Training Manual

"Climate Smart Aquaculture Technologies"

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CLIMATE SMART AQUACULTURE TECHNOLOGIES

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This e-book brings together insights and expertise from various specialists and faculty members of TNJFU, MANAGE and other allied institutions, focusing on Climate Smart Aquaculture Technologies. It aims to provide comprehensive knowledge on climate-resilient aquaculture practices for extension professionals, students, researchers, and academicians engaged in fisheries and aquaculture development.

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Foreword

Aquaculture today faces a dual challenge: sustaining livelihoods and food security while adapting to the unpredictable realities of climate change. Rising temperatures, shifting rainfall patterns, and water scarcity are no longer distant threats they are present-day realities reshaping how we manage aquatic resources. In this context, Climate Smart Aquaculture (CSA) emerges not just as an option, but as an imperative.

This training manual on *Climate Smart Aquaculture Technologies* has been designed as a comprehensive guide for farmers, policymakers, and students alike. For farmers, it offers actionable tools and techniques such as water-saving systems, integrated farming methods, and climate-resilient species selection to make aquaculture more efficient, adaptive, and profitable. For policymakers, it provides insights into evidence-based practices that can inform strategies promoting sustainability, inclusiveness, and resilience in the sector. And for students the future stewards of aquaculture, it serves as both a knowledge foundation and a call to innovate responsibly.

The pages ahead delve into pioneering CSA techniques like biofloc systems, recirculatory aquaculture, integrated multi-trophic aquaculture (IMTA), selective breeding for climate tolerance and carbon-smart pond management. These are not just technological interventions but transformational strategies that blend ecological consciousness with practical ingenuity.

As you explore this manual, may it deepen your understanding, expand your vision, and spark collaborative action. By working together across farms, institutions, and communities we can turn aquaculture into a climate-resilient pillar of global food systems.

Dean
Dr. M.G.R FC&RI, Ponneri

Preface

Climate change poses significant challenges to global food systems, particularly to aquaculture, which plays a vital role in ensuring food and nutritional security. At the same time, aquaculture offers immense potential to contribute to climate resilience, sustainable livelihoods, and environmental sustainability when supported by appropriate technologies and management practices.

This manual, *Climate Smart Aquaculture Technologies*, brings together scientific knowledge, practical experiences, and emerging innovations aimed at promoting climate-resilient aquaculture systems. The chapters cover key themes such as climate-smart production practices, sustainable breeding technologies, recirculatory aquaculture systems, carbon footprint management, aquaponics, and integrated farming approaches. Together, they highlight strategies that enhance productivity while minimizing environmental impacts.

The publication is intended to serve as a reference for students, researchers, extension professionals, policymakers, and practitioners working in fisheries and aquaculture. By integrating scientific insights with field-level applications, this manual aims to support informed decision-making and capacity building for sustainable aquaculture development.

The editors sincerely acknowledge the valuable contributions of all authors and institutions involved in compiling this manual. We hope this resource will contribute meaningfully to strengthening climate-resilient aquaculture and advancing sustainable food systems.

Editors

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1. The rise of climate smart aquaculture – transforming the future fish farming

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Introduction:

Climate change is certainly not a forthcoming event, but it is a current issue what the entire world is witnessing. The major action points include the adoption of methodologies to reduce the already happened unprecedented changes and the other one is to avoid further addition to the already existing negative impacts.

Climate change refers to variations that occur in the statistical distribution of weather over extended periods, typically ranging from decades to millions of years. Climate change is considered an additional output of human civilization.

Who is responsible Climate change?

Humans have been recognized as the major contributor to climate change through the use of fossil fuels (coal, oil, and gas) for energy supplies as well as deforestation and forest degradation that emit greenhouse gases (GHGs) into the atmosphere

Green house gases (GHGs):

- The increased accumulation of GHGs including Carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), and fluorinated gases in the atmosphere over the years has been linked to these human activities
- Carbondioxide is the single most important greenhouse gas in the atmosphere related to human activities, accounting for approximately 64% of the warming effect on the climate, mainly because of fossil fuel combustion and cement production.

Global Carbon Budget:

According to the Global Carbon Budget report released in 2022, the concentration of carbon dioxide (CO_2) in the atmosphere has increased from approximately 278 parts per million (ppm) in 1750, the beginning of the Industrial Era, to 414.7±0.1ppm in 2021.

Growth of Human Population:

- World‘s population – 8.2 billion (2024)
- India‘s Population – 1.4 billon (2024)
- In 2050, food production requirements will rise around 60 per cent to feed a world population of 9.3 billion.

Who will provide Nutrition?

- **Fisheries** and aquaculture continue to be an important source of **food, nutrition, income and livelihood to millions of people**
- Fisheries sector is recognized as the **'Sunrise Sector'** and is instrumental in sustaining livelihoods of around 30 million people in India particularly that of the marginalized and vulnerable communities.

Fish – capture fisheries

- Fish is known to be the cheapest protein source.
- Fish (including shellfish) provides essential nutrition for 3 billion people and at least 50% of animal protein and minerals to 400 million people from the poorest countries.
- Over 500 million people in developing countries depend, directly or indirectly, on fisheries and aquaculture for their livelihoods
- The sources of fish can be broadly divided into two sectors, such as capture and culture.
- The capture fishery solely depends on the nature for the production.
- However, the capture fishery production has reached its maximum potential, and there is only a little scope is left to increase the production.

Fish – culture fisheries

- Culture is a controlled or semi-controlled production system that is carried out in freshwater, brackish water or marine water.
- Thus the focus is on aquaculture productions as there is vast scope for increasing the production

Aquaculture – Production

- According to FAO (2020), aquaculture's contribution to global fish production has continued to rise, reaching 82.1 million tons (46%) out of the estimated 179 million tons of global production.
- Furthermore, the share of aquaculture production out of the global fish production is expected to grow from the current 46 to 53% in 2030 (FAO, 2020).

Effect of climate change:

- Rising in temperature
- Ocean acidification
- Diseases and harmful algal bloom
- Changes in rainfall/Precipitation patterns
- Sealevel rise
- Uncertainity in external input supply

- Changes in sea surface salinity

Climate change is the biggest disruptor for aquaculture:

- Direct effect - influencing the physical and physiology of finfish and shellfish stocks in production systems,
- Indirect effect - alters the primary and secondary productivity, and structure of the ecosystems, input supplies or by affecting product prices, fishmeal, and fish oil costs, and other goods and services needed by fishers and aquaculture producers.

Effect of climate change on Aquaculture:

- Poor growth and survival of fishes
- Water quality detoriation
- Weakened ocean carbon sink capacity
- Thermal statification
- Increased virulence of warmer water pathogens
- Increased water acidity levels
- Flooding may loss of organisms in low land areas
- Flooding pollutes the water and environment
- Increased costs of production due to possible increase in costs of inputs such as fish feeds and seeds
- Increased species mortality

The consequence of climate change in brackish water/coastal aquaculture:

Contribution of Agriculture/Aquaculture – GHGs:

- Aquaculture activities - such as power input, transport, and feed production are considered the main pathways of the sector's contribution to GHGs
- The sector's contribution is rather relatively small despite being significant when compared to other food production sectors
- The contribution of aquaculture to global GHGs particularly CO_2, emission in 2010 was estimated at 385 million tons, ~7% of the agricultural sector's contribution that year. Recent estimates by IPCC (2019) show that agriculture, forestry, and other land uses contributed about 13% CO_2, 44% CH_4, and 82% N_2O emissions from anthropogenic activities for the period 2007–2016, accounting for 23% of net anthropogenic emissions of GHGs.

Urgent concern?

- The most urgent concern is whether the sector is growing sustainably and fast enough to meet the future projected demand exacerbated by a rapidly growing human population and a changing climate.

Climate smart aquaculture (CSA):

- Climate smart aquaculture (CSA) is such an integrative approach that combines adaptation and mitigation of climate change, with links to environmental, social and economic pillars of sustainability

CSA:

CSA –AIM:

- Sustainably increase food production and income
- Adapt and build resilience to climate variability
- Mitigate/reduce and/or remove GHG emissions from agricultural practices (FAO, 2013).

Climate resilient adaptations:

Climate smart Aquaculture technologies:

- Integrated fish farming (cattle, poultry, and crops in addition to fish farming)
- Integrated Multitrophic Aquaculture system
- Aquaponics
- Biofloc technology
- Recirculatory Aquaculture system
- Seaweed culture
- Climate smart carp hatchery

Integrated fish farming:

- Integrated fish farming (IFF) is a sustainable system of aquaculture where sequential linkages between two or more farming activities (Agriculture, Poultry, Cattle, Horticulture) are utilized with fish farming as the major component.
- Integrated aquaculture like any other integrated farming system involves recycling of by-products and interconnected nutrient flow of one system as input for other, thus maximizing the production from a unit area at minimum cost.
- This system paves path for an organic aquaculture management system that can augment integrated soil water fertility management (ISWFM) and can boost biodiversity and biological cycles.

Integrated Multi trophic Aquaculture system:

- The principle of IMTA is based on ―The solution to nitrification is not dilution but extraction and conversion through diversification.‖ IMTA transforms leftovers and uneaten feed from fed organisms into harvestable crops, it improves economic and environmental sustainability while decreasing eutrophication and promoting economic diversity.

- Commercially important culture species or fed aquaculture species (e.g. finfish/shrimp)
- Organic extractive aquaculture species (e.g. shellfish/herbivorous fish)
- Inorganic extractive aquaculture species (e.g. seaweed) .

Aquaponics:

- It is an integrated multitrophic framework that consolidates the segments of recirculating aquaculture and hydroponics, in which the nutrient-rich water from the fish tank is utilized for plant growth.
- Nutrients recycling will be performed efficiently through the transfer of minerals from aquaculture to hydroponics, while water recycling decreases water usage.

Biofloc technology:

- Bioflocs are the association of microorganisms, micro and macro invertebrates, filamentous organisms, extracellular polymers, faeces and uneaten feed which are suspended in the water column
- Biofloc culture system can solve two problems at once, firstly, the elimination of water exchanges to maintain water quality and second the reduction of protein inputs.
- It reduces the nitrogen and ammonia from the culture system and improves the environmental control over production.
- It also acts as nutrient trappers which can be useful in feed management, thereby reducing the feed cost.

Recirculatory Aquaculture system:

- Recirculating aquaculture systems (RAS) are intensive tank-based culture system which facilitates water reuse using different treatment steps.
- A typical RAS unit consists of a culture tank, along with a solid removal unit followed by a nitrogen removal and disinfection unit.
- These units recycle the outlet water from the culture tanks and are circulated back to the culture tank, which reduces the dependence on water and gives almost complete control over the culture system.

Seaweed culture:

- Seaweed farming has numerous advantages such as feedstock for bio-ethanol creation, as the mode of carbon sequestration and ocean acidification mitigation, as a helpful alternative for coastal living.
- Seaweed sap is used as a foliar spray as a bio-stimulant to increase the productivity of crops
- Like micro algae seaweeds also possess bio-mitigation properties in the live form as well as in the form of biochar.

- Like plants, seaweeds utilize carbon dioxide and release oxygen, thus help to reduce the amount of greenhouse gas.

Climate smart carp hatchery:

- There are 2198 eco-carp hatcheries and 417 fiberglass reinforced plastics (FRP) carp hatcheries are operating in India.
- Due to the lack of technical knowledge to hatchery managers/owners, these hatcheries are following the conventional techniques that are incapable of withstanding the climate change impact
- A climate smart carp hatchery with more control over key water parameters (DO, pH and temperature), through important modifications like a cooling tower/chiller, sensor-based monitoring and slow sand filter for recirculation of water have the potential to sustain the aquaculture sector by ensuring continuous production and supply of quality carp seed irrespective of the climate change risk.

Conclusion

- Aquaculture being one among the topmost contributor and fastest-growing food sector; it is necessary to adopt the best method of culture, taking into account the need as well as the sustainability.

2. Role of aquaculture in achieving Sustainable Development Goals (SDGs)

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Sustainable Development Goals (SDGs)

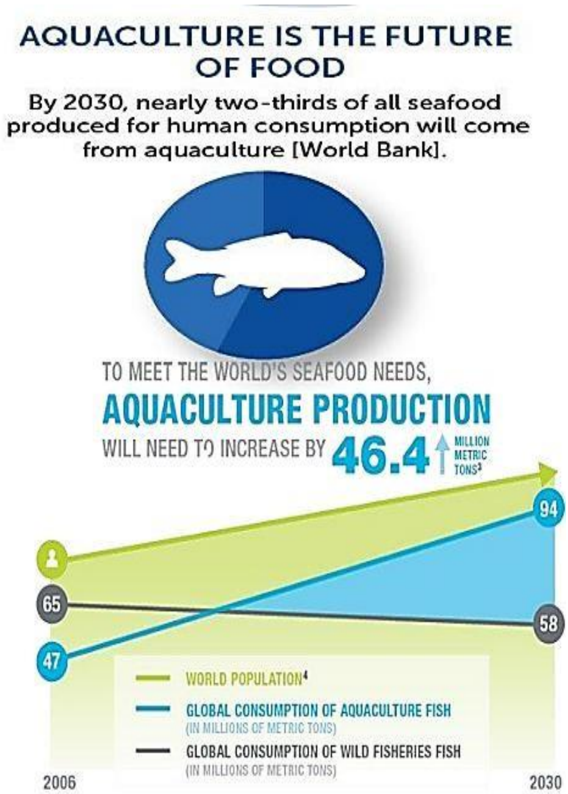
The 2030 Agenda for Sustainable Development outlines 17 Sustainable Development Goals (SDGs) that provide a roadmap to a prosperous, equitable, and sustainable future. These goals aim to eradicate poverty and hunger, improve health and nutrition, reduce inequalities, and build inclusive societies while staying within planetary boundaries. Addressing the challenge of feeding a projected global population of 9.7 billion by 2050, with a rising demand for animal proteins, aquaculture offers significant potential in achieving these global goals.

On 25 September 2015, countries adopted a set of 17 Sustainable Development Goals (SDGs)with specific targets to be achieved over the next 15 years.

Food Systems and the SDGs

Food systems are intrinsically linked to the SDGs through resources, environments, economies, and human well-being. Fisheries and aquaculture support the livelihoods of over **120 million people** worldwide, primarily in developing countries. Meeting the 2030 Agenda requires partnerships, innovation, and holistic strategies at multiple levels, with aquaculture playing a pivotal role.

Aquaculture can be well-positioned to be part of the solutions but progress toward its contribution to achieving the SDGs is dependent on good governance at all levels (local, national, regional and international) of decision-making.

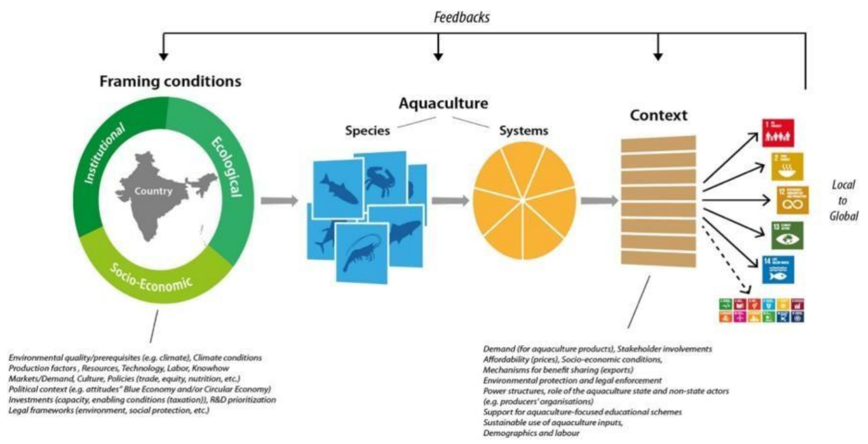


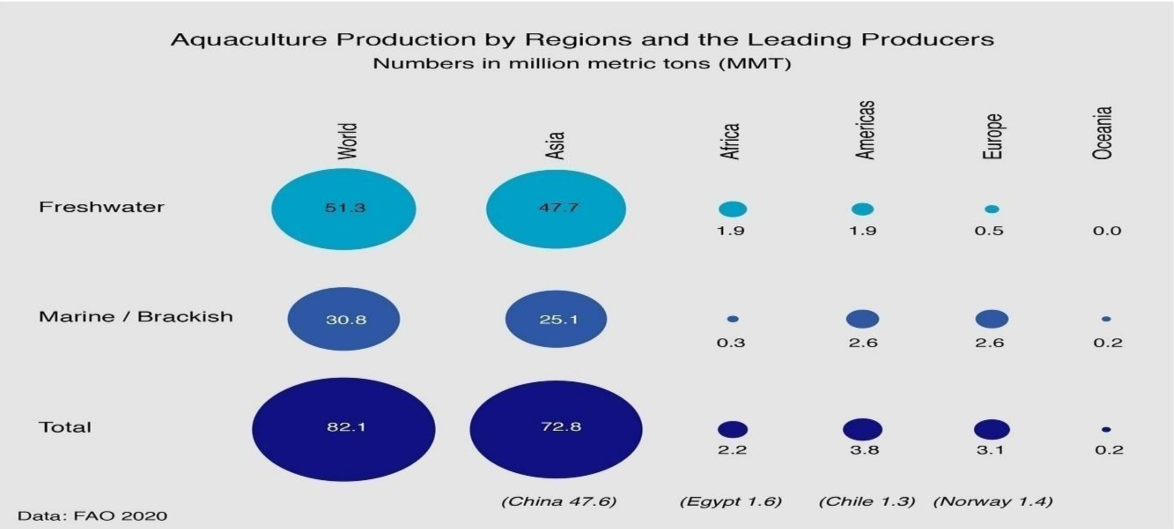
The SDGs are indivisible – no one goal is separate from the others, and all call for comprehensive and participatory approaches

How AQUACULTURE contribute to achieving SDGs?

