by a factor of 25 to approximately 2 million tons (Khan et al., 2016). Only around 10% of farmed fish is consumed at home, with the remainder being sold. Urban regions consume 42% of all marketed farmed fish, and that percentage is rapidly increasing. Beyond carps, there has been diversification and specialization into commercial species like

Tilapia and Pangas, which has increased yields and helped advance the fisheries sector along the "product cycle" (Hernandez et al., 2018).

The international fish trade is a significant source providing foreign currency for the country, with macroeconomic and microeconomic benefits. Fisheries and aquaculture are Bangladesh's second-largest export business which is expanding at a rate of 5-8 percent per year and the most important contributors to the country's export earnings (Shamsuzzaman et al., 2017). Exporting fish, shrimp, and other fisheries products generate a significant amount of foreign currency (Islam & Haque, 2018). Except for 1998-99, when the EU imposed a shrimp embargo, Bangladesh's shrimp exports have continued to expand. From fiscal years 2000–2001 to 2016–2017, the export trend did not maintain straight up. Regardless, there have been ups and downs from the beginning to the present. Bangladesh produces and exports a wide range of fish species. The European Union (EU), the United States of America (USA), and Japan are the primary export countries of Bangladeshi fish and fisheries products (Rahman & Hossain, 2009).

5.1.1.1 Domestic market dominating fish

Pangas, carp, and Tilapia are popular aquaculture species in Bangladesh. Figure 3 shows that the production of Pangas, Tilapia and all carp species are high. Since carp species are comparatively more expensive than other species, income is likely the most significant factor in determining carp intake (Alam, 2002). The availability of alternative species has an impact on carp consumption as well. Consumer preference for Pangas, Tilapia and carp was mostly driven by their lower cost as compared to other fish, year-round affordability, and fair market price. Type of body, color, and flavor are also vital in affecting the demand for different types of carp. Pangas farming alone was responsible for 53.69 percent of household income, ranging from 10.84 percent to 100 percent (Ali *et al.*, 2013). Most farming households were involved in a range of industries, many of which were tied to Pangas aquaculture (e.g., feed manufacturing), with only a tiny percentage in other types of agriculture. Improvements in drinking water, housing, health facilities, sanitary facilities and economic security have all contributed to a higher standard of living for farm owners since adopting Pangas culture. Almost all farmers said their social and economic circumstances had improved, and several said they could now eat higher-quality food than before (Uddin et al., 2019).

Pangas and Tilapia have been the most popular commercially cultivable species in recent years due to their excellent yields, increased reactivity to external feeding, and the availability of seeds to suit farmer demand. Pangas and Tilapia can be exported after meeting local demand, increasing the country's economic contribution. The Pangas and Tilapia export markets are fiercely competitive, with changes in product types, shapes, and packaging occurring often as well as buying habits (Alam et al., 2012).

Commercial production of non-native Pangas began in Mymensingh in 1990 and quickly grew to 3,00,000 thousand kg nationwide by 2008 (Belton & Azad, 2012), which has led the fish's value to plummet, making it the cheapest widely available fish species in Bangladesh (Dey, 2008, Little et al., 2016). As carp culture uses few manufactured inputs, provides small marketable surplus, and employs only unwaged domestic labor, homestead carp culture is poorly integrated into the larger capitalist economy. According to several research, even though the economic value of consumed fish and sold fish on the market are typically identical, better-off pond owners prioritize carp production first and foremost for home consumption, rather than for the monetary profits generated. This is because, over a certain level, fish can be harvested at a low opportunity cost in terms of labor and capital, and carp has a high satisfaction value as a culturally desired food item. As a result its production thus helps to household happiness both in terms of emotional fulfillment and solely monetary or calorific rewards (Ahmed & Diana, 2015). However, the financial side of production should not be overlooked as Carp raised in this manner have significant profit margins (up to 100% for fish fed on a regular basis), and several fish farmers from higher income group specifically that they used leftover fish sales to meet expenses linked to irrigated rice (boro) farming.

In all the countries, Tilapia is quite inexpensive when compared to other fish species. Pond polyculture in Thailand is the most productive in terms of output, followed by that in China and Bangladesh. In Bangladesh, Tilapia is raised in a variety of conditions. Rohu (32%) and Tilapia (7%), which are highly preferred by consumers in Bangladesh. Compared to other countries Bangladesh has the smallest marketed Tilapia surplus among fish growers (Dey *et al.*, 2000). As Bangladesh is a developing country with over population and carp, Tilapia and Pangas provide nutrition to a major part of population so it can be easily said that this three spices are the domestic market dominating fish.

