

Potential and Challenges of Catfish Aquaculture in Pakistan

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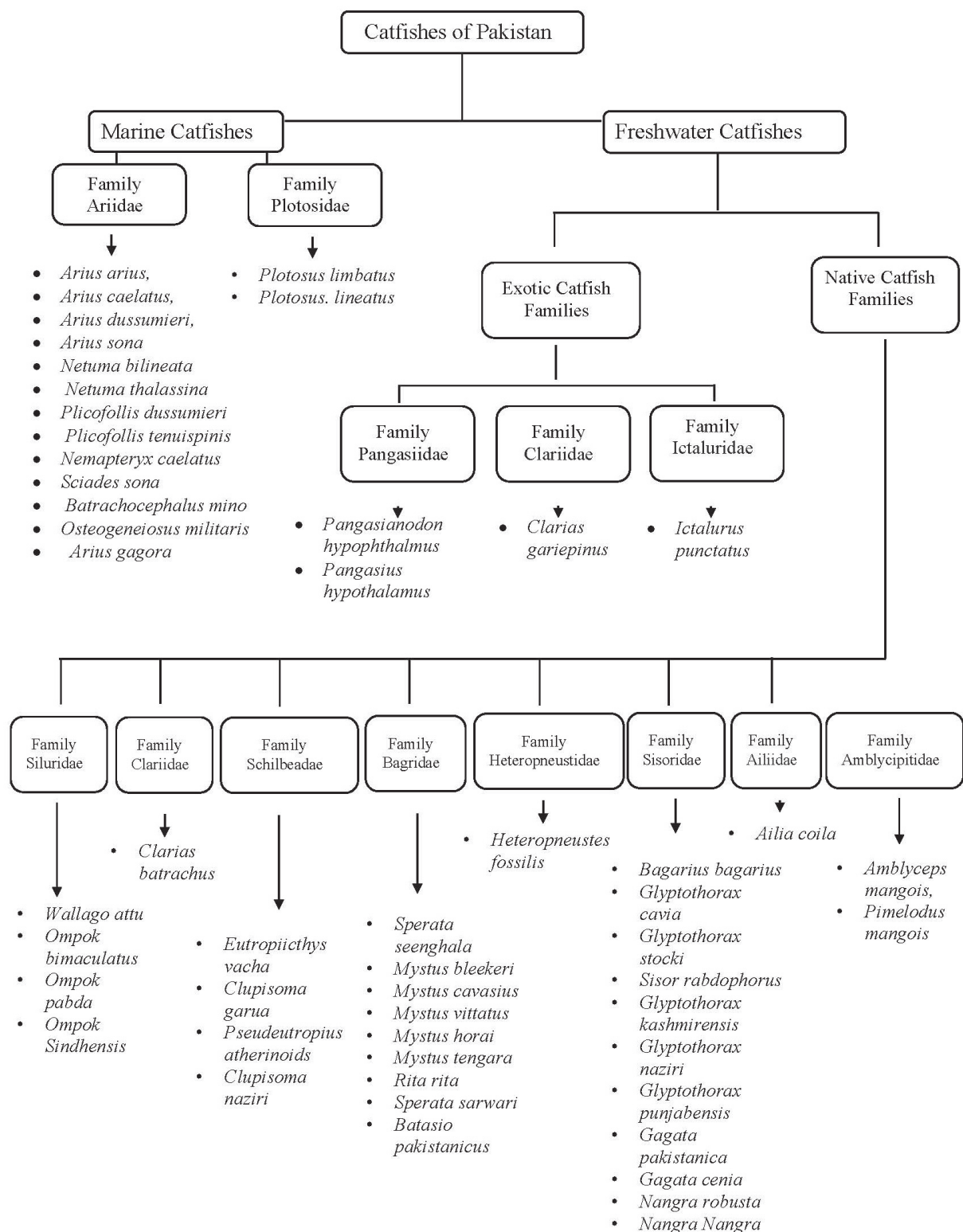
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Introduction

Aquaculture has emerged as the fastest growing food source in an effort to meet the demands of a growing population (FAO, 2006). The global population is rapidly increasing, resulting in an alarmingly high hunger ratio that necessitates the provision of shelter, clothing, and food. Poverty is major threat to global food security and can only be achieved by the inland fisheries and aquaculture sectors. Additionally, fisheries resources also contribute in GDP of any country (FAO 2004). In this perspective, aquaculture can meet the needs of developing countries in terms of livelihood, food security, social development and a source of income (Nowsad et al. 2015). It can contribute in reducing hunger by the production of aquatic protein and through the generation of income sources (Garcia-Rodriguez and Cruz-Aguero 2011). From past two decades, the overall consumption of fish and fisheries products have increased due to the rapid growth of aquaculture production (FAO, 2004). Globally, carp, tilapia, salmon, and catfish are prevalent choices for fish farming activities. By the year 2030, freshwater species, including carp and catfish, are estimated to dominate global aquaculture production, making up the majority at 62% (FAO, 2020).

Among Ostariophysi, the second largest superorder of fishes, order siluriformes is considered to be rich in diversity including 477 genera, 39 families and approximately 4000 species (Senthilkumaran and Kar 2021; Fricke et al. 2019; Ferraris, 2007). It includes major groups of catfishes that are commercially and economically important throughout the world. Majority of these catfish are cultivated in Asia as they can bear temperate environment (Punhal et al. 2018). About 107 species of catfishes are present in Asia and Europe (Ditcharoen et al. 2019). Catfishes, belongs to the order Siluriformes, are a diverse group of fishes characterized by their whisker-like barbells around the mouth, just like cat's whiskers which helps in sensory perception. They possess scaleless skin and a distinctive adipose fin lacking fin rays. Additionally, their dorsal and pectoral fins are armed with sharp spines, serving a defensive purpose (Muhammad et al. 2017; Wang et al. 2016). They are preferred for food, due to high protein content, hardy nature, high fecundity and resilience nature (Senthilkumaran and Kar 2021). Besides this, they possess relatively high adaptability to artificial spawning, hatchability, culturing and resistance to diseases. These characteristics also make them excellent model organism in valuable research regarding evolutionary biology, fisheries, parasitology, economics etc. particularly in toxicology experiments, where their tolerance to environmental stressors like low dissolved oxygen and adaptability nature proves advantageous (Rejab et al. 2020; Turan et al. 2020; Senthilkumaran and Kar 2021; Tripathi et al. 2023). Notable catfish species, includes the Amur catfish (*Silurus asotus*), Channel catfish (*Ictalurus punctatus*), Striped catfish (*Pangasius hypophthalmus*), and African catfish (*Clarias gariepinus*) having approximately -0.62%, 0.53%, 0.52% and 0.33% contribution in total fish production by the end of 2014 and 0.49%, 0.91%, 4.3%, 5.1% respectively by the end of 2018 (FAO 2014, 2018).