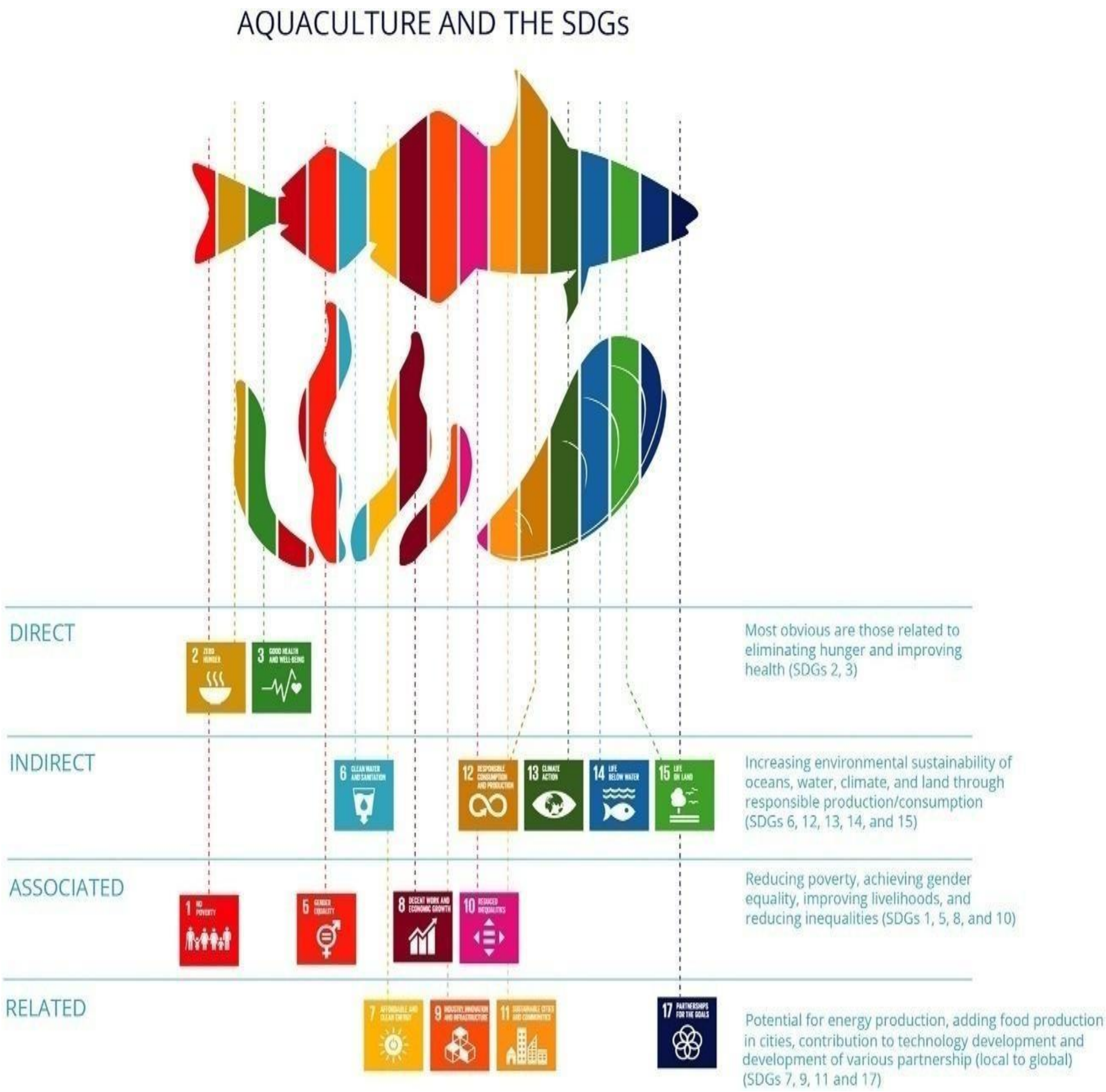
- The aquaculture value chain – whether it be the primary production stage or the subsequent product supply chain – can contribute to achieving SDGs at both national and regional levels
- Sustainable aquaculture has the potential to contribute significantly to ‗Oceans/blue economy' by promoting the socio-economic development of coastal populations
- It can increase supply to meet the demand and stabilize fish prices, in particular during periods of price hikes of other food commodities

- This requires the use of best aquaculture practices with minimal environmental impacts
- on coastal ecosystems.





Perspectives on aquaculture's contribution to the Sustainable Development Goals



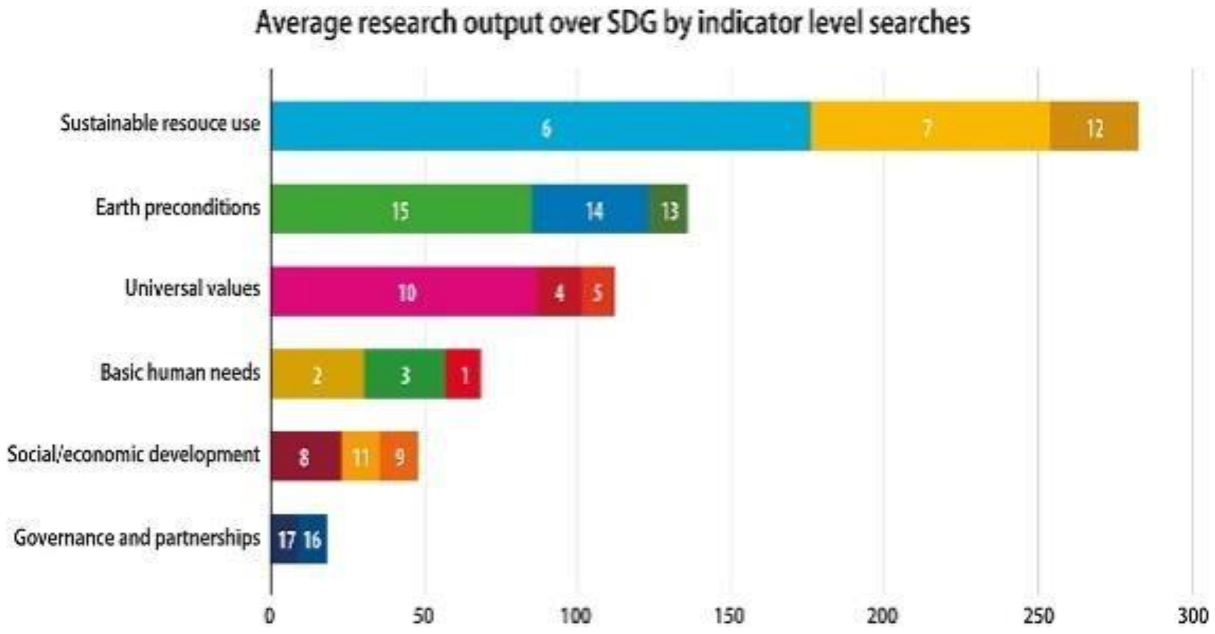
The 2030 Agenda focuses on the elimination of hunger and reduction of poverty and inequality (opportunity, resource access, gender, youth) in all their forms. The 2030 Agenda is highly relevant for policy-making, planning and management for sustainable development of aquaculture

In particular, the following SDGs:

- 1 (end poverty),
- 2 (end hunger),
- 5 (gender),
- 6 (water),
- 8 (growth, employment, decent work),

- 12 (production and consumption),
- 13 (climate change),
- 14 (marine resources & ecosystems)
- 15 (biodiversity)

Have all significant bearing for aquaculture.



SDG 1 – No Poverty

Role of Aquaculture:

Employment for over 20 million people globally, particularly in developing regions. Promotes economic empowerment of small-scale fish farmers.

Example:

In Bangladesh, integrated rice-fish farming has lifted thousands of farmers out of poverty by diversifying income sources. Microfinance initiatives supporting women in aquaculture in Bangladesh.

SDG 2 – Zero Hunger

Aquaculture's Contribution:

- Produces affordable protein and micronutrients.
- Enhances nutritional security for undernourished populations.

Example:

- Tilapia farming in Africa has improved protein intake in malnourished regions.

- Biofortification programs in India enhance fish with essential micronutrients, addressing malnutrition in vulnerable populations.

SDG 3 – Good Health and Well-being

Key Contributions:

Fish as a source of Omega-3 fatty acids, improving cardiovascular health. Biofortified fish species combat micronutrient deficiencies.

Success Story:

Tilapia farming in Africa addressing malnutrition. Community aquaculture programs in Indonesia promote fish consumption among children, reducing malnutrition rates.

SDG 5: Gender Equality

Contribution:

Women comprise 50% of the aquaculture workforce in some regions, particularly in post-harvest activities.

Example:

In Vietnam, women-led cooperatives manage aquaculture supply chains, empowering local communities.

SDG 8 – Decent Work and Economic Growth

Economic Impact:

Boosts income for coastal and rural communities. Sustainable practices create long-term economic benefits.

CaseStudy:

Export-oriented shrimp farming in Southeast Asia.

SDG 12 – Responsible Consumption and Production

Sustainability in Aquaculture:

Emphasis on eco-friendly practices: Recirculating Aquaculture Systems (RAS), organic farming. Reduces dependence on wild fish stocks.

Example:

Integrated Multi-Trophic Aquaculture (IMTA).

SDG 13 – Climate Action

Climate Resilience:

Low carbon footprint compared to terrestrial meat production.Mangrove-associated aquaculture mitigates coastal erosion.

Research Insights: Carbon sequestration in seaweed farming.

SDG 14 – Life Below Water

Sustainable Fisheries Management:

Protects biodiversity through reduced fishing pressure. Enhances conservation efforts (e.g., restocking programs).

Innovation: Development of aquafeeds using plant-based or insect protein.

More efficient production allows aquatic systems to maintain their natural balance. Reduced waste generation (e.g. ammonia) from mariculture farms prevents events that threaten aquatic life, such as harmful algae blooms. Additionally, higher fish welfare decreases disease and parasite transmission between wild and farmed fish.

SDG 17-Partnerships for the Goals

Work on fish welfare involves international stakeholders from various sectors, including academia, advocacy, industry, and government. In working to improve fish welfare, we promote sustainability, economic stability, food safety and security, and more humane treatment of farmed animals.

Aquaculture Influence on SDGS

Aquaculture type	Sustainable Development Goal				
	SDG 1No poverty	SDG 2 Zero hunger	SDG 5 Gender equality	SDG 8 Decent work and economic growth	SDGs 12, 13, 14 & 15 Environmental sustainability
Subsistence aquaculture	* Less family expenditure on food	*** Major household protein source	*** Equal opportunities at family level	** Valued work, but limited impact	*** Low impact, integrated development
Small-scale commercial aquaculture	** Generates some income	*** Sales at family and local levels	*** Equal opportunities at	** Some local economic impact	*** Low impact, integrated development
SME aquaculture	*** Generates significant income	** Sales at local level	** Opportunities skewed towards males	*** Dynamic and progressive culture	** Can have cumulative impacts Low impact, integrated development
Industrial aquaculture	* Efficient and increasingly automated	* Most produce high value an	* Opportunities skewed towards males	** Long value chain, foreign	** Can have impacts

Relevance of Sustainable Development Goals to aquaculture development

Sustainable Development Goals	Relevance to aquaculture
1 End poverty in all its forms everywhere	**
2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture	***
3 Ensure healthy lives and promote wellbeing for all at all ages	*
4 Ensure inclusive and quality education for all and promote lifelong learning	*
5 Achieve gender equality and empower women and girls	**
6 Ensure availability and sustainable management of water and sanitation for all	**
7 Ensure access to affordable, reliable, sustainable and modern energy for all	**
8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	***
9 Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	**
10 Reduce inequality within and among countries	*
11 Make cities and human settlements inclusive, safe, resilient and sustainable	*
12 Ensure sustainable consumption and production patterns	***
13 Take urgent action to combat climate change and its impacts	**
14 Conserve and sustainably use the oceans, seas and marine resources for sustainable development	***
15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	**
16 Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	*
17 Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	**

International guidance on aquaculture

Existing guidance and initiatives designed to promote sustainable aquaculture, such as

- The Code of Conduct for Responsible Fisheries, and its Technical Guidelines,
- The 2000 Bangkok Declaration and the 2010 Phuket Consensus
- The FAO Blue Growth Initiative, including the Ecosystem Approach to Fisheries and Aquaculture

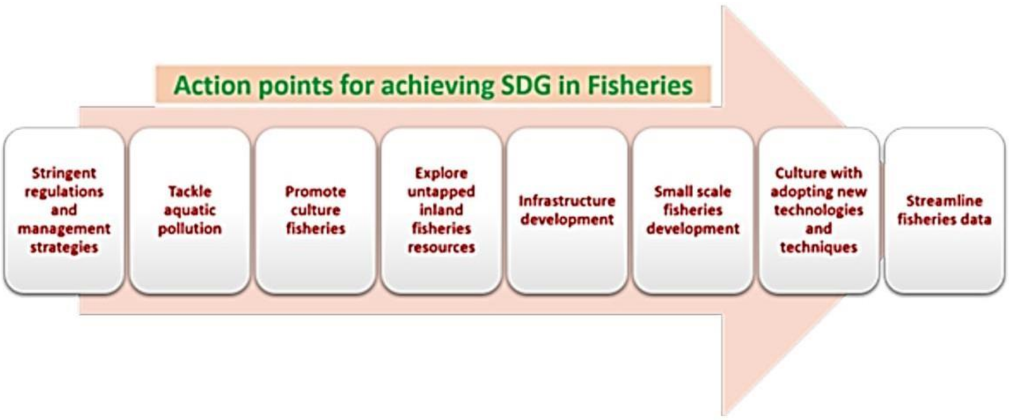
Policy instruments and initiatives should be strengthened in certain key cross-cutting areas, including:

- Fight against poverty, eliminate hunger and create decent work
- Leave no one behind: equity, human rights, access and opportunities for all (sites, skills, finances, inputs, market knowledge, for example)
- Efficient use of resources and waste reduction
- Resilient aquaculture systems
- Sharing and conservation of genetic resources
- Fair and productive value chain

Achieving Sustainable Development Goals in Indian Fisheries:

- Culture fisheries l Implementing sustainable aquaculture practices using environmentally friendly techniques such as recirculatory systems, integrated multi-trophic aquaculture, and organic and biodynamic aquaculture
- Diversifying the species of fish and shellfish grown in aquaculture operations to reduce the risk of disease and improve overall productivity
- Encouraging the use of renewable energy sources, such as solar or wind power, in aquaculture operations

- Developing mariculture to increase the efficiency and sustainability of aquaculture operations l Ensuring responsible fish farming using responsible feeding practices, minimizing the use of antibiotics and chemicals, and ensuring the health of farmed fish.
- Promoting transparency and traceability by implementing traceability systems to ensure that farmed fish can be traced back to the farm of origin, and providing transparent information about the origins and sustainability of farmed fish to consumers
- Developing sustainable feed sources using sustainable feed ingredients, such as plant-based proteins, and minimizing the use of fishmeal and fish oil in feed
- Collaboration and partnerships by working with governments, NGOs, and the private sector to develop and implement sustainable aquaculture policies and practices
- Investing in research and development for new sustainable aquaculture technologies and practices and to improve our understanding of the environmental impacts of aquaculture



SDGs relevant to aquaculture development implementation requirements

Implementing the SDGs also requires that several outstanding conceptual and practical challenges should be addressed including:

- How to deal with trade-offs between different sustainable development objectives
- The nature of environmental capacity or limits to growth
- Integration and complexity
- Environmental assessment and precaution
- Adaptive planning and management systems
- Human and labor rights
- Capacity development of institutions
- stakeholder participation and empowerment

Recommendations

- Aquaculture has emerged as the main driver of blue growth and a key component of food security which is central to SDGs
- Aquaculture faces challenges that need to be addressed by solution oriented research, innovative approach and integrated efforts
- Growth trajectory of aquaculture should be shaped by giving attention to ecological, social and economic pillars of SD
- The transformative pathways optimism identified for modern aquaculture hold out optimism in the potential of this sector for meeting the expected outcomes.

The SDGS are truly transformative. They are interlinked, calling for new combinations in the way policies, programmes, partnerships and investments pull together to achieve our common goals

3. Climate Smart Breeding Technologies in Aquaculture

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Introduction

Climate change has profound influence on fish breeding through influencing endocrine axis components like brain-pituitary-gonad (BPG) and brain-pituitary-interrenal (BPI) axes. BPG axis is the major reproductive axis influencing reproductive processes like early gonadal differentiation, pubertal onset and completion, seasonal annual reproductive cycle, spawning cycle and different sexual behaviours (Fig. 1). The external factors which influences BPG axis includes temperature, photoperiod, salinity, dissolved oxygen, pH, water current, and turbidity. Internal factors includes neuroendocrine feedback, endocrine pathways, paracrine pathways and autocrine pathways. Studies in different fish species have clearly indicated that temperature, photoperiod, and salinity plays an important role in controlling maturity in aquacultured fish. Similarly, different hormonal preparations used for induced breeding target elements of reproductive BPG axis.

