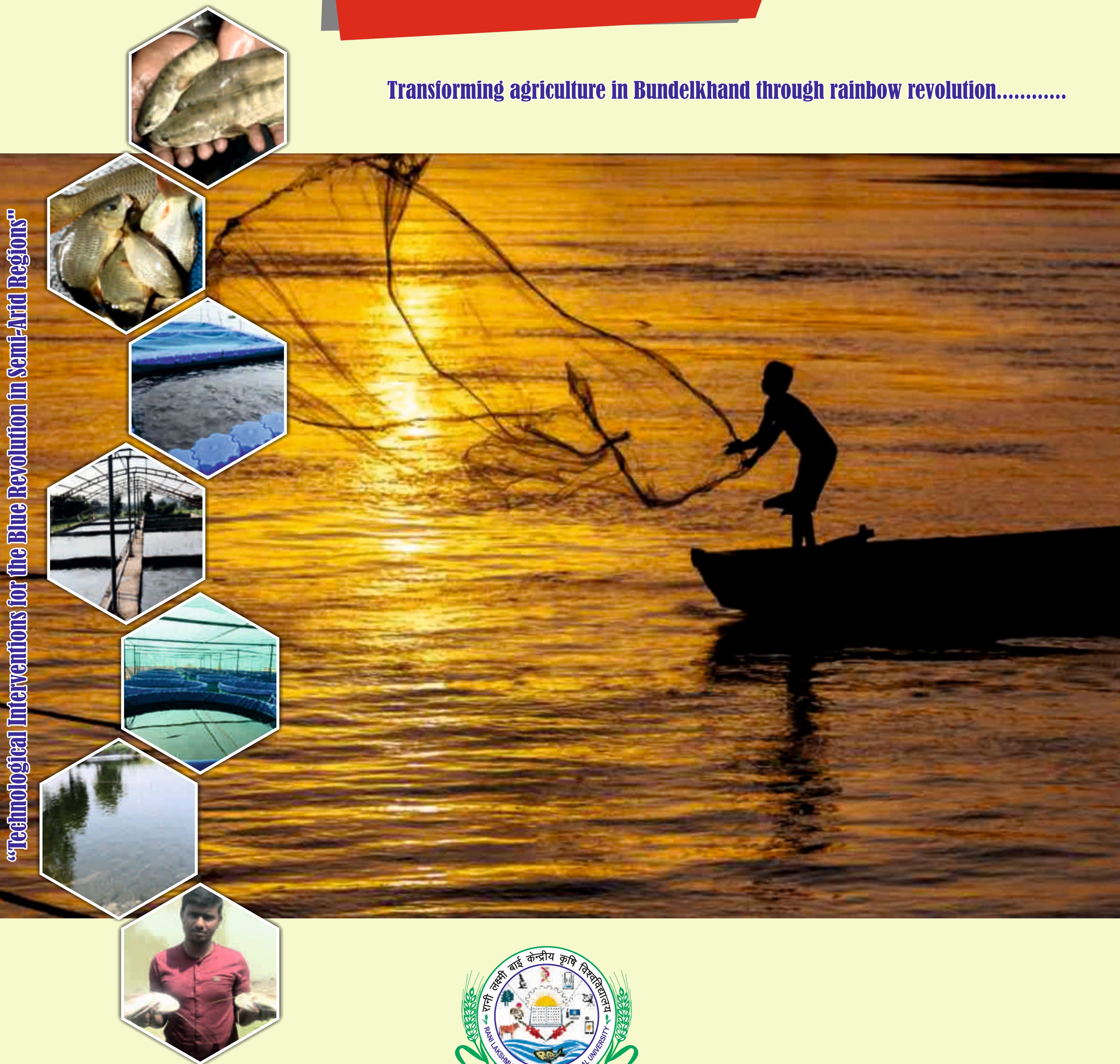
XIII[th] Issue

Volume 07, No. 01
January-June, 2025

AGRI-Life

Transforming agriculture in Bundelkhand through rainbow revolution............



"Technological Interventions for the Blue Revolution in Semi-Arid Regions"

Rani Lakshmi Bai Central Agricultural University
Jhansi-284 003 (U.P.) India

AGRI-LIFE

Volume : 07 Issue : 01
January-June 2025

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Published by : Directorate of Education,
Rani Lakshmi Bai Central Agricultural University, Jhansi-284 003 (U.P.)

From the Vice Chancellor's Desk.......................................

Fisheries and aquaculture are among the fastest-growing food sectors globally, playing a vital role in ensuring nutritional security, creating employment, and supporting rural development in India. In particular, semi-arid regions like Bundelkhand—once considered unsuitable for aquaculture—are now undergoing a silent transformation through the adoption of scientific fish farming practices such as cage culture, farm ponds, and reservoir-based systems.

Integrated Fish Farming Systems, which combine aquaculture with agriculture or livestock, are proving highly effective in enhancing resource efficiency and income diversification. Innovative technologies like Biofloc and Recirculatory Aquaculture Systems (RAS) have further expanded possibilities for high-yield fish production with minimal water use—crucial for water-scarce regions.

Fish is a vital source of nutrition, rich in high-quality protein, omega-3 fatty acids, and essential micronutrients crucial for human health. India's shift from marine-based exports to inland aquaculture species like pangasius, rohu, and tilapia signals growing global demand for farmed freshwater fish. To compete in international markets, the country has to prioritize value-added products such as frozen fillets and ready-to-eat items, while ensuring compliance with global standards of quality, safety, and traceability. This calls for strong institutional leadership in research, training, and policy support.

A key challenge is the development of cost-effective, nutrient-rich fish feed using locally available agro-industrial byproducts and plant-based proteins. Reducing dependence on imported fishmeal will not only cut costs but also improve sustainability. Research-practice integration is essential to creating region-specific, species-appropriate solutions that are both economically viable and environmentally responsible.

Beyond food production, fisheries offer new opportunities in ornamental fish farming—a high-value, low-input sector with potential in urban areas, eco-tourism, and women-led microenterprises. Bundelkhand, with its emerging infrastructure and community engagement, is well-positioned to become a hub for inland and ornamental aquaculture.

As we advance, fisheries must be viewed as a holistic value chain—from seed to feed, farm to fork, and local production to global markets. I appreciate the editorial team of *Agri-Life* magazine for dedicating this special edition to the dynamic fisheries sector and for highlighting the innovations and opportunities shaping India's blue economy.

I am very much hopeful that this special issue will promote the fish farming in semi-arid regions like Bundelkhand.

Fish for all, forever.

(A.K. Singh)
Vice Chancellor

Editorial

“Technological Interventions for the Blue Revolution in Semi-Arid Regions"

Fisheries and aquaculture have emerged as sunrise sectors in India, contributing significantly to food and nutritional security, as well as economic growth. The ongoing Blue Revolution is not just about increasing fish production—it represents a multidimensional transformation driven by technological innovations, ecological balance, and socio-economic inclusion. This special issue of *AgriLife Magazine*, dedicated to "Technological Interventions for Blue Revolution in Semi-Arid Regions," is timely, especially for regions like Bundelkhand, known for water scarcity and agrarian distress.

Bundelkhand, spanning Madhya Pradesh and Uttar Pradesh, holds immense potential for sustainable fisheries development. Once viewed as an agriculturally disadvantaged region, it is now gradually evolving into a freshwater aquaculture hub through scientific interventions. The articles in this issue, authored by experts, explore scalable and practical approaches to advancing aquaculture in such semi-arid areas.

The issue covers a variety of topics, including polyculture of aquatic species, the introduction of high-value species, and integrated fish-livestock-agriculture systems. These methods offer opportunities for rural empowerment and sustainable livelihoods. It also highlights innovative technologies like biofloc, cage culture in reservoirs, and aquaculture in saline soils—tailored to the agro-climatic conditions of Bundelkhand and other similar regions. We’re particularly excited to feature articles on ornamental fish farming, on-farm feed formulation, and seed production of catfish and Pangasius, providing new entrepreneurial avenues for smallholders and youth.

Additionally, the issue delves into critical aspects of fish health management, bio-remediation, and zoonotic disease prevention, all essential for robust fish production systems. The role of fish as a vital source of protein and its potential to combat malnutrition is emphasized under the umbrella of "blue nutrition." The issue also discusses the export potential of freshwater fish, positioning India to strengthen its footprint in the global aquaculture market.

I express my heartfelt gratitude to all the contributors for their valuable insights, and special thanks to Dr. Pramod Kumar Pandey, Editor & Dean Fisheries and Dr. Abhishek Srivastava, Theme Special Editor whose efforts were instrumental in bringing this issue to fruition. We believe this edition will serve as a crucial reference for researchers, extension professionals, policymakers and farmers, driving forward the Blue Revolution not only in semi-arid regions but also in every corner of our country for boosting prosperity, sustainability and nutritional well-being.

Towards a Blue and Bright Future!

(Anil Kumar)
Editor-in-Chief

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Prospects of sustainable fisheries development in Bundelkhand region

Abhishek Srivastava*, Sudhanshu Raman, Neelesh Kumar and Pramod Kumar Pandey

Abstract : India's fisheries and aquaculture sector is crucial for food security, employment, and livelihood, contributing to the country's socio-economic growth. As the 2nd largest fish producer globally, India's inland fisheries contribute over 75% of total Indian fisheries output. The Bundelkhand region is characterized by semi-arid conditions, frequent droughts, water scarcity, and erratic rainfall pattern. The region possesses substantial water resources, including rivers, reservoirs, large tanks, community/panchayat and private ponds, etc.; however, the region's potential is not fully utilized. To achieve sustainable fish production in the region, innovative, climate-resilient fish farming practices must be developed, with a focus on proper water resource management, diversification through improved fish species, adoption of climate-inclusive farming systems (RAS, biofloc, aquaponics, and integrated fish farming etc.), as well as supplementary fish feed and fish health management. Additionally, capacity building for fish farmers, financial support, and effective fish marketing strategies can significantly improve the potential of the fisheries sector in the Bundelkhand region.

Introduction:

The fisheries and aquaculture sector in India has taken the form of an industry and is playing an important role in food/nutritional security, employment and revenue generation and livelihood in the country. It also contributes to the efficient utilization of aquatic resources and the restoration of ecosystems. India is the 2nd largest fish producing country in the world, with a total fish production of 184.02 lakh tons in 2023-24, contributing approximately 8% to global fish production and inland fisheries contribute more than 75% of total fisheries output. Further, aquaculture is one of the fastest growing food production sectors and has demonstrated its vital role in food and nutritional security for a significant portion of the population and contributes importantly to the socio-economic growth of the country. It has a vast potential for sustainably utilizing wide variety of inland water resources to enhance the total fish production of the country.

Bundelkhand region is a distinct geographical region of central India comprising 14 districts: seven each in Uttar Pradesh (Lalitpur, Jhansi, Jalaun, Hamirpur, Mahoba, Banda and Chitrakoot) and Madhya Pradesh (Chhatarpur, Tikamgarh, Damoh, Sagar, Datia, Niwari and Panna). The Bundelkhand region is rocky; the agriculture in the region is rainfed, and poor soil as well as low productivity further aggravates the food security and economic hardships of the farmers. Further, the region is affected by semi-arid conditions, frequent droughts, water scarcity and erratic rainfall pattern. These climatic challenges also impact traditional fisheries in the region. The region has significant water resources including rivers, reservoirs, large tanks, community/panchayat and private ponds etc. which can contribute significantly to fisheries and aquaculture. Despite being rich in diverse aquatic resources, the fisheries potential of Bundelkhand region has not been properly utilized. There is ample potential to augment fish production in the Bundelkhand region; however, this necessitates the development and dissemination of innovative, climate-friendly fish farming practices that can result in sustainable fish production and good profits, even with limited land and water resources. Sustainable development of fish farming in the region can be done by adopting strategies like proper management

College of Fisheries, Datia
Rani Lakshmi Bai Central Agricultural University, Jhansi
**E-mail: abhifish2000@yahoo.com*

of water resources available in Bundelkhand region, selection of improved species for fish farming, selection of climate inclusive fish farming systems, management of fish supplementary feed and health etc., the details of which are as follows.

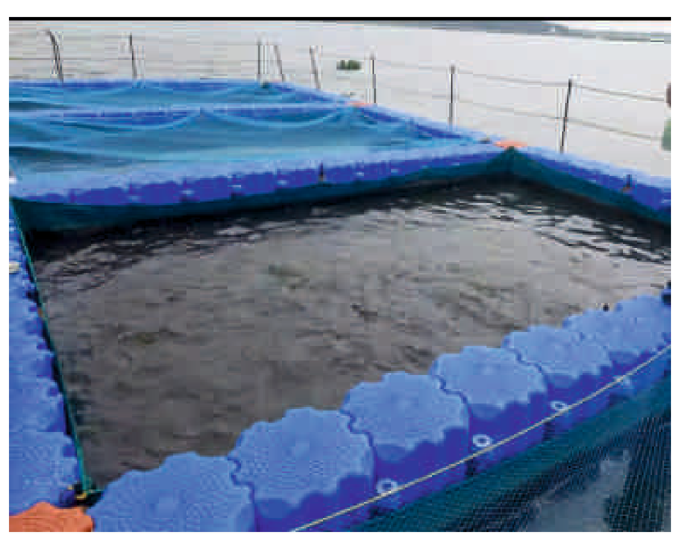
Diversification of fish species

Carps are the backbone of freshwater aquaculture activities and are being cultured widely all over the country. In Bundelkhand region, majority of fish farmers are also doing composite fish farming, comprising mainly Indian major carps (catla, rohu and nain/mrigal) and exotic carps (silver carp, grass carp and common carp). In the present scenario, diversification of aquaculture through the selection of climate-resilient suitable fish species can be an effective solution for the development of fish farming in this region. It can help aquaculture systems to become more resilient to climate change impacts, improve the fish productivity, profitability,

food security and nutrition from a limited water area and can also reduce the production risk. The suitable fish species for diversification in Bundelkhand region may include indigenous magur, pangas catfish, singhi, murrel/snakehead, amur carp etc., which demonstrated a greater ability to withstand climate change factors like poor water quality (low dissolved oxygen) and can also thrive in shallow aquatic environment. Apart from this, these fishes get a good price in the market, due to which the fish farmer gets more economic benefit. In addition to this, genetically improved fish species viz. Jayanti rohu, GIFT tilapia, amrit catla, GI freshwater prawn etc. can be useful for promoting fisheries in the region. Additionally, intercropping minor fish species (*Puntius gonionotus*, *Labeo fimbriatus*, *Labeo calbasu* and *Puntius sarana* etc.) along with major carp in the same pond can enhance resource utilization and increase overall productivity/fish yield, and profitability.

Fish farming in floating cages in reservoirs

The Bundelkhand region has significant potential for cage culture development. This climate-inclusive technology of fish farming is gaining recognition as an emerging method for fish culture in this region. This method facilitates the scientific raising of climate-resilient and locally important fish species in floating cages utilizing existing water bodies such as ponds, lakes, and reservoirs. Fish farming in floating cages in reservoirs offers several advantages. This method allows for intensive fish farming in an environmentally sustainable manner from a limited



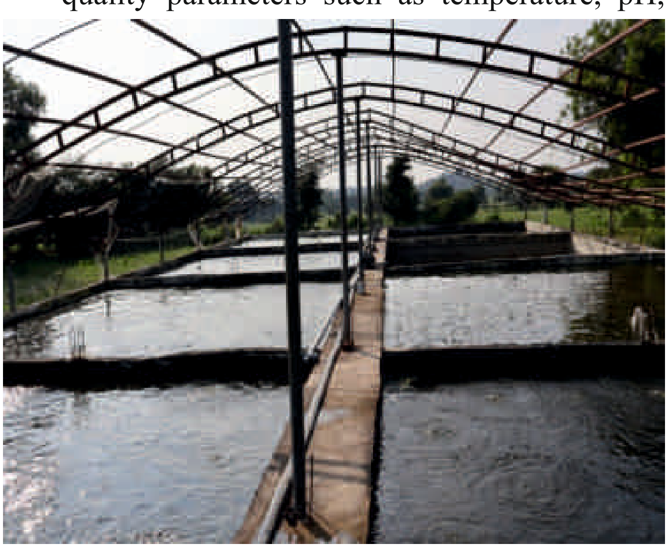
area. Further, this system facilitates the monitoring and management of water quality, supplementary feeding, fish growth, survival, and health effectively. Thus, it can be helpful in increasing fish productivity, achieving economic benefits, conserving biodiversity and ensuring food security in the Bundelkhand region.

Use of climate-friendly intensive fish farming systems to increase fish productivity

Fish farming in Bundelkhand region has always been challenging due to lack of suitable land and for fish farming, climate change, high temperature, water shortage and irregular rainfall etc. In view of the current climatic conditions, it is essential to develop and disseminate fish farming techniques that maximize production and profitability while minimizing land use. To successfully address the above challenges, climate-friendly intensive fish farming systems such as recirculatory aquaculture system (RAS), biofloc, aquaponics and freshwater integrated multi-trophic aquaculture (IMTA) can be adopted in this region to improve the fish productivity and income of the farmers. The details of these systems are as follows:

❖ **Recirculatory aquaculture system (RAS):**

RAS is a high density climate-resilient fish farming technology that operates in a controlled environment. It involves the recycling and reuse of water following the filtration and removal of suspended matter and metabolites. This system facilitates accurate management of water quality parameters such as temperature, pH, oxygen, and ammonia level in water. In this system, water obtained from fish farming tanks is kept clean and oxygenated through mechanical and biological filters, aeration process etc. and after improving the water quality, it is reused in fish farming. Through the recycling of water, RAS effectively reduces the necessity for fresh water intake, which is especially advantageous in regions facing water scarcity, such as the Bundelkhand area. Thus, this system can be adopted by the fish farmers of the Bundelkhand region to acheive enhanced fish production while using limited water and space effectively.



❖ **Biofloc technology:**

It is an emerging environmentally friendly, high density fish farming technology in which higher fish production/productivity can be achieved from a limited area by improving the water

quality (especially ammonia level), fish growth, and health by using microorganisms (such as heterotrophic bacteria, algae and protozoa etc.). It is also considered as limited or zero water exchange system. In this technique, appropriate carbon-nitrogen ratio (12-15:1) is maintained in the fish farming tank/pond by proper use of carbohydrate sources (jaggery/molasses, corn starch, rice husk, tapioca etc.) that stimulates the growth of floc/heterotrophic bacteria which contribute significantly in improving the water quality, specially ammonia, in fish culture system and and in turn produce a cellular protein. These microorganisms also act as natural food for fish. In this technique, there is less need for protein rich supplementary feed, which gives more profit to the farmers. Due to its adaptability to different climatic zones, low environmental impact, and higher biosecurity, the biofloc technology is considered an eco-friendly alternative to traditional fish farming systems. The fish species which can tolerate high solid concentration and tolerant to poor water quality are more suitable for biofloc technology such as singhi, magur, pangas, pabda, anabas, tilapia etc. Due to water scarcity, this technique can be very useful for the Bundelkhand region to augment fish productivity.

- **Aquaponics system**:

It is an integrated farming system combining aquaculture and hydroponics (growing plants in a soil less environment) techniques in a recirculating environment, where fish and plants grow in a symbiotic relationship. In this technique, fishes are reared at higher density in tanks and plants are grown in polyhouse under controlled environment. In this system, the ammonia present in the fish waste is being converted into nitrate by the beneficial nitrifying bacteria present in the biological filter through the nitrification process and this nitrate and other nutrients are being utilized by the plants being grown in the hydroponic system. Further, these plants help in filtering and purifying the water, which is again used in the fish culture tank. In hydroponic unit, plants are grown without use of any chemical fertilizers and harmful pesticides/insecticides. Different vegetables like lettuce, mint, spinach, tomatoes and herbal plants are good choice for aquaponics. This system has adaptability to changing climatic conditions and provided food security in a sustainable way under controlled environment, utilizing limited water and space. Therefore, it holds considerable significance for the Bundelkhand region. Moreover, this system is more applicable for urban and peri-urban areas where land availability is a major constraint. Small and marginal farmers can also establish small scale backyard/rooftop aquaponics units, preferably with ornamental fish species, to get a regular income with limited resources.

- **Freshwater Integrated Multi-trophic Aquaculture (IMTA):**

IMTA in freshwater is a multi-level fish farming system in which fish are reared along with other aquatic organisms, such as algae/aquatic plants, prawn, and shell fish (mussels), which leads to maximum use of nutrients. The system emphasizes the recycling/utilizing of waste generated by one species as a resource/food for another species, promoting a more balanced ecosystem and minimizing the negative environmental impacts of traditional aquaculture, such as eutrophication. This technique is environmentally friendly and improves the quality of water, which results in an optimal increase in the survival, growth rate and health of the fish.

Keeping in view the climate change and scarcity of water resources in the Bundelkhand region, the use of the above mentioned climate-inclusive fish farming methods will contribute to water conservation, enhance fish production, and elevate the socio-economic conditions of fish farmers.

Integrated Fish Farming (IFF)

The land holding capacity of farmers is decreasing day by day owing to the pressures of increasing population, socio-economic needs, and urbanization. Consequently, there is a necessity for the formulation of a strategy to achieve increased production of diverse food from limited land holdings. In addition to this, considering the challenges of water resources in the Bundelkhand region, integrated fish farming can provide a sustainable and profitable solution.

Integrated fish farming is based on the principle of recycling of waste materials and resources, which involves farming of fish along with livestock or/and agricultural crops, with a view to optimizing the production efficiencies and achieving maximal biomass harvest from a unit area, with due environmental considerations. This system benefits from the abundant availability of natural fish food (plankton) which subsequently lowers the costs associated with supplementary fish feed.

Importance of Integrated farming System:

1. Recycling/utilization of all farm waste for sustainable fish production.
2. Enhancing production per unit area and efficient use of farm space.
3. Diversification of farming system.
4. Lowering the production cost.
5. Keeping the environment clean.

IFF offers many combinations as per the suitability of any crop in a particular region/area. The common combinations include animal husbandry-fish integration (cattle-cum-fish farming, poultry-cum-fish farming, pig-cum-fish farming, duck-cum-fish farming and goat-cum-fish farming etc.), agriculture-fish integration (paddy-cum-fish farming), horticulture-fish integration (fruits, vegetable, flower) and animal husbandry-cum-agriculture/horticulture-cum fish integration.

Additionally, in order to utilize the unused pond dykes, various horticultural crops, including fruits, vegetables, and flowers can be grown on the pond dykes and the nutrient-rich pond water can be used for irrigation in these crops, thereby reducing the production costs.For this purpose, dwarf type, less shady fruit plants (banana, papaya etc.), sesonal vegetables (bringal, tomato, chilies, onion, garlic, gourds, cabbage, cauliflower etc.), flower plants (marigold) and medicinal plants can be grown on pond dyke to get diversified products from the unit area and to generate addition Income without involving addition land. Moreover, nutrient rich pond water can also be used in nearby agricultural fields, which reduces the cost of fertilizers. Consequently, an integrated fish farming system has the potential to serve as a source of employment and supplementary income for fish farmers and rural communities. Further, this approach can address water problems in the region by adopting water conservation techniques and make fisheries more climate-resilient and sustainable.

Use of community or panchayati ponds for fish culture

In rural areas, community or panchayati ponds are constructed and used mainly for rainwater harvesting, irrigation, small-scale fisheries and other domestic purposes. Due to the scarcity of water resources in the Bundelkhand region, effective use of these ponds can play an important role in the development of fisheries. These ponds are frequently noted to be in poor condition, receiving human and animal waste as well as dirty water from the entire town, resulting in a decline in water quality. Manytimes these ponds are also covered with aquatic weeds. Through effective management, these community/panchayat ponds can be utilized for fish culture. Climate-friendly fish farming approaches like organic aquaculture, poly culture and biofloc can be promoted in these ponds. Furthermore, nano-bubble technology, which employs extremely small bubbles referred to as nanobubbles, represents a novel and efficient approach to water purification and oxygen enhancement. This method can be applied in these ponds to enhance water quality, specifically the dissolved oxygen content, thereby reducing fish mortality, improving fish growth and pond productivity. Since these ponds are usually shared by local communities, fish farming in these ponds can provide employment to many families and can improve their nutritional standards and socio-economic status. Furthermore, the judicious utilization of these ponds contributes significantly to the conservation and management of water resources.

Furthermore, rainwater harvesting based fish farming is a sustainable and water-conserving farming technique, in which rainwater is collected and stored in ponds or reservoirs and is used for fish farming. In this environmentally friendly method, sustainable fish production can be acheived with low investment.

Supplementary feed management for sustainable fish production

Supplementary feed plays a vital role in growth, reproduction and other metabolic activities of fish. In semi-intensive and intensive fish production systems, fish are fed with supplementary feed to meet their nutritional requirements. In semi-intensive fish farming, the supplemental feed accounts for around 50–60% of overall operating/recurring expenditure. Hence, to increase fish production and achieve higher profitability, focus should be on using balanced supplementary feed by incorporating locally available cheap feed ingredients and adopting appropriate feeding strategies. For successful fish farming, it is important that the supplementary feed should be nutritionally balanced, environmentally friendly and available at low cost. Furthermore, incorporating a range of herbal (such as amla, ashwagandha, ginger, garlic, aloe vera, tulsi etc.) powder/extract into the supplementary fish feed can enhance growth, survival, immunity and health status of fish, eventually leading to sustainable fish production. Additionally, herbal substances are natural, cost-effective, readily available and biodegradable, and have minimal or no negative impacts on fish, humans, and the environment.

Fish health management in fish culture

Proper management of fish health is very important for sustainable fish farming, especially in intensive fish farming systems. Without this, the risk of diseases in fish increases, which can lead to

production and economic losses. Fish health management includes timely prevention, diagnosis, and treatment of diseases in cultured fish using approved medicines/chemicals. Additionally, improving water quality and implementing bio-security measures can safeguard the fish from harmful pathogens. Nowadays, there is an increasing trend in the use of probiotics within the aquaculture sector. These probiotics can be used in water and supplementary feed periodically to maintain optimal soil and water quality, as well as for improving fish health. Thus, it can be concluded that keeping fish healthy can results in improved growth performance, survival, feed conversion, and overall profitability.

Conclusion

Currently, fish farming is gaining popularity as a significant enterprise due to its potential for ensuring food security, enhancing livelihoods, conservation of natural water resources, and promoting the growth of the rural economy. In light of the numerous challenges such as irregular rainfall patterns, water scarcity, and insufficient infrastructure, the strategic management of available water resources, adoption of climate -resilient fish species and culture systems, capacity building for fish farmers, financial support, and effective fish marketing strategies can significantly improve the potential of the fisheries sector in the Bundelkhand region. To achieve this goal, there is an urgent need for policy makers, researchers, fish farmers and other stakeholders to work together to develop fisheries in a sustainable manner in Bundelkhand region.

Polyculture fish farming: A sustainable practice for fish production

Neelesh Kumar[1]*, Chandra Pal Singh[2], Abhishek Srivastava[1], Pramod Kumar Pandey[1] and Bijay Kumar Behera[3]

Abstract : Polyculture is the practice of culture more than one fish species together in the same aquatic environment, offers a highly sustainable alternative to conventional monoculture systems. This approach leverages the distinct ecological niches and feeding habits of different species, promoting a more efficient utilization of natural resources within the pond or enclosure. For instance, herbivorous fish can feed on algae and aquatic plants, detritivores can feed on organic waste, and carnivorous species can control populations of smaller, undesirable fish, thereby reducing the need for external feed inputs and minimizing waste accumulation. The diverse biological interactions also contribute to improved water quality, as different species contribute to nutrient cycling and waste breakdown. This integrated approach boosts productivity and minimizes aquaculture's environmental impact, making polyculture a robust, sustainable method for fish production.

Introduction

Polyculture in fish farming is an aquaculture practice that involves cultivating multiple species of fish within the same pond or aquatic system. The roots of polyculture trace back over 2,000 years to ancient China. The Chinese statesman Fan Li wrote Yang Yu Ching (book on Fish Breeding), the first known book on fish farming, around 475 BC. Because the Chinese term for common carp sounded like the emperor's family name, Li, common carp cultivation was prohibited during the Tang dynasty (618–907 AD). This ban inadvertently led to the development of polyculture, as farmers began cultivating multiple species in the same ponds to maintain productivity. It has since spread throughout Southeast Asia and other parts of the world, including India, where it has been adapted to local conditions and species. In these early systems, ponds were often fertilized with manure to promote the growth of natural food organisms. Different fish species with complementary feeding habits were stocked together, each occupying its own ecological niche, thus maximizing resource utilization and increasing yields. This method aims to optimize resource utilization, enhance ecological balance, and increase overall fish production. Polyculture involves stocking different fish species with complementary feeding habits in a single pond. This approach allows for better utilization of natural food sources and reduces competition among species.