5.1.1.2 Foreign market dominating fish

Shrimp is the most widely traded commodity in the world, accounting for 18% of the global seafood market (Alam, 2016). After textiles, shrimp farming is Bangladesh's second most profitable export industry which brought in US$ 456 million in 2006 (Rahman & Hossain, 2009). Bangladesh is ranked fourth in terms of shrimp farming area and sixth in terms of output volume among countries that produce shrimp (Rahman & Hossain, 2009). Bangladesh is a minor player in the vibrant global seafood trade system. Shrimp and products linked to shrimp are exported from Bangladesh to more than 40 countries. Following the European Union, which imports more than 70% of Bangladesh's shrimp exports, the United States comes in second with a quarter of all exports. Shrimp is Bangladesh's second largest export industry, behind garments, which brought in US$ 456 million in 2006 (Loures & Ergen, 2021). Bangladesh is the fourth largest shrimp producer in the world. In terms of shrimp farming area, it ranks sixth in terms of production volume. Shrimp contributes around 6% of national GDP and 5% of national income. Earnings from exports shrimp accounts for almost 93 percent of sectoral export earnings.

From figure 11 and 14 we can see that price of all shrimp species are high compared with production. It can be assumed that shrimp industry in Bangladesh gained this high price value by exporting it to the international market.

5.1.2 Decrease of capture fish production

Overfishing and indiscriminate killing of juvenile, use of pesticides in agriculture are identified the reason of less capture fish production. Fish farming in the more manageable interior closed waterways holds more potential given the enormous regions of ponds, baors, and coastal shrimp farms. From 1983–1984 to 1997–1998, the productivity of ponds, bass farms, and shrimp farms increased steadily and more than doubled. Pond yields in particular seemed to almost triple during that time. Many NGOs work with landless, tiny, and marginal farmers on fish and shrimp culture programs, and the productivity of these ponds is typically higher than that of many privately managed ponds. The productivity of the culture fisheries has undoubtedly increased as a result of

these ongoing measures. By creating product and marketing plans and ensuring a steady supply, the competitiveness can be further strengthened (Alam, 2018).

5.1.3 Adoption of contemporary aquaculture technologies

Bangladesh fisheries institute developed several aquaculture technologies under extension strategy- polyculture of carps, monoculture of Tilapia and monoculture of silver barb. Despite beginning with a monoculture, Bangladeshi Pangas producers later switched to a polyculture using native and exotic carps for several reason (Alam *et al.*, 2019). The operational expenses for Pangas-carp polyculture, such as seeds, medications and chemicals, irrigation, and labor costs, were positively linked with capital investment. Initiatives from the public and commercial sectors are working together to embrace various programs in the aquaculture industry in Bangladesh. One such project is the World Fish Center's Development of Sustainable Aquaculture Project (DSAP). Enhanced aquaculture methods used in the DSAP to increase production efficiency include improved water management, better pond management, low-cost feeding and fertilizing, and training fish farmers (Murshed-E-Jahan *et al.*, 2008). Long-term training provided by the DSAP had a considerable and advantageous effect on raising the participation farmers' production, profitability, and efficiency. Because of the project related support, project farmers may have increased their investments due to their skills and expertise. Greater production in DSAP was a result of the increased investment in aquaculture over the years.

5.2 Reasons of fish diversity and production loss

From Shannon diversity index it is found that the species richness in Bangladesh is low. Inland open water resources provided about 90% of the country's fish production in the 1960s, but due to manmade factors such as overfishing, the implementation of Flood Control, Drainage, and Irrigation Projects, and environmental degradation, fish production in inland open water, particularly in rivers and flood plains, has declined significantly over the last three decades. Natural disasters are common in Bangladesh. It is subjected to several natural disasters each year, including floods, cyclones, riverbank erosion, drought, and other calamities, as a result of its geographical