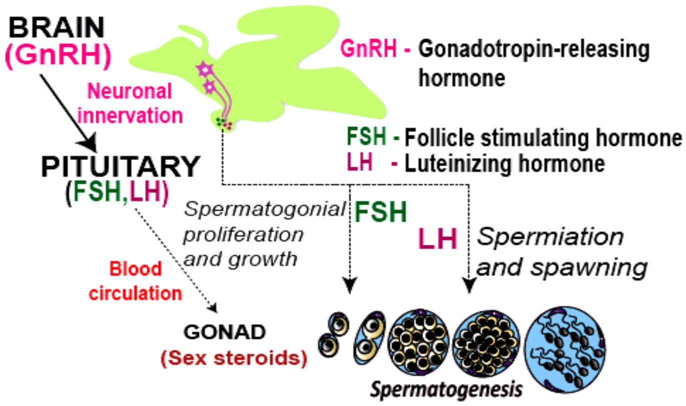


Fig. 1. Reproductive BPG axis in cultured fishes

Climate change has severe impact on annual seed production of cultured finfish and shellfish. Bhattacharya et al. (2022) reported that in Assam state of India, the seed production centers have suffered from significant economic loss through escape of brood fish from hatcheries because of extreme climatic events like abnormally high floods. In Thiruvallur District Poondi, common carp seed production centre resulted in complete failure of common carp spawning few years before. Additionally, climate change has severe impact on captive spawning as aquacultured fish stocks exhibit different forms of reproductive dysfunction (Selvaraj et al., 2021). The different climate smart breeding technologies suggested for agriculture and animal science field is shown in Fig. 2.

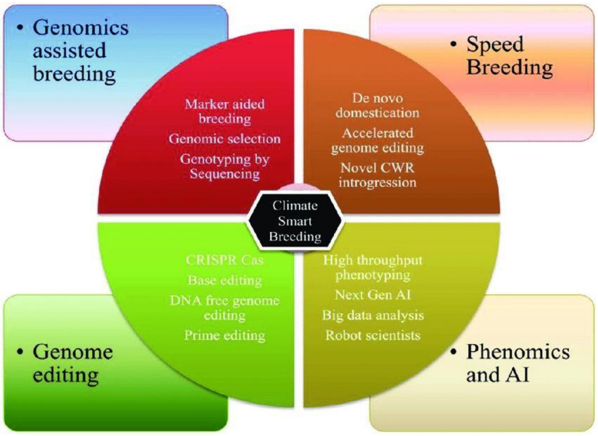


Fig. 2. Summary of Climate Smart Breeding Technologies

(Source: http://dx.doi.org/10.5772/intechopen.94847)

Climate Smart Breeding Technologies

The different climate smart breeding technologies include climate smart FRP hatchery, gene editing technologies - CRISPR-Cas 9 (popular method), surrogate broodstock technology, molecular breeding methods, cryobanks - germ cells including spermatazoa, and evaluation of climate smart inducing agents for breeding. In addition to this, other methods have been suggested for agriculture and other animal science field.

Climate smart carp hatchery; Presently, there are more than 2198 eco-carp hatcheries and 417 fiberglass reinforced plastics (FRP) carp hatcheries in India. However, due to the lack of scientific knowledge to hatchery managers/owners, these hatcheries are presently following the conventional techniques that are incapable of withstanding the climate change. A climate smart carp hatchery developed by ICAR-CIFA with more control over key water parameters like dissolved oxygen, pH and temperature, through important modifications like a cooling tower/chiller, sensor-based monitoring and slow sand filter for recirculation of water have the potential to sustain the aquaculture sector by ensuring continuous production and sustainable supply of quality carp seed irrespective of the climate change risk (Rasal et al., 2023).

Use of Recirculatory Aquaculture Systems (RAS) for Fish Breeding: Several studies have indicated the use of RAS based systems for breeding of finfish and shellfish. In India, RAS based systems are used for breeding of seabass and cobia. The technology can be replicated for other cultured finfish and shellfish.

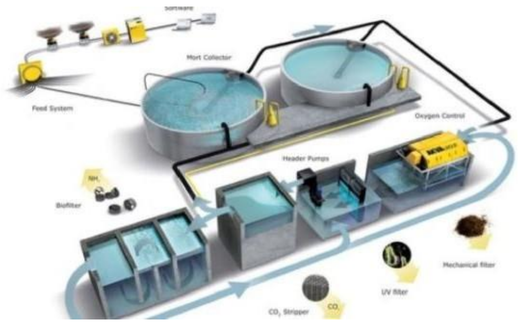


Fig. 3. Different RAS based models for climate smart fish breeding (Source: Images were obtained through Google Images)

Genome editing (GE) techniques for climate smart breeding

Emerging molecular biology techniques are used to make targeted (inserting, deleting or substituting) changes to an organisms DNA. Various GE techniques are CRISPR/Cas, zinc finger nuclease (ZFN), transcription activator-like effector nuclease (TALEN), oligonucleotide directed mutagenesis (ODM), and meganucleases. CRISPR/Cas based genome editing technique is widely used. CRISPR modifies internal DNA/RNA in a sequence-specific manner and is reprogrammable. Cas (CRISPR-associated) proteins are enzymes that can cut DNA at specific locations. CRISPR-Cas system uses RNA molecules to guide Cas enzymes to specific DNA sequences and then precisely cuts the target in DNA.

COMPONENTS OF CRISPR

1. Protospacer Adjacent Motif (PAM): 2–6-base pair DNA sequence next to the DNA sequence targeted by the Cas9 nuclease; a component of the invading virus or plasmid which distinguishes bacterial self from non-self DNA. 5'-NGG-3‘.

nuclease	PAM	size (kDa)
SpCas9	NGG	150
(engineered) SpCas9-VQR	NGAG	150
(engineered) SpCas9-VRER	NGCG	150
(engineered) SpCas9-NG	NGN	150
(engineered) SpCas9-xCas9	NG/GAA/GAT	150
(engineered) SpCas9-Sc++	NNG	150
(engineered) SpCas9-SpG	NGN ("near-PAMless")	150
(engineered) SpCas9-SpRY	NRN ("near-PAMless")	150
FnCas9	NGG	180
(engineered) FnCas9-RHA	YG	180
SaCas9	NNGRRT	115
(engineered) SaCas9-KKH	NNNRRT	115
St1Cas9	NNAGAA	125
NmCas9	NNNNGATT	120
GeoCas9	NNNNCRAA	120
AsCas12a	TTTV	145
(engineered) AsCas12a-RR	TYCV	145
(engineered) AsCas12a-RVR	TATV	145
FnCas12a	TTTV	145
Cas12j	TTN	75
Cas12e	TTCN	110
Un1Cas12f1	TTTN	60
CnCas12f1	CCN	55

2. CrRNA (CRISPR RNA): Contains the guide RNA (locates the correct section of the host DNA) + a region that binds to the tracrRNA forming an active complex

3. Trans-activating crRNA (tracrRNA): Discovered by Emmanuelle Charpentier in *Streptococcus pyogenes*. Partially complementary to crRNA forming a crRNA/tracrRNA hybrid. This hybrid acts as a guide for the endonuclease Cas9 (cleaves the invading nucleic acid).

4. CAS proteins- enzymes that can cut DNA at specific locations

Protein	Function
Cas 1 and Cas 2	They are present in most known CRISPR systems They are metal-dependent endonuclease responsible for the integration of new spacers
Cas 3 , Cas 9 , Cas 10 , Cas 12 and Cas 13	Endonucleases responsible for the cleavage activity
Cas 4	It has endonuclease and spacer acquisition activity
Cas 5	Part of the cascade complex involved in the crRNA biogenesis
Cas 6	Part of the cascade complex, it is the key protein of the crRNA biogenesis , in which the pre-crRNA transcript is processed into mature crRNA
Cas 7	Part of the cascade complex , that has multi-subunits forming the backbone of the complex
Cas 8	Part of the cascade complex, which interacts directly with the PAM, allowing Cascade binding

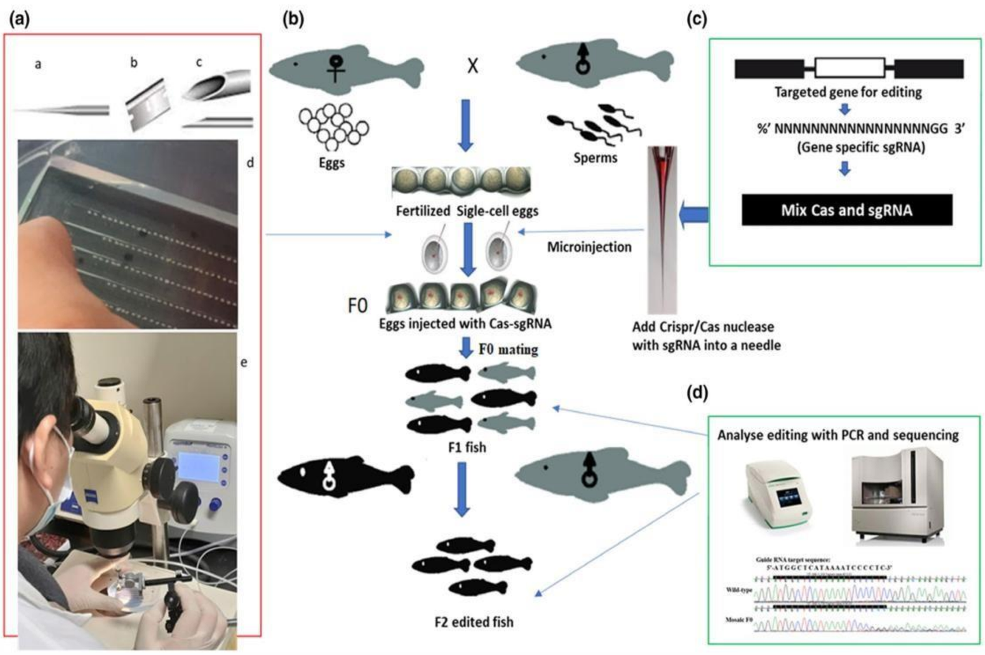


Fig. 5. General Procedure of CRISPR in fish

Applications of CRISPR based technology in aquaculture for growth and reproduction

Targeted traits	Species	Edited gene	New phenotypes	References
Growth	*Sparus aurata*	Myostatin	Increased growth	Khalil *et al.*, 2017
	Ictalurus punctatus	Myostatin	Increased growth	Khalil *et al.*, 2017
	Cyprinus carpio	Sp7a/sp7b/mstn(ba)	Muscle development	Zhong *et al.*, 2016
	Crassostrea gigas	Myostatin	Increased growth	Yu *et al.*, 2019
	Pagrus major	Myostatin	Increased growth	Kishimoto *et al.*, 2018
	Lethenteron morii	Kctd10/wee1/soxe2/wnt7b	Growth related	Zu *et al.*, 2016
	Megalobrama amblycephala	Myostatin	Increased growth	Sun *et al.*, 2020
	Paralichthys olivaceus	Myostatin	Increased growth	Wang *et al.*, 2021
Reproduction	*Salmo salar*	Dnd, dmrt1/nanaos2-3/foxl2, gsdf	Ablated germ cells, and sex	Wargeilus *et al.,2016*
	Oreochromis niloticus	Sf-1,dmrt1, amhy, dmrt1 wnt1a/b, and foxl2	Sex, gonad development	Li *et al.,2014*
	Ictalurus punctatus	Lh	Sterilisation	Qin *et al.,2016*
	Acipenser ruthenus	Dnd1	Surrogate production	Baloch *et al.,2019*
	Silurus meridionalis	Cyp26a1	Advanced meiotic initiation	Li *et al.,2016*
	Paralichthys olivaceus	Gsdf	Sex	Wang *et al.,2021*

Surrogate Broodstock Technology

Two different species whose biological properties are similar has to be selected for surrogate broodstock technology. The main considerations for surrogate broodstock technology are: the germ-line chimeras; chimera is a single organism composed of cells from different zygotes; to make germ-line chimeras, the PGCs are isolated and transplanted into the embryo of other species. The donor genotypes are restored in the next generation

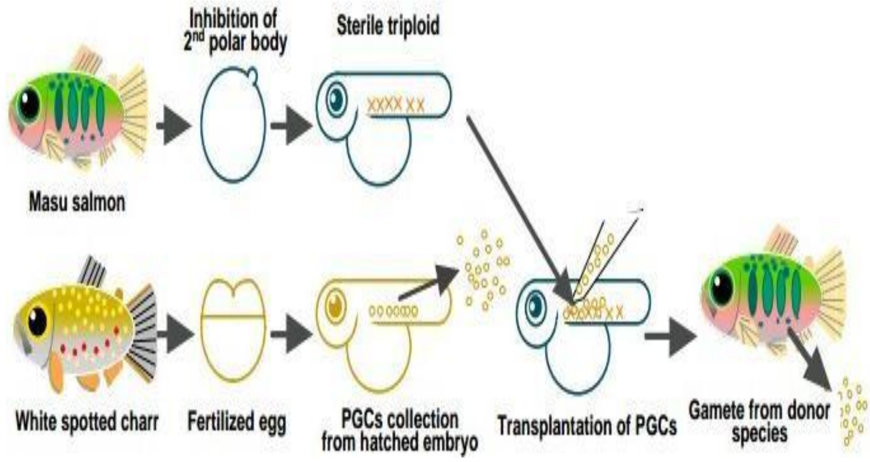
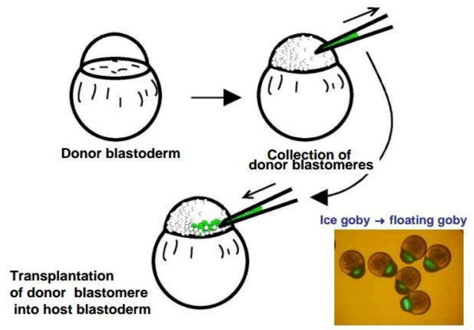


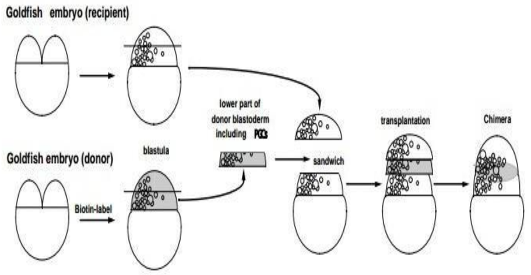
Fig. 6. Diagramatic sketch of surrogate broodstock technology in fish

Perspectives on surrogate production: Control of total egg production between species with large and small body size fishes; preservation of genetic diversity host: single parents, Donor: primordial germ cells (PGCs) with many diversity; wide range adaptation to water between marine and freshwater fish

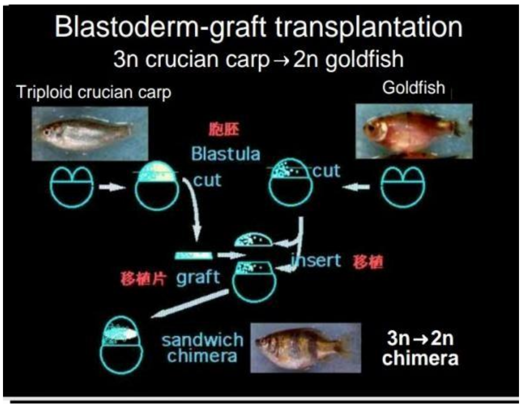
The different methods used in surrogate broodstock technology are: blastomere transplantation; transplantation of a blastoderm graft; transplantation of visualised PGCs and transplantation of isolated PGCs. The figures are shown below:

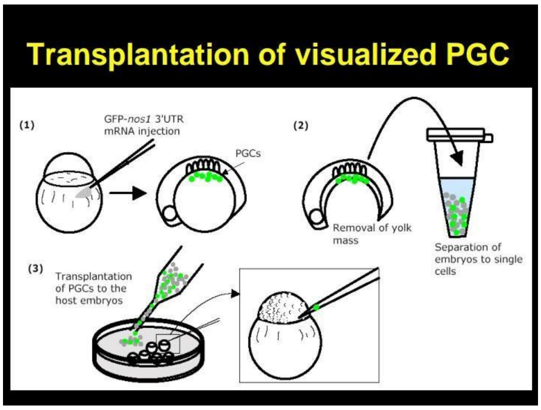


Blastomere transplantation



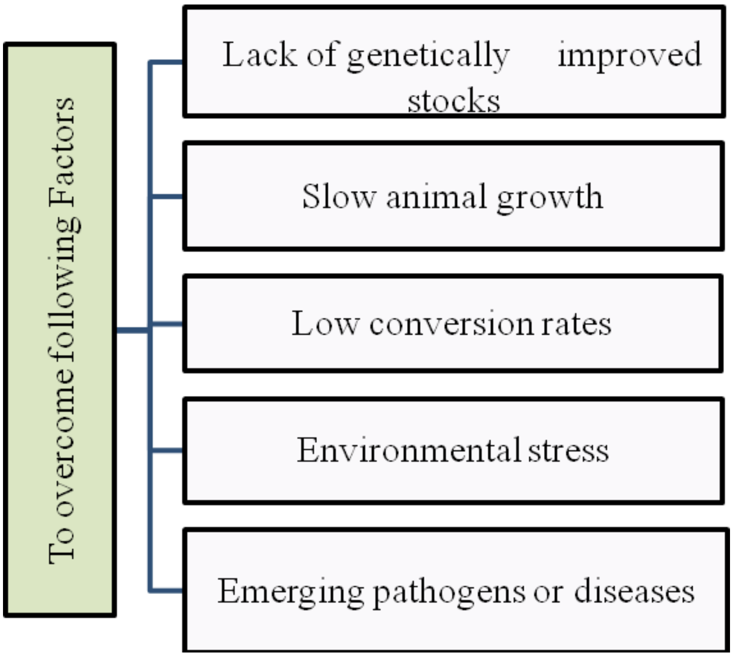
Blastoderm graft transplantation





Molecular Breeding for Climate Smart Aquaculture

Molecular breeding is essential in present climate change to target different superior traits like growth and quality broodstock. Molecular breeding in aquaculture reduces the inbreeding depression, accelerates breeding programs with genetic improvement of species with desirable trait i.e fast growth rate, disease resistant, climate change and improved FCR leads to aquaculture stocks that are more productive and resilient.