In the United States, catfish are regarded as a key species for aquaculture. In late 18s and early 19s Bull heads were cultured on a large scale for the purpose of sport fishing (leary, 1910). To increase aquaculture production and recreational fishing, the channel catfish, *Ictalurus punctatus*, has been introduced into more than 32 nations, including the UK, Brazil, China, India, Thailand, and Russia (Welcomme, 1988; FAO, 2006). Fishes are introduced to almost all parts of North America where the suitable water resources are available (Moyle, 1976). The private hatcheries and the government have propagated about 7 species of the catfishes for recreational fishing and



stocking purposes. These species include the blue catfish, white catfish channel catfish, flathead catfish, yellow bullhead catfish, and black bullhead catfish. Among them, the second most cultured catfish is the blue catfish (Dunham et al 2008). On the other hand, the channel catfish is a fish that has been cultured worldwide and brought into more than 32 nations, including China, India, Thailand, and Russia, in order to increase aquaculture production (FAO, 2006). Channel catfish has significance performance in freshwater and its production is moving toward sustainability (Engle, 2003). Besides this, it also made a hybrid with the blue catfish. This combination proved to be efficient for pond culture (Dunham et al. 2008). Because it shows a high growth level and resistance

to the bacterial diseases. Moreover, this new hybrid species tolerates low level of oxygen (Arias et al 2012). Another fact that makes it culture friendly is that both the blue catfish and the channel catfish have a low survival rate in high density and have higher chances of disease when cultured separately, however their hybrid has remarkably high rate of survival even in high stocking densities.

Additionally, African catfish has recently gained the attention of fish sector all over the world because of its advantages. It can tolerate the high temperature and low DO that make them more resistant to the stress (Olaleye, 2005). In addition to that it has the ability to show resistance against diseases and their breeding can be done under captivity. These species can even survive at the highest stocking density (Van der Waal, 1998).

Potential of Catfish Culture in Pakistan

Pakistan is enriched with a great variety of fishes along with streams, rivers, dams and oceans (Ahmad et al. 2020). It has 1120 kilometers of coastline and 3,102,408 hectares of inland water reserves (Samuel et al, 2011). It has 225 wetlands, among which 74% are freshwater while rest are marine water wetlands (Muhammad et al. 2019). In addition to that, it has world-class fish wharf, with Karachi Fisheries Harbor being the most significant since it handles 90% of the nation's fish and seafood imports as well as 95% of its fish exports. Moreover, Sindh and Baluchistan coastlines are also noteworthy for their abundant natural fish fauna reserves (Pirarat et al. 2017).

Pakistan has 233 freshwater and 800 marine water species, among which 31 freshwater species and 120 marine water species are of commercial importance (Altaf et al. 2015; Laghari, 2018). Pakistan's Indus River is habitat to more than 180 different fish species. The world's largest land and rock filled dam, Tarbela dam with six barrages (Jinnah, Guddu, Kotri, Chasma, Taunsa and Sukkur) are constructed on Indus River in Pakistan (Mirza and Mirza 2011). Despite of all these resources, there are only few fish species and water resources that are been explored for culturing. Many researchers reported that there are many continental areas in Sindh and Baluchistan, Pakistan that have high capability for fish production but unfortunately these are untouched until now. The effective use of these unutilized areas for fish farming needs careful planning. The data deficiency is another element in the sector of aquaculture. The data validity is questionable or sometimes the data is insufficient. There may be hundreds of fish farms which are not registered so they cannot be surveyed by the fisheries department because of their poor power resources and insufficient operational funds (Nazir et al, 2016). To meet the increasing demand for fish, food security, employment opportunities and for strengthening the national GDP, the fish production sector is making progress. However, still there remains a crucial need to further develop and expand the aquaculture sector (Shah et al. 2018). By paying more attention to fisheries, the economy of the country can be boosted (Mohsin et al. 2015).

In Pakistan, only few species like *Labeo rohita*, *Cirrhinus mrigala*, *Catla catla*, *Cyprinus carpio*, *Hypophthalmichthys molitrix*, *Ctenopharyngodon idellus*, and *Hypophthalmichthys nobilis* are frequently cultured. Among them, *Catla catla*, *Labeo rohita*, and *Cirrhinus mrigala* command higher market value due to consumer preferences. However, the culturing of Catfishes, Snakeheads and tilapia are in developmental phases (Laghari, 2018). In a recent study done by Rossignoli et al. 2023 on challenges of saline aquaculture in Pakistan, they found that Rohu is the most commonly stocked fish species among farmers, followed by Catla, Mirgal, Common Carp, and Grass Carp, with varying percentages. On the other hand, Catfish and Tilapia are stocked by only a small percentage of farmers (medium and large-scale farmers), with more than 90% preferring carp species and about one-tenth (12%) of farmers harvest species other than Carp, like Tilapia or Singhari (catfish) (Rossignoli et al. 2023). Although, catfish cultivation has its perks when compared to carp farming as it can endure low-oxygen environments, handle crowded conditions well, and support high stocking densities with artificial feeds (Ali et al. 2015). Despite of that, here most of the catfish production relies on wild resources as these are easily accessible and affordable sources for freshwater food. Consequently, these fishes are predominantly consumed by the local communities

in the area which results in overexploitation and thus risk of the loss of these valuable fishes (Ali et al. 2015). In addition to that, many researchers reported climatic change, water pollution and other anthropogenic aspects as contributing factor in decline of these fishes in both freshwater and marine water sources of Pakistan (Noman et al. 2018; Gilani et al. 2020; Afreen et al. 2022; Malik et al. 2023). Such kind of circumstances reflects the consumer interest and thus need of proper culturing of catfishes. There are many cultivable and economical important catfish species in Pakistan. The data regarding the exact number of catfish species in present in Pakistan is scarce but on the basis of previous documentation it can be concluded that there are approximately thirty plus freshwater indigenous catfish species belonging to 7 different families (Siluridae, Schilbeidae, Bagridae, Sisoridae, Heteropneustidae, Claridae and Amblycipitidae) that are being reported in freshwater resources of Pakistan (Ferraris, 2007; Rafique and Khan 2012; Muhammad et al. 2017). On the other hand, about 15 seawater catfish species belonging to 2 different families i.e. Ariidae (sea catfishes) and Plotosidae (eel catfishes) are documented by various researchers (Farooq et al. 2016; Sattar et al. 2016). Among these, there are many species that are commercially important for food and ornamental purposes throughout the world. But in Pakistan none of these are preferred by farmers. However, the wild sources of these species are heavily under the pressure of overfishing which leads to the decline in the population of these commercially important species. Furthermore, among freshwater catfish species of Pakistan 31 species have special IUCN status indicating 17 % species as near threatened, 14% as endangered and 6% as vulnerable (Figure 1).