disadvantages, particularly its location at the northern foot of the Himalayas and at the southern tip of the funnel-shaped Bay of Bengal. As a result of climate change events, a rising trend in frequency has been observed in recent years (Rahman et al., 2022a). As a result of Aila's destruction, those who were affected have started to sell their own possessions, switch from their previous jobs, and, in the worst cases, travel to cities in search of new sources of income. Freshwater and river fishing, agricultural work, and construction work are among the most frequent economic pursuits in the study region. The overall fish production in 2007-08 was only 41.36 percent of total fish production. Inland open water sources contributed 20% to 25% less to production in the late 1970s, according to a decreasing trend. This reduction has been particularly severe in the case of significant and valuable fish such as carp, which once produced around 30% of total fish production but now accounts for only 56% (Tsai and Ali 1987). From 19,000 kg in 1985 (DoF, 1987) to 1,872 kg in 2008, the catch of carp hatchlings from natural ground has decreased tremendously (System, 2008). 260 fish species, 24 shrimp species, and 12 foreign fish species live in inland open water fisheries. Inland open water capture fisheries produced roughly 90% of total fish produce on in the early 1970s, but only 41% in 2007-08, a significant drop due to environmental degradation and species extinction (Karim *et al.*, 2010). There are roughly 143 minor indigenous species among the 260 fin fish species that were abundant in the past.

Due to intensification, which included increased fish stocking density, supplemental energy-rich fish feed (e.g., cereal or rice bran and full pelleted feed), and pond aeration, fish yields in the Philippines were significantly greater than in Bangladesh (Uddin & Takeya, 2006). Furthermore, rice-fish integrated farming does not work in areas where rice is the main crop, such as Bangladesh. Bangladesh produced 2370 kg of Aman rice and 1157 kg of fish. In 2003 these numbers were lower than in the Philippines.

5.2.1 Formalin effect

Shrimp culture is a long-standing tradition in the coastal districts of Khulna, Satkhira, Bagerhat, and Cox's Bazar. People used to construct small dikes to confine tidal water in low lying intertidal zones and collect shrimp and finfish after 3-4 months and under this approach, no fry were stocked, and only wild shrimp seeds were used. With increased prices and demand in foreign markets

following the country's independence, interest in shrimp farming grew. Shrimp farms were springing up in remote areas at the mouths of coastal rivers because of saline water inundation. Shrimp culture systems grew substantially from the late 1970s to the early 1980s. Until the mid-1990s, the industry grew very rapidly but until the late 1990s the local shrimp hatcheries were not established. Shrimp farming has significant societal consequences, as well as changes in economic patterns and distribution. Almost all farm-raised shrimp is processed and frozen for export (Rahman & Hossain, 2009).

Pangas production dropped considerably during and after the surge in food prices in late 2007 and early 2008 but recovered afterwards. Reduced demand, attributed to low-income consumers substituting rice for Pangas due to the result of declining actual earnings, was the root of the drop in production. (Alam, 2018). Pangas aquaculture plays a critical role in enhancing fish supply and accessibility, particularly for low-income consumers, and so improving food security on a national scale.

The use of formalin for preservation threatens shrimp and prawn goods for foreign markets, in addition to local markets (Alam *et al.*, 2007). Dishonest traders have put or sprayed formalin onto fish or shrimp to prevent rotting and lengthen shelf life (Yeasmin *et al.*, 2010, Begum *et al.*, 2013). Due to the presence of harmful microorganisms, foreign matter, and poor sanitary quality, the Bangladesh shrimp export trade has previously experienced significant losses as a result of detention and rejection of imported products. The EU banned imports from Bangladesh in 1997, which had a significant impact on export income and employment, affecting around 1 million people employed at various stages of the local shrimp supply chain (Cato & Dos Santos, 1998). Following the EU's 1997 ban on Bangladeshi shrimp imports, processing companies were compelled to improve their facilities and infrastructures to meet international standards. According to Cato and Lima dos Santos (1998), the 1997 ban cost Bangladesh's shrimp-processing industry US$14.66 million in lost income (Cato & Dos Santos, 1998). Since 2004, no signs of harmful bacteria, pesticides, or heavy metals have been identified in shrimp transported from Bangladesh to the EU due to improvements in hygiene and sanitary conditions, notably at the processing level.

5.2.2 Sea level rise and salinity effect

Numerous species flourish in a mix of freshwater and saltwater reservoirs, and mangrove forests serve as the breeding grounds for thousands of them. In addition to natural disasters, the rich biodiversity of the Sundarbans is seriously threatened by ecological changes like rising salinity and the emergence of diseases like "top dying" of the Sundari trees. Key informants claim that the prevalence of prawn disease has grown as a result of rising water salinity. Additionally, increased water salinity may result in post larvae having a reduced reproductive rate and a higher mortality rate, affecting their population. Climate change has been connected to variations in population abundance and the occurrence of fish disease (Ahmed *et al.*, 2013).