Reasons for use of molecular breeding in aquaculture

Molecular markers

A molecular marker is a DNA sequence used to mark or track a particular locus on a particular chromosome i.e marker gene, that facilitates the study of inheritance of a trait or a gene. These markers must be readily detectable in phenotype. It represents genetic differences between individual organisms, referred as gene tags. There are few marker types: allozymes, mitochondrial DNA and nuclear DNA

Allozyme markers: The term _allozyme' refers to only those genetically different forms of an enzyme that are produced by the amino acid differences on the locus and reflect changes in the under lying DNA sequence. Depending on the nature of the amino acid changes, the resulting protein products may migrate at different rates (due to charge and size differences) when run through a gel electrophoresis subjected to an electrical field. The various gels used for electrophoresis are acrylamide, cellulose acetate and hydrolyzed potato starch. Allozymes in aquaculture helps in describing the genetic variability, genetic behavior, genetic drift in species and genome mapping, phylogenetic relationship between the different species of fishes.

Mitochondrial DNA: A small portion of the less than 1% DNA of eukaryotic cell is non nuclear and is located within i.e mitochondria in the cytoplasm of the cell so called as mitochondrial DNA, differs significantly from nuclear DNA in structure and mode of inheritance. The molecule is generally 16–20 kb in size and made up of protein coding genes, ribosomal RNA genes (rRNA), transfer RNA genes (tRNA) and a section generally known as the D-loop or control region, which is non-coding but is involved in the replication of the molecule. mtDNA is a circular molecule that undergoes no recombination and is maternally inherited. Unlike the nuclear genome, the mitochondrial genome contains very little non-coding DNA.

Characteristics of mtDNA: mtDNA is maternally inherited haploid single nucleotide; the entire genome is transcribed as a unit and is not subjected to recombination, provides the homologous markers; the replication is of optimum size, continuous, unidirectional and symmetrical with absence of introns; mtDNA is intensively studied and few set of universal primers have been developed initially in salmonids for analyzing and used ND-1 and ND-5/6 segments.

Nuclear DNA: DNA markers are the most widely used type of marker predominantly due to their abundance. They arise from different classes of DNA mutations such as substitution mutations (point mutations), rearrangements (insertions or deletions) or errors in replication of tandemly repeated DNA. DNA markers may reveal genetic differences that can be visualised by using a technique called gel electrophoresis and staining with chemicals (ethidium bromide or silver) or detection with radioactive or colourimetric probes.

DNA markers are classified as Type I and Type II markers. Type I are markers associated with genes of known function. RFLP markers, Allozyme are type I markers because they were identified during analysis of known genes. Type I markers have utility in studies of comparative genomics, genome evolution, candidate gene identification. Type II markers are associated with anonymous genomic segments. RAPD markers, AFLP markers, Microsatellite markers, SNP markers useful in aquaculture genetics for species, strain and hybrid identification, in breeding studies, and more recently as markers linked to QTL.

Single Nucleotide Polymorphism: Single nucleotide polymorphism (SNP) describes polymorphisms caused by point mutations that give rise to different alleles containing alternative bases at a given nucleotide position within a locus. Such sequence differences due to base substitutions. The SNPs are enormous in number, bi-allelic in nature as well as co-dominant, and scattered along the genome. SNP markers are most popular molecular markers and are linked with different phenotypes or genotypes of interest.

SNPs in fisheries are useful in genomic studies and diagnostic markers for diseases. In the Pacific oyster (*Crassostrea gigas*), SNPs occur, on average, every 40 bp in non-coding regions and every 60 bp in coding regions occurance makes in SNPs efficient type of marker to map or scan genomes. SNPs are being used as a genomic resource such as development genetic linkage map for fish species such as in Atlantic cod.

Restriction Fragment Length Polymorphism (RFLP): RFLP is a difference in homologous DNA sequences that can be detected by the presence of fragments of different lengths after digestion of the DNA samples with specific restriction endonucleases. Individuals, populations and species differ in size of fragments produced by restriction enzyme digestion of DNA which forms the identification of polymorphism.

Climate smart inducing agents and slow releasing devices for fish breeding

Combination of hormones like GnRH with hCG is used stimulate multiple elements of reproductive axis. Use of novel inducing agents like follicle-stimulating hormone releasing hormone to stimulate early stages of gametogenesis and other agents like dynorphin and kisspeptin can be used; use of slow releasing hormone devices like progesterone capsules and osmotic pumps including existing cholesterol pellets and development of species specific horomone implants for cultivable freshwater, brackishwater and marine finfishes and shellfishes. The exisitng inducing agents used and available in the market are shown in the images below.

Future perspectives

Rajiv Gandhi Centre for Aquaculture (RGCA), a research and extension wing of Marine Products Export Development Authority has established nucleus breeding centre (NBC) and broodstock multiplication centre (BMC) for finfish and shellfish in India. For example, RGCA unit at Kodiyaghat, Sri Vijaya Puram, Andaman and Nicobar Islands is operating a domestication of tiger shrimp project and serving as nucleus breeding centre for tiger shrimp in India. Similarly, GIFT tilapia project at Andhra Pradesh is serving as satellite breeding centre for GIFT tilapia in India. Since 2012, BMC for *L. vannamei* was established at Visakhapatnam, Andhra Pradesh and presently supplying domestically raised SPF L. vannamei brooders for hatcheries in India. Recently, Govt. of India has issued guidelines for establishment and operation of NBC/BMC in India for cultured finfish and shellfish. These centres in the future will be able to supply the broodstock for sustainable seed production in India. Also, the technology of speed breeding as achieved in Agriculture field will be able to adopt similar trend for aquaculture sector in the years to come. These centres will also support the impact of climate change on finfish and shellfish seed production in India. Further, gene editing technolgies need to be improved further and developed for Indian major carps in addition to the recently achieved selectively bred fish varieties like GI catla, GI freshwater prawn, and Jayanti rohu. Selective breeding methods need to be evaluated and standardized for other cultured fishes exhibiting slower growth.

4. Recirculatory Aquaculture System (RAS): An Environmental Solution and Climate Change Adaptation

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Introduction

As global populations continue to rise, the demand for sustainable food sources has intensified. Aquaculture, or the farming of aquatic organisms, has emerged as a vital solution for meeting this demand. However, traditional aquaculture practices have significant environmental drawbacks, including water overuse, pollution, and habitat destruction. Simultaneously, climate change introduces new challenges to aquaculture, such as unpredictable weather patterns, rising temperatures, and water scarcity. Addressing these twin challenges - environmental sustainability and climate resilience—requires innovative approaches.

Recirculatory Aquaculture Systems (RAS) have gained prominence as a transformative technology in aquaculture. These systems offer a controlled environment for fish farming while minimizing ecological impacts. RAS aligns with the goals of sustainable development and climate adaptation by conserving water, reducing pollution, and providing a resilient framework for food production. This essay explores the environmental benefits and climate adaptation potential of RAS, underscoring its role as a sustainable aquaculture solution.

1. Understanding Recirculatory Aquaculture Systems (RAS)

Recirculatory Aquaculture Systems (RAS) are highly advanced, land-based systems designed to optimize aquaculture processes by re circulating water within a closed-loop or semi-closed-loop system. These systems aim to address the inefficiencies and environmental challenges associated with traditional aquaculture methods.

Core Principles: At its core, RAS focuses on water treatment and reuse. Water from fish tanks is filtered to remove solid waste, treated for dissolved toxins, and re circulated back into the system, ensuring minimal water loss.

Key Components:

- **Mechanical Filters:** Remove particulate matter such as uneaten feed and fish waste.

- **Biofilters:** Use beneficial bacteria to convert harmful ammonia and nitrites into less toxic nitrates.
- **Aeration and Oxygenation Systems:** Maintain optimal dissolved oxygen levels for aquatic species.
  - **Temperature Control:** Ensures the water temperature remains ideal for the cultured species, independent of external climatic conditions.
  - **Monitoring Systems:** Automated systems track critical water quality parameters, enabling proactive management.

Applications: RAS is versatile and can support the farming of freshwater, brackish water, and marine species. It is particularly valuable in regions with limited water resources or harsh climatic conditions.

Environmental Benefits of RAS

Efficient Water Use and Conservation

Water scarcity is a pressing global issue, and traditional aquaculture methods exacerbate the problem through excessive water use. RAS offers a sustainable alternative by drastically reducing water consumption.

- **Water Recycling:** RAS re circulates up to 90-99% of the water, requiring only minimal replenishment to compensate for evaporation and system losses.
- **Enabling Aquaculture in Arid Regions:** By reducing dependence on natural water bodies, RAS allows aquaculture to thrive even in water-scarce areas.
- **Protecting Freshwater Resources:** By minimizing withdrawals from rivers, lakes, and groundwater, RAS preserves these ecosystems for other essential uses.

Reduction in Effluent Discharge and Eutrophication

Traditional aquaculture often discharges untreated effluents into nearby water bodies, leading to eutrophication, algal blooms, and biodiversity loss. RAS addresses these concerns through effective waste management.

- **Advanced Filtration:** Solid waste is mechanically removed and processed, often repurposed as fertilizer or biogas feedstock.
- **Bio filtration Efficiency:** Converts toxic ammonia into nitrates, reducing the environmental burden.
- **Minimized Discharge:** The small volume of effluents released from RAS is typically treated to meet environmental standards, ensuring minimal ecological impact.
- **Preventing Water Contamination:** By containing effluents within a closed system, RAS safeguards surrounding ecosystems from nutrient overloads and chemical pollutants.

Preservation of Natural Habitats

Aquaculture expansion often comes at the cost of converting sensitive habitats, such as mangroves and wetlands, into fish farms. RAS eliminates the need for such destructive practices.

- **Land-Based Operations:** RAS systems are constructed on non-sensitive land, avoiding habitat conversion.
- **Supporting Biodiversity:** By reducing reliance on wild fish stocks and natural water sources, RAS helps maintain the balance of aquatic ecosystems.
- **Avoiding Overfishing:** With RAS providing a reliable supply of farmed fish, pressure on overexploited marine populations is reduced.

Climate Change Adaptation through RAS

Controlled Environments for Resilient Fish Farming

One of the most significant advantages of RAS is its ability to operate independently of external environmental conditions. This feature is particularly valuable in the context of climate change.

- **Temperature Control:** RAS maintains optimal water temperatures regardless of external climate fluctuations, ensuring stable growth conditions for fish.
- **Reduced Dependency on Weather:** Unlike pond-based systems, RAS is not affected by droughts, floods, or storms, making it more resilient to extreme weather events.
- **Year-Round Production:** The controlled environment allows for continuous production, ensuring a stable food supply even during adverse climatic conditions.

Mitigating Climate-Driven Risks in Aquaculture

Climate change poses significant risks to traditional aquaculture, including altered water temperatures, salinity changes, and disease outbreaks. RAS mitigates these risks effectively.

- **Biosecurity Measures:** The closed nature of RAS minimizes exposure to external pathogens, reducing the risk of disease outbreaks exacerbated by climate change.
- **Adaptability to Species Needs:** RAS systems can be tailored to the specific requirements of different species, ensuring optimal growth even as environmental conditions change.
- **Reduced Habitat Competition:** By isolating aquaculture operations from natural water bodies, RAS minimizes conflicts over resource use between aquaculture and other sectors.

Reducing the Carbon Footprint of Aquaculture Practices

Sustainability in aquaculture must include efforts to reduce greenhouse gas emissions. RAS contributes to this goal through various mechanisms.

- **Energy Efficiency:** Modern RAS designs incorporate renewable energy sources such as solar and wind, reducing reliance on fossil fuels.

- **Proximity to Markets:** Land-based RAS facilities can be located closer to urban centers, reducing transportation-related emissions.
- **Efficient Resource Use:** By maximizing water and feed efficiency, RAS minimizes the overall environmental footprint of aquaculture operations

Water Quality Management in RAS

Water quality is the cornerstone of successful aquaculture operations. In Recirculatory Aquaculture Systems (RAS), maintaining optimal water quality is crucial to ensuring the health and productivity of cultured species. Unlike traditional systems, where water is exchanged frequently, RAS relies on the continuous recycling and treatment of water, making precise water quality management essential.

Key Parameters:

  - **Dissolved Oxygen (DO):** Adequate oxygen levels are vital for fish survival and growth. Automated aeration systems and oxygen injectors help maintain optimal DO levels.
  - **Ammonia and Nitrites:** Fish excrete ammonia, which is toxic in high concentrations. RAS uses biofilters to convert ammonia into less harmful nitrates, maintaining safe levels.
  - **pH Balance:** A stable pH range is critical for fish health. Acid-base buffering systems in RAS prevent pH fluctuations.
  - **Temperature:** Maintaining a species-specific temperature range is necessary for optimal growth. RAS allows precise temperature regulation.
  - **Turbidity and Solids Removal:** Suspended solids, if not removed, can clog systems and harm fish. Mechanical filters ensure water clarity.
- **Monitoring Systems:** Advanced sensors and automated systems provide real-time monitoring of water quality parameters, enabling rapid corrective actions.
- **Benefits:** Effective water quality management in RAS reduces stress on fish, minimizes disease outbreaks, and enhances feed efficiency, contributing to sustainable and profitable aquaculture.

Technological Components of RAS

The efficiency and effectiveness of RAS rely on cutting-edge technologies designed to optimize water use, maintain environmental conditions, and enhance system sustainability. The following are the critical technological components of RAS:

Water Treatment and Filtration Systems

Water treatment in RAS ensures the removal of waste products and the maintenance of water quality, enabling its continuous reuse.

Mechanical Filtration:

- Removes solid waste, such as uneaten feed and fish excreta.
- Typically uses drum filters or screen filters for efficient particle separation.

Bio filtration:

- Biological filtration systems employ beneficial bacteria to convert harmful ammonia into nitrates through the nitrification process.
- Bio filters provide a large surface area for bacterial colonization, enhancing their efficiency.

Chemical Filtration:

- Activated carbon filters absorb dissolved organic compounds and toxins.
- Ozonation and UV sterilization systems further enhance water clarity and eliminate pathogens.

Effluent Treatment:

- Any discharge from RAS is treated to meet environmental standards, ensuring minimal ecological impact.

Temperature and Oxygen Control Mechanisms

Maintaining optimal temperature and oxygen levels is critical for the health and productivity of aquatic organisms in RAS.

- **Temperature Control:**
    - Heat exchangers and chillers regulate water temperature according to the species being cultured.
    - Insulated tanks and pipes minimize heat loss and improve energy efficiency.
- **Oxygenation Systems:**
    - Diffusers and aerators ensure the uniform distribution of dissolved oxygen.
    - Pure oxygen injection systems can be used for high-density stocking, ensuring sufficient oxygen supply.
- **Real-Time Monitoring:** Sensors continuously track temperature and oxygen levels, sending alerts if values deviate from set parameters, allowing immediate intervention.

Renewable Energy Integration in RAS

Energy consumption is a significant operational cost in RAS. Integrating renewable energy sources enhances sustainability and reduces dependency on fossil fuels.

Solar Energy:

- Photovoltaic panels can power pumps, aerators, and monitoring systems.
- Solar water heaters provide cost-effective temperature regulation.

Wind Energy:

- Wind turbines generate electricity to supplement power requirements in regions with favorable wind conditions.

Bio energy:

- Waste biomass from RAS operations can be converted into biogas, which can be used to power heating and electrical systems.

Hybrid Systems:

- Combining multiple renewable sources ensures a reliable and steady energy supply, reducing operational costs and carbon emissions.

Socioeconomic Impacts of RAS

The adoption of Recirculatory Aquaculture Systems (RAS) extends beyond environmental and technological benefits, significantly influencing the socioeconomic fabric of communities and stakeholders involved in aquaculture. The following explores the profound socioeconomic impacts of RAS:

Economic Viability for Farmers and Stakeholders

RAS presents a viable economic model for farmers, investors, and other stakeholders by enhancing productivity and profitability.