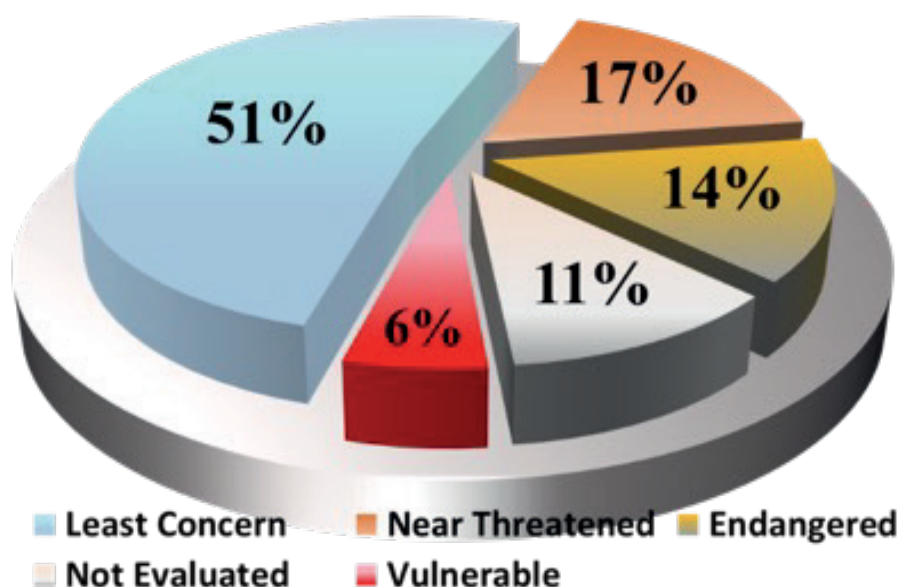


Figure 1. IUCN status of freshwater fishes of Pakistan

Table 1. Indigenous Freshwater Species of Pakistan

Family	Species	Distribution	IUCN status	Commercial value	Reference
Siluridae	<i>Wallago attu</i>	AJK, Balochistan, KP, Punjab, Sindh	Vulnerable	Very high	Rafique and khan 2012; Ferraris, 2007; IUCN 2020
	<i>Ompok bimaculatus</i>	KP, Punjab, Sindh	Near Threatened		
	<i>Ompok pabda</i>	AJK, Balochistan, KP, Punjab, Sindh	Near Threatened		
	<i>Ompok Sindhensis</i>	Sindh	Not evaluated		
Schilbeadae	<i>Eutropiichthys vachana</i>	KP, Punjab, Sindh	Least concern		Mirza 2003; IUCN 2009; Ferraris, 2007
	<i>Clupisoma garua</i>	AJK, Punjab, Sindh	Least Concern	Very high	
	<i>Pseudeutropius attherinoids</i>	Punjab, Sindh	Least concern		
	<i>Clupisoma naziri</i>	AJK, KP, Punjab	Near Threatened	Very high	IUCN 2019; Rafique and khan 2012; Ferraris, 2007
Bagridae	<i>Sperata seenghala</i>	AJK, Balochistan, KP, Punjab, Sindh	Least Concern	Very high	Rafique and khan 2012; Ferraris, 2007, Mirza 2003, IUCN 2009
	<i>Sperata sarwari</i>	Balochistan, KP, Punjab, Sindh, AJK	Not evaluated		
	<i>Mystus bleekeri</i>	KP, Punjab, Sindh	Least concern		
	<i>Mystus cavasius</i>	KP, Punjab, Sindh	Least concern		
	<i>Mystus vittatus</i>	KP, Punjab, Sindh	Least concern		
	<i>Mystus tengara</i>	KP, Punjab, Sindh	Least concern		
	<i>Rita rita</i>	Balochistan, KP, Punjab, Sindh	Least Concern	Very high	
	<i>Mystus gulio</i>	Balochistan, Sindh	Least Concern		IUCN 2019; Mirza 2003
	<i>Mystus horai</i>	Punjab	Vulnerable		IUCN 2020; Rafique and khan 2012; Ferraris, 2007
	<i>Batasio pakistanicus</i>	Punjab	Endangered		

Family	Species	Distribution	IUCN status	Commercial value	Reference
Sisoridae	<i>Bagarius bagarius</i>	Punjab, Sindh	Near threatened	high	
	<i>Glyptothorax cavia</i>	AJK, KP, Punjab	Least concern		IUCN 2009; Ferraris, 2007; Mirza 2003
	<i>Glyptothorax stocki</i>	AJK, KP, Punjab	Endangered		Rafique and khan 2012; Ferraris, 2007; IUCN 2020
	<i>Sisor rabdophorus</i>	Punjab and Sindh	Least Concern/ Very rare		
	<i>Glyptothorax kashmi-rensensis</i>	AJK	"Critically Endangered"		
	<i>Glyptothorax naziri</i>	AJK, Balochistan, KP, Punjab	Near threatened		
	<i>Glyptothorax punjabensis</i>	AJK, Balochistan, KP, Punjab	Endangered		
	<i>Nangra robusta</i>	Punjab	Endangered		
	<i>Gagata pakistanica</i>	KP, Punjab	Least concern		
	<i>Gagata cenia</i>	KP, Punjab, Sindh	Least concern		Mirza 2003; Ferraris, 2007; IUCN 2009
	<i>Glyptothorax pectinopterus</i>	AJK, KP	Least concern		
	<i>Nangra Nangra</i>	Punjab	Least concern		Mirza 2003; Ferraris, 2007; IUCN 2007
Amblycipitidae	<i>Amblyiceps mangois</i>	AJK, Sindh, Balochistan, Punjab	Not evaluated		Ferraris, 2007; Mirza 2003
	<i>Pimelodus mangois</i>	AJK, Sindh, Balochistan, Punjab	Not evaluated		
Ailiidae	<i>Ailia coila</i>	Punjab, Sindh	Near threatened		Ferraris, 2007; Rafique and khan 2012; IUCN 2020
Heteropneustidae	<i>Heteropneustes fossilis</i>	KP, Punjab, Sindh	Least Concern		Muhammad et al. 2017; Ferraris, 2007; IUCN 2019
Clariidae	<i>Clarias batrachus</i>	Restricted areas of Punjab	Least Concern	High	Rafique and khan 2012; Ferraris, 2007; IUCN 2019