5.2 Role of aquaculture sector to the welfare and economic development in Bangladesh

In the result section the GDP growth of Bangladesh, aquaculture's contribution in GDP and population growth have been shown. Aquaculture in Bangladesh contributed on enhancing economy in many ways. The Bangladeshi agrarian economy has a great deal of potential for future development, and one of the most productive and active industries is the aquaculture sector. First, by adding value, the aquaculture sector contributes to the GDP of the economy. Fish and fish products bring in a sizable amount of precious foreign currency as exports. Second, a significant portion of the population is employed by the aquaculture industry. Third, for those with limited incomes, fish and fish products offer an affordable source of vital nutrients.

5.3.1 Poverty alleviation and employment generation

The fishing sector supports national economies significantly in terms of both direct and indirect employment (Béné et al., 2016). Bangladeshi development organizations have long promoted aquaculture as a means of eradicating poverty. The emphasis has largely been on "small-scale" enterprises. Due in large part to the scope and depth of its ingrained poverty, Bangladesh has been the target of substantial international development efforts, particularly in the rural regions. Foreign development agencies and regional non-governmental organizations (NGOs) have given a number

of significant multilateral and bilateral donor-funded aquaculture establishment and productivity-boosting projects, as well as numerous smaller initiatives, a great deal of attention and support since the late 1970s (Belton & Azad, 2012).Aquaculture is increasingly being recognized as a source of decent income for households, particularly cash income for subsistence and semi-subsistence households in rural farming settings, despite the fact that it is not always the primary source of revenue. In Bangladesh, fishpond operations, combined with crop production and other on-farm activities, contributed easily between 5 and 10% of total household income (Bouis, 2000).

Globally, it appears that aquaculture has increased food availability and provides income to individuals, particularly those who are directly involved in the industry. The value that the fishing industry adds to the economy significantly boosts national prosperity (Abila, 2003). Many nations rely heavily on the sale of fishing licenses and other fishery-related fees for revenue. Bangladesh also rely on taxes which are imposed on the export of fish as well as the importation of fishing equipment, motors, and fuel (Shamsuzzaman et al., 2020). Several scholars have looked at the employment contribution of fisheries to national economies in addition to the cash value of fisheries produce. Evidence suggests that in developing countries, when chronic unemployment exists or when there are few alternatives to fishing, the level of employment in the fishery that maximizes national revenue in the rest of the economy and contributes the most to the balance of trade is greater than the level of employment that maximizes resource rent (Béné *et al.*, 2016).

Artificial breeding breakthroughs and the successful adoption of polyculture technologies based on an indigenous feeding and fertilizing regime, supported by an expanding domestic and international market, have created much more room for an occupational shift, changing labor use patterns, and increased employment and household participation in aquaculture over the last two to three decades. Another immediate benefit of aquaculture development for the poor would be increased employment and earnings. In theory, if the poor do not have access to property, they can at least contribute labor, particularly in large-scale enterprises where the land is owned by the upper income group.

Rural women in Bangladesh are subjected to a severe gender-based division of labor and societal taboos that limit their mobility and prevent them from participating in income-generating activities beyond the household. Several studies show that if women are given specialized training, they may

successfully participate in and own aquaculture. This is partly due to the fact that aquaculture is generally a homestead-based activity that fits well with prevalent cultural norms. Women are actively involved in the feeding, harvesting, and processing of fish catch, according to a number of other research (Hamid & Alauddin, 1998, Faruque, 2007). Women's growing engagement in fish production could help improve household nutrition, especially because their increased control over the production process could lead to more control over intra-home food and income distribution, which would benefit women, children, and the elderly.