- **Increased Yield:**
    - The controlled environment of RAS facilitates high stocking densities, leading to increased fish production compared to traditional methods.
- **Cost Efficiency:**
    - Although initial setup costs are high, the long-term operational costs, particularly for water and feed, are significantly reduced due to efficient resource use.
    - Reduced disease outbreaks in RAS systems lower costs associated with veterinary care and stock losses.
- **Market Access:**
    - RAS enables year-round production, ensuring a consistent supply of high-quality fish to meet market demand.
    - Premium prices can be fetched for fish produced using sustainable and eco-friendly practices.
- **Job Creation:**
    - The establishment and maintenance of RAS facilities create employment opportunities, from system design and installation to daily operations and marketing.

Addressing Food Security in a Changing Climate

As climate change disrupts traditional food production systems, RAS emerges as a reliable solution for ensuring food security.

Sustainable Protein Source:

- RAS supports the production of fish, a nutritious and affordable protein source, essential for addressing global malnutrition.

Climate Resilience:

- By operating independently of external climatic conditions, RAS ensures stable food production even in regions affected by droughts, floods, or temperature extremes.

Diversification:

- The ability to farm a variety of species, including high-value fish and shellfish, enhances dietary diversity and nutritional availability.

Community Empowerment:

- Small-scale farmers can adopt RAS to enhance their livelihoods and contribute to local food systems, reducing dependence on imported seafood.

Promoting Green Aquaculture Practices

RAS aligns with global efforts to promote sustainable and environmentally friendly aquaculture practices.

Reduction in Ecological Footprint:

- Efficient resource use and waste management in RAS minimize the environmental impact of aquaculture operations.

Compliance with Regulations:

- The closed-loop nature of RAS ensures compliance with stringent environmental standards, enhancing the reputation of aquaculture operations.

Consumer Awareness:

- With growing consumer demand for sustainably sourced food, RAS provides a competitive edge by adhering to green practices.

Integration with Circular Economy:

- By repurposing waste products, such as converting solid waste into biogas or fertilizers, RAS contributes to a circular economy model.

Challenges in Implementation of RAS

Financial and Technical Barriers

Implementing Recirculatory Aquaculture Systems (RAS) presents significant financial and technical challenges that limit its widespread adoption. One of the primary barriers is the high initial investment required for infrastructure, including tanks, water treatment units, and monitoring equipment. The costs associated with land acquisition and site preparation further exacerbate the financial burden, making RAS less accessible to small- scale farmers.

From a technical perspective, RAS requires advanced knowledge of system design and maintenance. Complex components such as biofilters, oxygenation systems, and automated sensors necessitate skilled labor for installation and operation. Additionally, the cost of repairing or replacing specialized equipment can be prohibitive. The integration of these systems with existing aquaculture operations often demands substantial technical expertise, which may not be readily available in many regions.

Government subsidies and financial incentives are often insufficient to offset these costs. Moreover, the lack of access to affordable credit or loan schemes tailored for aquaculture enterprises further limits the adoption of RAS. Addressing these barriers requires a coordinated approach involving policy reforms, financial support, and capacity building.

Energy Consumption and Alternatives

RAS is known for its intensive energy requirements, primarily for water circulation, aeration, and temperature regulation. These processes are energy-intensive, leading to high operational costs and carbon emissions. In regions where electricity costs are high or unreliable, energy consumption poses a significant challenge to the sustainability of RAS. However, alternative energy solutions present promising opportunities. Renewable energy sources such as solar, wind, and biomass can significantly reduce the carbon footprint of RAS operations. For instance, integrating solar panels for powering pumps and aerators can lower energy costs while ensuring a sustainable energy supply. Similarly, the use of energy-efficient technologies, such as variable-speed pumps and advanced insulation materials, can enhance the overall efficiency of RAS.

Promoting research and development in energy optimization and encouraging the adoption of renewable energy systems are crucial for overcoming these challenges. Additionally, governments and private entities can play a pivotal role by offering incentives and grants for RAS operations that integrate sustainable energy practices.

Knowledge Dissemination and Capacity Building

A major hurdle in implementing RAS is the lack of awareness and technical knowledge among stakeholders. Many farmers and aquaculture practitioners are unfamiliar with the principles and benefits of RAS, leading to resistance to adoption. Furthermore, the limited availability of training programs and educational resources hinders the development of requisite skills.

Capacity building initiatives are essential to bridge this knowledge gap. Workshops, seminars, and hands-on training programs can equip stakeholders with the technical know- how required for RAS operations. Establishing demonstration farms can serve as practical examples to showcase the benefits and feasibility of RAS. Collaboration between academic institutions, government bodies, and industry players can foster knowledge dissemination and drive innovation in the sector.

Additionally, incorporating RAS-focused curricula in aquaculture education and promoting research partnerships can accelerate capacity building. Efforts should also focus on developing user-friendly manuals and multilingual resources to cater to diverse audiences. By addressing these knowledge barriers, RAS can become more accessible and appealing to a broader range of stakeholders.

Future Prospects of RAS with Respect to Environmental Solution and Climate Change Adaptation

The future of RAS holds immense potential as an environmentally sustainable solution and a climate change adaptation strategy. RAS's ability to minimize water usage and prevent environmental contamination aligns with global efforts to conserve natural resources. By reusing water through advanced filtration systems, RAS significantly reduces freshwater dependency, addressing water scarcity issues exacerbated by climate change.

In terms of climate adaptation, RAS provides a controlled environment that mitigates the impacts of extreme weather events and fluctuating temperatures on aquaculture production. This ensures consistent yields and reduces the risk of stock losses, contributing to food security in a changing climate. Additionally, the modular and scalable nature of RAS allows for its adaptation to various geographic and climatic conditions, making it a versatile solution for sustainable aquaculture.

Innovation and technological advancements are expected to further enhance the efficiency and sustainability of RAS. For instance, the integration of artificial intelligence and IoT (Internet of Things) technologies can enable real-time monitoring and optimization of system parameters. Advances in biofiltration techniques and nutrient recycling can improve water quality and reduce waste.

Moreover, the adoption of circular economy principles in RAS can enhance its environmental benefits. By utilizing fish waste as a resource for producing fertilizers or bioenergy, RAS can contribute to waste valorization and reduce environmental pollution. Public and private sector collaboration, along with supportive policies and incentives, will be instrumental in realizing the full potential of RAS.

Conclusion

Recirculatory Aquaculture Systems represent a transformative approach to sustainable aquaculture, offering solutions to pressing environmental challenges and climate change impacts. While significant financial, technical, and knowledge barriers exist, strategic interventions can pave the way for widespread adoption. Leveraging renewable energy sources, enhancing capacity building, and fostering innovation are critical to overcoming these challenges.

The future of RAS is promising, with its potential to conserve water, reduce environmental pollution, and adapt to climate variability. By aligning RAS development with global sustainability goals, it can play a pivotal role in securing a resilient and environmentally sustainable aquaculture sector. Collaborative efforts among stakeholders, including policymakers, researchers, and industry players, will be essential to harness the full benefits of RAS as a climate-smart solution.

5. Carbon footprints in Aquaculture

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Introduction

Followed by China and the United States, India is found to be the world's largest greenhouse gas emitter. The main sources of carbon emissions arecoal-fired power plants, livestock, and paddy fields.Even though fossil fuel combustion is the main source of CO_2 emission, about one-third of the greenhouse gas emission is contributed by agriculture and land use change. Emissions are rising rapidly, but per capita emissions are well below the global average (The Carbon Brief Profile, 2019).

Aquaculture, the fastest-growing food sector, improved food and nutrition security, economic growth, and employment creation. Even though aquaculture has a lot of benefits, it is also responsible for several environmental impacts. Those environmental impacts include chemical pollution, depletion or enrichment of nutrients, habitat loss, disease, introduction of exotic species, inefficient energy and biotic resource use, etc. Comparing these impacts from aquaculture, greenhouse gas emission is a global phenomenon. Carbon dioxide, methane, and nitrous oxide are the three major gases referred as greenhouse gases. The contribution of aquaculture to the total emission of greenhouse gases is very little, but the major concern is that aquaculture is one of the fastest-growing agricultural activities. The growth of the aquaculture industry relies on the use of formulated feed input, which will increase emissions of carbon dioxide and nitrous oxide as well. According to the Paris Agreement (COP 21), all signed parties have committed to reducing greenhouse gas (GHG) emissions by 2030. This goal necessitates more efficient production methods to achieve the expected doubling of yields without increasing the carbon footprint, which poses a significant challenge.

This chapter aims to present a general overview of carbon footprints in aquaculture and their management strategies.

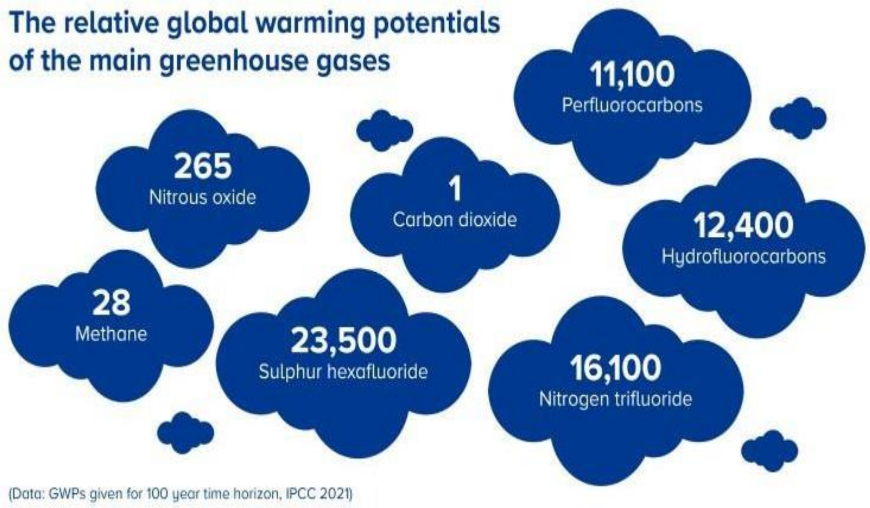
Carbon footprint

The concept of carbon footprint is derived from ecological footprint, which is used to assess the consumption of natural resources by a particular activity. The carbon footprint (CF) in aquaculture refers to the total amount of greenhouse gases (GHGs) emitted in the process of producing one kilogram of aquaculture product, such as fish, shellfish, or other farmed aquatic organisms.Carbon footprint is used to assess the total amount of greenhouse gases emitted over the lifecycle of a given product or service, from raw material collection, manufacturing, assembly, transportation, use, disposal, and waste disposal (Williams, 2009).

The carbon footprint of aquaculture is measured in grams of carbon dioxide equivalent (g CO_2eq) per standard serving of edible protein, which is 40 grams.

Global warming potential

Global Warming Potential (GWP) is the ability of various greenhouse gases to trap heat in relation to carbon dioxide (CO_2) over a given time, typically 20, 100, or 500 years. The reference gas, CO_2, has a GWP of 1, whereas other gases, such as nitrous oxide (N_2O) and methane (CH_4), have GWPs of 265-298 and 28-34 during 100 years, respectively. While long-lived gases like fluorinated gases (HFCs, PFCs, and SF_6) might have GWPs in the hundreds or tens of thousands, short-lived gases like methane have higher GWPs over shorter timeperiod. In general, GWP assists policymakers in creating plans to lower total greenhouse gas emissions and to meet climate goals by quantifying emissions in CO_2 equivalents (CO_2e).



History of carbon footprints

The term ―carbon footprint‖ originated from the ecological footprint concept but has evolved into a concept in its own right in recent years.An ecological footprint is the total area of land required to sustain an activity or population - environmental impacts, such as water use and the amount of land used for food production. In this way, a universally agreed definition of a carbon footprint is yet to exist.

Current scenario of carbon footprints

As of 2024, global carbon dioxide (CO_2) emissions have reached record levels, with fossil fuel emissions increasing by 0.8% to 37.4 billion tonnes and total CO_2 emissions, including land-use changes, projected to be 41.6 billion tonnes, a 2% rise from 2023. This increase is driven by higher coal consumption in emerging economies and a rebound in aviation and shipping emissions, which grew by 7.8%. India‘s emissions are projected to rise by 4.6%, contributing 8% to global emissions, with the power sector being a significant source, emitting 1.4 billion tonnes of CO_2 equivalent. Despite substantial investments in renewable energy, such as 83% increase in renewable projects to $16.5 billion, India has not committed to phasing out coal or fossil gas. Globally, the urgency for action is underscored by the United Nations Environment Programme, emphasizing enhanced efforts to limit warming to 1.5°C. While India‘s per capita emissions remain below those of developed nations, its total emissions are significant due to its large population and rapid growth. The current scenario highlights the critical need for coordinated strategies to reduce emissions and mitigate climate change.

Types of carbon footprint

According to Wiedmann et al. (2009), the carbon footprint is a concept that measures the amount of greenhouse gas (GHG) emissions that are either directly or indirectly associated with a certain activity.

Primary carbon footprints:

It is the controllable one and it is measured as the GHGs are released directly by burning of fossil fuels for energy consumption and transportation. GHG emissions from domestic sources, such as heating and electricity, and transportation sources, such as private vehicles, airplanes, buses, and trains, make up the majority of the direct footprint.

Secondary carbon footprint:

It is measured as the GHGs released indirectly during the life cycle of products used by an individual or organization.The indirect comprises of greenhouse gas emissions linked to food and services that an individual consumes, as well as the infrastructure that people utilize in tandem with the rest of society.

Assessment of carbon footprint

Life cycle assessment: Life Cycle Assessment (LCA), a systematic process for evaluating a product's environmental impacts from manufacture to recycling or disposal, is a "cradle-to-grave" approach. Informing decision-makers in industry, government, or non-government organizations (for example, strategic planning, priority setting, product or process design or redesign), choosing pertinent environmental performance indicators.

Product carbon footprints: PCF is a method that is specifically designed to calculate the carbon footprint of products, in which life cycle assessments that only consider global warming as an impact category. Product carbon footprint studies produce life cycle inventory data that record greenhouse gas emissions from a product's lifecycle and describe them according to their potential to cause global warming. These results are then converted into product carbon footprints, which are typically expressed as point values.PCF covers partially and it is like cradle to gate method.

Organizational carbon footprint (OCF): In terms of social, economic, energy, and individual travel planning, university campuses constitute a diverse ecosystem that has a significant influence on the host towns and regions. Therefore, it is essential to implement sustainable regulations in order to reduce this impact and encourage ecological behavior. Presenting a carbon footprint approach created especially to determine the carbon footprint of organization is the goal of this research (Battistini et al., 2023).A number of factors influence the urban impact that anorganization presence has on a particular area.

Carbon footprint in aquaculture

Global aquaculture acts as a major source of emission of greenhouse gases. The GHGs are emitted from the activities like production of feed raw materials, processing and transport of feed materials, rearing of fishes such as catfish, cyprinids, IMCs, salmonids, tilapia, shellfishes and bivalves (Subhashree et al.2022).The emission of GHGs was found to be 9.30 × 1010 g eq CO_2 and will increase to 3.83 × 1011 g eq CO_2 by 2030. Fish feed acts as an important source in releasing greenhouse gases.

Greenhouse gas emission from aquaculture systems:

Carbon dioxide: It is released during the respiration of biological components and mineralization of organic matters such as feed residues, faecal matter, manures and dead phytoplanktonwhich are mineralized by heterotrophic bacteria that lead to the release of carbon dioxide.

Methane: In pond aquaculture systems, bottom sediment is the primary site for methanogenic bacteria activity since it is the least aerated part of the pond ecosystem. Methanogenic bacteria utilize dissolved organic carbon (DOC) as a substrate for energy and biomass production.The DOC produces in the process of organic matter mineralization by heterotrophic bacteria, bioturbation of sediment by micro/macrobenthic organisms and some extent from the faecal matter of detritivorous fish. Methane gas is emitted from aquatic systems into the atmosphere by ebullition of gas bubbles and diffusive flux. An increase in temperature promotes methanogenesis, which contributes to greater CH4 emissions.

Nitrous oxide: It is produced by nitrifying and denitrifying bacteria during autotrophic aerobic nitrification, anaerobic denitrification and the annamox process.These bacteria need ammonia, which is generated during the decomposition of uneaten protein-rich aquafeed and fish faces. Algal photosynthesis also produces NO_3 and dissolved oxygen, increasing the fraction of N_2O produced through linked nitrification-denitrification.