Besides this, a few exotic species, due to their commercial and economic importance worldwide, have also been introduced into the natural resources of Pakistan. These include African Catfish (*Clarias gariepinus*) (Basharat et al. 2020), Channel Catfish (*Ictalurus punctatus*) (Abdul et al. 2007), Asian Catfish (*Pangasianodon hypophthalmus*) (Shah et al. 2014) and striped Catfish (*Pangasius hypophthalmus*) (Mehboob et al. 2017). In 2007 about 2000 fingerlings of Channel Catfish were imported from Thailand by national agriculture research center of Pakistan as a pioneer step to promote catfish culturing (Abdul et al. 2007). Earlier Asian Catfish was also introduced to Pakistan in early 2000s to diversify aquaculture production, however the exact documented introduction of this species was not reported. Likewise, in 2017 striped Catfish fry was imported from Thailand by group of progressive researchers and analyzed the effect of fenugreek as a feed additive on its survival, growth and body composition (Mehboob et al. 2017) which is followed by its culturing in earthen ponds having HAPAS by Khan et al. 2018. Recently, in 2020 another group of researchers in association with national agriculture research center of Pakistan imported African catfish from Thailand and successfully adapted it in the environment of Pakistan (Basharat et al. 2020). In order to expand the fisheries industry in Pakistan there is dire need of introduction of new species having high export potential. Currently there are about 64 different kinds of exotic species in water bodies of Pakistan. On the other hand, ill effect of these alien species is also being reported by many researchers (Imran et al. 2021; Bilal and Khan 2023). That is why, proper management and control policies must be formulated for such introductions, otherwise it can lead to long-lasting ecological damages to native diversity of Pakistan (Bilal and Khan 2023).

Major challenges of catfish culture in Pakistan

The major factors that affect the culturing of the catfish in Pakistan include the fish feed, breeding, water, climatic conditions, and antibiotics resistant genes. These are listed below:

Fish feed

The prosperity of aquaculture businesses is directly tied to nutritional excellence. Developing top-tier feed formulations demand comprehensive insights into the unique biology and dietary needs of various fish species (Khan et al. 2018). Most of the commercial aquaculture practices in Pakistan are of extensive while some are of semi-intensive nature which is far behind other countries (Basharat et al. 2020). In order to promote aquaculture industry, there is a dire need to go for intensive culture system with artificial feeding. Artificial feed includes many ingredients that have high market price. The increasing cost of feed ingredients resisting the effective production of catfish in developing countries as it indulges farmers towards the culturing of those species that can give efficient output in extensive and semi-intensive culture system. Feed Cost in the aquaculture account for about 50% of the production cost (Barrows et al., 2007). It is rising day by day because of the lack of attention of aquaculturist in calculating the exact relationship between the feed cost and the weight gain by the fish. Extrusion method is a technology that is used for the fish feed production. In this, high temperature, moisture and high pressure are required and different dies are used to attain desirable size pellet size (Watanabe and Pongmaneerat, 1993).

Catfishes required 40 cp feed for better growth (Pourjafar, 2007). These are mainly omnivores and carnivores in nature and possess simple digestive system having limited carbohydrases, thus there is requirement of artificial feed that have high protein contents (Ogello et al., 2014; Khalil et al. 2017). This can be fulfilled by adding fish meal or other kind of live feed in diet which made this practice a bit expensive. Nutritionists across the world are continuously in search for other plant-based protein replacements that can cut down overall feed cost. Usually, Small-scale farmers lacks knowledge about advances in fish culture and they exhibit reluctance toward adopting new technologies. But it is the time to drive the system towards the intensive aquaculture of the highest stocking density by the introduction of the high value fish species that have the high growth potential (Faheem et al., 2019; Mahmoud et al., 2019). For this aquaculturists must be aware about the selection of efficient feed that can give good FCR at minimum amount. This can lead to cut down

the cost of feed which in turn will be responsible for better output for farmers. As recently, Basharat et al. (2023) found that the highest weight gain for newly introduced African catfish occurred at an 8% feeding level. However, a comprehensive cost-benefit analysis revealed that feeding at a 4% rate yielded the most favorable outcomes for African catfish culture in Pakistan's earthen pond system. Such kind of practices by researchers can encourage farmers to go for intensive culture system that is more advantageous.

Water

Water is the primary element, which is crucial in maintaining a healthy aquatic environment and producing abundant fish food organisms. The change in physiochemical parameters of water can directly affect the growth of fish. The distribution of species in rivers is significantly influenced by temperature and turbidity, as these factors shows a stronger correlation with dissolved oxygen (DO) and pH (Arino et al. 2013). Now a days many factors i.e. climate condition, habitat fragmentation, water pollution by industrial and municipal wastes deteriorated the water quality of natural waterbodies. A study by Malik et al. 2023 found the abundance of heavy metal accumulation in Wallago attu from Pat Feeder Canal, Pakistan which resulted in prevalence of Pseudomonas aeruginosa, a normal microbiota in digestive tract of fish which becomes pathogenic during adverse condition. These conditions had impact on the survival chances of aquatic organism. Just like freshwater sources, our marine sources (Arabian Sea at Karachi coast) are also facing same issues of climatic changes and water pollution (Afreen et al. 2022). Data compiled by Noman et al. 2018 found that the marine catfish stock at Sindh coastline is continuously declining. Again, prevailing overexploited and adverse environmental and water condition in sea water are responsible for loss in biodiversity. On the other hand, Catfish farming in environments having low salinity levels, up to 10%, creates conditions inhospitable to catfish diseases, thereby it can be a viable strategy for disease control. In contrast, freshwater environments with 0% salinity provide favorable environment for the growth of catfish diseases (Fiess et al., 2007). These circumstances showed the need of intensive farming of catfish, where proper check and balance on water quality parameter can be maintained.