5.3.2 Food security and protein value of fish

A vast network of inland open water features, including rivers, canals, lakes created by nature and human activity, freshwater marshes, estuaries, brackish water impoundments, and floodplains, exists throughout Bangladesh. Bangladesh produces more than China and India combined, making its potential seafood resources some of the richest in the world. For people all throughout the world, fish is an important source of high-quality protein and minerals. With more than 60% of the total animal source protein consumed, it is the main source of animal protein in developing countries. The world's growing population and greater fish consumption both have an impact on the demand for fish globally. Fish makes up 63 percent of Bangladesh's protein intake, making it one of the most significant animal proteins (DoF, 2018; Haque et al., 2018). In Bangladesh, per capita fish supply increased from 7.6 kilogram per capita per year in 1990 to 19.2 kg per capita per year in 2013 (Sheets, 2016). During the same time, aquaculture's proportion of Bangladesh's fish supply went from 23% to 55%, and the number of farmed fish produced increased by 810%, from 0.2 million tons to 1.96 million tons (Bangladesh, 1994, Bangladesh, 2015, Bogard et al., 2017). Barbs and Tilapia, alien carp, giant catfish, and small indigenous species are the most widely consumed fish species categories among the poor in Bangladesh, according to numerous studies. According to Halim et al. (2017), increased fish consumption can boost fish output and boost rural household employment significantly. It was expected to alleviate malnutrition, particularly in countries like Pakistan as fish, has a lot of food potential (Ashraf *et al.*, 2011). Fish can be a significant source of iron in diet. This is especially important in Bangladesh, where iron deficiency affects 70% of women and children. Small indigenous species (SIS) of fish like the

mola carplet (*Amblypharyngodon mola*) contain high amounts of zinc, iron, and vitamin A. Mola could be termed a "bonus crop" With existing carp polyculture systems as several studies have shown that mola does not compete for feed with carp and does not require any additional costs, with the exception of fingerlings. Carp–mola polyculture systems have significantly higher production and profitability (P 0.1) than carp-only polyculture systems. These factors have an impact on carp–mola polyculture production and income in southwest Bangladesh.

Food security is the most important approach to improving a country's socioeconomic standing and combating hunger (Pradeepkiran, 2019). A series of peer-reviewed publications (covering only a small portion of a much larger pool of (gray) literature) looks at how international fish commerce might help developing countries with food security (Béné et al., 2016). In recent decades, the discussion over food security in emerging nations like Bangladesh has centered on achieving self-sufficiency in the production of grains and other major food items. With 143 million people living in a land area of about 1 475 000 km^2, Bangladesh is one of the world's most densely populated countries and about 76 percent of the population lives in rural areas, with about half of them living below the national poverty level. Aquaculture is Bangladesh's fastest-growing food-producing sector, with constant growth in overall production over the last few decades. Cereals and comparable commodities, on the other hand, have grown at a far slower pace. Aquaculture is considered to have the potentiality to improve food security among adopters and the general public due to its quick expansion (both in Bangladesh and in many other Asian countries). Aquaculture is said to improve food security directly by producing fish for home consumption, enhancing supply, and lowering market prices, as well as indirectly by contributing to farm diversification and the creation of new employment and revenue streams.'

5.3.3 Aquaculture contribution on establishment of blue economy development

Bangladesh's growth ambitions include the establishment of a blue economy. The shrimp species as black tiger shrimp (*Penaeus monodon*), brown shrimp (*Metapenaeus monoceros*), Indian white shrimp (*Penaeus indicus*) have been identified as the most promising fish species. Bangladesh earned US$ 446 million in the fiscal year 2016–17 by exporting 39,705 t of shrimp. The EU (which

accounts for over 80% of exports), particularly Belgium, Germany, and the Netherlands, is the largest export market.

The country's favorable meteorological conditions, as well as the availability of resources such as shrimp post larvae, feed, water conditions, and low-cost labor, have aided the establishment of shrimp aquaculture (Islam, 2003). Shrimp farming grew fast from 20,000 hectares in 1980 to around 276,000 ha in 2013, with marine shrimp farming accounting for 195,000 ha and freshwater shrimp accounting for 86,000 ha (Kabir & Eva, 2014, Paul & Vogl, 2011, Rahman *et al.*, 2013). In the low-lying tidal flood plains of numerous upazilas[4] of Bagerhat, Chittagong, Cox's Bazar, Khulna, and Satkhira districts, coastal aquaculture, mostly tiger shrimp (*P. monodon*), and six other species, are being practiced (AftabUddin *et al.*, 2021).

5.4 Reason of foreign value loss of Pangas

From 2009-2019 mean value of Pangas was 4,72,965 USD. But unfortunately, initiatives in recent years in Bangladesh to export value-added products to the international market through the creation of Pangas processing factories have failed. The main cause of failure is the unrestricted spread of Pangas farming, which allows farmers to utilize their land for fish farms, dig ponds, apply feed and medicine, and hire staff without regard for any standard laws and restrictions. Increasing Pangas farmers' profit margins by assuring quality production and value addition, both in the domestic and export markets, could be a market-based instrument for Pangas aquaculture development (Belton & Azad, 2012).