GHGs emitted during aquaculture operations

Aquaculture includes stages of operations such as construction of pond, filling of water, weed control, stocking, feeding, and management of water quality and harvesting of fish.Among farmed finfish and crustaceans, silver and bighead carps have the lowest greenhouse gas, nitrogen and phosphorus emissions, but highest water use, while farmed salmon and trout use the least land and water. It has been reported that CO_2 emission is higher in cultured channel catfish (3.14 kg CO_2/kg) compared to salmon (2.45 kg CO_2/kg fish).

a) Emission during feed production

A large portion of the carbon footprint in aquaculture comes from the production of fish feed. Fishmeal and fish oil (often sourced from wild-caught fish) are common ingredients in many aquaculture feeds, contributing significantly to greenhouse gas (GHG) emissions.The cultivation of crops for plant-based feeds (such as soy or corn) also generates GHGs due to fertilizers, land use, and transportation.

b) Emission from energy sources

Aquaculture operations, especially those in recirculating aquaculture systems (RAS) or intensive systems, require a lot of energy. This includes energy for water circulation, oxygenation, temperature control, and lighting. The type of energy used (renewable vs. fossil fuels) plays a big role in determining the carbon footprint. Operations that rely on fossil fuels have a higher carbon footprint than those that use renewable energy sources.

c) **Emission due to water quality management and transportation**

Water pumping and transportation of fish, feed, and equipment contribute to the carbon footprint. For example, transporting fish from farms to processing plants or retail markets via trucks, boats, or airplanes adds emissions.The transportation method, distance travelled, and frequency of shipments affect emissions.

d) Emission based on farming practices

Aquaculture farms use various farming practices that influence the carbon footprint, including the type of system used (e.g., open-net pens vs. land-based tanks) and the location of the farm (e.g., coastal vs. inland).Open-net pens can lead to the release of methane and nitrous oxide from the bottom of the sea, especially in areas where waste accumulation is high. Additionally, intensive farming methods that use high quantities of inputs may have a higher carbon footprint compared to extensive systems.

e) Emission during waste management

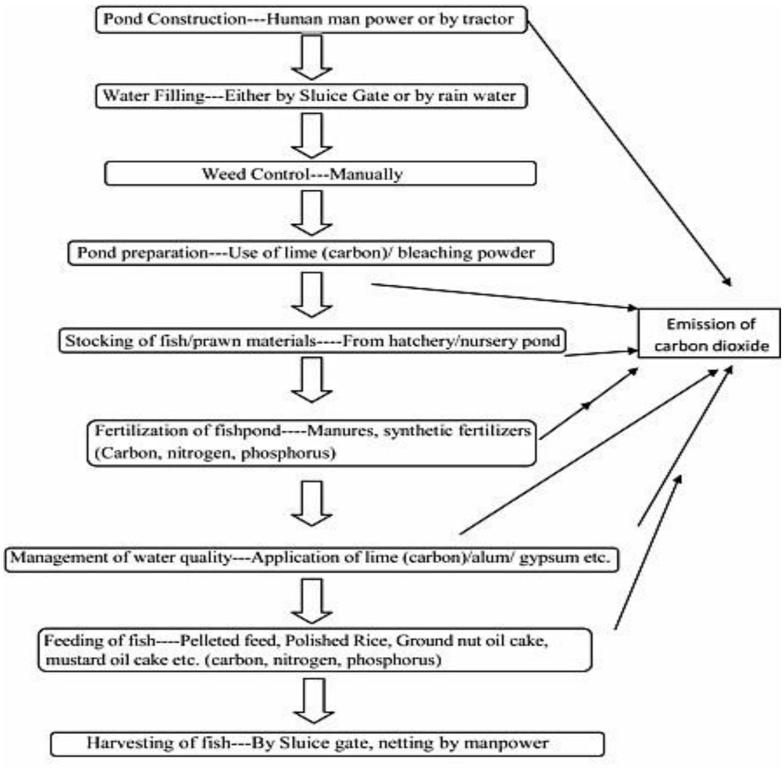
Fish farming produces waste in the form of uneaten feed, fish feces, and chemicals used in disease control. Improper waste management can lead to environmental degradation and the emission of GHGs. The breakdown of organic waste in water can produce methane, a potent GHG. Proper waste treatment can mitigate this issue.

f) Emission due to processing and packaging methods

After harvesting, fish undergo processing (e.g., filleting, smoking) and packaging. These activities, especially when done in energy-intensive facilities, add to the carbon footprint. The type of packaging material (plastic, Styrofoam, etc.) also plays a role, as these materials are often petroleum-based and not always recyclable.

g) Supply chain emissions

From the production of feed ingredients to the final product reaching consumers, the entire supply chain contributes to emissions. This includes the emissions from suppliers of raw materials, distribution, and retail.Improving supply chain efficiency, reducing waste, and using low-carbon alternatives can help reduce emissions across the sector.



Source: Adhikari et al. 2013

Factors affecting the carbon footprint in aquaculture

i. **Cultivable species:** based on the cultivable species, the type of feed and water quality will be varied. Maintenance of water quality for sensitive species may increase the carbon foot print from aquaculture. Similarly, input of high quality diet also increase the GHGs emission.

ii. **Farm size, design and farming method:** culture of same species using different farming techniques and in different geographical conditions lead to variations in carbon footprint. In general, advanced farming techniques such as RAS and aquaponic methods re having lower GHGs emissions compared to traditional farming methods.

iii. **Feed type:** it is the major GHG factor in fish farming. Feed alone contributes 70% of carbon emission from aquaculture activities. 1 Kg of animal based feed in shrimp farming may release up to 2.8 Kg of CO_2. Whereas the usage of plant based feed has minimum carbon emissions. Similarly, rearing of herbivore and omnivore fish having lower carbon footprint compared to carnivore fish farming.

iv. **Disease management:** in any aquaculture activity to maintain the fish heath and optimum production, farmers are using various drugs and chemicals. The extensive usage of chemicals and their transportation from production unit to farming area may increase the carbon emission. Additionally, disease causes mortality which in turn reduce the yield and increase the carbon footprint of the aquaculture activity.

v. **Water quality control:** maintaining the optimal water quality conditions, including nutrients level, is a crucial factor in aquaculture. Improper management of water quality has negative environmental impact and increase the carbon emission. For example, poor maintenance of O_2 urge the farmers to use aerators, motors and pumps which on the other side increase the carbon footprint. Furthermore, release of untreated and effluent is causing severe environmental damages.

vi. **Energy utilization:** the heavy usage of fossil fuels such as petrol and coal based products in aquaculture industry, especially in intensive shrimp farming, has significantly increasing the carbon footprint of aquaculture. Also, the usage of electricity as major energy source is also has significant implications on GHGs emissions from aquaculture.

Strategies for GHG emissions reduction in aquaculture

- Select the site which has minimum HGGs emission and avoid the carbon sequestration sites such as mangroves, salt marshes, estuaries and wetlands.
- Alternate use of feed, lowering the feed conversion ratio and use of insect and algal based feed ingredients which could lead to a GHGs emission reduction of 1-24%.
- Avoid the usage of fossil fuels for energy source and implement the sustainable renewable energy sources (solar, wind, and hydro power).
- Implementing polyculture systems with shellfish and algae which increase the yield per unit of water body and reduce GHGs emission.
- Emphasizing the use of safe, low-impact water treatments and controlling their use can decrease the risk of contamination, reduce reliance on natural water bodies, and enhance the water quality of aquaculture systems.
- Streamlining of transportation routes and sharing transportation and storage resources are key to enhancing the efficiency of product delivery and minimizing the carbon footprint of logistics.
- The industry is encouraged to commit to sustainable production and marine conservation by developing green aquaculture products. This strategy can increase market appeal and demand, reduce inefficient practices, and diminish the environmental impact during production.

6. Aquaponics as a promising strategy to mitigate climate change

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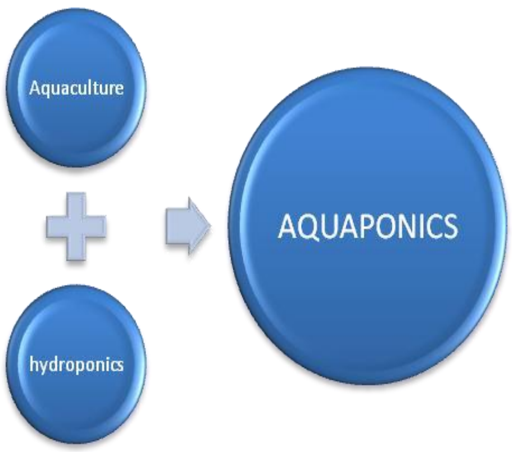
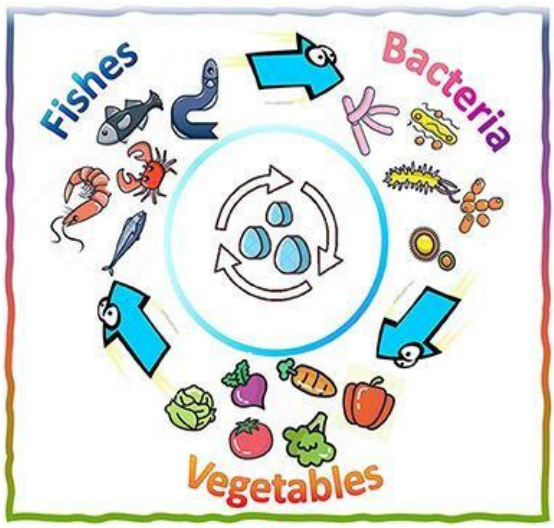
Subject Matter Specialist (Fisheries Extension)

KVK, Sikkal, Nagapattinam

Stand of aquaculture

- India stands 3rd in total fish production and 2nd in aquaculture globally
- Aquaculture contributes around 50% of the global food fish consumption
- Land and water resources are shrinking
- Intensification is the key tool for increasing production
- Aquaculture brings about socio-economic development in terms of income and employment through the use of unutilized and underutilized resources in many parts of the country





- ***Aqua* from aquaculture**
- ***Ponics* from hydroponics**

History

- Earliest form of aquaponics –Aztec (central & southern mexico)- *chinampas* – floating island- used to cultivate plants
- Introduction of fishes into aquaponics - south China & Thailand – rice cum fish culture
- modern aquaponics – 70s – expert from NA & North Carolina state (to reduce dependence on land, water and other natural resources)
- 1980s – 1st recirculating (closed loop) & aquaponic system was developed by Mark Mc Murthy- aquavegeculture system- Tilapia

- 1990s- Tom & Paula modified North carolina State university method to gravel cultured hydroponic vegetable bed

Majority of research- Agricultural Experimentation Station, University of Virgin Isles and Dr. James Rakocy is the leader of Freshwater aquaponics. He has developed vital ratios and calculations in order to maximize production of both fish and vegetables while maintaining a balanced eco-system.

Why Aquaponics:

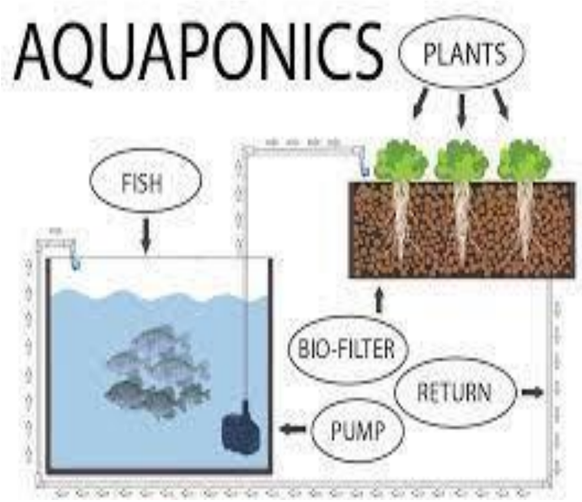
- Resources are decreasing– land and water
- Conventional pond culture- high water usage & management
- Soil borne pathogens are less
- Organic nutrients– no pesticide & inorganic fertiliser
- Limited water usage
- No water filtration needed
- Off season crops & easy harvesting

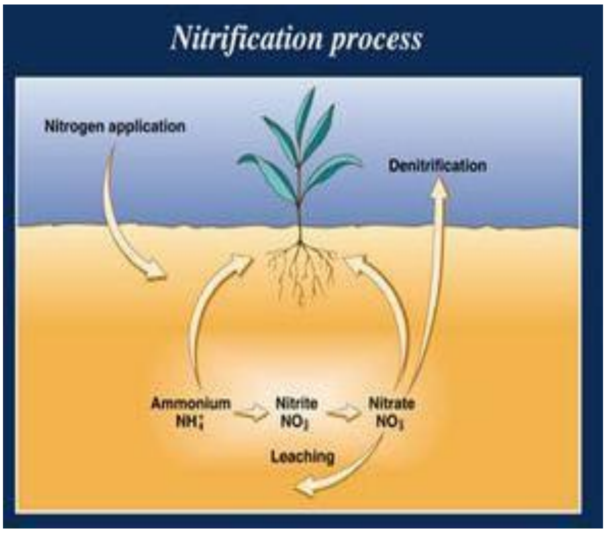
- Two agricultural products (fish and vegetables) can be produced from only one input (fish food).
- Extremely water-efficient (they use less than 20% of the water needed for normal soil farming).

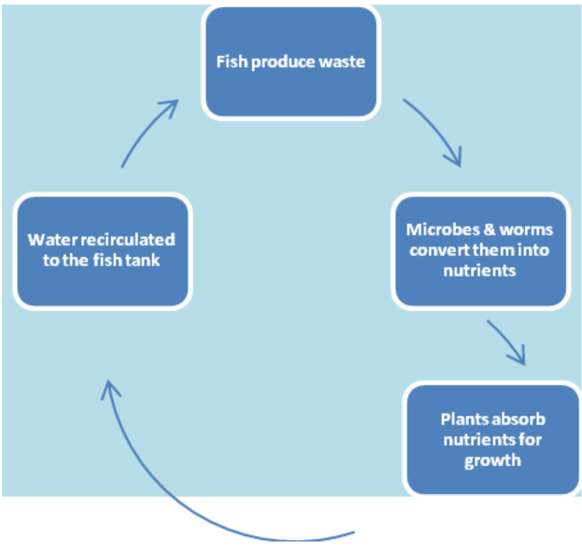
- Aquaponic food production creates ZERO waste during the process.
- Aquaponic units can be installed on non-arable land or in urban areas (rooftops, patios, community centers, etc.) and allow for high density crop production
- The technological requirements for each unit are very basic (primarily plastic containers, gravel, water pumps, plumbing, water and electricity).
- Harvesting methods are very simple.
- Soilless culture (aquaponics) removes most environmental factors that impair root growth in soil (soil compaction, shortage of water, insufficient soil aeration and soil temps).

Aquaponics model:

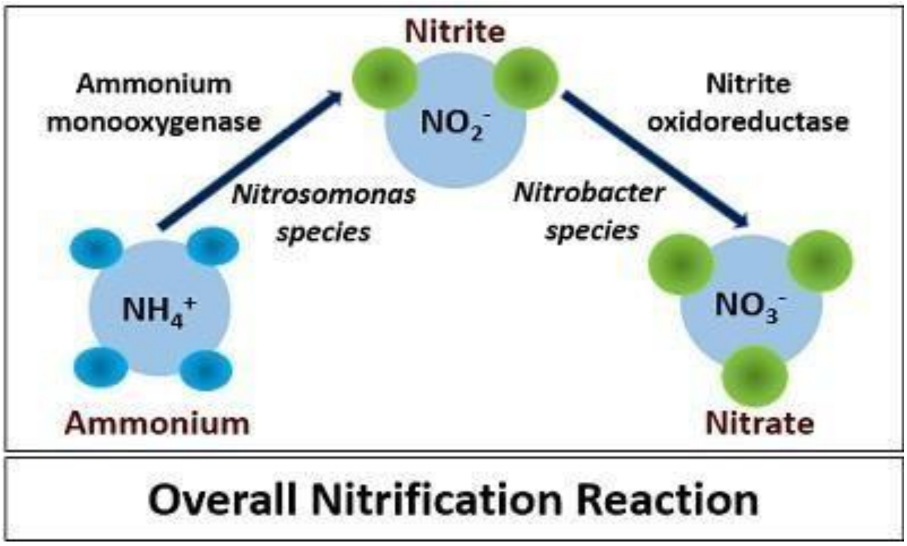
- Miniature of natural ecosystem







Principle of aquaponics – Nitrification:

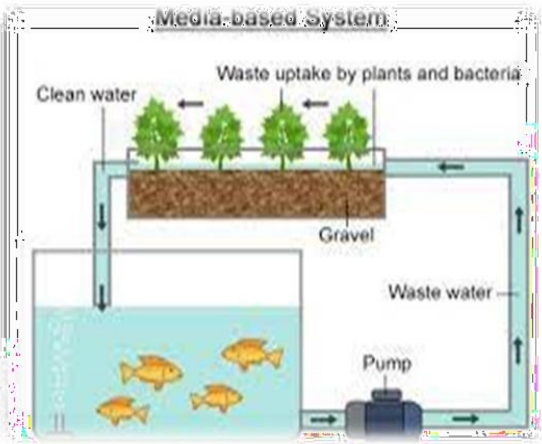


Designs/types of Aquaponics:

- Media-filled bed system/substrate
- Floating raft / deep water culture (DWC)
- Nutrient Flow Technique (NFT)

Media filled bed system:

- Flood and drain system
- A tank or container for filling gravel, silica or perlite for plant growth
- Bed is sporadically filled with water from fish tank
- Water drained back to fish tank after passing through the roots of the plants
- Plants extract the nutrients from water and give out purified water
- No biological filter required
- Multiple crop varieties are grown and no waste water discharge
- Suitable crops: Vegetables, lettuce, carrot, tomato, ladysfinger



Advantages

- Popular design for small scale aquaponics
- Less space and cost, suitable for beginners

- Biofiltration
- Provides better plant support and is more closely related to traditional gardening because of media

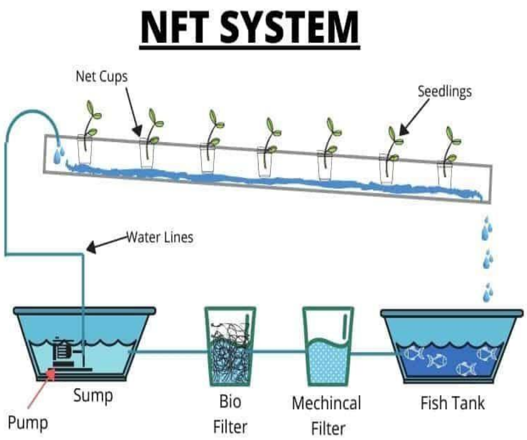
Suitable for various climate

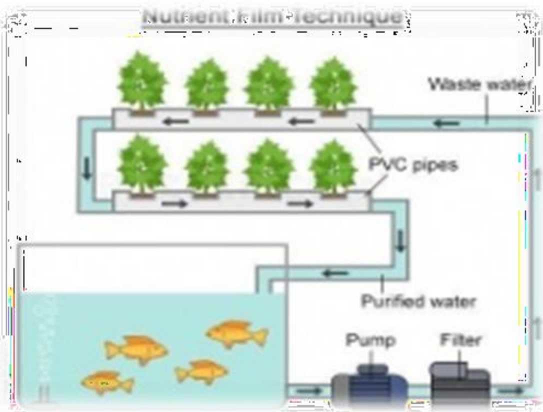
Disadvantages

Nutrient film technique

Fish tank -> solids filter -> biofilter -> NFT channels -> fish tank

- Plants are grown in long narrow channels
- Fish tank water is circulated through the pipes where the tip of the root touches bottom
- Unlike media bed, water flows consistently from the fish tank
- Nutrient absorption through thin film of water
- Light weight and vertical installation possible
- Best suited for leafy crops due to small roots





Advantages

- Efficient Nutrient Delivery: It provide a highly efficient means of delivering nutrients directly to plant roots that promote faster growth and higher yields
- Constant water circulation reduces algae and fungal growth
- Uses water efficiently

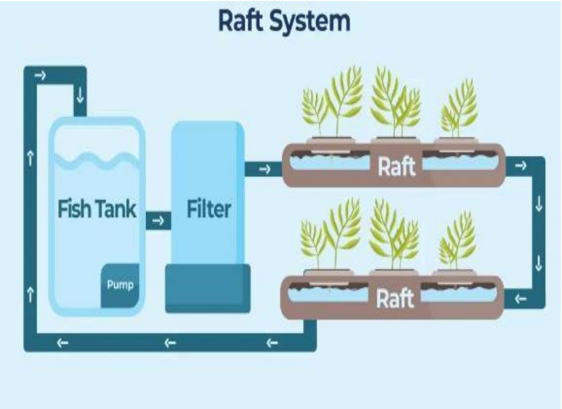
- NFT systems are suitable for growers with limited space, making them an excellent choice for urban and indoor aquaponic setups
    - Disadvantages
- Power cut
- Clogging of channels - Prevent it by keeping light away from the channels or using opaque materials. Regular cleaning may also be necessary.