In India, polyculture, particularly composite fish farming, has been widely adopted. The history of polyculture in India is deeply rooted in traditional practices and has evolved significantly over time. Here's a glimpse into its development. In India, polyculture is widely practiced, especially in states like Andhra Pradesh and West Bengal. The Government of India supports this initiative through the Pradhan Mantri Matsya Sampada Yojana (PMMSY), which aims to modernize the fisheries sector, increase fish production, and provide financial assistance to fish farmers.

Early Traditional Practices

Ancient texts like Kautilya's Arthashastra (321-300 B.C.) and King Someswara's Manasollasa (1127 A.D.) contain references to fish culture, indicating an early awareness of fish rearing in ponds. For centuries, a traditional practice of raising multiple fish species in small ponds existed in India, likely

[1]*College of Fisheries, Rani Lakshmi Bai Central Agricultural University, Datia Campus, Datia-475686, Madhya Pradesh, India*
[2]*College of Fisheries, Acharya Narendra Deva University of Agriculture and Technology, Ayodhya-224229, Uttar Pradesh, India*
[3]*National Fisheries Development Board (NFDB), Hyderabad, Telangana-500052, India*
**E-mail: neeleshrajpoot74@gmail.com*

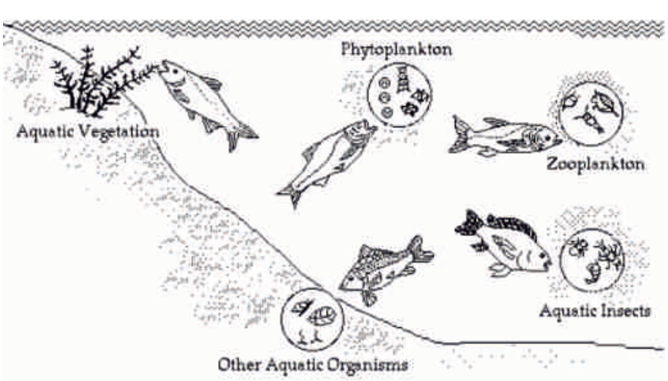
based on observations of natural cohabitation and the benefits of utilizing different food sources.

The Rise of IMCs and EMCs in Polyculture

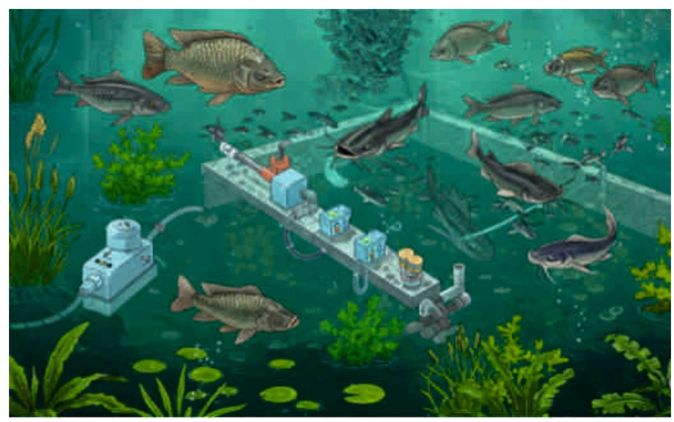
Initially, multispecies culture primarily involved Indian Major Carps (IMCs). These three native carp species, with their complementary feeding habits, formed the backbone of traditional polyculture systems in India. Significant advancements in productivity began in the early 19th century with the controlled breeding of carp in tanks that simulated river conditions. During the late 1950s and early 1960s, three exotic carp species were introduced to enhance polyculture systems. These introductions aimed to fill additional ecological niches and further increase overall fish production.

Modernization and Scientific Intervention

An important milestone was reached in 1971 when the Indian Council of Agricultural Research (ICAR) launched the All India Coordinated Research Project on Composite Fish Culture and Fish Seed Production. This project transformed traditional polyculture practices by introducing scientific principles of species selection, stocking densities, and pond management. Established in the early 1970s with support from the World Bank, the Fish Farmers Development Agencies (FFDAs) aggressively encouraged the use of contemporary aquaculture methods, such as polyculture of IMCs and IMC combinations with exotic carps and freshwater prawns. Research and development efforts led to the evolution of a six-species composite fish culture system, which became widely recommended. This system typically included catla, rohu, mrigal, silver carp, grass carp, and common carp, carefully chosen for their non-competitive feeding habits and efficient use of pond resources. Induced breeding techniques for carps, developed in the mid-20th century, ensured a stable supply of quality fish seed, further supporting the growth of polyculture.



Regional Variations and Current Status While the six-species model is a standard recommendation, species combinations in practice often vary based on seed availability, market demand, and local preferences in different regions of India. States like Andhra Pradesh and West Bengal have emerged as major centres for carp polyculture, with varying scales of operation and levels of specialization. Polyculture remains a dominant aquaculture practice in India, contributing significantly to inland fish production and the livelihoods of fish farmers. Modern advancements continue to refine polyculture techniques for increased efficiency and sustainability.



Selection of Fishes for Polyculture

In polyculture, the common carp is most frequently combined with the three Chinese carps (bighead, silver, and grass carp). Each of the following categories can also be used for other species. A fish that feeds on plankton must be a part of a polyculture system as plankton is often the most abundant food in a pond. The fish consumes the microscopic, free-floating organisms (zooplankton) and plants (phytoplankton) that proliferate in ponds that have been fertilized. The bighead carp and silver carp are two species that are representative of this group. Aquatic vegetation is the food source for the grass carp, which is kept in ponds to manage weeds, is most famous for this behaviour. The common carp, a bottom feeder fish mostly eat near the bottom of the pond and eat a wide range of decomposing organic debris, bacteria that live in or on the sediments, insects, worms, snails, and aquatic life like clams.

The mrigal, an omnivorous fish consumes aquatic plants, molluscs, snails, worms, and insect larvae. The African cat fish, a carnivorous fish employed to manage an undesirable carnivorous fish population. The driving idea is that by cultivating a variety of species with distinct eating preferences, fish productivity in ponds may be increased. The fish mix makes greater use of the natural food that is generated in a pond at various depths. Consequently, a greater yield is achieved.

Advantages of Polyculture

- ✓ Efficient polyculture systems may produce up to 8,000 kg of fish per acre annually in tropical settings, resulting in higher yields.
- ✓ Polyculture improves resource efficiency by maximizing the utilization of natural food generated in the pond through diverse feeding patterns.
- ✓ As ecological balance, certain species, such as tilapia, aid in oxygen balance by feeding on waste, whereas silver and bighead carps manage plankton levels, avoiding algal blooms.
- ✓ As economic stability, by reducing the chance of a complete crop failure, species diversification can help farmers earn more consistently.
- ✓ Proper utilization of compatibility of species and fully utilization of artificial feeds
- ✓ Make more economic return than monoculture under same condition
- ✓ Least chances of various epizootic diseases and parasites inside the culture systems

Challenges and Considerations

Complex administration would be guaranteeing species compatibility and ideal stocking ratios, polyculture necessitates meticulous planning and administration. In the Increased requirements for input, larger hatchery facilities and the requirement for high-quality fingerlings of various species may raise the initial outlay. Continuous keeping an eye might be challenging to monitor and maintain several species with different development rates and eating patterns.

Conclusion

Polyculture fish farming stands out as a highly sustainable and efficient method for aquaculture. By integrating multiple fish species with complementary feeding habits, it optimizes resource utilization and enhances overall productivity per unit area. This approach significantly reduces the environmental impact associated with monoculture, minimizing waste accumulation and the need for external inputs. Furthermore, polyculture often leads to improved water quality and a more stable ecosystem within the pond. From an economic perspective, it offers diversified income streams and greater resilience against disease outbreaks affecting a single species. Ultimately, polyculture fish farming represents a robust and environmentally responsible pathway towards meeting the growing global demand for fish protein, ensuring both ecological balance and food security.

Diversifying aquaculture by introducing high-yield and high-value fish species to boost production and profitability

Satya Narayan Parida*, Abhishek Srivastava and Pramod Kumar Pandey

Abstract : India is the second-largest fish-producing country, and it accounts for approximately 7% of the global fish production. Diversifying aquaculture by introducing high-yield and high-value fish species has significant potential to increase output and profitability, especially in developing countries like India. Achieving the best yields from fish seeds depends on their quality, but issues such as inbreeding and the spread of genetically inferior stock remain barriers. This article highlights the effectiveness of high-value fish species like the Jayanti rohu, Amrit Catla, Amur common carp, Pangasius, Magur catfish, and Striped Murrel. It also discusses the vital role of selecting the proper species in addressing these challenges. These species demonstrate measurable increases in market value, growth rates, and survival, ultimately benefiting farmers and enhancing food security.

Keywords: aquaculture, fish, inbreeding, food

1. Introduction

Fisheries and aquaculture represent a vital food production sector in India, making significant contributions to the food supply. They not only ensure food security for humans but also enhance agricultural exports and provide valuable employment and livelihood support to over fourteen million individuals involved in various fisheries activities. India is the second-largest fish-producing nation, accounting for approximately 8% of global fish production. Given that fish production has been expanding at a rate of 4-5% per year, enhancing processing, value addition, and the export of fish and fish products will significantly contribute to this goal. Encourage the commerce of fish for both domestic and international markets. In the financial year 2023-24, fish production reached 184.02 million tons and is expected to continue growing in the coming years. A fish farmer can improve fish productivity through two methods. The first method involves expanding the fish culture pond, while the second focuses on increasing productivity, which pertains to the total weight of fish produced in each pond. Expanding the farm's size is sometimes not feasible due to limited land availability, high land prices, or inadequate usable land and its associated water supply, resulting in production costs overshooting production value. Furthermore, effective management of fertilizers, feed, and water quality, along with the cultivation of genetically improved fish through selective breeding techniques, is essential for enhancing yield.

Fish seeds comprise 5-10% of production expenses, and procuring high-quality seeds is crucial for the growth of aquaculture. Cultural practices, including the stocking of inferior-quality seed and the simultaneous mixed mating of carps in the same hatching pond, lead to the generation of genetically compromised hybrid seeds that exhibit slow growth, decreased yields, and reduced profitability for farmers. Many hatcheries have been established nationwide following the successful implementation of induced breeding technologies. The production of seeds has been prioritized as they are the essential input in a culture system. India has achieved self-sufficiency in carp seed production. However, Indian carp hatcheries are seeing a decline in the quality of carp seed due to the mating of closely related individuals, known as inbreeding. Selective breeding is a program aimed at improving the genetic quality of a population by carefully choosing and mating only the superior fish (largest, heaviest, those with desired traits, etc.) in hopes that these selected brood fish will pass on their superior traits to future generations. Introducing

College of Fisheries, Datia
Rani Lakshmi Bai Central Agricultural University, Jhansi, India
**Email: satya.parida4@gmail.com*

potential selective breeding fish species will enhance the production and fertility of nursery breeds in developing countries, such as India, where many people rely on fishing or aquaculture for their income and food security. Fish species from selective breeding programs, such as Atlantic salmon in Norway and Channel catfish in the USA, have already been cultivated due to several economic factors, including survival, growth, disease resistance, and meat quality.

2. Fish species for better yield

I. Jayanti rohu (*Labeo rohita*)

Rohu was chosen as the candidate species for selective breeding because of its high consumer demand, impressive growth performance in polyculture carp production systems, and low disease susceptibility. The fish is often referred to as Jayanti rohu, since it was first introduced in 1997 on the 50th anniversary of Indian Independence (Swarn Jayanti) and is the most success species to be considered by farmers. The selective breeding of rohu in India began in 1992, undertaken by the Indian Council of Agricultural Research - Central Institute of Freshwater Aquaculture (ICAR-CIFA) in partnership with the Institute for Aquaculture Research (Akvaforsk), Norway, aimed at enhancing the growth rate of rohu. The selective breeding experiment for rohu began with six stocks as the initial population. Among them, five were selected from major rivers in India, including the Ganga, the Brahmaputra, the Yamuna, the Sutlej, and the Gomati. The sixth one was chosen from the ICAR-CIFA farm stock. The production cost of Jayanti rohu is relatively low, as it does not require high-protein feed and can be cultivated using locally produced plant-based feeds containing 25 percent protein. Two portions of the daily feed, comprising 3–4% of body weight, may be administered. To increase individual output, a moderate stocking density of 6000–7000 fingerlings per hectare is recommended. Compared to local rohu, Jayanti rohu reaches market size two months faster. Due to its appealing coloration, it also fetches a higher market price. Moreover, the Jayanti rohu does not pose a threat to the biodiversity of the aquatic habitat, as it is not a genetically modified organism (GMO).

II. Amrit catla (*Labeo catla*)

The launch of "Amrit Catla" demonstrates an enhancement of aquaculture practices, guarantees a quality fish seed supply, and promotes the country's fish farming sector. The Amrit catla program was initiated by ICAR-CIFA in 2010 to enhance the body weight of catla at the time of production. For the selective breeding program, nine strains of catla brooders were collected from Odisha, Andhra Pradesh, West Bengal, Bihar, and Uttar Pradesh. The program has achieved a total gain of 35% from the indigenous variety. Field testing in Odisha, West Bengal, Assam, and Maharashtra revealed that the enhanced Catla attained an average weight of 1.8 kg in polyculture systems, compared to 1.2 kg for indigenous strains within the same year. The National Fisheries Development Board (NFDB) obtained the Amrit Catla, facilitating its broader distribution and accessibility for farmers nationwide.

III. Amur common carp (*Cyprinus carpio haematopterus*)

The common carp is the most favored aquaculture species globally. The Amur common carp is a superior variety of Hungarian wild common carp. The common carp is widely distributed throughout Asian countries and beyond. The first stock development of common carp in India began in Karnataka via a selective breeding operation, which included the collection of five distinct strains. Among them, one strain each was

collected from localities in Karnataka, Indonesia, and Vietnam, and two were obtained from Hungary. Amur carp has the following prominent features: more rapid growth (~27% faster than the current stock), late maturation, takes artificial feed and feeding behavior comparable to common carp, less susceptible to diseases, slender body, and smaller belly compared to the existing common carp.

IV. Genetically improved farmed tilapia (GIFT) (*Oreochromis niloticus*)

Tilapia, sometimes referred to as "Aquatic Chicken," is a highly sought-after seafood commodity globally, seeing an annual market growth of 11 to 12%. The Tilapia (GIFT) Project was coordinated by the Rajiv Gandhi Centre for Aquaculture. The initiative is functioning well, with technical support from WorldFish, Malaysia. The only center in India has generated the 8th Generation of GIFT under Indian conditions through pedigreed selective breeding, having acquired the original germplasm from WorldFish. Currently, Tilapia ranks as the second most cultivated fish species globally, and WorldFish provides enhanced, rapidly growing, and robust GIFT seed to farmers to help fight poverty and hunger. Research assessing on-farm performance using a random sample of 213 GIFT and 256 non-GIFT farmers in Bangladesh revealed that the GIFT strain exhibited growth rates 27 percent and 36 percent higher than non-GIFT tilapia in monoculture and polyculture, respectively.

V. Pangasius/Pangas Catfish (*Pangasianodon hypophthalmus*)

In 1995-96, the exotic freshwater catfish Pangasius was introduced to India via Thailand and Bangladesh in West Bengal to expand the species variety and enhance the food supply for the growing population. The ponds and reservoirs in India are very favorable to pangasius culture. It is a good choice for farmers due to its single bone and lack of intramuscular spines, its strong market demand, rapid growth rate, and disease susceptibility, which is less pronounced compared to carp. Pangasius may be cultivated in India via either monoculture or polyculture with carp species. The species may attain a weight of 1 to 1.5 kg within one year, with normal annual yields ranging from 10 to 15 tons per hectare. This species can also grow well in intensive farming methods. In this technique, Pangasius seeds are stocked in high density to produce a large biomass in a confined space. Within 5 to 6 months of fish stocking, the average weight of Pangasius will reach 500 to 600 grams, and the production of 15-20 tons per hectare of pond can be achieved. A 100 g pangasius fillet should provide around 17 g of protein, 5.6 g of fat (1.6 g saturated), 90 mg of sodium. In response to the government's initiative for a "blue revolution" in aquaculture and fisheries, the enhanced cultivation of this species will remain a significant element of the nation's expanding aquaculture production. The cultivation of pangasius in cages is particularly appealing to several potential businesses, who have shown interest in leasing reservoirs for fish production in cages. The government bodies, such as the National Fisheries Development Board, have released a manual outlining guidelines for pangasius cage culture. Additionally, through its "Blue Revolution" initiative, it has financed and promoted numerous cage farming initiatives.

VI. Indian magur (*Clarias batrachus*)

The fish was designated as the State fish of Bihar. Due to a high growth rate, excellent food conversion, and considerable market value, the Indian Magur catfish species is the most promising species for freshwater aquaculture in India. Magur is a resilient species and an obligatory air-breather that often resides in low-lying aquatic environments, such as swamps, marshes, stagnant waters, and rivers. This demonstrates its capacity to survive under challenging ecological circumstances, including very low dissolved oxygen, high turbidity, and high ammonia levels. This species is gaining commercial importance in countries like China, India, and Bangladesh due to its high nutritional value, which includes a moderate amount of fat (1.0%), a lot of minerals (222.36 mg of calcium, 129.42 mg of phosphorus, 201.49 mg of sodium, and 262.09 mg of potassium per 100 g of tissue), and a high iron content (710 mg/100 g tissue). Moreover, it also has medicinal uses. There is another Magur species known as the Thai Magur (*Clarias gariepinus*) which is regarded as an invasive African catfish that was first brought to India in the 1990s and has since colonized several major rivers, and other aquatic environments around the nation. In 1997, the Ministry of Agriculture in India prohibited the cultivation, breeding, transportation, and importing of Thai Magur due to possible health risks and threats to aquatic biodiversity.

VII. Striped murrel (*Channa striata*)

Murrel is considered the state fish of both Andhra Pradesh and Telangana. This fish is distinguished by its dark brown color with light black lines throughout the body. It is an indigenous, air-breathing fish that withstands low dissolved oxygen levels. These species are ideal candidates for aquaculture due to their high demand, market value, and ability to survive unfavorable climatic conditions. Murrel cultivation may be carried out in communal ponds, tiny backyards, or shallow pools. They reach sexual maturity within 1-2 years and reproduce spontaneously throughout the year, with a notable surge during the monsoon season. Murrels are carnivorous; hence, they may be given high-quality protein-rich feed at 5% of their body weight initially, then reduced to 2-3% throughout later phases of development. In various retail markets, live snakehead fish are consistently priced at a high level, ranging from INR 400-500/kg (USD 6-8/kg). Harvesting typically occurs when the fish reaches a weight of 600-700 grams.

Conclusion

The profitability and long-term viability of aquaculture in India depend significantly on the availability of high-quality fish seed and the planned introduction of carefully bred species. India can make its aquaculture industry more resilient, sustainable, and economically strong by continuing to prioritize and invest in these genetically improved and diversified culture practices. The planned selection of high-yield species would help meet the growing needs for national food security.

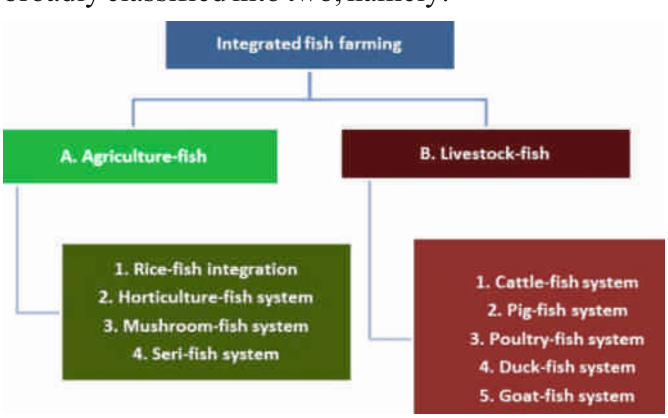
Integrated fish farming systems for sustainable livelihoods in Bundelkhand region

Sudhanshu Raman* and Abhishek Srivastava

Integration of fish culture with agriculture, livestock, and other farming elements, offers a comprehensive approach for resource management. These systems provide a sustainable and profitable means of livelihood in the semi-arid Bundelkhand region, which has few resources. Integrated fish farming boosts productivity, guarantees food and nutritional security, and boosts farm income by making use of on-farm waste, optimizing land and water use, and encouraging nutrient recycling. The socioeconomic status of small and marginal farmers could be greatly enhanced by this model, which would also support regional rural development and climate resilience.

Introduction

The integrated fish farming method combines culture of fish and cattle/crops. This type of farming offers great efficiency in resource utilization, as waste or byproduct from one system is effectively recycled. It also enables effective utilization of available farming space for maximizing production. The rising cost of protein-rich fish food and chemical fertilizers as well as the general concern for energy conservation have created awareness in the utilization of rice and other crop fields and livestock wastes for fish culture. Fish culture in combination with agriculture or livestock is a unique and lucrative venture and can provide a higher farm income, can provide a cheap source of protein for the rural population, can increase productivity on small land-holdings and can also increase the supply in Bundelkhand region. Integrated fish farming can be broadly classified into two, namely:



A. Fish farming with agriculture

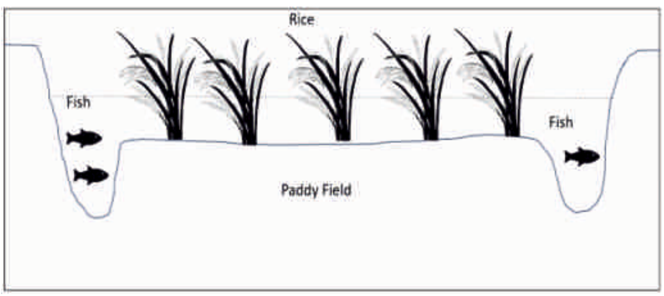
Agri-based systems include seri-fish, horticulture-fish, rice-fish, and mushroom-fish integration. This system produces fish and agricultural crops under one interconnected system by integrating fish culture with rice, bananas, and others.

1. Rice-fish culture

This kind of fish culture has a number of benefits, including (a) cost-effective land use, (b) minimal additional labor, (c) labor cost savings for supplemental feeding, (d) increased rice yield, and (e) additional revenue and a varied harvest that includes rice and fish from water, as well as sweet potatoes, onions, and beans from bund cultivation. Throughout the year, the paddy field holds water for three to eight months. Fish farming provides farmers with an off-season job and extra revenue because paddy fields stay flooded even after paddy harvest. Rice, varieties such as Panidhan, Tulsi, CR260 77, ADT 6, ADT 7, Rajarajan, and Pattambi 15 and 16 are appropriate for the culture of fish in conjunction with rice. In addition to having strong root systems, these can withstand flooding. Additionally, they can be cultured for four to five months following transplantation, and they have a 180-day lifespan. When fish reach marketable size, they are harvested. A 0.1-hectare rice field may be cost-effective for paddy cum fish culture. Typically, four 250 m^2 (25 x 10 m) rice plots can be created in this kind of space. A ditch that is 0.75 meters wide and 0.5 meters deep is excavated in each plot. Straw is embedded to strengthen the dikes that surround the rice plots, which can be up to 0.3 m high and 0.3 m wide. Five days following rice

[1]College of Fisheries, Datia
Rani Lakshmi Bai Central Agricultural University, Jhansi, India
*Email: sudhanshu147@gmail.com

transplantation, fingerlings (8–10 cm) or fish fry (1 cm) are stocked at a rate of 2,000/ha or 5,000/ha, respectively. However, daily supplemental feed can double the stocking density, especially if plankton is found to be depleted after 10 days of stocking fish. However, if some fertilizer is added in excess of what is needed for rice fields, the production of plankton in rice fields may increase. The rice fields are gradually drained off and the fish are harvested after ten weeks (if stocked with fry) or six weeks (if stocked with fingerlings). A week or so prior to the rice harvest, fish can be harvested. Under this culture practice, reports of individual fish growth of 60 g and a yield of 500 kg per hectare have been reported.



Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

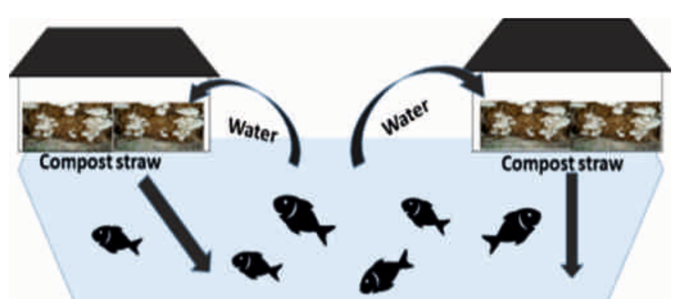
2. Horticulture-fish system

The top, inner, and outer dykes of ponds, as well as the surrounding areas, are the ideal locations for horticultural crop planting. While pond water is used for irrigation, silt and high-quality manure are used for crops, vegetables, and fruit-bearing plants. The success of the system depends on the selection of plants. They should be dwarfs, less shaded, evergreen, seasonal, and highly lucrative. Pineapple, ginger, turmeric, and chilli are grown as intercrops, and other dwarf fruit-bearing plants such as mango, banana, papaya, coconut, and lime are appropriate. Flower-bearing plants like marigold, chrysanthemum, gladiolus, rose, tuberose, and jasmine can help farmers make more money. Fish ponds could be used to recycle vegetable waste, particularly if fish pond have fish like grass carp. 5000 fish per hectare in a 50:15:20:15 ratio of grass carps, rohu, catla, and mrigal. Higher ratio of grass carp is recommended for this practices as the fish can effectively utilises the horticulture crop residues while releasing semi-digested faecal matters which are useful for other fish species. This integrated system fetched 20-25% higher return compared to aquaculture alone. The dykes of the ponds are also strengthened by planting horticultural crops and prevent from soil erosion.

Horticulture-fish system
Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

3. Mushroom-fish system

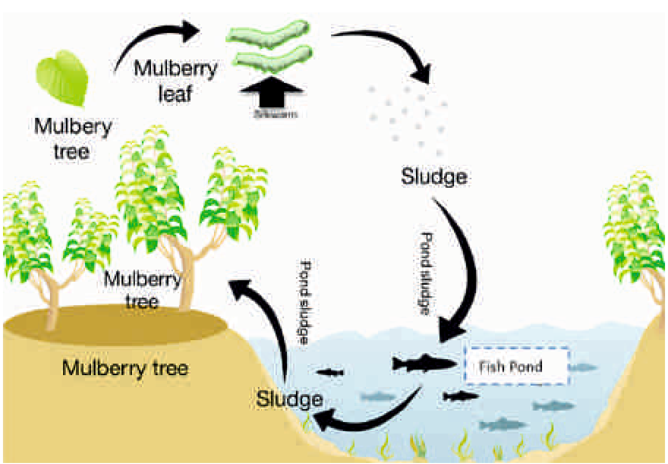
The cultivation of edible mushrooms is relatively new in India; three types of mushrooms—*Agaricus bisporus*, *Voloriella* spp., and *Pleurotus* spp., also known as European button, paddy straw, and oyster mushroom—are grown commercially. Since mushroom cultivation requires a high degree of humidity, there is an enormous potential for growth, along with aquaculture. The cultivation process involves using dried paddy straw chopped into 1.2 cm pieces, soaking in water overnight, and then draining the excess water. Horsegram powder (8 g/kg straw) and spawn (30 g/kg straw) are then added and mixed with wet straw in alternating layers. Perforated polythene bags are filled with substrate and kept in a room at 21 to 35 °C with the necessary light and ventilation. The mycelial growth occurs within 11-14 days. At this point, the polythene bags are opened, water is sprayed twice a day, and the mushroom crop is ready for harvest in a few days.



Mushroom-Fish System
Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

4. Seri-fish system

The mulberry is the producer in this integration, the silkworm is the primary consumer, and fish, which directly consumes silkworm waste, is the secondary consumer. Inorganic nutrient in the silkworm faeces is utilized by phytoplankton, and filter-feeding fish in turn consumes heterotrophic bacteria. The ideal temperature and humidity ranges are 15–32°C and 50–90%, respectively. The mulberry and pond sub-systems are connected by the seri-fish system. Harvested mulberry leaves are fed to silkworms, and the waste product from raising silkworms ends up in the fish pond as a combination of silkworm feces and mulberry leaves. Mulberry dykes yield leaves at 30 tonnes/ha/year, when fed to silkworm 16-20 tonnes of waste is produced. Half of the 1 ha mulberry-pond system is set aside for the dyke, with the remaining portion serving as the water area. Mulberries are interplanted with vegetables in the winter. It is possible to produce 30 tonnes of mulberry leaves per hectare and 3.75 tonnes of vegetables per hectare.