Temperature

All metabolic, physiological, and biological functions, including feeding, reproduction, migration, and distribution of aquatic organisms, are influenced by temperature. Catfish's temperature is only 1 °C above or below the water temperature. The metabolic activity of the warm water fishes is higher at the high temperature however the cold-water fishes such as salmonids show the best activity at the low temperature. These cold-water fishes including salmonids and the white fishes slow down their growth and consumption of food at high temperature. The water temperature also linked with the initiation of certain diseases. The immune system of the majority of the fishes shows their best activity at 15 °C (Sapkota et al. 2008). Under the natural conditions fishes can easily tolerate the seasonal changes in the water temperature but these changes should not be abrupt because this can lead to the death of the fishes. If fishes are put into the poor water temperature alterations, then it can show cardiac and muscle paralysis. Their digestion process slows down and their food remains undigested or partially digested which can result in the blotting of the fish. Moreover, the transfer of the fish to too much cold water can cause ammonia autointoxication (Bohl, 1989).

In Pakistan, under the prevailing extensive culture system having no check and balance on physiochemical parameters, there are high risk of disease outbreak. The wild sources of Pakistan are also being reported as victim of climate change and anthropogenic activities. This may cause the loss of catfish diversity along with other aquatic fauna and flora, as catfish production mainly relies on these wild resources (Ali et al. 2015). A study at the Taunsa Barrage of Indus River revealed that catfishes are stressed due to certain anthropogenic factors i.e. natural habitat disturbance, overfishing, water pollution etc. (Muhammad et al. 2017). Such conditions provide favorable environments for pathogens to grow. Furthermore, changes in average water temperature as a result of climate change can indirectly affect the catfish sector by increasing pathogen load along with reduction

in host sensitivity, transmission rates, and survival probabilities (Kumar et al., 2018). Likewise, another study by Gilani et al. 2020 claimed that the distribution of *Glyptothorax kashmirensis* in AJK, Pakistan was impacted by environmental variations and found that during summer months, rising temperatures significantly alter fish distribution in both Jhelum and Poonch Rivers of Azad Jammu and Kashmir. Moreover, increased turbidity is also associated with higher relative fish abundance in these river systems.

Impact of Anthropogenic activities on water quality

Anthropogenic activities are also responsible for poor water composition.

These activities include:

- Enhancement of suspended particles in the water after cutting and Logging of commercial forestry.
- Increase in the concentration of the metals in the drainage water by the metal mining by the men that exposed rocks surface area to the rainfall.
- Discharged of large volumes of organic waste in water in the forms of sewage
- Embryo Larval toxicity test with organic compounds.

pH

The hydrogen ion (H⁺) concentration in soil and water is measured using the pH scale. When pH below is 7 it become acidic and when rise from 7 become basic. The ideal pH for catfish growth is 6.5-8.5 and the optimum value for best growth is 7.5-8.5. However, it varies from species to species and aquatic ecosystem (Assefa et al., 2019). In fish pond the pH rise during day time due to the start of photosynthesis because phytoplankton utilize CO₂ and it declines during night as a result of the process of respiration and aquatic flora and fauna dissipate CO₂ into water. When pH fluctuate it causes the stress for fish and in results the production of mucus increases on body as well as gills. Fish eyes become opaque and diverge inside and disturb buoyancy of catfish.

Dissolved oxygen

One of the most important factors in aquaculture is dissolved oxygen (DO). Maintaining adequate DO levels in the water is critical for effective production since oxygen has a direct impact on feed intake, illness resistance, and metabolism. As a result, it is important to maintain dissolved oxygen levels in aquaculture systems above 4 parts per million (ppm). Ponds' dynamic oxygen cycle changes during the day as a result of phytoplankton respiration and photosynthesis. The significant element in a farmer's daily work is controlling the balance of photosynthesis and respiration as well as the growth of algae. (Alexander et al. 2010). Due to the accumulation of oxygen (O₂) from photosynthesis during the day, maximum DO will happen in the late afternoon. DO levels decrease because phytoplankton (microscopic algae) typically consumes the most O₂ and because photosynthesis does not occur at night. Ponds experience critically low DO when algae blooms dissipate. Besides this, a lot of oxygen is required for subsequent bacterial breakdown of the dead algal cells. It is vital to remember that water's DO content rises as temperature falls and falls as salinity rises (Khan and Thulin 1991). Even in the summer, the level of oxygen is sufficient and the growth of the plant is high, while the level of oxygen can decline in the autumn and the plants may die. Low oxygen levels enhance the eutrophication process. Hence the declining level of the dissolved oxygen is a major challenge for the fish culture.

Ammonia

The breakdown of decaying organic materials, including algae, plants, animals, and uneaten food, results in the production of ammonia in ponds. In water, ammonia can be found in two different

states: as the gas NH_3 or as the ion ammonium (N^{1-14+}). The gaseous form of ammonia is risky to cultural animals and can irritate the gills and cause respiratory issues (Koteswar et al 2017). The pH and water temperature of the pond affect the ammonia levels. There are several actions that can be taken if the water in the pond contains high amounts of ammonia. It can be compensated by filling the pond with fresh water, reduce the stocking density, and aerate the pond during emergencies as precautions and it will decrease the pH (Koskivaara et al. 1991).

Stocking density

The production of catfish and the profitability of the farms is determined by a major factor called as this stocking density because stocked in density affect the growth, health, water quality and the feeding of the fish. Aquaculture utilizes the natural aquatic resources more efficiently due to which it provides food security and increases the family incomes especially for the underdeveloped countries because of the supply of high-quality nutrition. This causes the reduction in poverty (Kubtiza and Ono 2010). Because stocking density directly influences fish growth and survival, it plays a significant role in determining the aquaculture system's profitability (Gibtan et al. 2008). Fish can be addressed by the highest stocking density which in result causes the decrease in the growth rate of the fish and their final weight (Kamstra, 1993). High stocking density can also affect the survival rate and the feeding of the fish (Stankus, 2021)). A high stocking density, however, also contributes to the producing a large number of fishes, which enhances the biomass production. Because of these relationships between fish growth and stocking density it is compulsory to find out the stocking density of the production system.