▣ Suitable crops: herbs and lettuce

Raft/Deep water culture (DWC)

Fish tank -> DWC Raft-> mechanical & biofilter > fish tank

- It needs floating styrofoam boards where plants are grown
- Plants are held in holes in the raft and the water is pumped to the raft tank after filtering it
- Plants are constantly and deeply immersed in the water for nutrient uptake and sent back to fish tank



Advantages

- Roots are flooded with nutrient, water and oxygen –healthy and faster growth
- Relatively cheap, easy to set up and operate
- There is no possibility of clogs in water pumps

Disadvantages

- Excess water sometimes weaken the plants
- Since roots are submerged for 24 hrs, it's important to also have the air pump running across the day to help balance the oxygen levels in the water
- Needs both mechanical and biological filter

Components

- Fish tank
- Grow bed (medium)
- Water Pump
- Aerator
- Biofilter
- Mechanical filter

Plants and fishes

Aquaponics unit at KVK, Sikkal

Different stages of construction

Candidate fish species for Aquaponics

- **GIFT Tilapia**
  - Genetically improved farmed tilapia, monosex
  - Short term growth
  - High resistance to disease
  - Omnivorous feeding behaviour
  - High palatability

- **Pacu (*Piarachtus brachypomus*)**
  - Faster growth rate
  - Low FCR
  - Omnivorous feeding behaviour
  - High market value

Indian major carps

Ornamental fishes

- Koi carp
- Gold fish

Nursery rearing of fishes

- High stocking density of fishes
- Aquaponics is best suited- birds protection
- Easy pond management

Feasibility for harvesting


Feeding of fishes

- No natural fish production
- Depends only on Supplementary feeding
- Floating pellet feeds or Conventional feeding (rice bran and GNOC)
- Feeding: Body weight – 3-7%
- Feed should contain high protein (CP >30)

Feeds with low FCR is preferred

- 3 times a day
- Daily observation of fishes are required during feeding

Suitable crops for horticulture

- Brinjal (local variety)
- Chilli (Arka Harita and Co 1)
- Lady‘s finger (Arka Nikita)
- Amaranthus (Co 1)
- Tomato




Pest management

- Foliar spray of Neem oil of 5ml per litre at weekly intervals
- Foliar spray of Fish amino acid of 5 ml litre at weekly intervals


Water quality management

- Quality of water- determines the end product
- Regular monitoring of water quality is necessary
- **pH**
  - Ranges from 6.5 to 8.5
  - Should be monitored once in 3 days by test kits
- **Temperature**

- 80 – 85° F

- Dissolved oxygen
  - Needed for survival of fish
  - Should be more than 5 ppm
  - Aerator can support oxygen
- Alkalinity - 150-200 mg/l
- Hardness - >40 mg/l
- Nitrate
  - Safe for fish and great for plants
  - Ammonia and Nitrite
  - Highly toxic to fishes
  - If pH level rises it is highly dangerous
  - Should be less than 0.5 ppm in aquaponic system
  - Avoid overfeeding or overcrowding

Factors influencing the amount of available nutrient to plants – lessons learned

- Density of fish population (stocking density)
- Amount of uneaten feed in water
- Amount of plants in the system
- Water flow rate

Comparison of different systems

Pond culture	Aquaponics
▣ More land space	▣ Less space
▣ Pond management is difficult	▣ Easy
▣ Can be inorganic	▣ Purely organic
▣ More water usage	▣ Less due to re-circulation
▣ Fish can feed on natural food and survive	▣ Should depend on supplementary feeding
▣ Only seasonal crops	▣ Suitable for off season crops also
▣ Could not control	▣ Controlled climate

Role of aquaponics in empowering environment

- ▣ Biodiversity conservation and ecosystem health
- ▣ Climate resilience
- ▣ House hold production

- Empowering small scale farmers

Pros of Aquaponics

- Use less water
- All natural fertilizer source from fish waste.
- No reliance on mined and manufactured fertilizers.
- Efficient, sustainable and highly productive.
- Produce is free of pesticides and herbicides.
- Fish are free of growth hormones and antibiotics.
- Allows continuous production of food.
- Produces both a protein and vegetable crop.
- Integrated system is sustainable and earth-friendly.
- Eliminating soil eliminates soil borne diseases.
- Aquaponics lets you grow your food all year round by regulating your growing needs or using greenhouses.
- Low water usage, aquaponics uses approximately 90% less water than conventional farming. The water used is recycled, so it is rarely changed or discarded.
- Since there is no soil involved in Aquaponics, there are very few weeds.
- Plants grow faster in the aquaponics system because of their access to the nutrient-rich water 24 hours a day.
- An aquaponics system can be a source of income for you and your family if you grow commercially.
- Aquaponics does not require large areas of land and is inexpensive to set up.
- With Aquaponics, you can grow your food without the use of harmful chemicals or fertilizers.
- By growing your own food, you can have food security and food independence

Cons of Aquaponics

- The very high initial start-up costs (compared with both hydroponics or soil production systems) of aquaponics is one of its weaknesses;
- Aquaponics requires deep expertise in the natural world. In order to be successful, farmers need to have knowledge not only on growing vegetables but also on how fish and bacteria work. And technical skills regarding plumbing or wiring are also needed;
- As a follow up from the previous point, it‘s often hard to find a perfect match between the needs (such as pH, temperature, substrate) of fish and plants
- Aquaponics has fewer management options (an issue developed ahead) compared with stand-alone aquaculture or hydroponics;
- Mistakes managing the system can quickly cause its collapse

- Daily management is needed
- It's energy demand, which means it has energy costs
- Fish feed needs to be purchased on a regular basis
- The products of aquaponics alone aren't enough to ensure a balanced diet
- Moreover, an effective aquaponics system needs to have effective filtering of organic solid – which is the function of bacteria or algae. Over two-thirds of the failures in aquaponics systems happen because of ineffective solid waste removal.

Potential of further Research

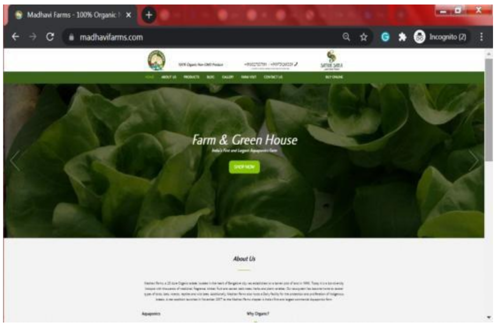
- Biological (species of plants and animals)
- Electrical (controlling the parameters & making more efficient)

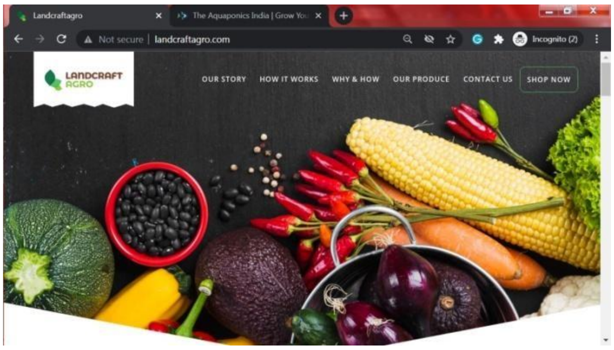
Future Aquaponics

- ICT – IoT enabled aquaponics, AI integrated aquaponics
- Automation of the system using IoT
- Sensor unit interfaced with microcontroller continuously monitors essential parameters
- Data collected is stored into cloud and control can be done both online and offline (pH, temperature and turbidity)

List of few commercial Aquaponics farms in India

- Madhavi farms, Bengaluru- established in 2017
- LandCraft Agro, Maharashtra
- Red otter farm in Uttarakhand
- India aquaponics





Success stories

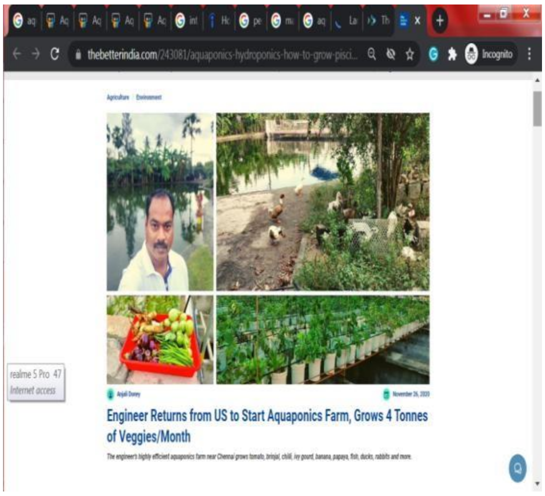
An Uprooted Tree Helped Kerala Farmer Earn Up to Rs 4 Lakh From Fish & Veggie Farming

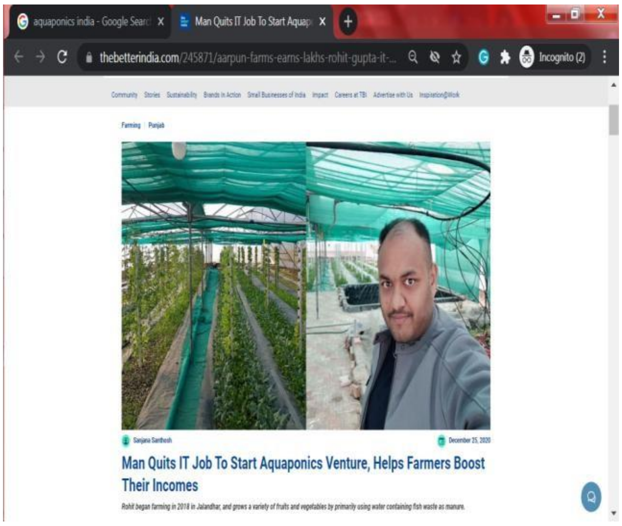
Vijayakumar Narayanan, a passionate farmer and agriculture consultant in Kerala, has been successful in implementing the aquaponics method of farming wherein fish and vegetables are grown together using fewer resources.

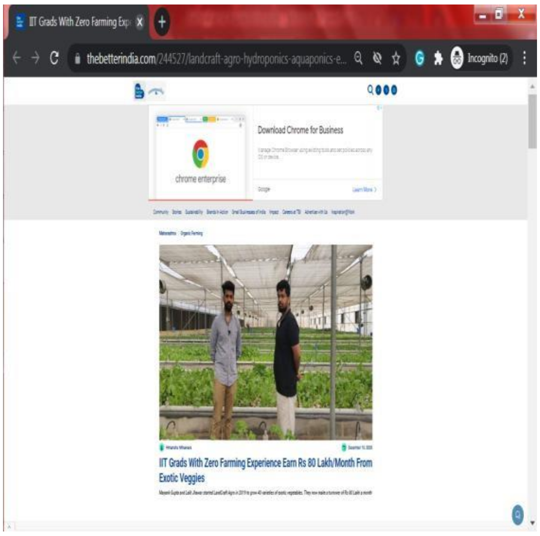
By Anagha R Manoj

October 4, 2022

Back in 2012, when Palakkad-native Vijayakumar Narayanan returned from Muscat after toiling in various jobs for 20 years, he was unsure of what to do next. He could always farm at his ancestral house in Nanniyode but what?







7. Disease and Biosecurity Protocols for Fish and Shrimp Health Management

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Introduction

Aquaculture play a great role in food security and livelihood and are a source of income and social development in developing countries. Huge loss of production in aquaculture is occurring because of many reasons. Disease is the most serious constraint that causes damage to the livelihood of farmers, loss of jobs, reduced incomes, and food insecurity. As finfish/shellfish aquaculture expands globally, in terms of numbers and biomass production, species diversification, geographic regions and rearing methods, the challenges faced by the sector from disease and health issues also diversify and emerge.

Climate change and evolving fish/shellfish husbandry may also contribute to the balance or imbalance of pathogen, host, and environment interaction with novel pathogens being observed or isolated annually and more familiar diseases emerging in different global regions and species. Many of these diseases or pathogens have no recommended treatments, vaccines or management methods established or developed. For many of the established aquaculture species such as carp, tilapia, salmonids as well as some of the marine species (sea bass, sea bream, grouper), there are commercial vaccines for a limited number of diseases and authorized treatments for specific pathogens, although there is considerable variation from country to country even within a geographic region. The viral, bacterial, parasitic and fungal diseases of most significant impact for global aquaculture.

What causes diseases?

The OIE International Aquatic Animal Health Code lists several infectious diseases of importance and significance to global aquaculture and aquatic production. They are all caused by pathogens (virus, bacteria, parasites and fungi) and are capable of spreading through the movement of infected host species. Non-infectious diseases are also common in aquaculture and, although they generally receive less attention than exotic diseases, can have equally devastating effects on production over a very short period. Such diseases are usually caused by ubiquitous opportunistic agents or other biotic and abiotic conditions. For example, inadequate management, poor water quality, inappropriate nutrition, aquatic environmental degradation, and exposure to chronic or acute contamination have all been linked to mass mortalities of a wide range of cultured and wild species.

Why do disease outbreaks occur?

The rapid and ongoing development of all aquaculture sectors continues to call for better health management and improved capacity to face new health challenges. This is particularly apparent with increased interest in species diversification, as well as new grow-out techniques. The rapid expansion of these sectors continually exceeds the rate of education, research and adaptation of expertise in health management.

Although our capability to manage most of these health issues has grown immensely over the last 20-30 years, the new challenges continue to call for further improvements. A multitude of factors has contributed to the health problems currently faced by aquaculture. Over the past three decades, aquaculture has expanded, intensified, and diversified, based heavily on movements of live aquatic animals and animal products (broodstock, seed and feed).