Sericulture fish integrated system
Source:https://openknowledge.fao.org/server/api/core/bitstreams/f5e05778-894b-4b07-948e-f3b25bb47da6/content

B. Livestock-fish system

Cattle-fish systems, pig-fish systems, poultry-fish systems, duck-fish systems, goat-fish systems, and rabbit-fish systems are all examples of livestock-fish systems. Excreta from ducks, chicks, pigs, and cattle are either recycled for fish consumption or fed directly to fish as part of this practice. As a result, it reduces the cost of chemical fertilizers and additional feeds cost for fish culture. In many nations, combining fish culture with livestock farming is popular, and the resulting revenue is higher than that of solely raising fish in ponds.

The main potential linkages between livestock and fish production is use of nutrients, particularly reuse of livestock manures for fish production. The term "nutrients" primarily refers to elements like phosphorous (P) and nitrogen (N), which act as fertilizers to support natural food production. Based on the type of livestock used for integration there are many combinations in livestock-fish systems. The key ones are covered below.

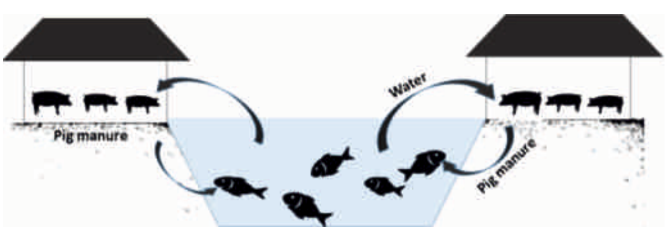
1. Cattle-fish culture

Fish farming using cow manure is one of the common practice all-overs the world. Cowsheds are constructed in the vicinity of fish ponds and waste are discharged into fishponds. Every year, a cow excretes 3,500–4,000 liters of urine and more than 4,000–5,000 kg of dung. Cow manure particles sink slower (6 cm/min) than any other livestock. This gives fish enough time to eat the edible parts of the dung. In fishponds, manuring with cow dung, which is high in nutrients, increases the number of bacteria and natural food organisms called detritus. One hectare of pond can be adequately manured by five to six cows. In addition to 9,000 kg of milk, about 3,000-4,000 kg fish/ha/year can also be harvested with such integration. To make handling cow manure easier, a cowshed should be constructed adjacent to a fish pond. Fish also utilizes the fine feed wasted by cows, which consist of grains.

Livestock-fish system
Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

2. Pig-fish system

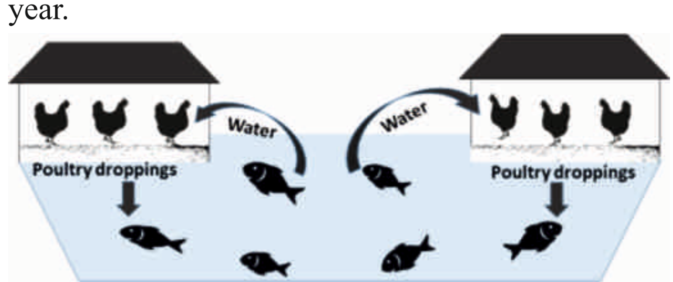
In China, Taiwan, Vietnam, Thailand, Malaysia, and Hungary, this integration system is widely used. Pigs are primarily fed crop waste, aquatic plants, and kitchen scraps. One tonne of ammonium sulphate is equal to the waste generated by thirty to thirty-five pigs. Pig stalls close to the fish pond are used to raise exotic breeds like Hampshire, Landrace, and White Yorkshire. Pig shed can be constructed on the dry side of the bund or on the bund that separates two fish ponds, depending on the size of the fish ponds and their manure needs. Small ditches that pass through pond bunds are then used to release the liquid manure (slurry) into the fishponds. Pig manure can also be applied to fishponds by dissolving it in water, or it can be heaped in specific areas. Moreover, pig manure contains about 70% of digestible food for fishes besides certain digestive enzymes. Rearing 40-45 pigs on the embankment is adequate to fertilize 1ha fish culture pond. Pigs can be integrated with fish such as common carp (1:2:1), silver carp, and grass carp. Within six months, pigs reach slaughter maturity (60–70 kg), and each litter produces six–12 piglets. Integrated pig-cum-fish culture system has potential to produce about 3000-4000 kg/ha/yr fish, 4500 kg/yr pig meat and 800 no. of piglets every year.



Pig-Fish system
Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

3. Poultry-fish culture

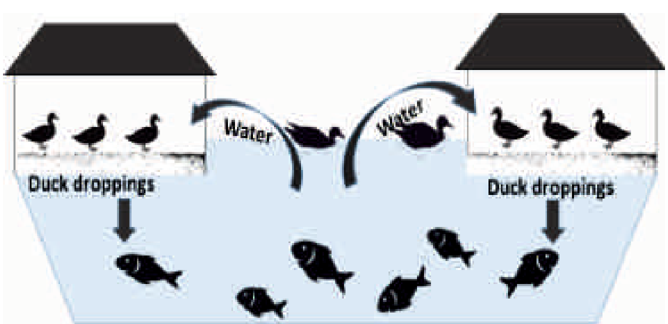
In this farming system, poultry farming is integrated with fish culture. In this fish ponds get fertilized by the chicks droppings that are high in phosphorus and nitrogen. Chicken shed is built above water level with bamboo poles, poultry droppings from housing directly fertilizes fish ponds, which helps in production of the planktons. This plankton acts as food for the fish. Farmers receive good and quick returns from the production of broilers. For this kind of system, obtaining high-quality chicks, housing, brooding, feeding, and disease control are crucial. The best birds for fish poultry integration are those kept in intensive systems. Birds are housed in enclosures with no access to the outdoors. A layer made of chopped straw, dry leaves, sawdust, or groundnut shell that is 6–8 cm thick is adequate. Rhode Island or Leghorn birds are favored in poultry-fish systems, because of their superior growth and ability to lay eggs. About 2500 chicks per hectare are used in this system. Every day, 30-35 kg/ha of deep poultry litter is added to the pond. One adult chicken can produce roughly 25 kg of compost poultry manure annually, and 1000 birds can supply enough manure for one hectare of water. Integrated poultry-cum-fish culture system has potential to produce about 3000-4000 kg/ha/yr fish, 3500 kg/yr chicken meat and 60,000 t0 1,00,000 eggs every year.



Poultry-Fish Culture
Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

4. Duck-fish culture

Duck-fish integration is the most common form of integration. A fish pond provides ducks with an excellent, disease-free environment because it is a semi-closed biological system that is home to a variety of aquatic plants and animals. In return, ducks provide a secure habitat for fish by consuming dragonflies, tadpoles, and baby frogs. Duck droppings fall straight into the pond, where they provide essential nutrients that support the development of organic food. Two advantages result from this are (1) no energy is lost and (2) fertilization is uniform. In India, the breed most commonly utilized in this system is the "Indian runners." People call ducks "living manuring machines." Duck droppings contain 20% inorganic and 20% organic materials, including carbon, phosphorus, potassium, nitrogen, calcium, and other elements. It is a great source of fertilizer for fish ponds to produce fish food organisms. Ducks also remove unwanted insects, snails, and their larvae—which can harbor human-infecting waterborne pathogens and fish pathogens—in addition to manuring. Furthermore, when ducks agitate the pond's shoreline, they release nutrients from the soil. In duck-fish culture, ducks can be kept in screened resting places above the water or sometimes allowed to roam freely. Bamboo split sheds or floating pens can also be hung in the pond to allow for regular manuring. Usually, 15 to 20-day-old ducklings are selected. One duck produces about 125- 150 gm/day excreta. So, 200-300 ducks are sufficient for 1 ha pond area. When raising fish with ducks, it is best to release fingerlings bigger than 10 cm because the ducks may consume the fingerlings. Integrated duck-cum-fish culture system in a pond of 1 ha water spread area has a potential to produce about 4000-5000 kg fish, 25000 - 30000 duck eggs and - 600-700 kg duck meat in an annual year.



Duck-Fish Culture
Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

5. Goat-fish culture

It is the simultaneous farming of fish and goats on the same piece of land. The pond water can be used to clean the goats and their sheds, and the goat dung, which is high in organic materials, can be effectively utilized as manures for the fish pond. Fish, meat, and milk can all be produced from the same system through integrated goat-cum-fish culture. Goat urine is equally rich in N and P, and the animal's excreta contains 60% organic carbon, 2.7% N, 1.78% P, and 2.88% K. The goat's urine and nutrient-rich excreta can be used as pond manures, recycling the organic wastes of the goat into fish culture and using the water from the fish pond for goat rearing. By maximizing space utilization with minimal maintenance, this integration system has significant potential to improve milk, meat, and fish. One hectare of fish pond can be fertilized with 50–55 goats. One hectare of fish rearing space can accommodate roughly fifty to fifty-five goats. Without additional feeding and fertilizer, an integrated goat-cum-fish culture system could yield 750–800 kg of meat annually and 3500–4000 kg of fish/ha.

Goat-Fish Culture
Source: "Guide to integrated fish culture in northeast region of India" by Dorothy et al, 2025

Conclusion

It is possible to increase crop productivity using the same resources by integrating fish culture with agriculture crops, horticulture crops, animal husbandry, etc. in a single system or in a multi-crop integration system. By using the by-product of one crop to benefit another, it is possible to produce a variety of crops (both vegetal and animal) in a sustainable manner that is both economical and environmentally friendly. Approximately 95% of the system's nutritional needs are met by integrated farming through resource recycling.

As a result, these farming methods guarantee the judicious use of resources and raise revenue and profit. Depending on the availability of resources, marketing potential, and consumer demands, multiple crops may be integrated. Based on resources, management expertise, and investment capacities, the profit margin rises as the number of integrating businesses increases.

Farmer-friendly ornamental fish farming: A small-scale approach to the blue economy

Sachin Onkar Khairnar*

Abstract: This article provides an overview of the practical, farmer-friendly aspects of ornamental fish farming in both rural and semi-urban areas. It addresses key challenges while highlighting the income potential of this venture. The article emphasises the importance of women empowerment, family participation, and government support in this field. Furthermore, it highlights that promoting small-scale ornamental fish farming not only facilitates livelihood diversification but also contributes to biodiversity conservation, playing a significant role in advancing the broader goals of the blue economy.

Background

Ornamental fish are vibrant, attractive aquatic species primarily reared for decorative purposes in aquariums, garden ponds, and water features. Their dazzling colours, fascinating patterns, and graceful movements make them a favourite among hobbyists, collectors, and aquarists worldwide. The ornamental fish industry has been growing steadily, offering significant potential for small-scale farmers and entrepreneurs. However, challenges such as knowledge gaps in breeding, inadequate infrastructure, and dependency on wild capture hinder its full potential. This article outlines key challenges and highlights the wide range of opportunities available in ornamental fish farming, with a focus on practical, farmer-friendly approaches.

According to FAO reports, the global ornamental fish trade is valued at approximately US$20 billion and continues to expand, driven by increasing urbanisation, changing lifestyles, and the rising popularity of home aquariums. More than 125 countries participate in this international trade, with Asia serving as the primary hub. The report further states that Japan, Indonesia, and Singapore are among the leading exporters, while the United States and several European countries dominate global imports. Despite its commercial value, over 90% of marine ornamental fish and a significant portion of freshwater species are still sourced from the wild, posing serious threats to aquatic biodiversity.

Status of ornamental fisheries in India

India contributes around 0.4% of global ornamental fish exports and ranks 31st among exporting countries. With a domestic market estimated at Rs. 600 crore and the potential to reach Rs. 5,000 crores, the sector is expanding rapidly at an annual growth rate of approximately 20%. While the trade is concentrated in West Bengal, Tamil Nadu, Kerala, and Maharashtra, interest is growing in inland states such as Bihar, Punjab, Rajasthan, and Madhya Pradesh. India has over 7,000 ornamental fish shops and more than a million hobbyists, indicating a strong domestic market.

India has abundant marine ornamental fish resources, especially in the lagoons and coral reefs of Lakshadweep and Minicoy Islands, the Andaman and Nicobar Islands, the Gulf of Kutch, the Kerala coast, the Gulf of Mannar, and Palk Bay, which host a diverse range of visually appealing species. The potential for freshwater ornamental fish is enormous, with many species inhabiting hill streams, major river systems, reservoirs, and lakes across the country. Notably, the rivers and Himalayan streams of the northeastern states are rich in a diverse range of freshwater ornamental fish species.

India has a diverse range of freshwater fish species, particularly in the Northeastern hills and the Western Ghats, where there are about 300 species, including 155 ornamental varieties. Of these, 117 are endemic,

College of Fisheries, Bihar Animal Sciences University, Kishanganj (Bihar)
**E-mail: sachinkhairnar5983@gmail.com*

yet only a small portion of them is utilised in the domestic ornamental fish trade, with most imported from exotic sources. Many indigenous fish, such as barbs, rasboras, and danios, have significant potential in this market but remain under exploited.

Ornamental fish can be broadly classified based on their reproductive nature into livebearers and egg layers. Popular livebearers such as guppies, mollies, platies, and swordtails are ideal for beginners due to their ease of breeding and maintenance. Among egg-layers, goldfish, koi carp, tetras, barbs, gouramis, angelfish, and catfish are in high demand. Indigenous species from biodiversity hotspots, such as the Western Ghats and Northeast India, not only provide unique opportunities for diversification and conservation-based farming but are also highly valued in international markets.

Practical aspects of ornamental fish farming

Ornamental fish farming is a low-cost and space-efficient venture that can be started by anyone, even with limited resources. A backyard or rooftop area of just 500 ft^2 is sufficient to begin a small-scale breeding and rearing facility.

Basic infrastructure

- Poly-lined pits, small tanks or ponds made from ferrocement, plastic are affordable, easy to install, and suitable for breeding and rearing (Fig. 1).
- Aeration systems (such as air pumps or diffusers) to maintain adequate oxygen levels in the water.
- Simple filtration units to remove waste and ensure clean water.
- Green shade nets to protect fish from direct sunlight, rain, and predators.

Poly-lined pits	Circular tanks	Plastic tanks

Fig. 1. Various types of tanks used for rearing ornamental fish.

Water quality management

Maintaining good water quality is essential for healthy fish growth (Table 1).

Table 1. Optimum range of key water quality parameters

Parameter	Optimum range
Temperature	24–28°C
pH	6.5–7.5
Dissolved Oxygen	> 5 mg/L
Ammonia	Minimal (near 0 mg/L)

Regular monitoring and partial water exchange (around 20–30% weekly) help in maintaining optimal water conditions.

Feeding management

A balanced diet is crucial for growth and colouration. Fish can be fed with pelleted feed containing 30–35% protein, supplemented with natural colour enhancers such as spirulina or other carotenoid-rich ingredients, and live feeds like artemia, daphnia, tubifex, and bloodworms, especially during breeding and larval stages. A small live feed culture unit using containers or tubs can be easily maintained on-site.

Breeding and fry management

Commercially important livebearer ornamental fish species (guppies, mollies, swordtails, and platies) are popular due to their vibrant colours. They are easy to breed due to internal fertilization and release of free-swimming fry. They are hardy, prolific breeders with males smaller and more colourful than females. Males have a gonopodium (a modified anal fin) that serves as a copulatory organ for sperm transfer at the time of internal fertilisation; females store sperm and give birth to fully formed youngones after approximately 4-6 weeks of internal development, depending upon the fish species, visible as a gravid spot before release. Females are cannibalistic and may eat their newborn fry; hence, it is essential to transfer them to separate breeding tanks with aquatic plants or use breeding traps to protect the fry immediately after birth.

In contrast, breeding commercially valuable egg-laying ornamental fish species, such as goldfish, koi carp, angelfish, tetras, barbs, and gouramis, involves depositing eggs on submerged substrates or plants, with specific requirements for water quality, spawning sites, and sometimes parental care or the removal of eggs to prevent predation. After successful spawning, it is essential to transfer the fry to nursery tanks to prevent predation by adult fish, and to conduct size-based grading using fine mesh or sieves to ensure uniform growth and minimise cannibalism.

Marketing opportunities

Ornamental fish can be sold through:

- Local aquarium shops and pet stores.
- Weekly markets and fairs.
- Online platforms such as WhatsApp, Facebook, OLX, or IndiaMART.
- Direct-to-customer sales.
- Even a modest unit can generate monthly income ranging from ₹8,000 to ₹10,000, depending on species and market demand.

Urban ornamental fish farming and role of women empowerment

Ornamental fish farming offers an excellent home-based business opportunity, especially for urban households, women, and senior citizens. With minimal investment and space, it can provide steady supplemental income. Women have historically been involved in the fisheries sector, but recent trends show a shift toward aquaculture, where their contributions are recorded at 12 and 19 % in fisheries and aquaculture, respectively. This shift highlights the evolving gender dynamics in these sectors and the importance of recognising women's contributions. Women play an essential role in ornamental fisheries, often collaborating through self-help groups and cooperatives. They are involved in breeding, rearing, and marketing ornamental fishes, contributing to their livelihood and empowerment. A significant portion of rural women who attended training on ornamental fisheries went on to establish their backyard, rooftop, or aquarium units, or they have contributed to expanding their family business.

Urban residents can utilise:

- Wall-mounted aquariums in living rooms or verandahs.
- Multi-layered racks with small tanks for breeding and rearing.
- Indoor aquariums with decorative appeal that also serve as rearing units.
- Terrace or rooftop units with protective roofing and controlled lighting.
- These setups can be managed easily within the home environment.

Women and family involvement

This enterprise is particularly suitable for:

- Women who can handle feeding, cleaning, and basic management.
- Elderly family members who can assist in observation and light duties.
- Students and youth who can contribute by learning basic techniques and helping with sales and recordkeeping.
- This makes ornamental fish farming a family-friendly microenterprise.

High-demand fish for urban markets

Easy-to-breed species (Fig. 2) suitable for urban units include:

- Livebearers: Guppies, mollies, swordtails, platies.
- Egg layers: Goldfish, tetras, barbs, danios.
- With experience, families can try premium species like discus, flowerhorn, and arowana, which have good market value.

Government support and schemes

The Government of India has promoted ornamental fish farming through schemes like the Pradhan Mantri Matsya Sampada Yojana (PMMSY) and Blue Revolution. Financial aid, training programs, and infrastructure support are provided through the National Fisheries Development Board (NFDB) and the Marine Products Export Development Authority (MPEDA). Under PMMSY, an investment of Rs. 576 crore aims to generate 7 lakh jobs in the ornamental sector. Additionally, a World Bank-funded project has allocated Rs. 500 crores for ornamental aquaculture development.

Fig. 2 Easy-to-breed ornamental fish species

Conclusion

Ornamental fish farming is a promising option for self-employment and income generation, especially in rural and semi-urban areas. It requires limited land, low capital, and basic training. With the growing domestic and international demand and increasing government support, small-scale farmers, farm women and youth can turn this vibrant hobby into a sustainable business. By adopting best practices and building market linkages, ornamental aquaculture can offer stable income, promote biodiversity, and contribute to the broader blue economy.

Suitability of biofloc technology in varied agro-climatic condition in India

Amit Mandal*

Abstract : Biofloc Technology (BFT) is an advanced and sustainable aquaculture system that promotes high-density fish or shrimp farming with minimal water exchange. It works by converting waste nutrients, especially ammonia from fish excreta and uneaten feed, into microbial biomass (biofloc) through the addition of a carbon source (like molasses or jaggery). These bioflocs not only maintain water quality by reducing toxic nitrogen compounds but also serve as a supplementary protein-rich feed for the cultured species. BFT is highly suitable for areas with limited water resources and offers improved biosecurity, reduced environmental impact, and better feed conversion efficiency. However, it requires careful monitoring of water parameters, aeration, and system management. BFT is considered cost-effective due to its reduced need for water exchange and lower dependence on commercial feed, as the biofloc itself serves as a supplemental protein source. It significantly cuts down feed costs, which are a major expense in aquaculture. Additionally, higher stocking densities and better feed conversion ratios (<1.2 to <1) lead to increased productivity per unit area, making the system economically efficient in the long run.

Introduction

The growing per capita food consumption demand in world directs to high intensification of aquaculture industry which depends on intensive use of land and water resources, which areFig. Sustainable modern intensive aquaculture systems in very scarce situations in India. But intensification is now creating several problems in aquaculture viz. increase high protein fish feed demand, increase of environmental pollution through release of waste water from culture system to surrounding water bodies, disease etc. The region specific standardization of ecosystem based modern aquaculture technology is required to enhance aquaculture productivity for promoting food security and safety of environment (Fig. 1). The eco-friendly sustainablebiofloc technology (BFT) is proved as the new 'blue revolution' in aquaculture sector based on minimal water exchange and requirement of less water and land compared to traditional pond aquaculture. The diverse biofloc consortium (bacteria, protozoa, planktons, micro-algae, organic matter etc.) efficiently ameliorates total ammonia nitrogen (TAN) to improve water quality. Biofloc enhances feed utilization efficiency and growth performance, health status, body colouration and flesh qualities of fish. The farmers are facing difficulties to fetch good returns from their commodities in biofloc system due to lack of following reasons: region specific standardization regarding selection of suitable carbohydrate source and it's required amount for

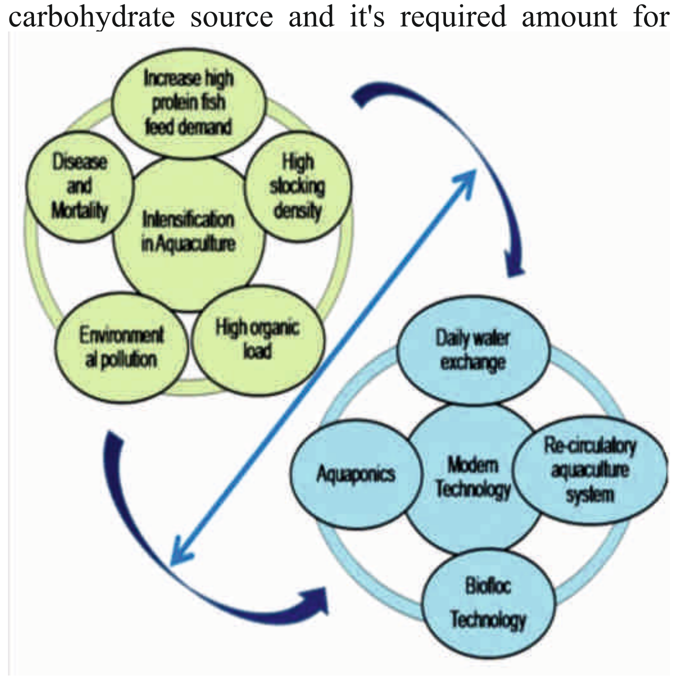


Fig. 1 Sustainable modern intensive aquaculture systems

College of Fisheries, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab
**E-mail: amitmandal@gadvasu.in; Mobile: +91-8360645163*

management of required carbon and nitrogen ratio (C:N), methods for biofloc development, optimum stocking density of species, feed and feeding management, water quality management, mechanical operations and technical efficiency, scientific knowledge and public awareness etc.

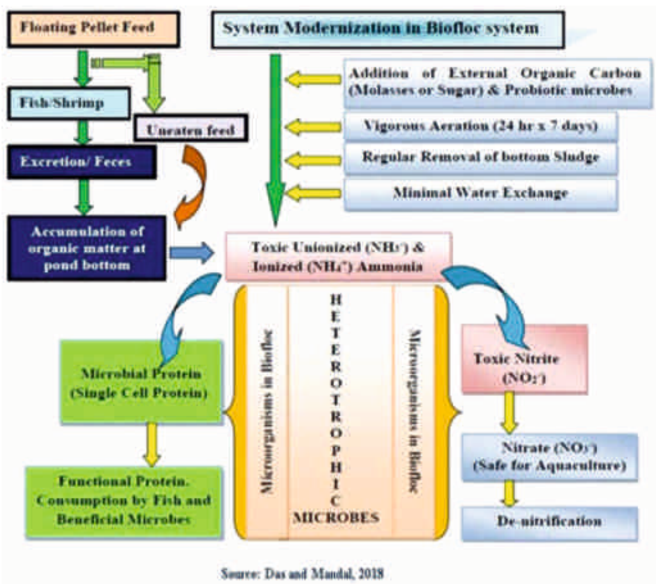


Fig. 2 Mechanism of biofloc technology

Principles of biofloc technology

BFT enables intensification at a relatively reasonable investment and operating cost. BFTmainly focus on more efficient use of nutrient input with limited or zero water exchange. The main principle of BFT is the recycling of nutrient by maintaining a high carbon/ nitrogen (C/N) ratio in the water in order to stimulate heterotrophic bacterial growth that converts ammonia into microbial biomass (Fig. 2). The microbial biomass will further aggregate with other microorganisms and particles gets suspended in the water forming what has been called "biofloc", which eventually can be consumed in-situ by the cultured animals or harvested and processed as a feed ingredient. Henceforth, BFT isconsidered as a promising system for a sustainable and environmentally friendly aquaculture system, and has been applied both at laboratory and commercial scale for various aquaculture species.

Importance of BFT in Indian aquaculture context

- **Water conservation:** BFT minimizes water usage (85-90%), and crucial in water-scarce regions of India especially the land locked states.
- **Year-round production:** Enables continuous aquaculture which is unaffected by seasonal variations.
- **High-density farming:** Supports high stocking densities (30-70 no/100 L), maximizing productivity (15 to 20 times per unit area) from same unit area.
- **Land use efficiency:** Can be established in small spaces by addressing land constraints w.r.t. urban areas of India.
- **Improved biosecurity:** Reduces disease outbreaks by maintaining controlled conditions.
- **Pollution control:** Limits environmental impact by recycling water and managing waste effectively.
- **Climate smart system:** Operates in controlled environments, unaffected by erratic monsoons (climate resilient aquaculture).
- **Human resource development:** Promotes skilled and semiskilled jobs in aquaculture technology and management which can be considered as one of the lucrative options for unemployed youth, graduating students and entrepreneurs.
- **Government support:** Aligns with Indian government initiatives (promoting sustainable aquaculture practices).

Carbon-nitrogen ratio management in biofloc system

The supplementation of external carbohydrate is necessary to maintain ideal carbon-nitrogen ratio(C:N) of 12-15:1 in biofloc system. Various carbohydrates like cellulose, sugar and cassava meal, wheat flou), wheat and corn mea), glucos), sugarcane bagass), tapioca, molasses and jaggery have been proved as the suitable carbohydrate source in biofloc system. In biofloc system, initially the carbon source applied based on the amount of feed and the protein percentage of the feed is applied (Fig. 3). During the culture period, as the floc volume increase and available nitrogen source increases due to unutilized feed, excretion etc., and the carbon addition should be based on the TAN level in the culture system. If the TAN level goes beyond 1mg/L, the carbon source addition is recommended with C:N ratio of 15:1. Example: Suppose: 1.5mg/L TAN is measured in 15000L tank (carbon source used rice flour 40% carbon content) = (0.0015x 15000) = 22.5gm of TAN. If we want to maintain the C: N ratio with 15:1 =15x 22.5 = 337g of carbon is required.