Fastest growth ability, ease of cultivation and ability to resist disease are some of the characteristics of the catfish due to which the catfish culture has been increasing (Jamabo and Keremah 2009). The cultivation of the catfish can be done in the high stocking density technology, Biofloc technology (Yusuf et al, 2015). According to the recent research cultivation of the catfish in high density by the use of the Biofloc system allow the cultivation of 50 catfishes in hundred liters of water (Ogunji et al 2008).

Breeding techniques

Breeding techniques for catfish in Pakistan comprise a range of methods that are aimed of boosting aquaculture. Here primarily, emphasizes was given to carp species, but it is now delving into catfish species in order to enhance their production. Usually, catfishes undergo breeding in natural water resources thus they face survival pressure due to water pollution and other prevailing conditions (Khan and Khan 2018). Keeping this fact in mind, induced breeding of few catfishes has been carried out but still these efforts are not enough. In 2014, under Aquaculture and Fisheries Program, NARC, Pakistan, Khan et al. 2014 for the first time undergo induced breeding of Giant Catfish, *Sperata seenghala* by using different hormonal analogues (ovaprim, HcG, LHRH and ovatide). They reported best performance with HcG with 2 doses at 10 $\mu\text{g}/\text{kg}$. Likewise in 2020, induced breeding of *Rita rita* was performed by Hayat et al. 2020 at Fish Biodiversity Hatchery Punjab Fisheries Department, Chashma, Mianwali as an initiative for the conservation and domestication of this endangered species. Recently, the acclimatization of *Clarias gariepinus* has been carried out which leads Ameer et al. 2021 to undergo Comparative study of the efficacy of two different hormones Ovaprim and hMG (menotropin) to induce breeding in exotic *Clarias gariepinus* at Muzafargarh Fish Hatchery Punjab, Pakistan.

Culture systems

In Pakistan different type of culture systems are used which includes the cage cultures system, pond culture system, recirculating culture system and Biofloc Technology. However, catfish production mainly based on the wild sources, which causes their over exploitation due to high consumer demand. Despite of this fact, very limited work is being carried out on catfish culturing. In 2019, Jalbani et al. 2019 first time undergo rearing of Catfish, *Rita rita* with Live

and Prepared Feeds in Cemented Cisterns and found that chopped chicken viscera could be good option for its culturing (Jalbani et al. 2019). Likewise, currently Parveen et al. 2022 successfully tried polyculture of *P. hypophthalmus* with Indian and Chinese carp to achieve sustainable higher production in Pakistan. Besides these, there are many other commercial and economically important catfishes that are present in Pakistan but no published information is available at the moment on their culturing from Pakistan. If culturing of these species could develop, Pakistan would be able to earn a lot of foreign exchange by exporting these fish in future.

• **Cage Culture**

Globally, the production of the catfishes in different culture system is also increasing day by day. In Europe Asia and Africa, the culturing of the catfishes in the cages have been done successfully (Bardach et al. 1972). Previously, in Bangladesh, there is focus on the pond culture for catfish production. (Karim, 1987). But now because of large number of the water bodies the aquaculture industry is focusing on catfish production through cages culture.

Besides this, by using the combination of the catfishes and tilapia many of the integrated systems are being practiced and developed (Marshall and Levy 2011). Stocking of species with different feeding habitats is done in the polyculture because there targeting the high valued species is not possible. In most intense culture systems, the nutrient utilization efficiency is 30% (Beveridge and Phillips, 1993). However, with the integrated cage cum pond system, the nutrient consumption efficiency is 50%, resulting in significantly less odor emission into the surrounding area (Yi, 2001).

• **Recirculating culture system**

An enclosed system known as a recirculating aquaculture system simply replaces the water that is lost during evaporation and cleaning processes. Management of the waste and the recycling of the nutrients are the opportunities provided by the recirculating culture system (Piedrahita, 2003). This method also improves hygiene and disease management (Summerfelt et al., 2005). In this, a wide variety of organisms can be raised, including a wide range of species from freshwater to seafood products and fingerlings to grow-out production (Davis and Arnold, 1998). Recirculating aquaculture systems are primarily concerned with nutrient recycling through integrated farming and technological advancement (Martins et al., 2010a). The aquaculture community in the United States and other countries are very interested in recirculating systems in aquaculture (Xie et al, 2007). Beginners can learn how to manage and keep the system in good working order so that fish or other aquaculture plants and animals can be raised in a healthy environment. Regarding quantity, China produces around 67% of the world's aquaculture products while accounting for 49% of the total value in 2006 (FAO, 2008). A number of significant issues related to this industry have recently arisen in China, including the country's limited land and water resources along with the ongoing degradation of the aquatic ecosystem, various disease outbreaks, and challenges with wastewater and sediment treatment (El-Olemy et al. 2014). New culture methods are being preferred in order to reduce waste production, meet fuel demands, and optimize water usage. A recirculating aquaculture system is an aquatic system built on land in which the water is partially reused following mechanical and biological treatments in order to reduce water and energy usage, as well as the release of nutrients into the environment (Martins et al., 2011).

• **Pond raceway system**

In 2008 a large number of the channel catfish production was reported (USDA, 2009). The production was 92% in Alabama, Mississippi and Texas. In Alabama the channel catfish production sector is the most important sector in the aquaculture industry (USDA, 2009). Primarily the production of the channel catfishes is done in the watershed ponds or in the embankment ponds. After culturing the catfishes are harvested by seining. The production of channel catfishes in ponds can be significantly increased if it is raised through various ways that maintain water quality (Boyd and Tucker, 1998). Traditionally, production of the channel catfish in the ponds produces 5000 kg/

ha of catfish and the maximum production is about 7000 kg/ha. The production increases to 10,000 kg /ha in Alabama but there is lack of proper aeration for maintaining dissolved oxygen (Boyd and Hanson, 2010). An optimum value of the feed Conversion ratio is required for the proper ponds management. The average value of FCR is 1.6-1.8 which is considered to be the best value for pond management (Boyd and Tucker, 1998). For more profit and sustainability, the catfish farming should be well managed and efficient. So, in addition to the improvement in the fish production in the ponds there is the high need of using different efficient techniques for catfish productions.