The major market for Pangas is Europe, which might be a target for Bangladeshi exporters (Belton & Azad, 2012). Fillets produced in Bangladesh, on the other hand, frequently have a yellow tint, which is commonly associated with lesser quality and disliked by European consumers (Little et al., 2016, Belton & Azad, 2012) contrast Vietnamese Pangas fillets are white and in high demand among European consumers. Due to its popularity and cost, Pangas from Vietnam is often exported to high-value markets. While there are other factors that contribute to the lack of Pangas exports to overseas markets, the color of the fillets is the most important (Hoque et al., 2021).

The establishment of an internationally recognized certification scheme is required for the production of certified farmed Pangas in Bangladesh through a responsible farming system (Haque et al., 2021). Pangas farming is regulated in Vietnam by a number of certifying organizations, one of which being the Aquaculture Stewardship Council's (ASC) Pangas aquaculture dialogue (PAD) standard.

5.5 Comparison between freshwater aquaculture and marine aquaculture

Climate change is likely to worsen these ecological consequences (Islam et al. 2014; Ahmed and Diana 2015) A multitude of detrimental environmental and social effects that have been linked to shrimp farming make it difficult for this industry to develop sustainably. Moreover, shrimp farming resulted in farmers' social exclusion and poorer living conditions rather than raising standards of living and community wellbeing. Despite the fact that shrimp farming has produced some short-term job possibilities, the cost of destruction outweighs these advantages. The main negative effects on the environment include pollution, disease breakout, loss of biodiversity, and conversion of mangroves and agricultural fields into shrimp ponds and ghers. These effects of shrimp farming are primarily caused by improper management techniques and inadequate strategies involving water quality, seed supply, irrigation systems, and fishing resources. Additionally, shrimp farming in Bangladesh costs around 12% more than it does in the Philippines at the same level of input prices, showing that there is limited opportunity for comparative advantages to increase export revenues (Ling et al, 1999) (Rahman & Ahmed, 2002). It has become urgently necessary to implement appropriate management strategies to lessen the negative environmental effects of the expansion of the shrimp farming industry.

Despite the fact that carp is the most widely farmed aquatic fish in Bangladesh, it contributes very little to the international aquatic product trade. With carp some other freshwater fish Tilapia, Pangas can contribute more in the economy of Bangladesh as these fish have a lot of potential for cultivation and less environmental effect. Bangladesh may surpass other Asian nations in terms of grow-out cultivation and seed production of these fish.

[4] Upazila is a district's subunit and a type of administrative region in Bangladesh.

6. Conclusion

The aim of this study was to analyze fish production, fish diversity of Bangladesh across the millennium and figure out how economy of Bangladesh is dependent on fisheries. The study found that, aquaculture sector of Bangladesh has huge potential to bloom and compete in the international market. However, the diversity of freshwater fish is high. Shrimp farming is considered as one of the main produced species as it has many known economic advantages. However, this shrimp industry also creates several environmental and social issues. If these issues are taken into consideration, the cost of destruction is substantially higher than these advantages even though it has produced some short-term employment possibilities.

Adopting an ecosystem-based approach to sustainable aquaculture might be an option but it requires proper governance to overcome socioeconomic challenges, and coordinated management, policy, and scientific effort. Policies should concentrate on challenges, such as lowering production risk and technical inefficiency, promoting consumer acceptability, and creating new markets for fish products to ensure the continued, healthy expansion of fish production in Bangladesh. High-yielding species should also be used together with more advanced technology for intensive fish farming. In order to accurately calculate the aquaculture farms' profitability, farmers need also keep track of all operating expenses by using record books. Furthermore, effective government oversight can guarantee the accessibility of high-quality fish seed and fish feed. In Bangladesh, there is a high chance of disease spread. Along with adopting and implementing aquaculture health management, it is necessary to develop disease prevention measures including diagnostics and mitigation methods. Furthermore, Bangladesh is well-suited and well-positioned to develop into an ecotourism destination. Recreational fishing might be an option as these benefits the nation tremendously and provide as a crucial tool for sustainable economic and social development, including the eradication of poverty, the creation of jobs, and the improvement of rural areas.

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