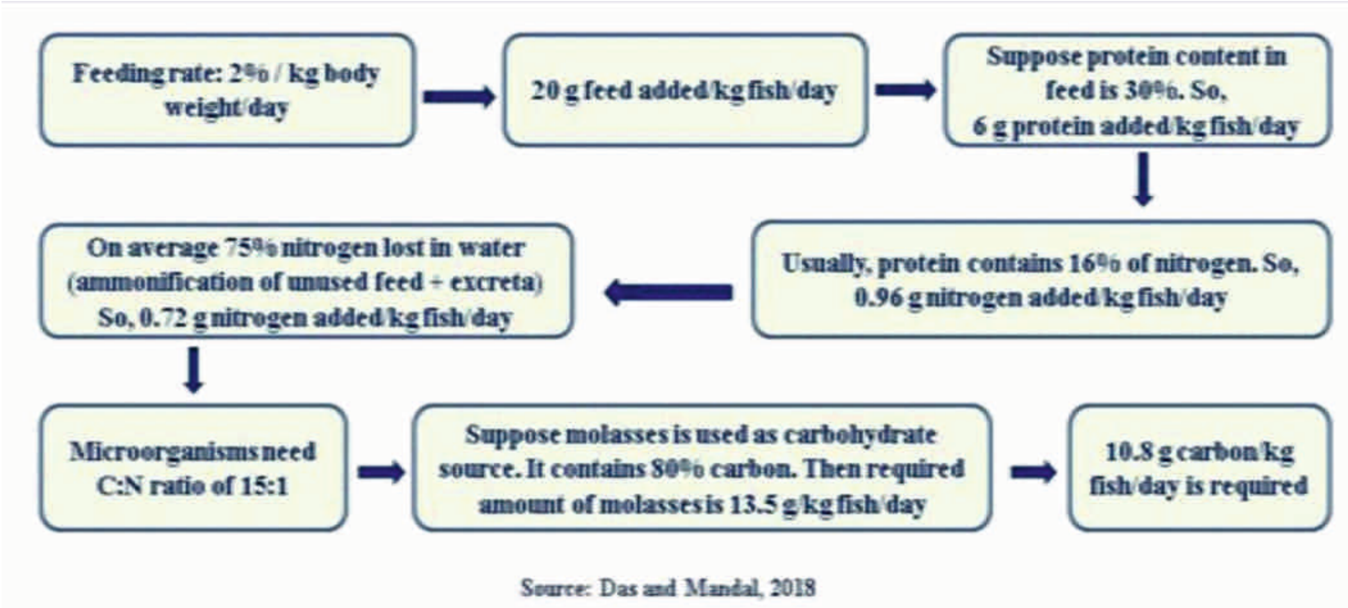


Fig. 3 Carbohydrate addition in biofloc system

Table 1. Composition of starter inoculums used in biofloc tank

1.	Ground water (150L), pond soil (2-3 kg), ammoniumsulphate/urea (1.5 g), carbohydrate source (30g) orGround water (130L), Pond water (20 L), carbohydrate source (30g), probiotic (10g).	NFDB
2.	Freshwater (1L) carbohydrates (200 mg), pond bottomsoil (20g), ammonium sulphate (10 mg), yeast powder(25 g), curd (500 g).	Das &Mandal, 2021

Selection of fish species in BFTas per Indian context

The selection of suitable species in biofloc aquaculture system should meet the following criteria viz. detritivorous and omnivorous feeding habit to absorb the biofloc microbial particles, high tolerance to high levels of suspended particles and moderate changes in dissolved oxygen and other water quality parameters and also resistance ability to high density. According to the National Fisheries Development Board (NFDB, Hyderabad) guidelines, harbivorus and omnivorous species (Nile tilapia, pangas, common carp, singhi, anabas, freshwater prawn, ornamental koi carp, gold fish etc.) could be the suitable for culture in biofloc system. NFDB has reported the stocking density of fish seed in collapsible/FRP tanks with 100 nos./ 1000 L water (min. 1000 nos per 15,000L tank - depending on species). The farmers who want to start biofloc system for the first time; they can stock food fish @ 50-100 nos. fingerlings/1000 L water (depending on species) and ornamental fish @35-50 nos. fingerlings/1000 L water (depending on species).

Feed and feeding strategies

Feeds that are species-specific and nutritionally balanced encourage fish growth while reducing waste. Feed with exact size (800 micron to 2 mm) and required protein and fat content (26-38% protein and 4-8% fat) engineered with specific bouncy (floating/sinking) are considered the keys to promote growth. Apart from the costly conventional feed ingredients (fish meal, soybean and ground nut cake) unconventional ingredients such as algae, insect meal, and plant-based proteins can also be utilized upto a certain limit without compromising nutritional quality and exerting additional pressure on fish meal. Feeding strategies including demand based frequent feeding of 2-2.5% of feed in biofloc can be divided for three to five times enhance growth performance. Together, these tactics increase systems operations' sustainability, profitability, and environmental effect while providing a route towards more environmentally friendly aquaculture methods in India.

Challenges and Limitation

Effectiveness of biofloc technology is hampered by certain limiting issues, despite of the many benefits of BFT. The growth of heterotrophic bacteria and high load of solids may lead to excessive turbidity in the system, which might block the gills of fish species. BFT necessitates higher energy consumption for aeration and mixing as it requires continuous power supply. Stable energy is one of the problems in India. Development of biofloc needs minimum 15-20 days which eventually delays the production cycle during the initial culture period. Farmers are not frequently using floc culants for biofloc development of faster rate. Unregulated use of carbohydrate leads to high load of solids. Till date, region specific suitable species selection has not been optimized besides there is lack of optimization of stocking density, dietary protein and lipid requirement. Excessive application of feed, carbohydrate, chemicals and drugs are also hindering the production performance of cultured species.

Future Perspective

The region specific technological optimization, trained and skilled person are very important for wider adoption of BFT across the country. Solutions such as modifying technologies to the agro-climatic conditions across Indian states, including ensuring the availability of long-lasting affordable tank materials, tank layout modifications, strengthening equipment performance, sharing knowledge and developing specialized education programs (need-based capacity building training) are essential for overcoming challenges and utilizing BFT to its fullest potential. To encourage investments and increase the adoption rate, government programs like Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PM-MKSSY) offer financial and technical help. The selection of suitable candidate species is essential to the success of BFT. Special attention must be paid to BFT succession patterns in order to dispel misunderstandings. In fact, this might be the solution to the aquaculture industry's antibiotic use issues. Nowadays, farmers are also practicing seed rearing of fish in biofloc tank which is very cost effective and also fetching high economic return in a small period of time. This is also helping in multiple seed rearing throughout the year. So, in coming future, great scope will be generated for the stakeholders. The technology will be very efficient in meeting the needs of the cultured species for a higher yield in the near future by understanding the standard operating procedures through necessary alteration of the key parameters. It is also possible for the farmers having no access to open water systems, can adopt BFT. Apart from this, it will also support the live fish market, ensuring that the public has access to fresh and live fish for consumption.

Cage culture in Bundelkhand regin

Partha Sarathi Tripathy*, Rahual Kumar Gurjar, Kajal Kumari and Prince Kumar

Abstract: The Bundelkhand region, spanning parts of Uttar Pradesh and Madhya Pradesh, possesses vast underutilized water resources, including reservoirs, rivers, and ponds, offering significant potential for inland aquaculture development. Cage culture, an efficient and eco-friendly method of fish farming in open water bodies, emerges as a sustainable solution to address the region's agricultural and livelihood challenges. The present article provides a comprehensive overview of the cage culture system, emphasizing its relevance to Bundelkhand's semi-arid conditions and socio-economic context. Various types of cage structures, from fixed and floating to submersible and submerged cages, are discussed along with the stepwise procedures of cage installation, maintenance, and harvesting. Additionally, species-specific feeding charts for Indian Major Carps (IMC), Tilapia, and Pangasius are presented to guide optimal growth and productivity. The study underscores the transformative potential of cage culture in Bundelkhand, particularly under the framework of government schemes like the Pradhan Mantri Matsya Sampada Yojana (PMMSY). With scientific planning, quality input, and strategic investment, cage culture can play a pivotal role in enhancing fish production, ensuring food and nutritional security, and generating income and employment in the region.

1. Introduction

Bundelkhand is a historically and geographically significant region located in central India, encompassing parts of southern Uttar Pradesh and northern Madhya Pradesh (Gupta et al., 2014). It is a transitional zone marked by undulating terrain and lies predominantly within the Vindhyan mountain range (Singh and Slabunov, 2015). The region spans approximately 70,747 km² and has an average elevation of 250–300 meters above sea level. As per the 2011 Census, Bundelkhand has a population of around 18.3 million, with a population density of 260 persons per square kilometer. Out of this, 14 million people live in rural areas. Culturally rich and linguistically distinct, the people of Bundelkhand primarily speak Bundeli and Hindi, and are known for their resilient socio-cultural identity. Historically, the region was part of the ancient Chedi kingdom during the post-Vedic period and has witnessed the rise and fall of several princely states such as Orchha, Panna, Banda, Bijawar, and Ajaigarh. Important towns and cities include Jhansi - the largest city in the region—and Sagar, the second largest, along with other historically significant places like Khajuraho, Kalinjar, Mahoba, and Chitrakoot. Today, Bundelkhand is recognized as both a distinct geographical and cultural region and has been proposed as a separate state. The area includes the Jhansi and Chitrakoot divisions of Uttar Pradesh and the Sagar division of Madhya Pradesh. Despite its historical and cultural richness, the region faces developmental challenges, particularly in water resource management and agricultural productivity. These challenges make it a compelling site for the promotion of alternative livelihood strategies such as cage culture, which holds promises for enhancing fish production and rural livelihoods in the region.

2. Water Resources of the Bundelkhand Region and Potential for Cage Culture

The Bundelkhand region, situated between the Indo-Gangetic plains to the north and the Vindhyan ranges to the south, is spread across 14 districts - seven each in Uttar Pradesh (Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda, and Chitrakoot) and Madhya

College of Fisheries, RLBCAU, Datia Campus, Madhya Pradesh-475686
**E-mail: rabul92@gmail.com*

Pradesh (Datia, Tikamgarh, Niwari, Chhatarpur, Damoh, Sagar, and Panna). Despite being semi-arid and largely rocky, the region is endowed with a diverse range of surface water resources that include rivers, reservoirs, and ponds, offering substantial potential for inland fisheries development and cage culture practices.

Bundelkhand is part of the Yamuna River system. Major rivers that traverse the region include the Yamuna in the north, Ken in the east, Betwa, and Pahuj in the west. Other significant rivers like the Dhasan and Tons cut across deep ravines and plateaus, though their utility for irrigation is limited. However, the water in these rivers remains largely free from industrial pollution, making them suitable for fish production and aquatic ecosystem health.

Reservoirs are the most prominent and promising water bodies in the region for aquaculture and cage culture. In Uttar Pradesh's Bundelkhand area alone, the total reservoir area spans 70,436 hectares, with Lalitpur district accounting for the largest share ofapproximately 42,000 hectares. These water bodies, though currently underutilized, are considered "sleeping giants" with immense potential to support fish production. There are numerous large, medium, and small reservoirs managed by the Irrigation and Fisheries departments, such as Rajghat (22,400 ha) and Matatila (10,368 ha) in Lalitpur, Kamla Sagar (2,462 ha) in Jhansi, and Brahmanand Sagar (5,754 ha) in Hamirpur. Presently, average fish productivity in these reservoirs is quite low about 30–35 kg/ha/year, in contrast to the potential yield of 100–500 kg/ha/year based on reservoir size.

The second major water resource is the network of ponds, including revenue, irrigation, fisheries department, and private/community ponds. The total pond area is approximately 22,365 hectares, though a significant proportion is seasonal. In Jhansi Division, only 14% of ponds retain water above five feet year-round, while in Chitrakoot Division this number is slightly higher at 18%. Efforts are underway to enhance pond-based aquaculture through the construction of khet talabs (farm ponds) under agricultural schemes, which can be leveraged for spawn/fry rearing or grow-out aquaculture.

Despite the low per capita fish consumption in the region due to socio-religious practices, Bundelkhand contributes around 14% of Uttar Pradesh's total fish production. In FY 2020–21, the total fish production from Bundelkhand was 108,119 tons, with 82,269 tons from aquaculture and 25,411 tons from open water bodies, including reservoirs and rivers. Productivity rates for aquaculture ponds in Bundelkhand districts are comparable to national standards, averaging 4.2–4.4 tons/ha/year, while open water productivity ranges between 0.2–0.3 tons/ha/year. The fish produced is largely pathogen-free due to the pollution-free nature of the region's water bodies. Bundelkhand hosts 16 private hatcheries and several government seed production farms with a combined capacity of nearly 285 lakh fish seed annually. However, constraints like paucity of quality seed, lack of formulated feeds, and insufficient candidate species diversification persist.

The vast expanse of underutilized reservoirs, clean water quality, and a growing number of trained entrepreneurs due to schemes like Pradhan Mantri Matsya Sampada Yojana (PMMSY) make Bundelkhand a high-potential zone for cage culture development. With assured markets, opportunities for both horizontal and vertical aquaculture expansion, and relatively lower competition due to low local demand, fish produced here can be targeted for external markets and export.

3. Cage culture in the region

Cage culture is a form of aquaculture wherein fish are reared from fry to marketable size within floating enclosures, or cages, placed in natural or man-made water bodies such as reservoirs, lakes, and rivers. These cages are typically constructed from mesh netting and are designed to allow free water exchange with the surrounding environment. Unlike pen culture, which involves enclosing a portion of the water body with a bottom substrate, cage culture units are bottomless and remain suspended in the water column, minimizing disturbance to the benthic ecosystem. This system ensures continuous access to oxygenated water, facilitates efficient waste dispersion, and helps maintain optimal water quality. Due to their structural flexibility and scalability, cage culture systems are well-suited for high-density fish farming and can be effectively implemented in both freshwater and marine environments (Islam et al., 2025).

4. Advantages of cage culture

Cage culture presents numerous advantages, particularly in regions like Bundelkhand with vast underutilized reservoir resources:

- **Resource efficiency:** It makes use of existing water bodies without the need for land acquisition or construction of ponds, thereby conserving agricultural land and minimizing capital investment.
- **Cost-effective and locally adaptable:** The technology is simple and can be developed using locally available materials, making it economically feasible for rural communities and small-scale farmers.
- **Environmentally sustainable:** Since many cage-cultured species such as carps feed lower in the food chain, their cultivation exerts less pressure on the environment. Moreover, the free-flowing water system dilutes waste, reducing the risk of eutrophication when managed properly.
- **Productivity enhancement:** Cage culture enables the intensification of aquaculture in areas with limited pond infrastructure, significantly improving fish yield per unit area.

5. Types of cage culture

Cage culture systems are broadly categorized based on their structure, placement, and operational design. The choice of cage type depends on the water body, depth, current flow, and environmental conditions. The four primary types of cages used in aquaculture are:

5.1. Fixed cCages

Fixed cages are the simplest and most cost-effective type, commonly installed in shallow water bodies such as rivers, canals, and small lakes with depths ranging from 1 to 3 meters (Fig.1a). These cages are anchored firmly using poles driven into the substrate, forming a stationary structure. They are easy to construct and suitable for low-budget operations. However, their applicability is limited due to their reliance on specific shallow water conditions and lack of adaptability to varying water levels.

5.2. Floating cages

Floating cages are the most widely used and versatile type in modern aquaculture (Fig.1b). These cages are supported by a floating frame and suspended in the water column, without any contact with the bottom. Ideal for water bodies deeper than 5 meters, they are deployed in reservoirs, lakes, and even open seas. Available in various shapes and sizes (square, rectangular, circular), floating cages can withstand diverse water conditions and are easily accessible for monitoring, feeding, and harvesting.

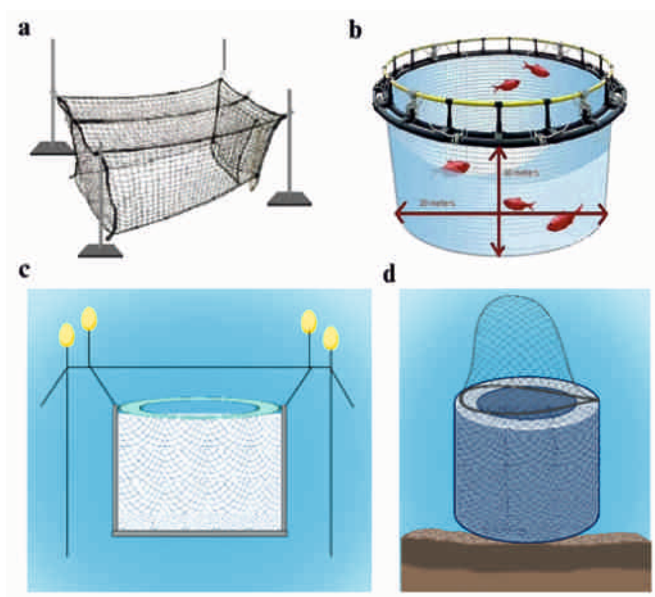


Fig.1. Illustration of different cages. a. Fixed Cage, b. Floating Cage, C. Submersible Cage and d. Submerged Cage.

5.3. Submersible cages

Submersible cages are designed to be raised or lowered in the water column using a system of floats and anchors (Fig.1c). These cages remain just beneath the surface and can be adjusted vertically based on water temperature, oxygen levels, or storm conditions. The frame may be elastic or rigid, and the cages often feature hinged doors for efficient fish handling at different depths. They offer improved environmental control but require more technical expertise and infrastructure.

5.4. Submerged cages

Submerged cages are permanently located below the water surface and are constructed with robust frames to withstand underwater pressure (Fig.1d). They are designed for use in offshore or turbulent aquatic environments. However, due to challenges in feeding, monitoring, and harvesting, their use remains limited. These systems require specialized equipment and are not commonly used in inland or small-scale operations.

6. Steps of cage culture

The success of cage culture hinges on a systematic approach that encompasses multiple critical stages—from selecting an appropriate site to harvesting the marketable fish. Each stage plays a pivotal role in ensuring high productivity, fish welfare, and economic viability.

6.1. Site selection

The first and foremost step is site selection, which directly influences the overall performance of the cage culture operation. Ideal sites should be located in water bodies that are free from pollution, local contaminants, and effluents. A minimum water depth of 5 meters is essential to maintain adequate oxygen levels and prevent temperature extremes. In large reservoirs, it is preferable to place cages in protected bays to shield them from strong winds and wave action. In smaller reservoirs, especially those close to irrigation inlets, cages should be installed in calm, deeper sections with continuous water flow. The chosen site must also be away from grazing animals, wild fish populations, and high human activity zones to minimize disease risks, competition, and physical disruption.

6.2. Procurement of cage materials

Once a suitable site has been selected, the next step involves the procurement of cage materials. Essential components include structural materials like galvanized iron or High-Density Polyethylene (HDPE) pipes for frame construction, durable HDPE or nylon netting, and anchoring systems comprising mooring ropes, chains, and buoys. Safety features such as handrails, catwalks, and access platforms are also included to facilitate routine management activities and ensure worker safety.

6.3. Frame fabrication

Following material procurement, the process moves to frame fabrication, where the cage structure is designed and assembled. Cages may be circular, square, or rectangular, depending on the species to be cultured, the hydrological characteristics of the site, and the desired stocking density. Circular cages are generally preferred in open water environments due to their structural rigidity and efficient water circulation. Square or rectangular cages, on the other hand, are cost-effective and more commonly used in calm freshwater bodies like lakes and reservoirs. The frame must be corrosion-resistant, durable, and easy to maintain.

6.4. Floating the frame

The next step is floating the frame, which involves attaching flotation devices such as sealed plastic drums, HDPE pontoons, or foam-filled units to the structure. Proper placement and distribution of these floats are critical to maintaining the frame's balance and stability. The cage must remain evenly buoyant, even after adding accessories such as nets, catwalks, and fish stock. Regular inspection of floatation aids ensures that they remain functional and undamaged, which is vital for the structural integrity of the cage and the safety of both workers and fish.

6.5. Catwalk

After the frame is floated, a catwalk is installed along the perimeter of the cage. This serves as a stable working platform for routine activities like feeding, fish health monitoring, sampling, and net cleaning. Constructed from non-slip materials such as marine-grade aluminum, pressure-treated wood, or HDPE grating, the catwalk enhances operational safety. In larger or rougher water conditions, additional safety features such as handrails can be included.

6.6. Installation of cages

The installation of cages follows the catwalk fitting. At this stage, the inner net chamber is securely fixed to the frame using durable ropes, clips, or rings to prevent deformation or detachment during culture. Ensuring the net hangs properly without sagging is important to promote good water exchange, maintain dissolved oxygen levels, and allow efficient waste removal. Proper net installation also minimizes fish crowding and escape, while ensuring smooth swimming and feeding.

6.7. Selection of stocking materials

The selection of stocking materials plays a crucial role in determining the success of cage culture. Only healthy, active, and uniform-sized fingerlings or juveniles should be used. Preferred species include tilapia, carps, or sea bass, and they must be sourced from certified hatcheries that follow disease-free protocols. Before stocking, fish should be visually inspected for deformities, signs of stress, or disease. In some cases, a short quarantine period may be necessary to observe the fish and rule out potential pathogen carriers.The actual stocking phase involves gradually introducing the fingerlings into the cage system after acclimatizing them to the site's temperature, water chemistry, and flow conditions. Stocking densities must be tailored to the species' behavior, growth potential, and the carrying capacity of the water body. Overstocking can lead to competition, stress, and disease, while understocking results in underutilization of resources and lower yields.

6.8. Grow-out period

Once stocked, fish enter the grow-out period, which is the longest and most management-intensive phase. This period may last from 3 to 8 months or more, depending on the species, environmental conditions, and management practices. During this phase, farmers monitor fish health, feeding behavior, swimming patterns, and growth rates. Regular sampling is conducted to assess size, adjust feeding schedules, and estimate biomass. Early detection of stress or disease symptoms is critical for prompt intervention and maintaining optimal growth.

6.9. Supplementary feeding

Supplementary feeding is vital to achieving marketable size and healthy fish. Feed must be species-specific and nutritionally balanced in terms of protein, lipids, and energy. Floating feeds are ideal for surface feeders like tilapia, while sinking pellets are used for bottom dwellers like carps. Feed is typically administered 2 to 3 times a day, and careful monitoring of feed intake is necessary to avoid overfeeding or underfeeding. Monitoring Feed Conversion Ratio (FCR) helps ensure feed efficiency, cost-effectiveness, and water quality management.

6.10. Cage and stock maintenance

Throughout the culture period, cage and stock maintenance must be regularly performed. This includes cleaning fouled nets, inspecting the structural frame and flotation aids, and checking for disease outbreaks or physical damage. Timely maintenance helps prevent stock losses, maintains water quality, and ensures long-term sustainability of the operation.

6.11. Harvesting

The final stage is harvesting, which is carried out once the fish reach marketable size. Harvesting is typically done during the cooler hours of the day to reduce stress. Fish are gently collected using nets, sorted based on size and quality, and either sold live or processed based on market demand. A successful harvest marks the completion of the production cycle and paves the way for the next cycle of cage culture.

7. Feeding chart for cage culture of commercially important species

7.1. Indian Major Carps (IMC): Catla, Rohu and Mrigal

In cage culture, IMCs are typically fed with a combination of rice bran and oil cakes or formulated pellets (Ganesh and Rajanna). Feeding rates vary with fish size and environmental conditions.

Feeding schedule:

Fish weight (in g)	Feed type	Protein content (%)	Feeding rate (% of body weight/day)	Feeding frequency
1-100	Rice bran + oil cake (1:1 ratio)	~20	8-10	2 times/day
101-300	Formulated sinking pellets	20-22	6-8	2 times/day
301-500	Formulated sinking pellets	20-22	4-6	2 times/day
501-700	Formulated sinking pellets	20-22	3-4	2 times/day
701-900	Formulated sinking pellets	20-22	2-3	2 times/day
>900	Formulated sinking pellets	20-22	1.5-2	2 times/day

7.2. Nile Tilapia (*Oreochromis niloticus*)

Tilapia are efficient converters of feed and thrive in cage culture systems. Feeding rates should be adjusted as the fish grow.

Feeding schedule:

Fish weight (in g)	Feed type	Protein content %	Pellet size (mm)	Feeding rate (% of body weight/day)	Feeding frequency
3-5	Floating pelleted feed	32	0.8	6	3-4 times/day
5-25	Floating pelleted feed	28	1.2	4	3 times/day
25-100	Floating pelleted feed	28	1.8	3	2-3 times/day
100-250	Floating pelleted feed	24	3.0	3	2 times/day
250-400	Floating pelleted feed	24	4.0	2	2 times/day
>400	Floating pelleted feed	20	6.0	2	2 times/day

7.3. Pangasius (*Pangasianodon hypophthalmus*)

Pangasius is a fast-growing species suitable for high-density cage culture. Feeding practices should be carefully managed to ensure optimal growth and water quality.

Feeding schedule:

Fish stage	Feed type	Protein content %	Pellet size (mm)	Feeding rate (% of body weight/day)	Feeding frequency
Fry to Fingerling	Floating crumble feed	30-35	0.5-1.0	<10	4-5 times/day
Fingerling	Floating pelleted feed	25-30	1.5-2.0	5	2 times/day
Grow-out (3-5 mo)	Floating pelleted feed	25-30	3.0-4.0	3	2 times/day
6 months	Floating pelleted feed	25-30	4.0-6.0	2	2 times/day

Conclusion

Cage culture presents a highly promising opportunity for enhancing fish production and rural livelihoods in the Bundelkhand region, where traditional aquaculture practices are limited by seasonal water availability and land constraints. The region's vast underutilized reservoirs, pollution-free water bodies, and increasing support through government schemes like the PMMSY create a favorable environment for the expansion of cage-based aquaculture. By following scientific steps in cage installation, site selection, species-specific feeding protocols, and regular monitoring, fish farmers in Bundelkhand can significantly increase productivity and income. The adoption of species like Indian Major Carps, Tilapia, and Pangasius in cage systems—coupled with good management practices can help transform the region into a hub of sustainable inland aquaculture. With appropriate policy support, skill development, and infrastructure investments, cage culture can play a vital role in ensuring nutritional security and economic empowerment in Bundelkhand.

Sustainable aquafarming in salt-affected regions: A new horizon for Bundelkhand

Ganesh Kumar[1]*, Abhishek Srivastava[1], Pramod Kumar Pandey[1] and Thangaraj Priyadharshini[2]

Abstract: Inland salinization affects approximately 424 million hectares of top-soil globally, with India accounting for 6.72 million hectares of salt-degraded land and 0.2 million square kilometers of inland saline groundwater (ISGW). The Bundelkhand region in Central India, characterized by semi-arid conditions and extensive salt-affected soils (Usar/Reh), faces significant challenges in conventional agriculture and freshwater aquaculture. This article highlights the inland saline aquaculture as a sustainable alternative for utilizing salt-affected lands and saline groundwater resources. Inland saline aquaculture utilizes non-coastal saline groundwater for farming aquatic organisms, offering the dual benefit of production and land rehabilitation through salt reduction. Water quality parameters in Indian inland saline systems typically show salinity of 6.73 ppt, pH 8.48, and dissolved oxygen 5.02 mg L^{-1}. Suitable species for Bundelkhand's saline waters include euryhaline finfishes (Lates calcarifer, Sparus auratus), crustaceans (Litopenaeusvannamei, Macrobrachiumrosenbergii), and salt-tolerant freshwater species (Oreochromisniloticus, Chanoschanos). L. vannamei has emerged as the most successful species due to its rapid growth, high salinity tolerance, and market demand. The cluster farming model presents a promising solution for salt-stressed regions like Bundelkhand while supporting both local development and national economic growth.

Key words: Aquaculture, Bundelkhand region, Inland saline water and Cluster farming model

1. Introduction

Inland salinization has emerged as a significant global concern, affecting both land and water resources. According to data compiled from 110 countries, approximately 73% of surveyed land indicates salinity issuesimpacting an estimated 424 million hectares of topsoil (0–30 cm) and 833 million hectares of subsoil (30–100 cm). Notably, over 20% of the world's irrigated arable land falls within salt-affected zones. In the Indian context, nearly 6.72 million hectares of land suffer from salinity-related degradation, while inland saline groundwater (ISGW) extends across an area of roughly 0.2 million square kilometers. The Indo-Gangetic plains, a non-coastal agricultural heartland in northern India, are particularly affected covering an estimated 1.2 million hectares spread across seven states: Rajasthan (375,000 ha), Haryana (232,000 ha), Bihar (153,000 ha), Punjab (151,000 ha), Uttar Pradesh (137,000 ha), Madhya Pradesh (139,000 ha), and Jammu & Kashmir (17,000 ha). This widespread salinization has significantly diminished productivity in many of these regions.