The pond raceway culture consisted of the raceways which had the highest stocks of the catfish fingerlings. Water circulation is facilitated through the cultural unit, and an airlift pump is also utilized in the process. A good waste management system is used to remove the body solid fish waste from the raceway ends (Hawcroft et al 1994). In addition to that this system was successful in the research setting but this system also had some disadvantages due to unequal water flow and poor solid waste removal system (Tucker and Kingsburg, 2009). In Pakistan in 2015, an important catfish species *Sperata seenghala* was first time introduced in culture system by utilizing both indoor fiberglass circular tanks and outdoor concrete raceways (Ali et al. 2015).

• Biofloc system

The production of the catfish can be increased by the use of a Biofloc system in close containers. These systems allow the cultivation of the catfish in high density thus increasing the production of catfish (Kareem et al 2015). Basically, the Biofloc system is the collection of various organisms that includes the algae fungi bacteria protozoa. The cultivation of the catfish in high density produces more waste so a regular stirring is to be done for the removal of the waste. The Biofloc systems increase the ratio of carbon and nitrogen by the addition of organic carbohydrate which stimulates the growth of heterotrophic bacteria. By using probiotics in Biofloc, you may improve the water's quality, increase the amount of nutrients for feed, and prevent harmful bacteria (Yusuf et al 2015).

It is a successful enterprise to cultivate catfish in high density using a Biofloc method. For small-scale or domestic industries, this may be a good option. More research has revealed that in such systems, it is simple to determine the survival rate of the fish, food conservation ratio, total revenue, and profit. Additionally, studies also inferred that the business's R/C ratio runs from 1.47 to 1.68, demonstrating its high profitability (Hilge, 1981).

Diseases

Any disorder that affects an aquatic animal's regular physiological processes is considered a disease. Fish illness outbreaks raise production costs due to the investment in dead fish, treatment expenditures and reduction in development during restoration (Khalil et al., 2001). We are less aware of fish disease concerns in nature because predators quickly remove unhealthy species from the community. Under natural circumstances, parasites and bacteria might not be significant, but in captivity, where animals are overpopulated and stressed, they can cause serious issues (Locke, 2010).

Protective Barriers against Infection

Fish have four infection-resistance mechanisms:

- Mucus
- Scales and skin
- Inflammation
- Antibodies

A physical barrier known as mucus (slime coat) prevents disease-causing organisms from entering fish from the environment. It also functions as a chemical barrier since it has lysozymes

and immunoglobulins, which can destroy pathogens (Elsherief et al, 2014). In addition to lubricating the fish and facilitating movement through the water, mucus is crucial for osmoregulation. The fish's skin and scales serve as a physical barrier to prevent harm. A window gets opened for bacteria and other organisms to begin an infection when this barrier got damaged.

A biological, non-specific response to an invasive protein is inflammation (Hien, 2008). An invasive protein could manifest as a bacterium, virus, parasite, fungus, or toxin. Pain, bloating, redness, heat, and loss of function are all signs of inflammation. It is the body's protective response and an effort to wall off and eliminate the invader. A particular cellular response, antibodies are molecules created to defend against invasive proteins or organisms (Dung 2008). When a fish is exposed to an invader for the first time, antigen antibodies develop to prevent the fish from infection by the same organism in the future. Additionally, for a fish to develop an effective immune system, exposure to sub-lethal levels of pathogens is crucial. A sterile environment will provide little immunity to disease in an animal (Elsherief et al, 2014).

Disease Types

Fish are susceptible to both infectious and noninfectious diseases. Pathogenic organisms may be found in the environment or transported by other fish (Olatoye and Basiru, 2013). They are infectious, and some type of treatment may be needed to control the disease outbreak. Noninfectious diseases, on the other hand, are brought on by environmental issues, nutritional deficits, or genetic defects. Noninfectious diseases are not transmissible and may not have any treatment options available.

Infectious Diseases

• Parasitic Disease

Most often, minute creatures called "protozoa" that exist in the aquatic environment are the cause behind parasitic infections in fish. Fish that have protozoan infestations in their gills and skin experience itching, weight loss, and eventually death (Young and Blenden, 2011). The majority of protozoan infections can be effectively treated with common fisheries chemicals like copper sulphate, formalin, or potassium permanganate (Plumb, 1997).

As fishes act as the host for various tapeworm species so it becomes source of nourishment for parasites. As a result, the host gets worse and develops other illnesses. Large numbers of eggs are produced by parasites, and many of them go through different stages of their life cycle in several hosts.

Tapeworms

The catfish tapeworm (*Corallobothrium fimbriatum* and *Ligula intestinalis*), the Asian tapeworm (*Bothriocephalus opsarichthydis*), the bass tapeworm (*Proteocephalus ambloplitis*), and others are among the causative organisms. The type of tapeworm varies with the species of host fish. All fish are vulnerable, but black basses, Chinese carps, catfishes, sunfishes, and golden shiners are particularly sensitive (Serrano, 2005). Fish frequently not show any visible symptoms, but they may become sluggish lose weight, or become sterile. In rare cases, such as severe Asian tapeworm infections in grass carp, the abdomen swells and the intestines get blocked. Tapeworm presence is determined by microscopic examination (Burrige 2006).

The use of tapeworm-infected broodfish, purchasing infected fry and fingerlings, or exposure to surface water containing hosts for tapeworms all increase the risk of infection. Tapeworms may also be introduced via the droppings of fish-eating birds in and around the pond. Aquaculturalists avoid keeping or purchasing contaminated fry, fingerlings, and broodfish. They drain, dry, and disinfect ponds between fish crops, eliminating or reducing exposure to intermediate hosts. Currently, no treatment drugs are available. (Lillehaug et al, 2003).

• Bacterial Disease

Internal infections caused by bacteria are frequently bacterial diseases that need to be treated with medicated diets containing antibiotics that have been approved for use in fish by the Food and Drug Administration (Saad et al., 2014). Fish with bacterial infections frequently develop hemorrhagic spots or ulcers along the body wall and in the vicinity of their eyes and mouths. Additionally, they could have bulging eyes and an inflated, fluid-filled belly. External bacterial infections are also possible; they can cause skin erosion and ulceration. Rough treatment has been linked to external bacterial infections like *Columnaris* (Singh and Lakra, 2011).