In regions like Bundelkhand in Central India, land degradation has emerged as a major barrier to sustainable development in the primary production sector. Characterized by semi-arid conditions, erratic rainfall, poor water availability, and salt-affected soils, the Bundelkhand region presents significant challenges to traditional agricultural systems. With much of the land suffering from varying degrees of salinity and sodicity, conventional crop production often becomes economically unviable and agronomically unsustainable. Recent data reveal that Uttar Pradesh encompasses approximately 21,989 hectares of saline soils alongside a substantial 1,346,971 hectares of alkaline soils, while Madhya Pradesh accounts for around 139,720 hectares of alkaline soils.A considerable portion of these salt-

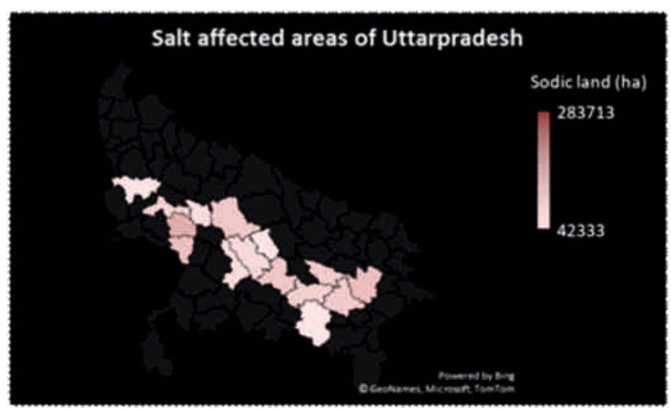
College of Fisheries, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Tuticorin, Tamil Nadu, 628 008, India
**E-mail: ganeshkaruppaswamy@gmail.com*

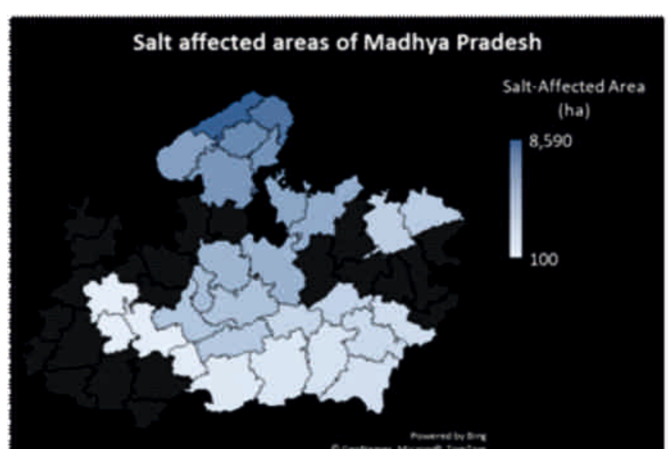
affected lands falls within the Bundelkhand region, which is already grappling with low rainfall, high evapotranspiration, erratic climate patterns, and poor groundwater quality. The widespread occurrence of salt-affected soils locally known as Usar or Rehimpairs soil health, reduces crop productivity, and limits livelihood options for the farming communities. High concentrations of soluble salts or exchangeable sodium not only reduce soil fertility and water infiltration but also negatively impact plant growth, leaving large tracts of land underutilized or barren. In such landscapes, the scope of conventional agriculture as a sustainable livelihood option is severely restricted. Parallel to the limitations in agriculture, traditional freshwater aquaculture practices too face hurdles in these saline environments. Poor-quality groundwater, high evaporation rates, and saline seepage render standard aquaculture techniques inefficient and ecologically unsuitable. As a result, both food production and income generation suffer in these salt-stressed areas. However, in recent years, the concept of saline or salt-tolerant aquaculture has emerged as a potential game-changer. By identifying specific niches or Inland saline areas within the landscape areas where saline water resources are available but not excessively degraded it becomes possible to design region-specific aquaculture systems that utilize salt-tolerant species, brackish water adaptations, and controlled input strategies. This paradigm shift from trying to adapt the land to conventional systems, to adapting systems to land constraints offers a promising approach for Bundelkhand and similar regions. With thoughtful integration of inland saline aquaculture technologies, the region can transform salt-affected lands from a liability into an opportunity, contributing to food security, livelihood diversification, and land-use optimization.

2. Classification of inland saline soil

U.S. Salinity Laboratory (USSL) classifies soils based on the electrical conductivity of the soil saturation extract (ECe). Salt-affected soils are typically classified using indicators such as ECe, exchangeable sodium percentage (ESP), soil pH, and sodium adsorption ratio (SAR). Based on these parameters, three main categories of salt-affected soils are recognized:

- Saline soils, with ECe> 4 dS m^{-1}, pH < 8.5, and ESP < 15, typically restrict plant growth but may still be manageable for certain types of aquaculture, where crop dependency is limited.
- Saline-sodic soils, where ECe> 4 dS m^{-1} and ESP > 15, often suffer from both osmotic stress and deteriorated soil structure, making them less suitable for conventional farming or aquaculture unless amended.
- Sodic soils, with ESP > 15 and ECe< 4 dS m^{-1}, and a pH between 8.5 and 10, have poor permeability and aeration, challenging water retention and infiltration properties, which are crucial for aquaculture pond construction and maintenance.





3. Inland saline aquaculture:

Inland saline aquaculture refers to the farming of aquatic organismsboth plants and animalsusing saline groundwater found in non-coastal (inland) areas. Unlike traditional coastal aquaculture, this method utilizes underground saline water resources. A significant advantage of this approach is its ability to lower the salt content in groundwater, thereby improving soil quality and enhancing the potential for agricultural activities in adjacent lands.However, successful inland saline aquaculture is feasible only in regions with substantial reserves of saline groundwater. In Indian conditions, the water quality parameters recorded during culture operations have shown average values of 30.27 °C (temperature), 6.73 ppt (salinity), 8.48 (pH), 5.02 mg L^{-1} (dissolved oxygen), 1544.83 mg L^{-1} (total hardness), 217.29 mg L^{-1} (total alkalinity), 177.22 mg L^{-1} (calcium), and 332.33 mg L^{-1} (magnesium).While these conditions are favorable for specific euryhaline species adapted to such environments, they can be unsuitable for many conventional freshwater aquaculture species. Elevated salinity, hardness, and mineral content may negatively impact the growth, survival, and reproduction of commonly farmed species, thereby limiting the scope of aquaculture in these regions unless proper species selection and adaptive management strategies are implemented.

4. Species with culture potential in salt-affected inland waters of Bundelkhand

The presence of inland saline groundwater in various salt-affected areas presents an opportunity for alternative and sustainable aquaculture practices. Utilizing this saline resource for fish and shellfish culture remains largely untapped in the region, despite global and national success stories demonstrating its potential.Globally, a variety of aquatic species have been successfully cultured in inland saline water. These include euryhaline finfishes such as *Lates calcarifer* (Barramundi), *Sparus auratus* (Gilthead seabream), *Dicentrarchus labrax* (European seabass), and *Argyrosomus japonicus* (Japanese meagre), all known for their high salinity tolerance. Crustaceans like *Penaeus monodon, Litopenaeus vannamei,* and *Marsupenaeus japonicus* are commercially valuable and well-adapted to saline environments. Molluscs such as *Saccostrea glomerata* (Sydney rock oyster), diadromous species like *Oncorhynchus mykiss* (Rainbow trout), and salt-tolerant freshwater species including *Oreochromis niloticus* (Nile tilapia), *Bidyanus bidyanus* (Silver perch), and *Macrobrachium rosenbergii* (Giant freshwater prawn) have also shown great potential. In the Indian context, species such as *Lates calcarifer, Pangasianodon hypophthalmus, Chanos chanos* (Milkfish), *Mugil cephalus* (Grey mullet), *Etroplus suratensis* (Pearl spot), and *Cyprinus carpio* (Common carp) are among the most commonly cultured in inland saline environments. Shellfish species like *Litopenaeus vannamei* and *Macrobrachium rosenbergii* are also reared in saline groundwater systems in India. Among these, *L. vannamei* (Pacific white shrimp) has emerged as the most widely adopted species in inland saline water aquaculture worldwide. Native to the Pacific coast from Northern Peru to Mexico, it was introduced in India on a pilot scale in 2009 and rapidly gained popularity due to its fast growth, high salinity tolerance, and market demand. It is now cultured successfully in inland saline areas, particularly in Punjab and Haryana, which exhibit water quality profiles comparable to certain salt affected regions of Bundelkhand.

Based on the water quality criteria observed in salt-affected areas of Bundelkhand, many of these species can be considered potential candidates for aquaculture development. However, it is important to note that species-specific tolerance and performance may vary significantly depending on localized water quality parameters, such as salinity levels, ionic composition (e.g., Na^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}), total alkalinity, hardness, pH, and temperature regimes. Therefore, systematic, location-specific research is necessary to evaluate species performance under the unique conditions of the Bundelkhand region. Studies focusing on physiological adaptability, growth performance, feed conversion efficiency, and reproductive viability are needed to determine the most suitable species combinations. In addition, long-term monitoring of water and soil quality, coupled with site-specific aquaculture models, can facilitate sustainable management practices.

Source:https://indiabiodiversity.org

5. Potassium level monitoring in inland saline water aquaculture

Inland saline waters, especially in regions like Bundelkhand, possess a unique ionic composition that differs significantly from natural seawater. While calcium and magnesium levels are generally elevated, potassium is often deficient, making it a critical limiting factor for aquaculture in these areas. Potassium is essential for osmoregulation, muscle function, and metabolic processes in aquatic species. Its deficiency can negatively impact not only shrimp such as *Litopenaeus vannamei*, but also a broad range of euryhaline and salt-tolerant species. Prominent candidate species for inland saline aquaculture include finfishes like *Lates calcarifer* (barramundi), *Sparusauratus, Dicentrarchus labrax, Argyrosomus japonicus*, and diadromous species such as *Oncorhynchus mykiss* (rainbow trout). Salt-tolerant freshwater species such as *Oreochromis niloticus* (tilapia), *Bidyanus bidyanus, Chanos chanos* (milkfish), *Etroplus suratensis, Mugilcephalus,* and *Cyprinus carpio* (common carp), along with shellfishes like *Macrobrachium rosenbergii* and molluscs such as *Saccostrea glomerata,* also show considerable potential for culture in these waters. To support optimal growth and survival of these species, potassium supplementation is necessary. Prior to stocking, the potassium concentration in pond water should be adjusted using potassium chloride (KCl) to reach approximately 50 percent of the salinity level found in natural seawater. Regular monitoring is essential, particularly when new water is introduced or after rainfall events, to ensure that potassium levels remain within the desired range.

The amount of potassium required for correction can be calculated using the formula:

Required K^+ (mg/L) = (10.7 × Desired Salinity) – Available K^+ in Inland Saline Groundwater (ISGW).

This helps in fine-tuning the ionic profile of the water to create a favorable environment for aquaculture.

6. Future prospects

Inland saline aquaculture represents a sustainable and economically attractive solution for regions with salt-affected land and groundwater, especially where conventional farming is no longer feasible. Shrimp farming, particularly with species like *L. vannamei,* has proven to be highly profitable due to its short culture cycle and strong market demand. However, expanding the culture system to include other resilient and salt-tolerant species broadens its applicability and enhances ecosystem stability and food security. The use of inland saline groundwater not only supports aquaculture but also contributes to land rehabilitation by preventing waterlogging, improving soil structure, and curbing secondary salinization. A promising development strategy is the cluster farming model, where large tracts of saline land are organized into cooperative production units. This approach enables shared infrastructure, improved input efficiency, and reduced production costs, while also generating rural employment and improving economic returns. Success stories from states such as Punjab, Haryana, and Maharashtra offer valuable insights and frameworks that can be adapted to Bundelkhand. With the right technical support, ionic management (especially potassium), and careful species selection, inland saline aquaculture can emerge as a transformative livelihood opportunity in the region, utilizing otherwise unproductive land and contributing to both local development and national economic growth.

The formulation of fish feed on the farm

Sudhanshu Raman*, Abhishek Srivastava, Girija Saurabh Behere and Ganesh Kumar

Abstract: A practical and economical way to satisfy the unique nutritional requirements of cultured fish species is to formulate fish feed on-farm. This article emphasizes the crucial elements and procedures needed to create species-specific feeds that are nutritionally balanced and made with ingredients that are readily available in the local area. Important topics covered include nutrient requirements (particularly protein-energy balance), ingredient selection, feed composition calculations, formulation techniques like Pearson's square, and useful feed preparation and application methods. To guarantee feed palatability, digestibility, and environmental sustainability, a focus is placed on striking a balance between scientific principles and practical skills. By producing high-quality feed, the method helps farmers increase fish growth, survival, and farm profitability.

1. Introduction

The process of choosing and combining the right feed ingredients to create a diet that contains the necessary amounts of vital nutrients is known as feed formulation. The nutrient needs of the cultured organisms cannot be satisfied by a single ingredient. A compounded ration that is nutritionally balanced, palatable, and simple to store can be made by choosing different ingredients in the right amounts. The creation of diets that contain all necessary nutrients and the appropriate control of numerous aspects pertaining to diet quality and intake are necessary to provide different aquaculture species with enough nutrition. Therefore, creating the perfect diet requires a lot of information. Cultured organisms can reach their full potential in terms of growth, reproduction, and survival when they are properly nourished. Protein: Energy is the most crucial factor in diet formulation, and it must be balanced to produce higher-quality feed that is both cost-effective and environmentally friendly. To create realistic fish diets, one must comprehend the following terms: crude protein level, energy level (which can be expressed as digestible energy (DE) or metabolizable energy (ME), specific amino acid levels, crude fiber level, and ash level. The main considerations in feed formulation are nutritional requirements, ingredient composition, digestibility, nutrient availability, and additives.

2. Pre-requisite for fish feed formulation:

Attributes to be noted prior to the feed formulation of fishes are given below

The above-mentioned information should be critically considered before making pellets which may otherwise affect the quality and economics of the feed.

3. Criteria for selection of feed

Rice bran and oil cake are the primary supplemental feeds used by fish farmers in our nation. Apart from these two, farmers utilize feed materials that are not profitable and some of the ingredients are harmful to the ecosystem of ponds. Increasing fish weight gain is the primary goal of supplemental feeding.

College of Fisheries, Datia, Rani Lakshmi Bai Central Agricultural University
**E-mail: sudhanshu147@gmail.com*

Therefore, the following crucial factors should be taken into account when choosing aquaculture feeds.

4. Nutritional requirement of fish:

A balanced diet is necessary to have a healthy fish that grows quickly. But of all the nutrients, protein is needed in significant amounts. Because of this, the term "protein demand" is often used to describe fish's nutritional needs. The majority of the other nutrients, such as minerals, lipids, and carbohydrates, are found in the other ingredients used to make fish feed. Therefore, if the demand for protein is met, there won't be a significant lack of other nutrients. Fish nutritional needs vary by species and age. According to studies, carps have a 35–40% nutrient (protein) requirement. Therefore, the provided feed should contain 35–40% protein to achieve the highest yield. Nevertheless, fish only get 5–15% of their total protein needs from their natural diets. Given all of the information above, farmers ought to make feed that contains 25–30% protein.

Requirements for Carp feeds					
S. No.	**Characteristic**	**Larval feed**	**Fry Feed**	**Grow-out Feed**	**Brood Stock Feed**
1.	Moisture, percent by mass, Max	10	10	10	10
2.	Total crude protein (Nx6.25), percent by mass, Max	35	35	25	25
3.	Crude fat or ether extract, percent by mass, Max	8	8	6	6
4.	Crude fiber, percent by mass, Max	6	8	8	8
5.	Acid insoluble ash, percent by mass,	2.5	3	3	3
6.	Max Gross energy, Kcal/kg, Min	4000	3500	3000	3000
7.	PUFA (n3+n6)	0.5%	0.5%	0.5%	1%

5. Calculating nutritional composition of feeds

The studies on commonly used fish feed ingredientsavailable in our country shows that the ingredients contain highnutrient content. The nutrient analysis of some of theingredients are given below.

Protein is the only nutrient that is estimated when determining the overall nutritional content of fish feed. The general unitary method makes it simple to determine the nutrient content of feed made from multiple ingredients. The method for figuring out feed's protein content is displayed below. Assume that one kilogram of feed is to be made with rice bran, fish meal, groundnut oil cake (GNOC), and flour as a binder. The ingredients to be used are as follows: 10% fish meal, 40% GNOC, 40% rice bran, 7% flour, and 3% vitamin and min premix. Here, it is possible to calculate the protein content of the feed made with these ingredients as follows:

Name of the ingredients	Nutrient content (%)		
	Protein	Carbohydrate	Lipid
Rice Bran	12.6	37.5	11.3
Wheat Bran	15.5	37	5.5
Groundnut cake	48	30	13.8
Mustard oil cake	30.33	34.38	13.44
Coconut cake	17	47	5.6
Tapioca flour	4	86	1.3
Broken rice	13	70	4.5
Fish Meal	60	11.6	3.7
Duck Weed	14.02	60.88	1.92

Ingredients	Protein content (%)	Does used (%)	Required quantity (g)	Protein available in feed (%)
Fish Meal	60	10	100	6
GNOC	48	40	400	19.2
Rice Bran	12	40	400	4.8
Flour	4.5	7	70	0.315
Vitamin & Mineral	-	3	30 g	-
Total		100	1000 g	30.315

6. Methods of feed formulation

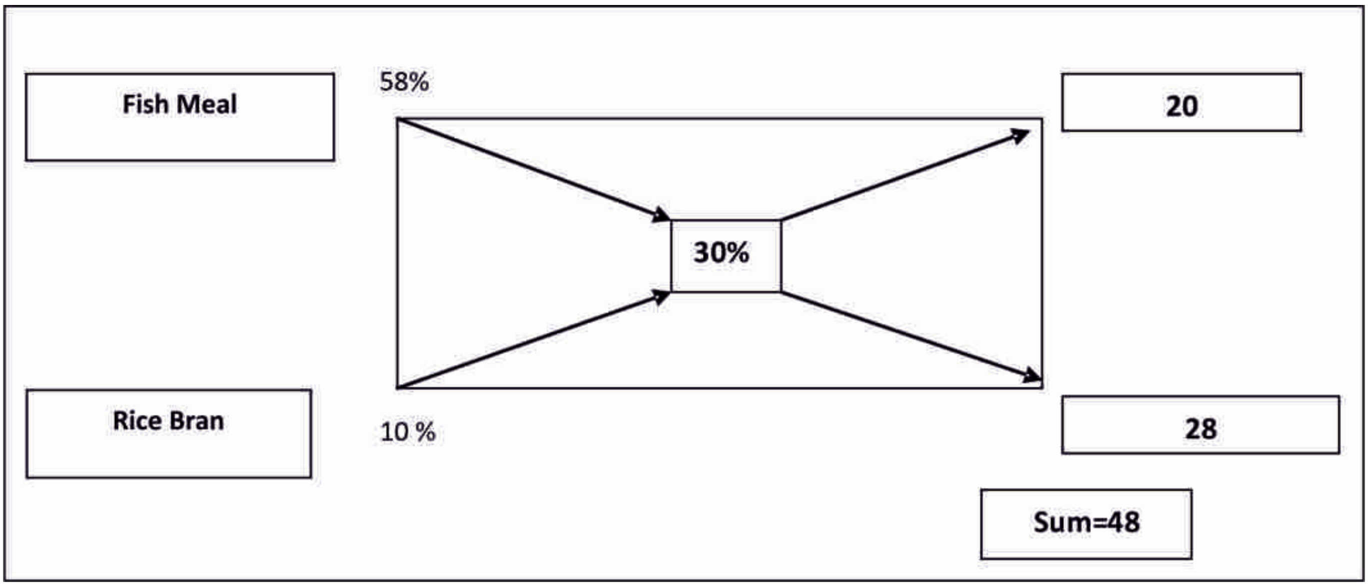
Pearson's square method

Example 1: - Two ingredients:

Determine how much rice bran (CP:10%) and fish meal (CP:58%) are needed to make a feed that has 30% crude protein.

1. Draw a square
2. Put the desired amount of protein in the square's center. 30% in this instance.
3. Put the two ingredients and their respective protein contents in the square's two left corners.
4. Determine the difference between the two ingredients' crude protein contents (58 and 10), then note the result (48) close to the square's lower left corner.
5. Subtract the desired protein level (30%) of the feed from theprotein content of each ingredient. Ignore positive ornegative signs. The difference between percentages ofprotein in rice bran(10%) and in the feed (20%) represents theamount of fish meal needed. The difference between fishmeal(58%) and the feed (28%) represents the amount of rice branneeded.
6. Add the differences obtained at the right corners of thesquare (20 and 28) and record their sum (48) near thebottom right corner. The sum in the right corner shouldequal the difference in protein content recorded near thelower left corner of the square.
7. Divide the differences obtained in step 5, which were 20 and28 by the sum obtained in

step 6, which was 48 and thenmultiply each by 100 to obtain the percentage of eachingredient needed for the feed, Thus, 41.67 Kg of fish meal and58.33 Kg of rice bran are combined to make 100 Kg offish feedcontaining 30% crude protein. The feed can also bedescribed as being composed of 42% fish meal and 58% ricebran.



Example 2: - More than two ingredients:

Using fish meal (C.P. 60%), GNOC (48%) De-oiled bran (C.P. 15%) and tapioca (C.P. 4%) a prawn diet with 32 % crude protein can be prepared as follows:

The first should be consisted of ingredients whose crude protein % is higher than the requested, second should be consisted of ingredients whose crude protein is lower than the request followed by average of their protein content.

First group:

De-oiled rice bran (15.6) + Tapioca (4) = 19.6%

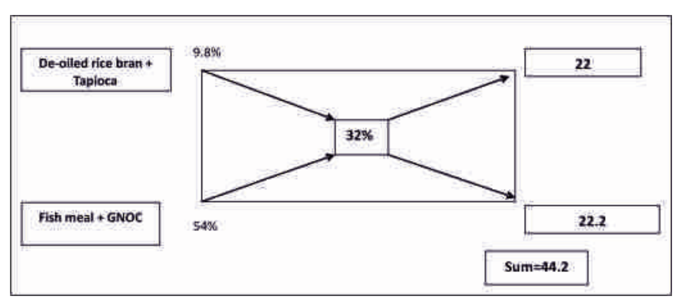
Average = 9.8 %

Second group:

Fish meal (60 %)+ GNOC (48 %) =108%

Average= 54 %

Now the average protein contents are put on the two left corners of the square, and the rest is same



Now add the figures on the right-hand side corners of the square: -

$$\text{Deoiled rice bran+Tapioca} = \frac{22}{44.2} \times 100 = 49.8\%$$

$$\text{Fish meal + GNOC} = \frac{22.2}{44.4} \times 100 = 49.8\%$$

7. Feed preparation

Fish farmers can easily prepare their own feed by combining various ingredients. Feed should ideally be prepared using a feed pelleting machine. Here is a brief description of the methods used to prepare mixed fish feed.

At least 20 to 24 hours before using, the necessary amount of oil cake should be soaked in twice as much water, and the oily water from the mixture's surface should be thrown away.

Fish meal and rice bran need to be properly sieved.

If using broken rice, it should be boiled.

In a container, combine all the ingredients. Then, boil the flour in the necessary amount of water to make it sticky (oil cake soaked in water). Combine the ingredients to create a paste, and then make small feed balls.

8. Feed application

The majority of fish typically feed during the day. The daily ration should therefore be split into two parts. The first part should be applied between 10 and 11 a.m., and the second part between 3 and 4 p.m. To prevent feed loss and maintain the quality of the water, the fish should be fed in feed trays. The feed trays must be positioned one foot below the water's surface in order to feed carp. Feed should be applied every day in a few specific areas of the pond if a feed tray is not feasible for any reason.

Simplified system of feeding strategy for the farmer		
Body weight of fish	**Amount of feed**	**Feeding frequency**
Upto- 50gm	3.0 gm	3 times/day
50-100 gm	4.5 gm	2-3
100-250 gm	5.0 gm	2
250-500 gm	6.5 gm	2
500-750 gm	8.0 gm	2
750-1000 gm	10 gm	2
>1000 gm	12 gm	2

9. Conclusion

The technical aspects of feed manufacturing are often considered as more of an art than a precise science, it must be experienced in person in order to fully understand the feed preparation methodology. This is due to the fact that the production of high-quality aquafeed involves many factors that are not always predictable or controllable by theoretical knowledge alone, including moisture content, particle size, binding properties, machinery performance, and ingredient behavior during processing.

While scientific principles guide the formulation of nutritionally balanced diets, the actual manufacturing process demands practical expertise to adjust and fine-tune equipment such as mixers, grinders, pelletizers, and extruders to ensure consistent feed quality.

A solid foundation in both the theoretical aspectssuch as nutritional requirements, ingredient compatibility, feed conversion ratiosand the practical skills are necessary for instantly solving issues during the feed production process. The above-mentioned skill and knowledge are necessary to produce optimal feed that satisfies the dietary and physical needs of a particular fish species. In order to keep our fish nutritionally adequate, the finished fish feed should also be physically stable, palatable, and appropriate for the aquatic environment.

Beyond fishmeal: Protein to profit

Joynal Abedin[1,2]* and Siddhant Boruah[2]

Abstract : Protein boosts immunity and increases fish growth. It is essential to aquaculture, which makes fish farming a sustainable and profitable business. Fish species and environmental factors affect the dietary protein needs, which must be balanced in feed formulation. Essential physiological processes like organ growth, muscle development, and cellular repair are supported by dietary protein. For the enzymatic interactions and complex biochemical pathways, protein plays a important role. Complete amino acid profiles are provided by premium animal proteins, such as fish meal, which makes them extremely digestible and biologically valuable. On the other hand, plant proteins, are less digestible, contain antinutritional factors, and frequently lack essential amino acids, despite being more economical and environmentally friendly. As intensive aquaculture relies on specially prepared feeds, it is essential to maintain the right protein levels to optimize fish performance and financial gains. The protein-to-energy ratio, species-specific amino acid balance, and effective feed processing techniques must all be carefully considered in order to maximize the use of protein in aquafeeds.

1. Introduction

The role of protein in fish feed is important as it makes aquaculture a successful venture by enhancing the growth rate and boosting fish immunity. The protein requirement of fish and other aquatic animals depends on their protein requirement, the environmental conditions they live in, and the cost-effectiveness of feed. All these must be carefully considered to ensure sustainable aquaculture. Among the various importance of protein in fish feed, some of the key physiologically essential roles are highlighted graphically in Figure 1.

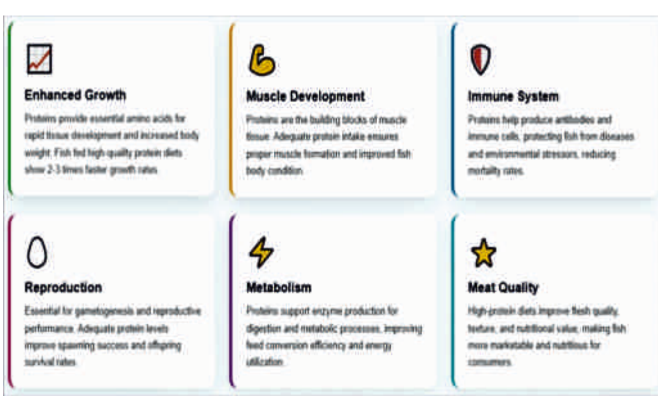


Figure 1. Graphical illustration of key physiological roles of dietary protein in fish feed

The knowledge of how dietary protein is utilized by the body involves a complex interaction of different physiological processes and the interplay of enzymes. Protein in fish diets is associated with many important developmental processes, not only contributing to their growth but to their general well-being. Fish protein is needed for muscle development, supporting organ growth, and aiding in cellular repair. The amino acid profile, ease of digestion, and protein's availability in the body determine the biological value of a protein source and high-quality animal proteins, such as fish meal, provides all the necessary amino acids needed by fish. When fish digest dietary protein, various enzymes break them down into amino acids, which are then used to synthesize essential proteins needed by the fish body.

Although plant proteins are affordable and environmentally friendly, they often pose challenges because they lack balanced amino acids profile, have antinutritional factors, and lower digestibility compared to animal proteins. To optimize protein utilization in fish feed, attention should be given to the protein-energy ratio (P:E ratio),balanced amino acids

[1]*Department of Aquaculture, Faculty of Fisheries Science, Assam Agricultural UniversityRaha, Nagaon–782103, Assam, India*
[2]*National Fisheries Development Board, Northeast Regional Centre, Guwahati-781022, Assam, India*
**E-mail: abedinjoy@rediffmail.com*

composition for specific fish species, and adoption of appropriate feed processing techniques.

Since intensive aquaculture systems rely completely on formulated feed, balanced protein in fish feed formulation is very important. Accurate protein nutrition enhances the growth, feed usage, making it economically feasible.

Fate of protein in fish feed

In aquaculture, fish meal is a major challenge from an economic sustainability point of view hence, researchers are finding suitable fish meal alternative that can aid in fulfilling all nutritional requirements of the fish. Microalgae protein offers distinct advantages, as they are rich in protein content with all essential amino acids and they can be produced easily without harming the environment.

Incorporating microalgae partially or fully into fish diets of Oreochromisniloticus has shown to promote better growth performance, reduce feed intake, and enhance feed conversion efficiency. These effects suggest that fish are able to convert feed into body mass more effectively. Additionally, microalgae-based supplements have been associated with lower lipid accumulation and increased muscle protein synthesis, indicating that they may offer superior nutritional value compared to conventional feed ingredients.

Alternative protein source to microalgae includes insect meal, single-cell proteins, and plant-based protein concentrates. However, their suitability must be evaluated based on the specific nutritional requirements of the target species and the overall production objectives. Regardless of any selected alternative protein source, it is essential to understand its nutrient profile, processing requirements, and the potential impact on fish health and performance. With the evaluation of the impact of changing environment on the aquaculture sector reveals important economic implications. By providing proper nutrition to farmed fish not only decreases the cost of feed but also enhances feed quality and market value of the harvested fish. Inclusion of fish feed with high-protein ingredients helps improve flesh firmness, colour, and nutrient composition, ultimately leading to improved marketability and higher profits for farmers. In aquaculture, the evaluation criteria for the use of protein should not be only its costs but also the benefits it offers, such as enhanced growth rate, improved fish survival, and enhanced product quality, which collectively contribute to increased profitability. Using targeted protein optimization can boost the production efficiency and strengthen the economic position of aquaculture. Experts today are paying more attention to the environment while choosing feed protein sources, and traditional fish meal production is being questioned due to fears of overfishing, pollution, and large carbon emissions. Transitioning to alternative sustainable proteins is a key strategy to lower the aquaculture industry's environmental impact, without compromising its efficiency or quality. Eco-friendly protein source reduces greenhouse gases, needs less land, and generates less waste, which in turn leads to sustainable aquaculture that aligns with global sustainability goals.

Challenges in Technology and Nutritional Optimization

Although alternative proteins have promising potential, major problems need to be addressed to match the nutritional value and digestibility of conventional protein sources to make the best use of nutrients and minimize waste. During fish feed formulations, protein structure, processing methods, and formulation techniques should be carefully considered. Due to digestibility challenges related to plant proteins and novel proteins, special techniques, enzymes, and tailored feed formulations are often used to mitigate these nutritional limitations.

Use of alternative protein sources

To enhance alternative protein source utilization requires knowledge about how different fish species digest this protein, its quality, and understanding manufacturing of technologies to maximize its utilization in fish feed. For alternative proteins to be effective in commercial aquaculture, developers must ensure balanced amino acid profiles, reduce antinutrient factors, and integrate strategies that increase digestion while enabling cost-effective scale-up of production. The challenges mentioned are still being studied, and the outcomes will guide in adoption of sustainable substitutes for conventional feed ingredients. New findings suggest that increasing protein levels in diets can improve feed consumption and weight gain in grass carp and leopard coral grouper. Previous research found that adding the appropriate amount of protein promotes the muscle fiber development and, in turn, enhances the production of healthy fish. The amount of protein fish receives influences more than just their growth rate. It also influences their health, immune function, feed efficiency, and overall production performance. Good quality protein is required to support the immune system and increase stress resistance in fish. They also examine possibilities for using insect meals as a protein source, highlighting their promising role in improving immune function. Protein plays a crucial role in helping brood stock development by improving growth, reproductive success, and the general well-being of brooders.

Figure 2 explains the common alternative sources of protein widely used in aquaculture. Studies have shown that correct amounts of dietary protein affect the development of fish gonads, fecundity, and their quality. Research on female Pengzecrucian carp (Carassiusauratus var. Pengze) suggests that higher protein (35.73%) in the diet leads to improved growth.

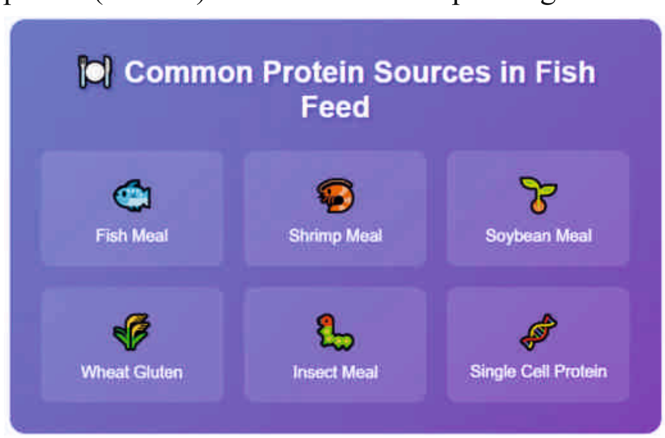


Figure 2. Common sources of protein in fish feed

The protein journey across fish life stages

According to studies, protein supplementation appears to boost reproductive performance. Highest fecundity was observed in rohu (Labeorohita) brood stock when they were fed with 250 g/kg protein diet, while feeding more protein to longfin yellowtail boosted both fecundity and hatching rate. However, researchers found that excessive protein in a diet can reduce a female climbing perch's reproductive capacity. All these findings underline the role of balanced diets for brood stock management in aquaculture.

Nutritional requirements for fish fry differ widely among fish species and are often challenging to meet their requirement. Several research reports have found that protein levels in feed directly affect how well animals grow, convert feed to energy, and their general health from birth to weaning. In the case of Mystusgulio fry, bioenergetic studies indicate a protein requirement of approximately 409–411 g/kg of feed. However, a level of 400 g/kg has been found sufficient to achieve optimal growth. In fry of rainbow trout, researchers found that the lysine requirement increases along with an increase in total protein in their diet. Lysine levels must be 16.8 to 23.4 g/kg of dry matter if the protein is kept between 310 and 469 g/kg of total diet weight. A study on Channastriata fry showed that 550 g/kg of dietary protein boosts growth and reduces fat content in the body.

To achieve maximum growth in rainbow trout (Oncorhynchusmykiss), at least 6.1% of their protein need to be lysine, along with sufficient levels of arginine. Nevertheless, we should recognize that adding more protein than necessary to diets can cause additional nitrogen waste and harm to nature; therefore, formulating a balanced diet is essential for sustainable aquaculture. Both fish and people benefit from the quality of protein in fish feed. Recent research showed that the type of protein fed to fish influences both their growth and the nutrient content of final fish meat. They also found that fish proteins may contain anti-inflammatory components that could manage metabolic issues in obese individuals, suggesting a wider benefit of quality protein in fish feed. Maintaining the health and development of fish while incorporating new protein sources is a serious challenge for the aquaculture industry. Even while fishmeal is the traditional protein source, environmental and economic factors are driving researchers to search for other alternatives. These alternative protein sources must be carefully evaluated for their potential impacts on gut health and immune function.

Captive breeding and seed production of yellowtail catfish (*Pangasius pangasius*)

Dorothy M.S.[1] and Sudhanshu Raman[2]*

Abstract: The yellowtail catfish (*Pangasius pangasius*) is a native to riverine species of the Indian subcontinent with high aquaculture potential due to its fast growth, air-breathing capacity, and tolerance to low dissolved oxygen. Its large-scale culture is still significantly hampered by the lack of quality seed. This article describes the effective method for using synthetic hormonal induction to breed *P. pangasius* in captivity and produce seeds. Using hormones like Ovaprim, Ovatide, or WOVA-FH at recommended dosages, sexually mature brooders were identified based on secondary sexual characteristics and induced to spawn. When fertilized eggs were incubated in flow-through systems, up to 70% of them hatched. Before progressively switching to prepared feeds, larvae were fed live zooplankton and *Artemia nauplii*. The fry demonstrated good adaptability to pond and tank systems and reached fingerling size in 4–8 weeks. Because of its boneless fillet and desirable flesh quality, yellowtail catfish are in high demand, and this protocol shows that captive breeding and mass seed production are viable methods of improving aquaculture.

1. Introduction

Pangasius pangasius is locally known by different common name such as deshipangus, pangus catfish, shark catfish or yellowtail catfish. This fish is native to Indian sub-continent and widely distributed in its major river system and in the natural water bodies of Myanmar. Owing to its rich nutritional value, mild flavour and delicate texture flesh, pangasius are on high demand in global market and therefore, widely introduced in different parts of the world for aquaculture purpose. In India, it is abundantly found in the major east coast flowing major river and reported grow upto 20-25 kg in its natural wild system.

Food and feeding habit

Yellowtail catfish is a bottom dweller and is omnivorous in its feeding nature. It prefers to feed on algae, soft aquatic plants, plankton, insects, decaying animals and vegetative matters. The adult or large size fish are carnivorous and voracious feeder and preys on snails and other mollusks. Hence, it is often considered as a good candidate species for controlling molluscan population in pond system. Like other Pangasiid species, this catfish is a migratory riverine fish that makes long-distance migrations upstream for refuge and spawning habitats and downstream for feeding and nursery habitats.

Prospects of aquaculture

Pangasius was introduced in India for aquaculture purpose during 1995-96 from Thailand through Bangladesh and since then its culture have immensely grown across the country. Pangus catfish is found to be a good aquaculture candidate due to its qualities like fast growth, air breathing, and tolerance to low dissolved oxygen. Fish can be farmed both at small scale level and large commercial level with high economic benefits and compatible in both monoculture and polyculture

[1]*National Fisheries Development Board, NERC, Guwahati-781022, Assam*
[2]*College of Fisheries, Datia, Rani Lakshmi Bai Central Agricultural University*
**E-mail: sudhanshu147@gmail.com*

system. It can be grown in pond and cages at high stocking densities. In pond system, ideal size of >0.4 ha and stocking density of about 10,000-15,000/ha (>100 g juvenile) are recommended. They recommended periodical water replenishment to maintain good water quality for better growth and higher survivability.

Being a voracious feeder, this catfish accepts any form and type of feed (floating, sinking or slow sinking) and can be fed with rice bran and farm made feeds for economical purpose in small scale fish farms. The scientists recommended to feed this fish with pelleted floating feeds containing about 30-32% protein and at about 3% body weight daily feeding in confined rearing for desirable yield and production. Pangas catfish can grow upto one kg size during one year growing period in the above condition with high survival rate (>90%).

Maturity and breeding nature

In its natural system, this fish attains sexual maturity in about four years of age and is a monsoon breeder that breeds when the water is warm and flooding. Spawning starts early in the monsoon season (between July and October) and peak during July. Wild broodstock typically spawn twice annually. In Indian water system, spawning starts in June or with the arrival of monsoon rain in the main stretch of river bed or migrates to adjoining rivers or inundated areas during monsoon. A mature female fish lay about 1.5 lakhs eggs/kg body weight. In spite of having huge potential for aquaculture, there is lack of fish seed for this catfish due to its inability to naturally spawn and reproduce under captive system. Fortunately, it matures and breeds under captive condition through hormonal inducement.

Captive breeding and seed production

Brood stock rearing and management: In captivity, the female fish take at least three years to reach sexual maturity (over 3 kg in weight), while males mature in their second year. Males mature earlier than females under captivity. For preparation of breeding, scientists have recommended to rear broodstocks of 3-4 years in low density (>1000/ha) while feeding @ 2% body weight regularly with high protein pelleted feed for about 3-4 months prior to breeding season. Prior to induced breeding, the selected brooders should be maintained in breeding pool with continuous aeration and water flow.

Sexual Dimorphism in matured brooders: Yellowtail catfish brooders do not differ in exterior colour but displayed physiological differences such as display of a swollen and soft abdomen with pinkish and protruding muscular genital opening in female. A pattern of black spots on the side of chin of female also differentiate it from the male. On gentle pressure on lower abdomen, female released eggs while male oozes out milt from vent. The readiness of female brooders can also be checked by simple catheterisation wherein the matured eggs can be seen shiny pale yellow in colour of uniformed sizes. The dorsal surface of the pectoral fin on matured male has rough surface while that of female was soft and smooth

Distinguishing features of mature male and female

Female	Male
Swollen and soft abdomen with pinkish and protruding muscular genital opening	Slender abdomen
A pattern of black spots on side of chin	No black spot
Smooth pectoral fin	Rough pectoral fin
On gentle pressure, female released eggs	Male released milt

Photosource: https://www.youtube.com/watch?v=411KymyUZHk

Step by step procedures for Induce breeding using synthetic hormones

- Selected healthy matured male and female brooders by its identifying features at the ratio 1 male:2 female (generally males are smaller than females as they mature earlier then female). Preferably female should be of about 1.5 kg size for better result and easy handling.
- Keep it in well showered and aerated water tank
- Carefully handle the brooders, take weight while wrapped in soft cloth or bag to prevent slipping and falling.
- Prepare the hormones based on the body weight of the fish and keep it ready in a syringe with a clear gradient of 0.1 ml.
- Firmly hold down the female fish and inject intramuscularly above the lateral line on the caudal peduncle with synthetic hormone like Ovaprim/Ovatide @ 1ml/kg body weight. Males need not be injected.
- Chaudhary (2022) used single dose of WOVA-FH, injected intramuscularly for both female and male @ 0.5-2.5ml/kg and 0.5-1.5ml/ kg respectively and reported upto 56% hatching rate.
- Release the injected brooders carefully into the breeding tank.
- In about 16 hrs, courting and water splashing will start where male chase the females for mating. As the fish will be manually stripped for eggs and milt, this signal readiness for stripping. Bright pinkish color genital opening of female also indicated the readiness of female for stripping.
- The injected brooders can be stripped 16 hours post injection.
- Firmly hold the fish and gently press the abdomen and strip eggs from the ripe female into a clean bowl. Then strip spread the male milt over the female eggs in the bowl. Gently mix them with a feather for fertilization. A small amount of physiological saline can be added for better fertilization.
- The eggs are sticky (1.3 mm in size). Wash the eggs repeatedly in water for 3-5 minutes for degumming.
- Unfertilized eggs are dull and opaque white and the nucleus disintegrate within one hour. Fertilized eggs are round, clear, golden-brownish in color, and sticky. After adding water, the fertilized eggs swell up.
- Incubate the fertilized eggs in flow through hatchery.
- Hatching will start after 24-26 h of incubation with 50-70% hatching success.
- Release the spent/stripped brooders into the tanks with proper water shower and aeration. It is recommended to treat the injected injured brooders with Oxytetracycline for recuperation.

- Newly hatched larvae are 3.0-4.5 mm in length with straight and transparent body bearing a yellowish yolksac.
- Nurse the newly hatched larvae (hatchlings) in the hatchery for 5 days preferably before transferring to the nursery tanks. Feed with live feeds such as live zooplankton, rotifer powder, newly hatched *Artemia* nauplii and finely chopped tubificid worms.
- Khan and Mollah (2004) recommended to the larval feeding start from second day onwards while Sahoo and Ferosekhan (2018) recommended from fourth day onwards, preferably with *Artemia* nauplii for higher survival.
- Collect the hatchlings through the tank's outlet by placing a piece of small mesh fabric over the mouth of the outlet. The hatchlings can be measured using an estimated measuring cup and transfer it to the Nursery tank.

Larval rearing

- Feed the hatched out larvae (hatchlings) with finely chopped tubificid worms, live zooplankton and *Artemia* nauplii twice daily from second day till 20 days of age. After 20 days, feed with only finely chopped tubificid worms.

- The larval feeding should start from fourth day onwards, preferably with *Artemia* nauplii for higher survival, and to add chopped chironomid larvae from 7-8 days onwards. Slowly wean from live feeds and switch to compound feed (dust) from 11-12 days onwards.
- Fry and fingerlings should be fed with atleast 35-40% crude protein in the diet and should be feed twice in a day preferably during night as fry and fingerlings of yellowtail catfish do not take feed during day time.

Fingerling rearing:

- The larvae appeared like adult in 15-20 days of hatching and these fry (15-20 mm size) can be transferred to fingerling production cement tank or earthen pond @ 100/m2 stocking density.
- The healthy ones are dynamic swimmers, have small mouth gap and are active feeders that easily accept crumbled feed and grow up to 1.5-2.0 g during 4-5 weeks culture.
- Thinning after rearing for 1-2 months is recommended for better growth and the grown fingerlings of 3-4 g can be stocked at density of 5-10/m2 and with proper feeding management, can grow up to 60-70 g in 4-8 months.
- For economical purpose, Chaudhary (2020) suggested to use farm made feed made of powdered wheat (30%), maize (25%), soyabean (15%), mustard oil cake (15%) and ricebran (10%), fishmeal (3%), vitamin (1%) and minerals (1%), mixed and made into small balls ensuring 35-40% protein content and fed at the rate of 5-10% body weight daily.
- To avoid stress and disease outbreak due to deterioration of water quality, periodical water replenishment and exchange is recommended as the fish is sensitive to stress.

Conclusion

Yellowtail catfish can be breed in captive condition though hormonal inducement during its breeding season in monsoon. Induce breeding can be done with pituitary extract or with synthetic hormonal such as Ovaprim, Ovatide and WOFA-FH that are commercially available in market at the recommended dose. Successful fertilization rate reported is upto 100% and hatching rate is upto 70%. The period of first feeding stage of the newly hatched out larvae till the tenth day is considered the most critical stage as mortality is high during these period. The hatchlings should be fed with live foods and slowly weaned to commercial feed. The fry and fingerlings easily accept crumble feed and grow well in any kind of aquaculture system. The success and growth of yellowtail catfish farming depends on the success of captive breeding and quality seed production in sufficient quantity. Yellowtail catfish can be a good candidate aquaculture species for India as they have relatively fast growth rate and promising market demand both local and internal level in terms of fillets. This catfish is a promising aquaculture species for India as it has high local consumer demand especially due to less spinal bones, mild flavor and white flesh.

Catfish seed production for drought-prone regions of Bundelkhand

Neelesh Kumar[1*], Bishal Mandal[1], Abhishek Srivastava[1] and Bijay Kumar Behera[2]

Abstract: The Bundelkhand explores the potential of catfish seed production as a viable and sustainable livelihood option for these areas. Catfish species, particularly native varieties, exhibit remarkable resilience to adverse environmental conditions, including low water levels, fluctuating temperatures, and poor water quality, making them ideal candidates for aquaculture in water-stressed environments. Focusing on efficient seed production techniques, such as induced breeding and nursery management, can ensure a consistent supply of fingerlings, crucial for establishing robust farming systems. This practice not only offers a reliable source of protein for local communities but also provides significant economic opportunities for farmers, diversifying their income beyond rain-fed crops. By promoting small-scale, low-input catfish farming, Bundelkhand can enhance food security, improve livelihoods, and foster climate-resilient aquaculture in the face of persistent drought.

1. Introduction

Bundelkhand is a semi-arid area that includes parts of Madhya Pradesh and Uttar Pradesh. It is known for its severe water scarcity, irregular rainfall, and frequent droughts. Farmers are forced into financial hardship as a result of these climate-related issues, which drastically reduce agricultural yield. Because of the species' exceptional tolerance to water-stressed situations, aquaculture-in particular, catfish farming-emerges as a possible alternative livelihood in such circumstances. The lack of high-quality seed (fingerlings) is still one of the key obstacles in catfish cultivation. The majority of Bundelkhand's farmers use seeds that are either poorly bred or wild-caught, which results in low survival rates and stunted growth. Creating a technique for producing sustainable catfish seeds that is suited to areas that experience drought can transform local aquaculture and offer a reliable source of income. This articlefocuses on the scientific, technical, and economical aspects of catfish seed production, also with a focus on the unique environmental challenges confronting Bundelkhand.

Why catfish for Bundelkhand?

Catfish, especially the Indian magur (*Clarias batrachus*) and the Asian stinging catfish (*Heteropneustes fossilis*), have physiological and biological benefits that make them ideal for areas that are prone to drought. Catfish, in contrast to many other fish species, can survive in stagnant and oxygen-depleted environments by employing a unique labyrinth organ to breathe atmospheric air. They are perfect for Bundelkhand's hot environment since they flourish in warm waters (up to 35°C). Additionally, by digging into mud, catfish can tolerate brief water shortages, lowering the danger of fatality during dry spells. Fingerlings attain marketable size (300–500 g) in 5–6 months under ideal conditions, therefore their rapid growth rate guarantees farmers faster profits. In addition, catfish are highly valued in both local and urban markets because to their flavor and nutritious content. In light of these benefits, encouraging catfish farming in Bundelkhand can improve both food security and revenue production. The absence of a well-organized seed supply chain is still a major problem, though.

Current challenges in catfish seed production

Large-scale catfish seed production in Bundelkhand is hampered by a number of issues. One of the main issues is the lack of high-quality broodstock, since

[1]*College of Fisheries, Rani Lakshmi Bai Central Agricultural University, Datia Campus, Datia-475686 (Madhya Pradesh) India*
[2]*National Fisheries Development Board (NFDB), Hyderabad -500052(Telangana) India*
**E-mail:neeleshrajpoot74@gmail.com*

many farmers find it difficult to find genetically superior, healthy broodfish. Brooders captured in the wild frequently have illnesses and function erratically. Since catfish do not spawn naturally in captivity, relying on hormone induction for breeding presents another significant obstacle. Many small-scale farmers do not have access to hormones (such HCG or Ovaprim) or the technical know-how to administer them correctly. Production is further complicated by high larval mortality rates, which frequently surpass 50%, as a result of bacterial infections, poor water quality, and insufficient feeding.

It is challenging to maintain steady water levels in hatcheries due to these problems being made worse by water constraint. Small-scale farmers cannot afford sophisticated recirculating aquaculture systems (RAS), and traditional earthen ponds lose water quickly. Furthermore, the majority of farmers in the area are not well-versed with contemporary aquaculture methods, which results in poor breeding practices and low output. A multifaceted strategy combining scientific breeding methods, water-efficient technologies, and capacity-building programs is needed to address these issues.

Tackling water scarcity: a scientific approach

Traditional pond-based systems for catfish seed production are unsustainable due to the regular droughts in Bundelkhand. To guarantee steady production, alternative water-efficient techniques must be used.

Biofloc Technology (BFT), which reduces the demand for water exchange by converting waste into microbial protein, is one efficient alternative. To keep the water in this system clean, aeration and carbon supplements (such molasses or wheat bran) are necessary. Recirculating Aquaculture Systems (RAS) are an additional choice that reduces water demand by filtering and recycling water. RAS is quite effective for small hatcheries, despite of its initial high investment.Tarpaulin-lined ponds, which minimize seepage losses, provide a more affordable option to clay ponds for farmers with limited resources. During dry seasons for aquaculture water requirements be met by groundwater recharge methods or by rainwater harvesting method. Farmers can continue to produce catfish seeds even during droughts by implementing these techniques.

Catfish seed production techniques

1. Broodstock selection and management

Healthy broodfish are the required for a successful seed production operation. It's critical to choose disease-free, rapidly growing brooders that weigh 200–300 g and are 8–12 months old. The genital papilla of males is sharp, whilst that of females is rounded and reddish. To increase fertility, broodstock needs to be fed with diet high in protein (30–35% crude protein) along with supplements like vitamins E and C. Gonadal development and spawning success are enhanced when brooders are conditioned in clean, aerated water at 26–30°C for two to three weeks prior to breeding.

2. Induced breeding techniques

Hormonal induction is necessary since catfish in captivity do not normally breed. The most successful techniques consist of:

- Hormonal injection:

a) Ovaprim (sGnRHa + Domperidone): 0.5 ml/kg for females, 0.2 ml/kg for males.

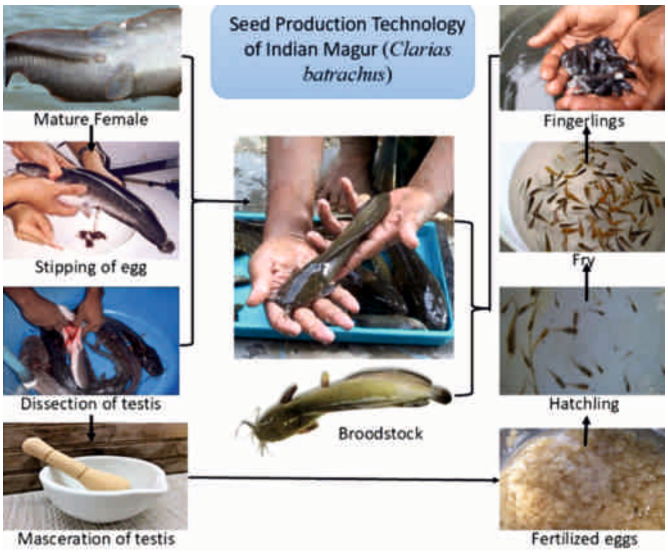
b) Human Chorionic Gonadotropin (HCG): 300–500 IU/kg body weight.

- **Stripping and artificial fertilization**

  Males are scarified to remove milt, while females are gently stripped to release eggs after receiving hormone injections for 10 to 12 hours. To aid in fertilization, eggs and milt are combined with salty water in a clean bowl.

3. Hatchery design and egg incubation

High hatching rates and larval survival are guaranteed in a well-designed hatchery. For incubating eggs, circular fiberglass or plastic containers with a diameter of 1-2 meters and mild aeration are best. The optimum range of some important water quality parameters such as temperature 28–30°C, pH 7.0–8.0, dissolved oxygen >5 mg/L and ammonia <0.1 mg/L. It takes 24 to 36 hours for fertilized eggs to hatch. Methylene blue therapy or light salt (1–2 ppt) can be used to prevent fungal infections.



4. Larval rearing and nursery management

The survival of the larva depends on the first two weeks. Before switching to live food, such as Artemia nauplii or micro-worms, freshly hatched larvae depend on yolk sacs for two to three days. They can be weaned onto starter meals or powdered fishmeal by 10–12days. Maintain an ideal stocking density (50–100 larvae per liter) as overcrowding raises mortality. Survivability rates are further increased by routine water quality testing and disease prevention strategies.

5. Water-efficient systems for drought-prone areas

Farmers can take the following actions to resolve water scarcity:

- Biofloc Technology (BFT): Reduces water exchange by recycling nutrients.
- Recirculating Aquaculture Systems (RAS): Minimizes water usage through filtration.
- Tarpaulin-Lined Ponds: Prevents seepage losses in small-scale setups.

Economic viability and market potential

Bundelkhand farmers can profitably produce catfish seeds because of the strong market demand. Table-sized fish sell for ₹150–200/kg, while fingerlings sell for ₹3-5 per piece. Profitability is further increased by government schemes like PMMSY (Pradhan Mantri Matsya Sampada Yojana), which offer subsidies for hatchery construction and training.

Conclusion

A sustainable answer to the water shortage in Bundelkhand is the production of catfish seeds. In order to address seed scarcity issues &less productivity, farmers can adopt scientific breeding methods, water efficient technology and better larval management. Scaling up catfish farming in the area requires government assistance, private sector participation, and farmer's training initiatives.

Bio-remediation and its application in aquaculture

Abhed Pandey*

Abstract: Aquatic plant possess an outstanding ability for assimilating nutrients and creating favourable conditions for microbial decomposition of organic matter. This ability can be exploited in the restoration process of natural streams, lakes, wetlands, waste water-treatment systems and village ponds. Bioremediation has been recognized as an inexpensive, effective and environment friendly, safe technology that offers new and innovative ways to clean up wastes. However, the use of the technology is limited by poor understanding of biodegradation process. This is a tool that can be used for abatement of pollution resulting from a variety of compounds, biodegradable as well as recalcitrant.

BIO-REMEDIATION

Bio-remediation consists of using living organisms to reduce or eliminate toxic pollutants. When macro and micro organisms and/or their products are used as additives to improve water quality, they are referred to as bio-remediators or bio-remediating agents. The newest attempt being made to improve water quality in aquaculture is the application of probiotics and enzymes to the ponds is known as bioremediation which involves manipulation of microorganisms in ponds, to enhance mineralization of organic matter and remove undesirable waste compounds.

Bacteria and other microbes are natural source of bioremediation tools, the most applicable one could be phyto-remediation. The use of specially selected and pollutant accumulating plants for environmental clean-up is an emerging area in pollution abatement. Phyto-remediation works best at sites with low to medium amount of pollution, and at sites contaminated with metals and nutrients. Once absorbed by the plants, toxic or heavy metals can be stored in the roots, stems or leaves; converted into less harmful substances within the plant; or changed into gaseous forms and released into the atmosphere through transpiration. Macrophyte-based waste water treatment systems have several potential advantages compared to conventional treatment systems:

- Low operating costs.
- Low energy requirements.
- They can often be fixed at the site where the wastewater is produced.
- They are more flexible and are less susceptible to the sock loading.
- Macrophyte can be used as fish/animal feed.
- Environmentally-friendly and aesthetically pleasing.

PHYTO-REMEDIATION IN AQUACULTURE

Aquatic habitats have degenerated because of pollution by both industry and other activities. Moreover, human activities have resulted in much higher flows of minerals and organic materials through aquatic systems, often leading to eutrophication and a huge drop in the biomass produced in such systems. The lack of dissolved oxygen in water bodies, through its uptake by microbes for decomposition of organic compounds, produces degrees of anaerobiosis that results in major growth of anaerobic bacteria and the evolution of methane gases. Farmers have harvested naturally produced aquatic plants for a number of purposes including animal feed, green manure and for their family feed resources. The best known of these

Department of Aquaculture
College of Fisheries (Bihar Animal Sciences University), Kishanganj (Bihar)
**E-mail: pandeyabhed@yahoo.com*

include the free floating plants; water lettuce (*Pistia*), water hyacinth (*Eichhcornia*), duckweed (*Lemna*), *Azolla* and also some bottom growing plants.