Besides this, certain antibiotics are in use but due to certain factor such as development of disease resistance in microbe, this method is not much appreciated by researchers. A recent study was reported by Mahmood et al. 2023 revealed that *Aeromonas hydrophila* that infected *Sperata sarwari* (Singharee) of different wild sites i.e. Head Baloki, Head Trimmu, Head Taunsa and Head Chashma got resistance against different antimicrobials i.e. sulfamethoxazole, ampicillin, neomycin, and norfloxacin. To get rid of this, currently other methods i.e. vaccines and probiotics, herbal treatments etc are being preferred globally for disease prevention.

• Viral Disease

Without specialized laboratory tests, it is hard to differentiate between bacterial and viral diseases. There are no specific treatments for fish viral infections, and they are challenging to diagnose. Although not all viral diseases have vaccines, immunization can shield fish against them.

• Fungal Disease

The fourth category of infectious diseases includes fungi. Although they are prevalent in the aquatic environment, healthy fish are usually unaffected by fungus spores. Fungi may infect sick tissue on the outer layer of fish when the fish are infected with an external parasite or bacterial infection or have been hurt during handling (Uedeme-Naa and Nwafili, 2017). When the fish is removed from the water, these areas may appear as brown matted areas or to have a cottony growth. For the majority of fungal infections, potassium permanganate is beneficial. Fungi are frequently a secondary problem, thus it's critical to identify and address the primary issues (Lumanlan-Mayo et al, 1996).

Table 2. Prevalence of catfish infectious diseases in Pakistan

Species	Locality	Pathogen	Prevalence (%)	Reference
<i>Sperata sarwari</i> (Singharee)	Lahore, Punjab	Copepod parasites (Lernaea)	26.66%	Batool et al. 2022
<i>Sperata sarwari</i> (Singharee)	Punjab (Head Baloki, Head Trimmu, Head Taunsa, Head Chashma)	<i>Aeromonas hydrophila</i> (bacteria)	6.25%	Mahmood et al. 2023
<i>Arius arius</i> , <i>Arius caelatus</i> , <i>Arius dussumieri</i> , <i>Arius sona</i>	Karachi coast, Sindh	Nematode parasites (<i>Raphidascaris acus</i> larvae, <i>Metabronema magnum</i> , <i>Haplonema immutatum</i> and <i>Hedru-ris bryttosi</i>)	22.22%	Sattar et al. 2016

Species	Locality	Pathogen	Prevalence (%)	Reference
Rita rita	River Punjkorha, KPK	Ectoparasite (Rhabdocornia magna, Camallanus, Senga taunsaensis and Helicometra fasciata)	33.4%	Ayaz et al. 2013
Mystus vittatus	River Punjkorha, KPK	Ectoparasite (Rhabdocornia magna, Camallanus, Senga taunsaensis and Helicometra fasciata)	22.2%	Ayaz et al. 2013

Non-Infectious Diseases

Environmental, dietary, and genetic factors can largely be categorized as noninfectious disorders. The most significant environmental diseases are major threat to commercial aquaculture. Low dissolved oxygen, high ammonia, high nitrite, or natural or man-made contaminants in the aquatic environment are examples of environmental diseases. Producers can stop the majority of environmental diseases with the right methods for regulating water quality (FDA, 2016).

To mitigate the disease frequency, it is necessary to understand the epidemiology of diseases along with the implementation of their risk analysis procedures. In intensive farming, keeping a good balance between the environment, the fish being raised, and disease-causing agents is tough but really important.

Environment sustainability

The external aquatic environment is directly linked with the sustainability of catfish farming. The main source of the pollution that degrades the water quality is said to be the immense amount of effluent that comes from catfish ponds that cannot be handled. The high seed mortality in many of the places is correlated with the low water quality. Therefore, for the sustainability of the catfishes, control of these effluent and thus water quality is necessary. Different efforts have been adapted for reducing the environmental pollution which include registration of new farms, establishment of new farms, demonstration and encouragement for supply of good agricultural practices. In addition to that reduction in stocking density are also suggested for in order to reduce the pollution.

High economic returns

The farming of the catfishes required a high level of investment for the infrastructural building operating cost that includes the feed and seed cost and the investment for the land. In the case of fishes, the production cost and the net profit are relatively lower than that of production cost and net profit of other species but still total net profit of the fishes per hectare is much higher than the other species because of the high productivity. The cost for the production is increasing day by day. In 2006 the production cost for the catfishes farming was reported to be 0.59 dollar per kg but in 2008 (Hien 2008) the production cost for the catfish was 0.70 kg per hectare.

Availability of the markets

The fast expansion of the catfish farming industry is linked with the accessibility of the export market. Over time, the markets for catfish fillets expected to continue to expand. White flesh fish are being replaced by striped catfish (Lin CK 1990). Before 2003 there were much limitations in the export markets of the striped catfishes, among which the US exporters was the most important one. Now the export of catfish was done to over 80 countries worldwide. In these 80 countries the markets shared about 48 percent in the European countries 9.2% in the Russia and 6.9% in US (Dung 2008). By improving the product quality with expansion of the export market the production

can be increased at a high rate.

Conclusion

Pakistan has high potential for catfish aquaculture as it is enriched with the resources that can assist in the aquaculture sector. Current article recommended some strategies that need to be adopted for the successful expansion of this sector. Advanced farming technologies should be adopted instead of traditional methods for expanding this sector at global level. The intensive farming systems should be the priority of the farmers which will lessen the deterioration caused by climatic change, pollution and overfishing etc. Furthermore, Farmers training and education should be utmost priority for promotion and strengthening of this sector.

Recommendation

To promote catfish culturing, following strategies are suggested for Research, farmers and government sectors regarding aquaculture in Pakistan

- Focusing on propagating catfish culture and their breeding techniques just like carp culture that can be standardized or transferred to fish farmers.
- Established breeding and rearing techniques for economically important exotic catfish species.
- The development and use of high-quality, catfish-specific feeds with alternative protein sources.
- Exploring the use of vaccines, herbal treatments and probiotics for disease prevention.
- Improving infrastructure and developing effective marketing channels to connect catfish farmers with domestic and international markets.
- Establishment of the stocking and conservation programs for the production of those catfishes whose stock is continuously declining.

Besides this, it is also necessary to organize aquaculture extension leadership and training programs in Pakistan to create awareness on substantial fluctuations in climatic variables. One proposed solution is to establish a more inclusive framework by training trainers from neighboring countries renowned for their innovative aquaculture industries, thus fostering increased capabilities and resilience in the face of environmental challenges.

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