In recent years a commonly occurring aquatic plant, "duckweed", has become prominent, because of its ability to concentrate minerals on heavily polluted water such as that arising from sewage treatment facilities. The growing awareness of water pollution and its threat to the ecology of a region and agriculture has also focussed attention on potential biological mechanisms for cleansing water of these impurities making it available for re-use. Another pressure that has stimulated interest in aquatic plants has been the over-use of fertilizers that has led to contamination of ground water supplies. A significant mechanism for scavenging nutrient loss, duckweed aquaculture is an activity that easily integrates into many crop/animal systems run by small farmers. It appears to have great potential in securing continuous food production, particularly by small farmers, as it can provide fertiliser, food for humans and feed for livestock and in addition decrease water pollution and increase the potential for water re-use.

Habitat of the Duckweed

Duckweed species are small floating aquatic plants found worldwide and often seen growing in thick, blanket-like mats on still or slow moving, nutrient-rich fresh or brackish waters. They are monocotyledons of the botanical family Lemnaceae and are higher plants or macrophytes, although they are often mistaken for algae. Duckweeds grow at water temperatures between 6 and 33°C. Many species of duckweeds have adventitious roots which function as a stability organ and which tend to lengthen as mineral nutrients in water are exhausted.

Compared with most plants, duckweed leaves have little fibre (5% in dry matter of cultivated plants) as they do not need to support upright structures. On the other hand, roots seem more fibrous. This contrasts with many crops such as soya beans, rice, or maize, where approximately 50% of the biomass is in the form of high fibre, low digestibility residues.

Duckweed species are adapted to a wide variety of geographic and climatic zones. They are found in all but waterless deserts and permanently frozen areas. They grow best in tropical and temperate zones and many species can survive temperature extremes. The natural habitat of duckweed is the surface of fresh or brackish water which is sheltered from wind and wave action. They do not survive in fast moving water (>0.3 m/second) or water unsheltered from wind which is an important attribute as they do not become weeds in water ways. The best nutritional situations for duckweed growth are in waters with decaying organic material, providing it with a steady supply of nutrients. A dense cover of duckweed inhibits competing submerged aquatic plants, which require solar energy for growth and they can also often exclude algae from bodies of water.

Growth and nutritive value of Duckweed

Duckweeds can double their mass in between 16 hours to 2 days under optimal nutrient availability, sunlight, and water temperature. This is faster than almost any other higher plant. Under experimental conditions their production rate can approach an extrapolated 183 metric tonnes/ha/year of dry matter although yields are closer to 10-20 tons of DM/ha/year.

Growth rates of duckweed colonies will be reduced by a variety of stresses: such as nutrient scarcity or imbalance, toxins, extremes of pH and temperature, crowding by overgrowth of the colony and competition from other plants for light and nutrients. However, when conditions are good, duckweed contains considerable protein, fat, starch and minerals which appear to be mobilised for biomass growth when nutrient concentrations fall below critical levels for growth. The reported nutrient densities in duckweed therefore vary according to conditions of growth. The concentration of nutrients in dry matter of a wild colony of duckweed growing on nutrient-poor water typically is 15 to 25% protein and 15 to 30% fibre. Duckweed grown under ideal conditions and harvested regularly will have (in dry matter) a fibre content of 5 to 15%, a crude protein content of 35 to 43%, and a polyunsaturated fat content of about 5%, depending on the species involved.

Any organic waste can be utilised to provide nutrients for duckweed. The most economical sources are wastewater effluents from homes, food processing plants, cattle feedlots, and intensive pig and poultry production. Solid materials, such as manure from livestock, night soil from villages, or food processing wastes, can also be mixed with water and added to a pond at suitable levels. All wastewater containing manure or night soil must undergo an initial treatment by holding it for a few days in an anaerobic pond, before using it to cultivate duckweed. There is an additional need when using such sources of nutrients to reduce solids and prevent the formation of a floating mat.

Duckweed-based wastewater treatment systems

The basic concept of a duckweed wastewater treatment system is to farm local duckweeds on the wastewater which needs to be treated. The rapid growing plants act as a nutrient sink, absorbing primarily nitrogen, phosphorus, calcium, sodium, potassium, magnesium, carbon and chloride from the wastewater. These ions are then removed permanently from the effluent stream following the harvesting of a proportion of the crop. Depending on the wastewater, the harvested crop may serve as: (i) an animal feed; (ii) feed supplement supplying protein and minerals; or (iii) fertiliser.

Maintenance of efficient duckweed growth requires an even distribution of a thick layer of plants across the entire water surface. Initial research has shown that there is a range of plant densities that supports optimum growth rate for prevailing conditions. In this case harvesting to maintain approximately1kg duckweed wet weight per m2 resulted in an extrapolated average yield of 32 tonnes DM/ha/year. The upper density appears to be that at which crowding limits growth (above 1.2 kg wet weight/m2) and the lower density (<0.6 kg wet weight/m2) is when growth is insufficient to prevent algal blooms.

Using duckweed as a feed/supplement

The composition of duckweed depends on the nutrient content of the water and the prevailing climatic conditions. Harvested duckweed plants contain protein ranging from 20% to 45% on a dry weight basisand may be used without further processing as a complete feed for fish. Duckweed protein has a better array of essential amino acids than most vegetable proteins and more closely resembles animal protein. It is, therefore, a source of high quality protein to be exploited for domestic animal production. Duckweeds grown on nutrient-rich water has a high concentration of trace minerals, K and P and pigments, particularly carotene and xanthophyll, that make duckweed meal an especially valuable supplement for poultry and other animals, and it provides a rich source of vitamins A and B for humans.

Use of duckweed in fish nutrition

Fish feed with high biological value and protein content are costly and frequently unavailable locally, which is a significant barrier to fish farming. Duckweeds grown on water with 10-30 mg NH_3-N/litre have high protein content (around 40%) of high biological value. Fresh as well as dried duckweedsare highly suited to intensive fish farming systems and duckweed is converted efficiently to liveweight by certain fish including carp and tilapia (Table 1).

Duckweeds is a conventional feed for fish. Its attributes are:

- It can be readily grown locally often in waste ponds that are polluted.
- It can be fed fresh and since it floats, by judicious setting of the rates of application it may be totally used by fish.
- It is used very efficiently by fish such as carp but other species might well cope with duckweed as

a component of the diet since it is particularly low in fibre and high in protein when grown under ideal conditions.

- It is relatively inexpensive to produce or may be regarded to have no cost where the opportunity costs of family labour are not taken into consideration.

Table 1. Summary of positive reports on inclusion of dried duckweeds in fish feed

Type	Inclusion level	Fish	Reference
Spirodela polyrrhiza	20% soybean meal replacement	*Cyprinus carpio*	Shrivastav *et al.,* 2022
	Large scale production standardized in pond, nutritional value as an animal feed ingredient		Sharma *et al.,* 2019
	20 %	*Labeo rohita, Cirrhinus mrigala* *Cyprinus carpio*	Ansal and Dhawan 2007, Ansal *et al.,* 2008
Lemna minor	10 to 20%	*Cyprinus carpio*	Goswami *et al.,* 2022
	13.2%	*Labeo rohita*	Guru and Patra 2007
	20%	*Labeo rohita*	Das *et al.,* 2007
	40%	*Oreochromis niloticus*	Tavares *et al.,* 2008
Lemna-	30% (fermented) 10% (raw)	*Polyr rhiza* *Labeo rohita*	Bairagi *et al.,* 2002
Wolffia spp.	28% (feed)	*Labeo rohita*	Pradhan *et al.,* 2019

Source: Ansal *et al.,* 2010 &Minich and Michael, 2024

The use of bio-remediators will gradually increase and the success of aquaculture in future may be synonymous with the success of bio-remediators that, if validated through rigorous scientific investigation and used wisely, may prove to be a boon for the aquaculture industry. Proteinaceous feed resources are generally in short supply, and in addition are usually the most costly components of the diets of fish in developing countries. Duckweed presents a protein source that is of great potential for feeding to fish. The nutrients in the water upon which the duckweed is grown critically affect its nutritional value particularly for monogastric animals where the fibre and protein contents of the duckweed are important elements. Fish production can be stimulated by feeding duckweed to the extent that yields can be increased from a few hundred kilograms per hectare/year to 10 tonnes/ha/year.

Fish disease management: Protecting aquaculture from emerging threats

**Ajaya Kumar Rout[1*], Sushree Swati Rout[2], Abhishek Srivastava[1], Anuj Tyagi[1]
Bijay Kumar Behera[3] and Pramod Kumar Pandey[1]**

Abstract : Fish disease management is crucial for the sustainability and productivity of aquaculture industries worldwide. Emerging threats, including new viral, bacterial, and parasitic diseases, pose significant challenges due to environmental changes, globalization, and intensive farming practices. These threats not only threaten fish health but also impact economic stability and food security. Effective management requires a multifaceted approach, incorporating early detection through advanced diagnostics, vaccination, biosecurity, and environmental management. Sustainable practices such as reducing antibiotic use and enhancing fish immunity are vital to prevent resistance and promote healthy stocks. International collaboration and continuous research are essential to monitor and respond to emerging diseases promptly. By adopting integrated disease management strategies, the aquaculture sector can protect against emerging threats, ensuring healthy fish populations, economic resilience, and sustainable growth in the face of evolving challenges in better way.

Introduction

Aquaculture has become an essential component of global food security, providing nearly half of the fish consumed worldwide. As the industry expands to meet increasing demand, maintaining healthy fish populations is critical for sustainable production. However, fish health remains a significant challenge, with diseases posing a substantial threat to aquaculture operations, economies, and food safety. Effective management of fish diseases is therefore vital to ensure the resilience and productivity of aquaculture systems.

Fish diseases are caused by a variety of pathogens, including bacteria, viruses, fungi, parasites, and environmental stressors. Historically, many common diseases could be controlled through traditional practices such as improved water quality, biosecurity measures, and the use of vaccines or chemotherapeutic agents. However, the emergence of new and more virulent pathogens, coupled with environmental changes, has complicated disease management efforts. Climate change, for instance, influences pathogen distribution and host susceptibility, leading to the appearance of novel diseases in regions previously unaffected.

Emerging threats in fish health include the spread of antibiotic-resistant bacteria, viral diseases like Infectious Salmon Anemia (ISA) and Koi Herpesvirus (KHV), and parasitic infections such as sea lice and protozoa. These threats are often exacerbated by intensive farming practices, high stocking densities, and globalization, which facilitate rapid pathogen transmission across borders. The movement of live fish, equipment, and feed can inadvertently introduce new pathogens into aquaculture systems, making disease outbreaks more frequent and severe.

To combat these challenges, a comprehensive approach to fish disease management is necessary. This includes early detection through advanced diagnostic tools, such as molecular techniques and real-time monitoring, which enable prompt response to outbreaks. Preventive measures like vaccination, improved biosecurity protocols, and environmental management are crucial to reduce disease incidence. Vaccination has proven effective against several bacterial and viral diseases, but the development of new vaccines for emerging pathogens remains a priority.

[1]*College of Fisheries, Rani Lakshmi Bai Central Agricultural University, Nauner, Datia, Madhya Pradesh-475661, India*
[2]*Department of Zoology, Fakir Mohan University, Vyasa Vihar, Nuapadhi, Balasore-756020, Orissa, India*
[3]*National Fisheries Development Board, Department of Fisheries, Government of India, Hyderabad-500052, India*
**E-mail: ajayarlbcau@gmail.com*

Furthermore, the sustainable use of therapeutics, such as antibiotics and antiparasitic drugs, requires careful regulation to prevent resistance development. Integrating health management with good aquaculture practices, including optimizing water quality, nutrition, and stocking densities, can strengthen fish resilience against diseases. Additionally, research into the microbiome and immune modulation offers promising avenues for enhancing fish health naturally.

International cooperation and information sharing are also vital, as emerging diseases often cross borders rapidly. Organizations such as the World Organisation for Animal Health (OIE) provide guidelines and facilitate collaboration among countries to monitor and control fish diseases effectively.

In conclusion, protecting aquaculture from emerging fish diseases demands a proactive, integrated strategy that combines technological innovation, sustainable practices, and global collaboration. As new threats continue to evolve, ongoing research and adaptive management are essential to safeguard the health of cultured fish populations, ensuring the industry's sustainability and contribution to global nutrition.

Why do fish get sick?

Understanding why fish get sick is the first step to protect them. Fish can get ill from bacteria, viruses, fungi, parasites, or even poor water quality. Many times, fish get stressed because of environmental problems like overcrowding, dirty water, or sudden temperature changes. Stress weakens their immune system, making it easier for pathogens to attack. For example, overcrowding in tanks or ponds makes fish compete for oxygen and space. When water quality is poor-such as high ammonia or nitrite levels—fish can get sick or die. Sudden changes in temperature can also give thermal shock to fish, making them more vulnerable. Fish that are stressed or weak are more prone to infection.

Some common fish diseases include:

Ich (White spot disease): This disease causes small white spots to appear on the fish's skin and fins. Fish often scratch against objects because of the itching.

Fin rot: Fish develop ragged or frayed fins. This disease often occurs when bacteria infect damaged fins.

Fungal infections: These look like cottony white or grey growths on the fish's body or fins.

Dropsy: Fish swell up with bloated bodies and scales that stick out like a pinecone. It is usually caused by internal infections.

Viral diseases: These can cause sudden death with very few visible signs but are very contagious.

How do emerging threats affect fish farming?

In recent years, new threats to fish health have appeared due to environmental changes and other factors. Climate change is one of the biggest reasons. As water temperatures rise, bacteria and parasites grow faster, increasing the chances of disease outbreaks. Warmer water also stresses fish, making them more vulnerable. Another cause is the introduction of new fish species into farms or nearby ecosystems. Sometimes, these new fish species carry diseases that local fish have never encountered. If not properly checked, these new infections can spread quickly. Poor biosecurity practices also increase risks. For example, sharing equipment between farms without disinfecting can transfer pathogens. Contaminated water sources or wild fish entering the farm can carry diseases. Furthermore, pollution and habitat destruction can weaken fish and make them more susceptible to illness. As environmental conditions change, some diseases that were rare before are now becoming more common.

Simple ways to prevent fish diseases

Prevention is always better than cure. Here are some simple but effective tips to keep your fish healthy and avoid disease outbreaks.

Maintain Clean Water: Water quality is the foundation of healthy fish. Regularly check water parameters such as pH, oxygen levels, ammonia, nitrites, and nitrates. Use test kits to monitor their levels, and take corrective actions accordingly. Keep the water clean by removing waste, uneaten feed, and dead fish daily. A proper filtration system helps to remove impurities and maintain good water quality.

Avoid overcrowding: Don't put too many fish into a small space. Overcrowding causes stress in fish and makes it easier for diseases to spread. Follow recommended stocking densities for your fish species and farm size.

Quarantine new fish: Whenever you bring new fish to your farm, keep them separate for at least two weeks. Observe them for signs of illness, and if they seem healthy, gradually introduce them to the main group. Quarantining helps to prevent introducing new diseases.

Buy healthy fish from reputable sources: Always purchase fish from trusted suppliers who follow BMP. Avoid buying sick or stressed fish, as they are more likely to carry diseases.

Feed fish properly: Feed your fish with good quality feed and in the right quantity. Overfeeding can pollute the water, while underfeeding weakens fish. Healthy fish are better able to resist disease.

Maintain good farm hygiene: Disinfect equipment like nets, tanks, and tools regularly. Avoid sharing equipment between different ponds or farms without proper cleaning.

Control wild fish and other animals: Wild fish or birds can carry diseases. Use nets or barriers to prevent wild animals from entering your farm area.

How to detect disease early?

Early detection is key to controlling fish diseases. Regularly inspect your fish for signs of illness.

- Changes in behavior: Fish swimming erratically, hiding, or staying at the bottom.
- Physical signs: White spots, lesions, ulcers, swelling, or frayed fins.
- Loss of appetite or unusual swimming patterns.
- Sudden deaths without clear reason.

Isolate affected fish immediately to prevent the disease from spreading to healthy fish. Carefully examine the fish and try to identify the problem. If you are not sure, consult a veterinarian or a fish health expert.

How to treat fish diseases?

- Isolate the sick fish in a separate tank or pond to prevent spreading the disease.
- Identify the disease if possible. You can consult a fish health specialist or veterinarian for help.
- Use approved medicines according to instructions. Do not overdose, as this can harm fish or make the disease worse.
- Improve water quality by changing water, cleaning tanks, and ensuring proper filtration.
- Reduce stress by minimizing handling and maintaining a stable environment.
- Follow proper quarantine procedures for preventing contamination from other tanks or ponds.

Dealing with emerging threats

As new diseases and threats appear, staying informed is very important. Keep yourself updated on reports from local authorities, fish health organizations, or extension offices. They often provide information on recent outbreaks and recommended actions.

Practice good biosecurity measures: disinfect equipment regularly, prevent wild or new fish from entering your farm, and avoid sharing tools or water sources with other farms. Educate yourself about new diseases and their treatments.

Work closely with experts—they can help you develop a disease management plan tailored to your farm. Attending training sessions and reading reliable sources will improve your knowledge and preparedness.

Long-Term Management and Good Farming Practices

Sustainable fish farming requires ongoing management. Keep detailed records of fish health, water quality tests, treatments, and any disease outbreaks. This helps you identify patterns and take preventive steps.

- Train your staff or family members on disease recognition, cleaning procedures, and emergency actions. Make sure everyone understands the importance of biosecurity.
- Prepare an emergency plan for disease outbreaks. This might include having a stock of medicines, quarantine tanks, and steps to follow if disease is detected.

- Maintain a clean environment - regular cleaning, disinfection, and water management are essential. Proper feeding, stocking, and water quality control build resilient fish that can resist diseases better.

Conclusions

Fish diseases can cause serious problems, but with good management practice and quick action, you can protect your fish and your farm. Always monitor your fish regularly, keep your water clean, and practice good biosecurity. When you see signs of illness, act fast and seek help from experts. Remember, new threats are always emerging, so stay informed by following local news and consulting with authorities. Build a healthy farm is a continuous effort, but your dedication will pay off in healthy fish and a successful business. When in doubt, don't hesitate to reach out to local extension officers or fish health specialists - they are there to help you. Protecting your fish today means a brighter, more prosperous future for your farm tomorrow.

Zoonoses: Public health significance and control from fisheries perspective

Anuj Tyagi* and Girija Saurabh Behere

Abstract: Zoonoses are diseases transmitted between animals and humans. While most attention is focussed on terrestrial sources, fish and aquatic environments also pose zoonotic risks. Integrated aquaculture systems and the use of animal manure can introduce pathogens into fish ponds. Humans may acquire infections through contaminated water, raw or undercooked fish, and improper handling. Fish-borne zoonoses include parasitic infections, bacterial diseases, and viral infections. Symptoms range from gastrointestinal issues to tissue infections and hepatitis. Although complete elimination of zoonoses is not feasible, risks can be minimized. Key strategies include regular screening of fishery products, hygienic processing, avoiding raw fish consumption, and coordinated efforts by government, researchers, and communities. Public awareness and good aquaculture practices are vital for preventing zoonotic diseases in fisheries.

Introduction

Intimate and mutually beneficial relationships between humans and animals date back centuries. Since the first interactions between humans and dogs, animals have been reared for food, milk, clothing, transportation, recreational purposes and companionship. Domestic and wild animals, and their associated ecosystems, also play a significant role in health and well-being of humans. Though most of these interactions have been beneficial for human health and existence, significant associated risks cannot be ruled out. These risks are further expected to increase in the near future. Rapid population increase and food demand have put great pressure on limited resources and resulted in opening of new areas for food production. This has resulted in increasing encounters of humans and their domesticated animals with wild populations. There are frequent transmissions of diseases from animals to humans called zoonoses. Integration of aquaculture with other agricultural/ livestock farming activities is very much common. Sometimes, aquaculture ponds get contaminated by sewage and land run-offs. Thus, entry of disease-causing agents in these ponds and subsequent transmission to fish consumers (zoonoses) is quite possible. We need to understand the process of zoonoses and its impact for better control of fish borne infections.

Zoonoses, transmission and human health

The World Health Organization defines zoonoses as diseases and infections which are transmitted naturally between vertebrate animals and man. The transmission of zoonotic infections is not unidirectional, i.e., from animals to humans, but can also occur vice versa. Zoonoses are multi-host infections in which one host happens to be human. It is also highly possible that a particular zoonotic infection shows no clinical signs or mortality in one host while still causing disease in another. Zoonotic transmission can be indirect through food and water or through direct exposure with animals during farming and recreational activities or through pets and vectors. The importance of zoonoses can be understood from the fact that more than 60% of infectious agents affecting human health in the last few decades have originated from animals or animal products. Wildlife has been a significant contributor, with more than 70% of total zoonotic infections coming from wild sources (animals, environment, etc.).

Zoonoses and fisheries

In comparison to their bovine and poultry counterparts, zoonotic infections from fishes are relatively less with mild to moderate intensities. Growing demand for fishery products has also resulted in intensive fish farming with an increased

College of Fisheries, Rani Lakshmi Bai Central Agricultural University, Noner, Datia-475686, Madhya Pradesh, India
**E-mail: anujtyaagi@yahoo.co.in*

risk of occurrence of new diseases. Continuous and enhanced focus on integrated fish farming, in which livestock wastes like cow dung, pig dung, poultry manure, etc., are used as inputs in aquaculture, may sometimes lead to zoonotic infections. Intensive fish farming cannot be supported by naturally available food alone, and there is always a need for supplementary feeding. Any zoonotic pathogen present in these byproducts as well as in fish feed may eventually get transmitted to humans via fishery intermediates. Thus, fish-borne zoonoses may emerge as a problem for both producer and consumer. Revenue loss due to product rejection and ill health can be the significant consequence of zoonoses for farmers and consumers, respectively. Thus, there is a need to create awareness among various stakeholders, such as fisheries researchers, students, farmers and consumers, about fish-borne infections communicable to human.

Types of Zoonoses

Zoonoses causing organisms may vary depending upon habitat and host. They may include viruses, bacteria, fungi, protozoa and parasites. Domestic and wild animals may serve as hosts for these zoonotic organisms.

1. Parasitic Zoonoses

Among the large number of helminthic parasites present on fishes, few species are capable of infecting humans. Some parasites are only present in tropical regions, and their prevalence may vary depending upon the socio-economic conditions and cultural habits. As ingestion is the main route of entry for these pathogens, communities with a habit of eating raw/undercooked fish can have an enhanced infection rate. Parasitic infections by nematodes, trematodes, cestodes and acanthocephalans have been reported in humans.

Most parasitic worms live in the small intestine and produce gastrointestinal disturbances (abdominal pain, nausea, vomiting), fever and anaemia. The worms may also invade the peritoneal cavity, urinary systems and other tissues, producing local organ-specific symptoms. Some worms may not invade tissue but instead may pass out with faeces or vomit. Anisakiasis or anisakidosis is the most important parasitic disease of humans acquired from marine fishes. This disease is most frequently caused by *Anisakis simplex.* Like most of the other parasitic infections, the disease is caused by larval stages of the worms. Diagnosis of parasitic infection is made by a combination of clinical symptoms coupled with a history of eating raw or undercooked fish and the presence of worms in stool/biopsied tissues.

2. Bacterial Zoonoses

Though aquatic environments harbour heavy loads of diverse bacterial communities, most of these are non-pathogenic to humans under normal circumstances. Human pathogenic bacteria are generally not indigenous to aquatic environments, and their presence indicates contamination of aquatic resources with human wastes in the form of sewage, etc. Once inside the aquatic environment, these pathogenic bacteria remain viable, grow and get accumulated in fishes through primary or secondary contact. In comparison to younger ones, older fishes are expected to carry higher bacterial loads and subsequent risk of bacterial zoonoses.

Important bacterial zoonotic pathogens are *Salmonella spp*., *Listeria monocytogenes, Vibrio parahaemolyticus, V. vulnificus, V. cholerae, Clostridium botulinum* and *Mycobacterium marinum*. Most of these are food-borne and cause typical gastrointestinal symptoms (abdominal pain, diarrhoea, nausea, vomiting, fever, anorexia) after a certain period of incubation (Fig. 1). Others, such as *Clostridium botulinum,* may act by producing toxins in unhygienically prepared food. Direct bacterial contact with hands or skin of other parts can also result in localised inoculation and symptoms at the site of contact. These symptoms may vary from general itching, tingling and burning sensations to swelling, lesions and tenderness at the infected site. Fish tank granuloma or fish-handler's disease, is the result of soft skin and tissue infection by *Mycobacterium marinum* through open wounds/cuts.

3. Viral Zoonoses

The risk of viral zoonoses from fishes cannot be ignored. Filter-feeding shellfish, including oysters, mussels and clams, can accumulate higher viral loads than surrounding waters. Any human pathogenic virus, present in water bodies contaminated with human waste, can get concentrated in aquatic organisms over a period of time. Viral concentration in shellfish may vary from ten- to hundred-fold when compared to the water column. Human disease outbreaks due to shellfish-borne enteric viruses have been reported worldwide. There are also some reports of hepatitis A due to consumption of contaminated shellfish. Viruses may cause a wide range of diseases in different individuals, ranging from aseptic meningitis, respiratory illness, myocarditis, fever, diarrhoea, rash, nephritis, etc.

Control of Zoonoses

The presence of various microbial communities in aquatic environments and associated zoonotic risks are integral parts of fisheries. Though it might not be possible to completely eradicate the zoonoses, the risk can be minimised by coordinated efforts of various stakeholders. The following measures can help in the control of zoonoses and risk reduction:

- Collaborative efforts by Government, Fisheries researcher, farmers and the medical fraternity for awareness creation, effective surveillance, monitoring and reporting of zoonoses.
- Regular screening of fishery products from potentially zoonotic areas.
- Establishment of a reporting mechanism for foodborne illness and the ability to trace back the area of origin of illness-causing fishery products.
- Adoption of good manufacturing practices by fish processing industry to avoid any post-harvest contamination with pathogens.
- Fish feed, manures and other aquaculture inputs from suspected zoonotic sources should not be prepared.
- Community sensitization about zoonotic risks of eating raw, undercooked fishery products.

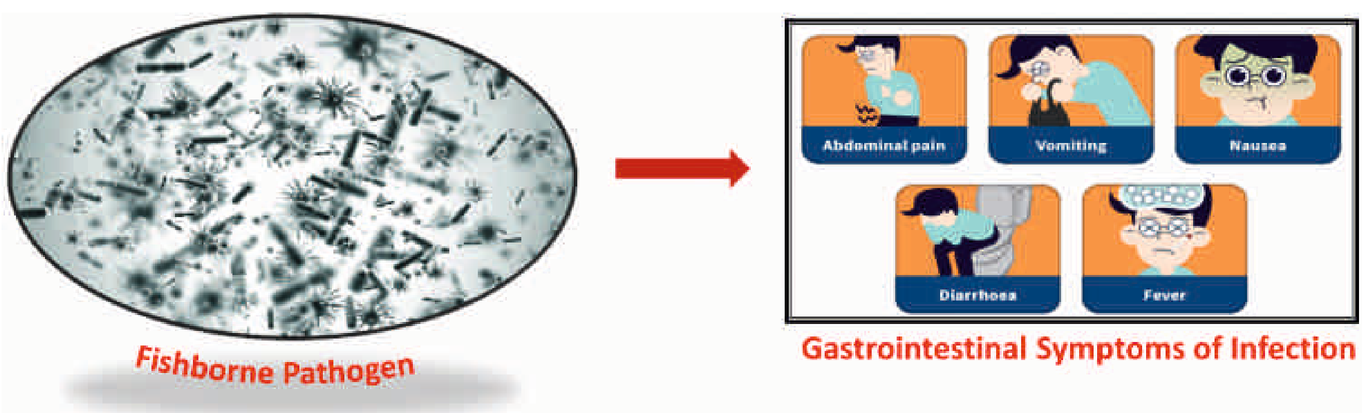


Fig. 1: Gastrointestinal symptoms after consuming the pathogen contaminated fish

Blue nutrition: How fish can nourish human body and feed the planet?

Girija Saurabh Behere*[1], Sudhanshu Raman[1], Ganesh Kumar[1], Anuj Tyagi[1] and A.U. Pagarkar[2]

Abstract: Fisheries and aquaculture industry are essential for enhancing global food security, nutrition, and economic development. Aquaculture has become the fastest-growing food production sector due to the steadily rising demand for fish and it is currently supplying more fish for human consumption than marine capture fisheries. 60% of the fish consumed worldwide is expected to come from aquaculture by 2030. Fish is widely accepted as a component of a healthy diet because it is inexpensive and provides a wealth of high-quality protein, essential fatty acids, vitamins, and minerals, particularly for underprivileged and nutritionally vulnerable populations in developing nations. The FAO reports that 3 billion people consume more than 20% of their animal protein from fish, and in some less developed areas, over 50%. In light of issues like food insecurity and climate change, the growing idea of "Blue Nutrition" emphasizes the important role that aquatic foods serve in preventing malnutrition, enhancing health, and sustaining sustainable food systems. Fish are known to be nutrient-dense super foods that improve immune system function, maternal and child health, and the risk of lifestyle diseases. Fish is a nutrient-dense, culturally varied, and environmentally friendly food source that is essential to reaching sustainability and global health objectives.

Introduction

The fisheries and aquaculture sector plays a vital role in improving food security and human nutrition. The consumption and demand for fish are continuously rising. Fisheries are considered the fastest-growing food production sector in the world. Compared to marine capture fisheries, aquaculture has provided more fish for human consumption, and it is estimated that by 2030, 60% of the fish consumed by humans will come from aquaculture. Fish is widely accepted by the majority of the population as part of a healthy diet. Apart from providing essential nutrients at an affordable cost, fish also contribute to the food and nutritional security of poor families in developing countries. As reported by FAO, fish can be considered a treasure trove of nutrients, supplying over 20% of the average per capita animal protein intake for 3 billion people, and over 50% in some less developed countries. In a world increasingly challenged by malnutrition, lifestyle diseases, and food insecurity, fish emerge not only as a super food but as a sustainable solution. Blue Nutrition is an emerging concept that emphasizes the critical role of aquatic foods, especially fish, in advancing global nutrition, food security, and sustainability. As the world grapples with challenges like malnutrition, climate change, and food system inequities, fish and other blue foods are gaining recognition as powerful agents of health and planetary well-being.

Fish are rich in essential nutrients, play a pivotal role in global food systems, and can serve as a critical lever for economic development and public health. In the quest for better health, sustainable nutrition, and economic well-being, fish stand out as a uniquely powerful solution. As a nutrient-rich, environmentally efficient, and culturally diverse food, fish symbolize a bridge between health and sustainability. Fish are nutrient-dense super foods, rich in high-quality protein, essential fatty acids (especially omega-3s), vitamins (like D and B12), and minerals (such as iodine, selenium, iron, and calcium). Regular consumption of fish can significantly improve maternal and child nutrition, enhances cognitive development, boost immunity, and reduce the risk of non-communicable diseases like cardiovascular disorders.

[1]*College of Fisheries, Rani Lakshmi Bai Central Agricultural University, Datia, Madhya Pradesh 475 661*
[2]*College of Fisheries, Shirgaon, Ratnagiri, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra 415 629*
**Email Address: girija_cof@yahoo.com*

Nutritional value and health benefits of consuming fish

As a rich source of proteins

Fish and fish products are excellent sources of high-quality protein. The bioavailability of protein from fish is 5–15% higher than that from plant sources. Fish contains all essential amino acids required for human health and is easily digestible by people of all age groups. Most types of fish and shellfish, when cooked and served at 100 grams, provide about 18–24 grams of protein, which is roughly one-third of the average recommended daily protein intake. The Recommended Dietary Allowance (RDA) for protein for adult men and women ranges from 45 to 65 grams per day. Therefore, a 100-gram serving of fish contributes about 15–25% of the daily protein requirement. Fish and shellfish together contribute to approximately 7.9% of global protein requirements and 15.3% of total animal protein consumption. Fish is a complete protein source, containing all nine essential amino acids required for growth and maintenance. The digestibility of fish protein is superior to that of most terrestrial meats, making it ideal for children, the elderly, and convalescing patients. Regular fish consumption supports tissue repair, muscle building, and immune system functioning, while its low-fat content—especially in lean fish-makes it suitable for calorie-conscious diets.

As a source of valuable lipids

Many fish species and nearly all shellfish contain less than 2.5% total fat, contributing less than 20% of total calories from fat. In almost all fish, total fat content is below 10%, and even in high-fat fish like herring, mackerel, and salmon, it does not exceed 20%. Many fatty fish are rich in long-chain omega-3 fatty acids, which play a vital role in visual and cognitive development during the first 1000 days of a child's life.

Fish is a great source of protein, omega-3 fatty acids, and other essential nutrients that support heart, brain, and overall health. Fish provide high-quality animal protein, vital omega-3 fatty acids, vitamins (like D and B12), and minerals such as iodine, selenium, and zinc. As the global population grows and climate change pressures intensify, leveraging the potential of fisheries and aquaculture is not only strategic but imperative. This article explores the health benefits of fish, the role of fish in global food security, sustainability concerns, and innovative pathways to ensure that fish are accessible to all.

Omega-3 fatty acids for heart and brain health

Fish, especially oily varieties like sardines, salmon, and mackerel, are the richest natural source of long-chain omega-3 fatty acids: EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid). These fatty acids play critical roles in heart health, cognitive function, and anti-inflammatory processes. All fish and shellfish contain some amount of omega-3s, but the quantity can vary significantly as concentrations are species-specific. These healthy fats support cardiovascular health, help regulate blood pressure, reduce blood triglyceride levels, and lower the risk of heart attacks. Additionally, omega-3s are essential for brain development and function. Multiple studies confirm that regular fish consumption reduces the risk of coronary heart disease, stroke, arrhythmias, and sudden cardiac death. DHA is essential for fetal brain development during pregnancy and supports cognitive function throughout life.

As a powerhouse of vitamins and minerals

Fish is a rich source of vitamin D, which is essential for bone and dental health, as it enhances calcium absorption. Fish has a diverse and rich vitamin profile. Among fat-soluble vitamins, vitamin E (tocopherol) is widely and uniformly distributed across all fish groups and is found in higher concentrations than in meat. Water-soluble vitamins are also present in significant amounts in fish, except for vitamin C (ascorbic acid), which is nearly absent. The content of vitamins such as B2 (riboflavin), B6 (pyridoxine), niacin, biotin, and B12 is relatively high. In fact, 100 grams of fish can contribute up to 38%, 60%, 50%, 33%, and 100% of the daily requirements of these vitamins respectively.

Fish are also rich in essential minerals such as iodine, selenium, and zinc, which strengthen the immune system and regulate various physiological functions. Fish also contains phosphorus, magnesium, iron, zinc, and iodine, which help reduce the risk of both malnutrition and non-communicable diseases that are often linked with energy-dense diets.

Unlike many other muscle meats and animal-based foods, fish is naturally low in sodium. However, it's important to note that sodium is often added during cooking in the form of table salt. Additionally, processed fish products such as surimi and fish sticks may contain high levels of added sodium.

Calorific value

The calorific value of fish is linked to its fat and protein content, which vary by species, size, diet, and season. Seafood typically contains fewer fats and calories compared to beef, poultry, or pork. Most lean or low-fat fish like cod, hake, flounder, and sole provide less than 100 kilocalories (418 kJ) per 100-gram portion. Even high-fat fish like mackerel contain no more than 250 kilocalories (1045 kJ) per 100-gram serving.

Fish as bioactive and functional food and fish in pharmaceuticals

Research is expanding into fish-derived bioactives for use in functional foods and nutraceuticals. Omega-3-enriched eggs, milk, and bakery products, as well as marine-derived peptides for blood pressure control, are emerging fields. Fish-derived bioactive compounds, such as peptides, have shown antihypertensive, anti-inflammatory, antioxidant, antimicrobial, anticoagulant, anticancer properties. These compounds may contribute to managing conditions like high blood pressure, diabetes, and arthritis. Further, the omega-3 fatty acids in fish are linked with lower risks of depression, age-related macular degeneration and Alzheimer's disease. DHA is also crucial for prenatal and early childhood brain development, underscoring fish's importance in maternal and child nutrition. Fish gelatin and collagen are gaining attention in biomedical applications like wound healing, drug delivery, and tissue engineering due to their biocompatibility and biodegradability.

Fish for weight management and metabolic health

Fish are generally low in saturated fats and calories. Consuming fish as part of a balanced diet may improve satiety, reduce cravings, and enhance metabolic rate, making it beneficial for weight management.

Beyond individual health, fish also contribute to sustainable food systems. Unlike many terrestrial animal proteins, fish-especially small-scale and low-trophic species-can be produced with a lower environmental footprint, requiring less land, freshwater, and feed inputs. Moreover, aquaculture innovations and sustainable fisheries management are making it possible to meet growing food demands without depleting ecosystems. The global fish supply per capita reached 20.5 kg in 2022, providing more than 3.3 billion people with 20% of their average intake of animal protein. For countries like Bangladesh, Cambodia, and Ghana, fish account for over 50% of animal protein consumption. Aquatic foods, particularly from sustainable aquaculture, are recognized as one of the most resource-efficient means to produce high-quality protein with a lower carbon and freshwater footprint than land-based livestock.

Livelihoods and economic inclusion

According to FAO, more than 820 million people worldwide depend on fisheries and aquaculture for their livelihoods. Small-scale fisheries provide employment to 90% of the capture fisheries workforce, offering vital income for rural and coastal communities. Fish are often one of the most accessible and affordable animal-source foods for low-income populations, especially in coastal and inland communities of Asia and Africa. Promoting policies and investments in fisheries and aquaculture can therefore help reduce poverty, ensure gender inclusion, and enhance livelihoods, especially for women who play key roles in fish processing and trade. In regions like South Asia and Sub-Saharan Africa, fish value chains also empower women, who play significant roles in processing, marketing, and trade. Ensuring inclusive access to fisheries resources thus contributes to gender equity and poverty alleviation.

Reducing waste and post-harvest losses

According to FAO, globally up to 35% of harvested fish is lost or wasted due to spoilage, inefficient processing, and distribution issues. Enhancing cold chains, developing value-added products (e.g., fish powder, surimi, fish oil capsules), and promoting traditional preservation techniques can minimize losses and extend shelf life. Fish waste valorization-turning skin, bones, frames, and entrails into gelatin, collagen, fertilizers, bioactive peptides, or bioplastics-is gaining momentum as a circular economy strategy.

Making fish accessible to all

Fish can be made accessible to all by fortification and preparation of fish based products. Fortified fish powders, fish-based snacks, and ready-to-eat meals have been developed to address micronutrient deficiencies in vulnerable populations. These are especially useful in school feeding programs, emergency relief, and maternal-child health initiatives. In India, fish-based nutrition bars and spreads enriched with calcium and omega-3s have shown promise in tackling anemia and under-nutrition among adolescent girls and children. School curricula and public health programs should include fish and aquatic foods as part of dietary recommendations, especially in areas plagued by protein and micronutrient deficiencies.

Fish and fish products hold a significant place in the human diet and offer tremendous benefits for leading a healthy life. As a rich and sustainable source of essential nutrients, fish can serve as a cornerstone in the fight against malnutrition, lifestyle diseases, and food insecurity. Promoting and investing in the sustainable development of fisheries and aquaculture can ensure that nutritious, affordable, and environmentally friendly food is available for all—today and for generations to come. Whether addressing heart health, combating malnutrition, supporting livelihoods, or preserving ecosystems, fish play a multifaceted role in human well-being. By investing in sustainable practices, embracing innovation, and promoting inclusive policies, we can ensure that fish remain a pillar of healthy diets and resilient food systems-today and for generations to come. In conclusion, "Blue Nutrition" is not just about eating more fish-it is a call to recognize, preserve, and responsibly utilize the oceans and inland waters to nourish humanity and sustain the planet. It aligns with the UN Sustainable Development Goals (SDGs), especially those related to zero hunger, good health, sustainable production, and climate action.

Table 1: Health Benefits of Fish Components and Their Functional Roles

Nutrient/Bioactive Component	Health Benefits	Sources in Fish	Relevant Functions
High-quality Protein	Muscle growth, tissue repair	All fish types	Essential amino acids, highly digestible
Omega-3 Fatty Acids (EPA & DHA)	Cardiovascular health, brain development, anti-inflammatory effects	Fatty fish (salmon, sardine, mackerel)	Lowers blood triglycerides, supports fetal brain
Vitamin D	Bone health, immune function	Fatty fish, cod liver oil	Enhances calcium absorption
Vitamin B12	Nervous system function, RBC production	All fish, especially shellfish	Prevents anemia, supports brain function
Iodine	Thyroid hormone synthesis	Marine fish, seaweed-fed fish	Prevents goiter, supports metabolism
Selenium	Antioxidant defense, immune support	Tuna, sardines, mackerel	Protects cells from oxidative damage
Calcium & Iron (from small fish eaten whole)	Bone strength, anemia prevention	Anchovies, dried small fish	Micronutrient security for children and women

Export potential and present status of freshwater fish from India: Opportunities and global prospects

P. Jayagopal[1], M. Karthikeyan[2]* and Girija Saurabh Behere[3]

Abstract : Inland fisheries and aquaculture are essential to global nutrition, food security, and economic development. Even though India is the world's second-largest producer of freshwater aquaculture, its export potential is still not fully utilized. Aquaculture accounted for 83% of the 70.4 MMT of freshwater fish produced worldwide. Common carp, catla, grass carp, and Nile tilapia are important species. India leads in inland capture fisheries and produces about 9 MMT from freshwater aquaculture, but exports less than nations like China and Vietnam. To increase India's market share in freshwater fish worldwide, strategic initiatives in value chain development, branding, and quality compliance can help India tap into the lucrative global seafood market.

Introduction

Aquaculture and inland fisheries are pivotal components of global food systems, offering substantial contributions to nutrition, employment and economic development. India, with its extensive inland water resources and rapidly advancing aquaculture infrastructure, is strategically positioned to become a significant role in freshwater fish exports. Despite being the second-largest producer of freshwater aquaculture globally, India has not yet fully capitalized on its export potential. This article explores the global and Indian scenarios of freshwater fish production, identifies key species, assesses export potential and discusses strategic interventions to boost India's share in global freshwater fish markets.

Global scenario of freshwater fish production

According to the State of World Fisheries and Aquaculture, global fisheries production reached 185.4 million metric tonnes (MMT), of which aquaculture and capture fisheries contributed nearly equally—94.4 MMT and 91 MMT, respectively. Within this framework, inland fisheries accounted for 70.4 MMT, comprising 59.1 MMT from aquaculture and 11.3 MMT from capture fisheries. The dominance of aquaculture in inland production is notable, with 83% of freshwater fish output originating from farmed sources.

As per the data reported by FAO in 2024, Among the top freshwater species cultivated globally, grass carp (6.2 MMT), Nile tilapia (5.3 MMT), silver carp (5.1 MMT), catla (4.1 MMT), and common carp (4.1 MMT) demonstrate the high demand and adaptability of these species in diverse aquaculture systems. India holds the second rank in global freshwater aquaculture production, contributing about 9 MMT, and leads in inland capture fisheries with an output of 1.89 MMT. The most traded freshwater fish globally include pangasius (primarily from Vietnam), tilapia (from China), and rainbow trout (from Chile), reflecting established value chains, branding strategies, and compliance with international quality standards.

Overview of production and resources in India

India's inland fishery sector is growing due to diverse water resources and government-led initiatives. According to the Department of Fisheries Annual Report (2023–2024), India possesses significant aquaculture resources including 3.15 million hectares of reservoirs, 2.45 million hectares of ponds and tanks, 1.25 million hectares of brackish water, 0.28 million hectares of rivers and canals, and 1.2 million hectares of floodplain lakes. These ecosystems are critical for cultivating a wide range of freshwater fish species.

[1]*The Marine Product Export Development Authority, 4272, Panampilly Avenue, Panampilly Nagar P.O, Kochi – 682 036, Kerala, India*
[2]*Department of Fisheries and Fishermen Welfare, Government of Tamil Nadu, Chennai - 600 035, Tamil Nadu, India*
[3]*College of Fisheries, Rani Lakshmi Bai Central Agricultural University, Noner, Datia - 475 686, Madhya Pradesh, India*
**E-mail: karthim05@gmail.com*

As per the data published by Department of Fisheries, GoI, India’s total fish production was 175.45 lakh tonnes (LT), of which 131.13 LT originated from inland sources, and 44.32 LT from marine fisheries. The inland sector's growth rate stood at an impressive 8.18% per annum. Andhra Pradesh emerged as the top inland fish-producing state with 45.06 LT, while Tamil Nadu produced 2.32 LT. The major freshwater fish species produced include Catla, Rohu, and Mrigal (67.36 LT), minor carps (3.45 LT), exotic carps (10.85 LT), and catfishes including Wallago attu and Pangasius (5.69 LT). In terms of high-value species, India produced 24,769 MT of scampi (with 2,132 MT exported), 6,197 MT of mud crab, 17,507 MT of seabass, 7,099 MT of tilapia, and 152,599 MT of pangasius in the year 2022-23.

Fish production and potential in Uttar Pradesh and Madhya Pradesh

Uttar Pradesh and Madhya Pradesh, with their vast inland water resources, represent significant yet underutilized regions for freshwater aquaculture. Uttar Pradesh, with over 400,000 hectares of ponds, tanks, and village water bodies, has immense potential for carp culture and seed production hubs. It has already initiated programs for composite carp farming and integrated aquaculture models.

Madhya Pradesh, endowed with 1.5 lakh hectares of reservoirs and substantial canal systems, is emerging as a leader in reservoir fisheries. The state government is actively promoting cage culture and pen culture in large water bodies. Moreover, the Bansagar and Tawa reservoirs have shown strong potential for pangasius and tilapia culture. With the right support in terms of seed supply, feed infrastructure, and market linkages, both states can become major contributors to India's freshwater fish export volume.

Present status of export of freshwater fish

As per the Department of Commerce Trade dashboard, India exported 2,338 MT of Scampi, which accounts for only 9.22% of the total scampi produced during 2023–24. India exported 6,420 MT of tilapia out of total tilapia (20,000 MT) produced in the country, including both capture and culture sources. India exported 2.1 MT of catfish (Pangasius) from India which less than 0.1% out of total Pangasius species produced. About 11,411 MT of Carps, Murrels and Eels are exported from India in various forms.

Despite the promising production statistics, India’s presence in the global freshwater fish export market remains limited. The primary challenges include:

- **Lack of international branding**: As per the report by MPEDA, Indian freshwater fish products lacks in the branding and global market recognition seen in Vietnamese pangasius or Chinese tilapia.
- **Food safety and traceability issues**: As per the report by EIC, export rejections are due to antibiotic residues and lack of traceability hamper market confidence.
- **Fragmented supply chains**: Poor cold chain infrastructure and inadequate logistics reduce the shelf life and export quality of perishable products.
- **Regulatory barriers**: Compliance with stringent international regulations (EU, USFDA, etc.) is often a challenge due to inconsistent domestic standards.
- **Low value addition**: Exported freshwater fish are often in raw or minimally processed forms, fetching lower unit value.

Export potential and opportunities

India’s rich species diversity and the expanding global demand for affordable protein present a strong case for scaling up freshwater fish exports. Specific opportunities include:

- **Promotion of high-demand species**: Species like pangasius, tilapia and scampi have established international markets. India can ramp up their production using improved seed and farming technologies.
- **Diversified aquaculture models**: By promoting polyculture systems (e.g., combining IMCs with pangasius or tilapia), India can optimize pond

productivity and increase income per unit area. Such integrated systems also promote ecological balance and resource efficiency.

- **Development of export-oriented clusters**: Establishing integrated aqua parks with facilities for seed production, feed mills, processing units, and quality control can enhance export competitiveness.
- **Value addition and analogue products**: Development of ready-to-cook (RTC), ready-to-eat (RTE), and fish analogue products can tap into health-conscious and convenience-seeking consumer segments globally.
- **Ornamental fish trade**: As reported by MPEDA, India has rich biodiversity in ornamental fish, especially in the northeastern states and Western Ghats. With adequate packaging and disease control, this sector can be a major export earner.
- **Traceability and certification**: As reported by EIC, adopting internationally recognized certifications (e.g., Global G.A.P., ASC) and implementing digital traceability systems can open up high-value markets.

Strategic interventions for export enhancement

To unlock India's export potential in freshwater aquaculture, the following policy and infrastructure measures are essential:

- **National Brood-stock Centres (NBCs) and Brood-stock Multiplication Centres (BMCs)**: Establishment of these centers for pangasius, scampi, and tilapia can ensure genetically improved, disease-free seed supply.
- **Reservoir leasing and management policies**: Implementing clear, long-term leasing policies for reservoirs can promote culture-based fisheries at scale.
- **Promotion of genetically improved species**: As per the reports by DoF, popularizing Genetically Improved Farmed Tilapia (GIFT) and GI-Scampi among farmers and in reservoirs can boost productivity and export quality.
- **Species-specific aqua parks**: State-wise integrated parks dedicated to specific export-worthy species can create economies of scale and improve compliance with export standards.
- **Food safety and international compliance**: As per the data reported by EIC, strengthening quality control labs and enforcing testing protocols for residues and pathogens are crucial for market access.
- **Public-Private Partnerships (PPPs)**: Involving private players in hatcheries, feed, processing, and export logistics can bring in investment and innovation.
- **Digitalization and export portals**: Creating a unified digital platform for freshwater fish exports can improve matchmaking between producers and global buyers.

Scope for increasing production of potential freshwater species

- There is huge scope for increasing production of freshwater species and their export. The following efforts are suggested for enhancing freshwater fish production.
- Establishment of satellite breeding centres in each state for GIFT and GI-Scampi
- Issuance of guidelines for the registration of freshwater farms and cultured species
- Issuance of guidelines for cage farming in open freshwater bodies for species like GIFT and Pangasius, etc.
- Establishment of integrated freshwater aquaculture parks to promote export-oriented aquaculture species
- Establishment of fish processing parks for freshwater and cold-water species with common infrastructure such as Effluent Treatment Plants (ETPs), power supply, etc., with financial support from the Ministry of Food Processing Industries (MoFPI) and the National Fisheries Development Board (NFDB). This will facilitate timely

processing of export-oriented aquaculture produce and ensure better price realization for farmers

- Implementation of land leasing and reservoir leasing policies to expand the culture area and diversify aquaculture species
- Training programs for the development of value-added products from freshwater species targeted at export markets
- Encouragement of public–private partnerships (PPPs) to attract private sector investment
- Promotion of culture-based fish production in large reservoirs

Way forward

To transition from a production-centric to a market-driven aquaculture system, India needs a holistic approach involving infrastructure development, regulatory reforms, research, development and farmer capacity building. Developing a freshwater fish export roadmap with clear targets, stakeholder roles, and timelines will be a key.

Investments in aquaculture start-ups, incubators, and innovation hubs can foster new product development, efficient logistics, and market access. International collaboration with leading aquaculture nations for training, technology transfer and joint ventures can further enhance India's competitiveness.

Conclusion

India's vast inland fisheries resources and growing aquaculture sector provide a strong foundation for becoming a leading exporter of freshwater fish. Strategic interventions focusing on high-potential species, value addition, international certification, and integrated supply chains can help India tap into the lucrative global seafood market. With concerted efforts from the government, private sector, research institutions and freshwater fish exports can emerge as a major driver of rural income, employment and foreign exchange.

Fisheries-Innovations

Ganesh Kumar T. and Sudhanshu Raman

1. **CIFA-Amrit Catla: A Milestone in Selective Breeding for Sustainable Aquaculture**

   ICAR-CIFA launched a selective breeding program in 2010 to improve the body weight of Catla catla, using nine strains from five Indian states. Through Combined Family Selection using phenotypic traits and microsatellite markers, the program achieved a 15% genetic gain per generation, with a 35% cumulative gain by the third generation. Field trials across Odisha, West Bengal, Assam, and Maharashtra showed the improved strain reached 1.8 kg/year in polyculture systems, compared to 1.2 kg in local strains. The improved variety was trademarked as "CIFA-Amrit Catla" on August 1, 2024.

2. **CIFA-GI Scampi: Advancing Freshwater Prawn Farming through Genetic Improvement**

   ICAR-CIFA has developed **CIFA-GI Scampi**, a genetically improved strain of the freshwater prawn *Macrobrachium rosenbergii*, aimed at enhancing productivity and profitability in scampi farming. This achievement is the result of a long-term selective breeding program launched in 2007 in collaboration with WorldFish, Malaysia. The program focused on developing a fast-growing strain by selecting prawn populations from diverse regions of India, including Gujarat, Kerala, and Odisha. After 14 generations of systematic breeding and rigorous genetic selection, the improved strain was officially registered in 2020. This development marks a major milestone in the advancement of freshwater aquaculture in India.

3. **India's First Organic Fisheries Cluster Launched in Sikkim**

   Union Minister Shri Rajiv Ranjan Singh launched India's first Organic Fisheries Cluster in Soreng district, Sikkim under the Pradhan Mantri Matsya Sampada Yojana (PMMSY) at the North Eastern Region State Meet–2025 in Guwahati, Assam. This landmark initiative aims to promote organic fisheries and aquaculture, aligning with Sikkim's commitment to sustainable and eco-friendly practices. Already known for its success in organic farming, the state now extends its green vision to the fisheries sector, marking a significant step toward holistic, sustainable development.

4. **ICAR-CMFRI Launched 'Fish Walk' in Kochi to Promote Marine Biodiversity Awareness**

   In a unique effort to promote awareness about marine biodiversity, the ICAR-Central Marine Fisheries Research Institute (CMFRI) successfully organized its first 'Fish Walk' in Kochi on October 19. Inspired by bird-watching activities, the initiative provided students and the public with a hands-on learning experience about marine life. Participants joined scientists and marine experts on field visits to marine fish landing centres, where they observed and documented a variety of marine species. The program also included basic data collection surveys, offering valuable insights into the marine ecosystem and the need for its conservation.

5. **India's Seafood Exports Reach Record High in FY 2023-24**

   India's seafood sector achieved a historic milestone in FY 2023-24, recording an all-time high in export volume by shipping 17,81,602 metric tonnes of seafood, valued at US$ 7.38 billion. Frozen shrimp continued to dominate the export basket, contributing ₹40,013.54

crore (US$ 4,881.27 million). It accounted for 40.19% of the total export volume and 66.12% of the overall dollar earnings. Notably, shrimp exports grew by 0.69% in terms of quantity compared to the previous year.

6. India's First Shrimp Shell Biorefinery Launched with ICAR-CIFT Support

In a major step towards sustainable fisheries, India's first shrimp shell biorefinery was launched on 20 January 2025 in Maharashtra by Longshore Technologies Pvt. Ltd., with technical support from ICAR-Central Institute of Fisheries Technology (ICAR-CIFT), Kochi. The innovative facility addresses the growing challenge of shrimp shell waste by converting it into valuable products, promoting a circular economy. This initiative sets a new benchmark for eco-friendly and sustainable practices in the shrimp processing industry.

7. Milestone in Indian mariculture sector

ICAR-Central Marine Fisheries Research Institute (CMFRI) has successfully developed seed production technology for golden trevally (*Gnathanodon speciosus*), a high value marine fish. The development is expected to open up a new avenue for sustainable seafood production and boost India's mariculture activities, including sea cage farming.

8. **Successful Hilsa Breeding Using Cryopreserved Milt by ICAR-CIFRI**

The ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore, has achieved a major breakthrough by successfully breeding hilsa (*Tenualosa ilisha*) using cryopreserved milt collected from the wild. Hilsa is a highly valued commercial fish of the Indo–Pacific region and holds cultural significance as the state fish of West Bengal. Since it is challenging to obtain both male and female hilsa simultaneously from the wild, cryopreservation and genebank development are crucial for ensuring its conservation and breeding. This milestone was made possible in collaboration with the ICAR-National Bureau of Fish Genetic Resources (NBFGR), Lucknow, which developed a reliable method for hilsa milt cryopreservation. The technique has now been successfully used to produce offspring, marking the first-ever successful breeding of hilsa using cryopreserved milt.

9. Aquatic Animal Health Surveillance under PMMSY

Under PMMSY, the Department of Fisheries implemented NSPAAD through ICAR-NBFGR with a total outlay of ₹33.78 crore to monitor aquatic animal diseases across India. The programme strengthened disease management and supported ecosystem health. A national network of 19 diagnostic labs, 31 mobile units, and 6 referral labs was established. India also engaged with WOAH and NACA to align with global aquatic health standards. This initiative ensured safer and more sustainable aquaculture practices nationwide.

10. Two new species of Congrid eels from Indian waters

ICAR–National Bureau of Fish Genetic Resources (NBFGR) discovered two new species of Congrid eels on 26 January 2024 from Indian waters. Belonging to the genus *Ariosoma*, the first species named *Ariosoma kannani* was collected from the Gulf of Mannar, Tamil Nadu, while the second species, *Ariosoma gracile*, was found along the Kochi coast, Kerala.

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