Type of fish	**Pathogen**	**Host**	**Causing disease**	**Symptoms**
Bacterial diseases in fish				
Fresh water	*Aeromonas hydrophilia*	All fish species	Aeromonad septicaemia	Red areas or spots on the skin, eyes, and fins, a swollen abdomen
Fresh water	*Pseudomomas fluourescence*	Cyprinid fishes & *Anguilla vulgaris*	Haemorrhagic septicaemia	Dark body coloration, exophthalmia, haemorrhage
Marine water	*Vibrio sp* *V. alginolyticus* *V. anguillarum* *V. cholerae* *V. ordalii*	All fish species	Vibriosis (petechial haemorrhagic vibriosis)	Darkened skin, hemorrhaging, ulceration, and skin lesions
Marine water	*Photobacterium damselae subsp.*	All fish species	Wound infections &	Gill pallor, swollen
Fresh water, marine water & ornamental fishes	*Edwardsiella tarda*	Both cultured & wild fish species	Edwardsiellosis	Casualty pigmentation, opacity of eyes, swelling of the abdomen,

Fresh water & ornamental fish	*Aeromonas salmonicida*	Salmonid Sp & Freshwater fishes	Furunculosis	Formation furuncle or boil-like lesions in
Fresh water & marine water	*Yersinia ruckeri*	Salmonid sp	Enteric red mouth disease (ERMD)	Septicaemia, haemorrhages
Fresh water	*Renibacterium salmoninarum*	Salmonid fish	Bacterial kidney disease (BKD)	Exophthalmia, multiple granulomas in kidney
Fresh water, marine water & ornamental fishes	*Mycobacterium marinum*	All fish species	Tuberculosis	Ulcerated skin, loss of weight, white nodule formation as
Viral diseases in fish				
Fresh water & marine water	Epizootic hematopoietic necrosis virus *(EHNV)*	Redfin perch, rainbow trout, murray cod, atlantic salmon	Epizootic hematopoietic necrosis (EHN)	Necrosis occurs in the liver, kidney and spleen, darkening of the body, lethargy, erythema, haemorrhages in gills & fins
Fresh water	Spring viraemia of carp virus (SVCV)	Cyprinidae & siluridae	Spring viraemia of carp (SVC)	Viremia, swim bladder inflammation Haemorrhages, pale skin, exophthalmia, skin darken
Freshwater	Tilapia lake virus (TiLV)	All stages of Tilapia	Tilapia lake virus disease	Necrosis in liver, exhaustion, skin bruising & erosion
Fresh water &	Viral	Salmonoids	Viral	haemorrhagic

marine water	hemorrhagic septicemia virus (VHSV)		hemorrhagic septicemia (VHS)	septicaemia, necrosis in liver, kidney & spleen bulged eyes, reddish tints on eyes
Marine water	Infectious salmon anemia virus (ISAV)	Salmonids	Infectious salmon anemia (ISA)	Anaemia, hemorrhage
Fresh water & marine water	Red sea bream iridovirus (RSIV)	Farmed red sea bream sp	Red sea bream iridoviral disease (RSIVD)	Lethargy, severe anaemia, enlargement of spleen, petechiae of the gills
Fresh water & marine water	Lymphocystis disease virus (LDV)	Teleost fish sp	Lymphocystis disease (LCD)	Pseudo-tumours, small nodules on the body surface and internal organs
Fresh water & ornamental fishes	Cyprinid herpesvirus 3 (CyHV-3)	Koi carps, gold fish, cyprinids	Koi herpesvirus disease (KHVD)	Large scale mortalities, bleeding gills, sunken eyes, pale patches on skin
Fresh water	Oncorhynchus masou virus (OMV)	Salmonids	Oncorhynchus masou virus disease	Necrosis, dark skin, exophthalmia
Fresh water & marine water	Viral nervous necrosis (VNN) or Viral encephalopathy and retinopathy (VER)	All fish species (larval & juvenile can significant loss than adult)	Viral nervous necrosis (VNN)	Necrosis, abnormal behaviour, targets central nervous system
Fresh water & marine water	Infectious hematopoietic necrosis virus	Salmonids	Infectious hematopoietic necrosis (IHN)	Necrosis of internal organs & tissues,

	(IHNV			darkening of skin, exophthalmia, haemorrhages around the eyes, gill & fins
Fresh water & marine water	Ictalurid herpesvirus 1 (IcHV1, commonly known as channel catfish virus, CCV)	Juvenile & adult cat fish	Channel catfish viral disease (CCVD)	Swollen abdomen, dark skin, enlarged spleen, pale kidney, fluid in abdominal cavity
Fresh water & marine water	Infectious pancreatic necrosis virus (IPNV)	Salmonids	Pancreatic necrosis (IPN)	Necrosis of internal organs & tissues, abdominal swelling, darkening of skin, internal damage to the pancreas & thick mucus in the intestine
Parasitic diseases in fish				
Freshwater fish & farmed fishes in fishes	*Ichthyophthirius multifiliis*	Young & small eels	Ichthyophthirias is (Ich) or White Spot Disease	White spots on the body, affect the epithelial tissue of gills, fins, skin, and damage respiratory, osmoregulatory and excretory functions
Fresh water,	*Ichthyobodo*	All type of fish	Ichthyobodosis	Gill and skin

marine water & ornamental fish	*necator*			damage, skin colour changes into steel grey colour, discharge of grey coloured mucus
Freshwater & marine fishes	*Trichodina spp*	Channel catfish	Trichodina	Affects the skin and gills, respiratory distress, loss of appetite, and skin colour changes to black
Fresh water	*Myxobolus cerebralis*	Salmonid, trouts	Whirling disease	Malformations of vertebral column, disturbed in equilibrium of fish
Cultured fishes	*Piscinoodinium pillulare*	Tropical fish	Velvet disease	dusty appearance (‗velvet disease') with excessive mucus production
Fresh water & marine water	*Dactylogyrus sp*	Cyprinid	Dactylogyrosis	Pale gills with increased mucus production
Fresh water	*Gyrodactylus*	All type of fingerlings	Gyrodactylosis	Dark and covered with a bluish-gray mucous layer
Cultured fish	*Argulus sp*	Carps, trouts	Argulosis or fish lice	Attachment area haemorrhagic or ulcerated
Fresh water	*Lernaea cyprinacea*	Carps	Lernaea (Anchor worm)	Haemorrhagic
Fresh water &	*Trypanosoma*	Clinidae,	Trypanosomiasi	Hypoglycaemia,

marine water	*(blood parasites)*	blenniidae, gobiidae	s	splenomegaly, anaemia
Fungi diseases in fish				
Fresh water & marine water	*Saprolegniasis sp*	Catfish	Saprolegniasis/ Cotton wool disease	Cotton-like growths on the skin, gills, fins, eyes, and mouth
Fresh water & estuarine	*Aphanomyces sp*	Juvenile individuals	Epizootic ulcerative syndrome (EUS)	Stress in fishes, mortality
Fresh water	*Branchiomycosis sp*	Carps	Gill rot disease	Acute toxicity & mortality
Bacterial diseases in shellfish				
Marine water & brackish water	*Hepatobacter penaei*	*L. vannamei, L. stylirostris, L. setiferus*	Necrotizing hepatopancreatit is	Softened shell and an atrophied hepatopancreas
Marine water & brackish water	*Vibrio parahaemolyticu s*	*Penaeus monodon, P. vannamei, P. Chinensis*	Acute hepatopancreati c necrosis disease (AHPND)	Reduced growth and whitening, hardening of the hepatopancreas dark spots or streaks on the hepatopancreas
Marine water & brackish water	*Leucothrix sp., Thiothrix sp., Flexibacter sp., Cytophaga sp.,*	*Penaeus monodon, P. merguiensis, P. indicus*	Filamentous bacterial disease	Colorless, thread-like growth on the body surface and gills as seen under a microscope, thick mat of filaments on the surface - interfere with respiration or hatching

Marine water & brackish water	*Rickettsia-like organisms*	*P. monodon, P. merguiensis, P. marginatus*, *P. stylirostris*	Rickettsial Infection	Lethargic, do not feed and congregate in the shallows along the edges of the pond
Marine water & brackish water	*M. marinum, M. fortuitum, Mycobacterium* s	All penaeids	Mycobacteriosis / Shrimp tuberculosis	Melanized nodules or lesions on the
Viral diseases in shellfish				
Marine water & brackish water	White spot syndrome virus (WSSV)	*P. monodon, P. indicus, P. japonicus,, P. merguiensis, P.*	White spot disease (WSD)	White spots on the exoskeleton and epidermis of the diseased shrimp, red
Marine water & brackish water	Infectious hypodermal and hematopoietic necrosis virus (IHHNV)	*P. monodon, P. stylirostris, P. vannamei, P. semisulcatus, P. setiferus, P. californiensis* and *P. japonicus*	Infectious hypodermal and hematopoietic necrosis disease	Irregular growth and also form cuticular deformities, whic h referred to as ―runt-deformity syndrome‖ (RDS)
Marine water & brackish water	Infectious myonecrosis virus (IMNV)	*P. vannamei, P. stylirostris, P. monodon* and *Fenneropenae us subtilis*	Infectious myonecrosis	White necrotic areas in striated (skeletal) muscles, especially in the distal abdominal segments and tail fan
Freshwater	*Macrobrachium rosenbergii* nodavirus (MrNV)	*Macrobrachiu m rosenbergii*	White tail disease	Lethargy and opaqueness of the abdominal muscle starting at

				second or third abdominal segment
Marine water & brackish water	Yellow-head virus (YHV)	*P. monodon, P. vannamei, P. japonicus, P. merguiensis, P. stylirostris, P. setiferus*	Yellow head disease	Pale-yellowish cephalothorax due to the discoloration of the hepatopancreas and gill
Marine water & brackish water	Taura syndrome virus (TSV)	*P. vannamei, P. stylirostris, and P. setiferus, P. chinensis*	Taura Syndrome /Red tail disease	Lethargy, anorexia, opaque musculature and reddish discoloration in the tail fan and pleopods
Marine water & brackish water	Monodon baculovirus	*P. monodon, P. merguiensis, P. semisulcatus, P. vannamei, P. esculentus, P. penicillatus, and M. rosenbergii*	Monodon baculovirus disease	Growth retardation, hepatopancreas of affected shrimps become pale yellow to brownish referred to as ―white turbid liver‖ instead of normal grayish green color
Marine water & brackish water	Hepatopancreatic parvovirus (HPV)	*Penaeus chinensis, F. merguiensis and P. indicus*	Hepatopancreatic parvovirus disease	Poor growth rate, atrophy of the hepatopancreas, anorexia, decreased preening activity
Parasitic diseases in shellfish				

Marine water & brackish water	Enterocytozoon hepatopenaei (EHP)	*P. monodon, P. vannamei and P. merguiensis*	Hepatopancreatic microsporidiosis (HPM)	EHP does not cause mass mortalities,no specific clinical signs for EHP infection, but it is often associated with stunted growth and white feces syndrome EHP was not the causative agent of WFS (Tangprasittipap et al., 2013))
Marine water & brackish water	*Zoothamnium, Epistylis, Vorticella, Anophrys, Acineta sp,*	*All penaeid*	Protozoan fouling	Fuzzy mat on gills and body surface respiratory and locomotory difficulties when present in large numbers
Marine water & brackish water	*Agmasoma* (*Thelohania*) spp., *Amesoma* (*Nosema*) spp., *Pleistophora* spp.,	*Penaeus monodon, Penaeus merguiensis, Penaeus marginatus*	Microsporidosis (Cotton Shrimp Disease/Milk shrimp disease/cooked shrimp)	Infected areas (cephalothorax, abdominal muscle, ovary) turn opaque white and cooked because of the presence of spores and other stages of the parasite -―cotton‖ or

				—milk‖ shrimp or —white ovary‖ disease
Fungal diseases in shellfish				
Marine water & brackish water	*Lagenidium* spp., *Sirolpidium* spp., *Haliphthoros* spp	All Penaeus species	Larval mycosis	Dead larvae at the bottom of the tank, rapid and high mortalities, muscle necrosis,
Marine water & brackish water	*Fusarium solani*	All Penaeus species	Black Gill Disease (Fusarium Disease)	Appearance of black spots on gill

Biosecurity for fish and shrimp health management

Biosecurity, or "hazard reduction through environmental manipulation" (Plumb, 1992, is ofte n defined aspractices that reduce the number of pathogens that enter a facility. Biosecurity is t he concept of protecting cultureanimals from contamination by diseases and of preventing the spread of diseases across boundaries, has becomeincreasingly important with the intensificati on of aquaculture production systems. A significant challenge to theexpansion of aquaculture production is the outbreak of disease. Potential economic losses from disease outbreaks are significant, and can affect the survival of the industry.

The occurrence of disease is a combination of the health of the animal, the condition of the environment, and the presence of a pathogen. The shrimp industry has to implement a biosecure production system to prevent the spread of infectious disease among farms. By implementing biosecurity, the risk of pathological events will be reduced.

Goal of biosecurity measures in aquaculture

- Reducing the risk of disease transmission
- Minimising the spread of the disease in the same farm or from one farm to another
- Promoting aquatic animal health
- Preventing new diseases in ponds
- Protecting human health (zoonoses, food safety)

Principles of biosecurity

- To identify hazards by understanding disease transmission and risk factors
- To assess and prevent risk factors
- To determine appropriate biosecurity measures to be undertaken on priority basis

Biosecurity

Biosecurity measures are the management practices that prevent non-infected, healthy animal populations from being exposed to infectious or parasitic agents. Common biosecurity measures include: proper disinfection of eggs with iodine at the time of water hardening; control of vertical disease transmission from parent to offspring using healthy, disease free broodstock; strict sanitation measures like cleaning and disinfecting hatcheries, holding facilities, tanks, ponds, handling and vaccination equipment, etc; traffic control, i.e., restricting entry of people and vehicles; proper treatment of incoming and recirculating water using mechanical filtration, UV light, and ozone; effluent treatment before the infected water from the plant is released into the open; proper handling and storage of feed; proper disposal of carcasses by incineration, burial, or composting and soon.

The principles of a good biosecurity measure apply to all systems whether they are land based (farm) or flow through (hatchery). Good biosecurity measures reduce the exposure to disease causing organisms by placing external and internal barriers.

External barriers

It aims at preventing the spread of disease-causing organisms onto and off an aquaculture farm or hatchery. This is achieved through

- Pathogen-free water source at all times for land-based aquafarms
- Total ban on movement of shrimp, prawn and fish from other farms, specially from those of poorer health
- Restrictions on movement of shrimp, prawn and first between different farm sites of the same company
- Limitation on visits to the aqua farm or access to a farm site i.e. by setting up gates and fences
- Fixing clear signs to direct traffic
- Strict sanitary measures (cleaning and disinfection) for people entering the farm, including usage of protectors clothing (disinfected), foot dips and hand hygiene
- Pest control management

Internal barriers

It aims at preventing the spread of disease-causing organisms within an aquaculture farm or hatchery. This is achieved through:

- Separation of each unit within a facility and isolation of these units from each other
- Defining sanitary units or areas on each farm site
- Setting up sanitary measures (i.e. cleaning & disinfection, pest control measures) inside each unit or area and on movement between different units or areas

- Restricting movement of tools and culture organisms
- Taking strict sanitary measures as protective clothing (regular disinfection), foot dips and hand hygiene
- Pest control management

Levels of biosecurity

Considering the diversity of the aquaculture industry, different levels of biosecurity will be applicable depending upon the purpose of the system and the species, stocking densities, frequency of movement of animals and farm/hatchery workers/visitors/owners into or out of the system, the economics involved, the potential impact of pathogen and other factors. Accordingly, the different levels of biosecurity include:

Conceptual biosecurity

Careful advance planning of facility, analysis of location (disease carriers, lab analysis of water supply), separate treatment planning with holding capacity (bath & dip), etc

Structural biosecurity

Includes cleaning and disinfecting the materials used in tanks, ponds and buildings, human traffic control and sanitation, effluent water recycling etc

Operational biosecurity

Includes daily active procedures like effective disease monitoring through routine disinfection like sterilisation of contact surfaces, control at the visitor's entry point and thorough check of carriers and sources of stocks etc, so as to prevent disease causing agents like virus, bacteria, protozoa, etc. from horizontal transmission of diseases.

Risk factors in disease transmission

The following factors are that come in contact with the aquatic animal (fish/shrimp etc) or pond water are the potent disease carriers that need to be suitably dealt with for an effective biosecurity measure:

- Fomite (ln animate objects): nets, buckets, siphons, footwear, clothing, vehicles, haulers, containers, etc
- Vectors (Living creatures): new livestock, predatory birds & other pets, people
- Direct contact between fish: dead or dying fish or other aquatic animal, contaminated feed
- Water sources: on-site sources, water reuse, transportation sources

Biosecurity programme for shrimp farming

Implementation of biosecurity measures in shrimp production sector should involve both the hatcheries and also the grow out ponds. Proper biosecurity measures should be put into place along with good management practices and treatments. The biosecurity measures to be followed in a shrimp farm are as follows. contamination. Anybody working with shrimp in one pond should wash his/her hands, legs and feet with proper disinfection solutions, after handling equipment or animals and before moving to work on the next pond. Other vectors of disease transmission include crabs, rodents, wild birds etc. which can contaminate the water in ponds. These vectors should be kept in control in the vicinity of aquaculture practices.

- Do not share equipment between ponds unless necessary. ln these cases, disinfect all equipment‘s prior to being re-used
- Ensure that the site is limited to one combined entrance and exit to establish a secure biosecurity perimeter. Restrict access to the hatcheries and farms to authorised persons only.
- Make sure that all vehicles have been cleaned and disinfected prior to arrival at site.
- Keep all surrounding areas of the hatchery or farm clean and disinfected.
- Thoroughly clean all equipment‘s such as sampling tubs, trays, nets etc. Rinse with clean water and then disinfect.
- Continuous biosecurity programmes: Continuous biosecurity routines take into account the different disease problems, which occur at different stages of production.
- Terminal Disinfection Programme for farms: The following procedures should be followed for each pond to be disinfected after depopulation or harvesting to

prevent the carry-over of infected organisms.

Stage 1 Removal of equipment and cleaning	All equipment‘s (feed trays, aerators of equipment and etc.) in use in the farm must be cleaning removed, cleaned, dried and disinfected before their proper storage for use in the next crop
Stage 2 Removal of dead and decaying organic matter	All dead and decaying organisms, of dead and surface (pond bottom) soil must be decaying organic removed for an effective cleaning matter and disinfection process
Stage 3 Water system	All water systems must be sanitised and kept in dried condition until its use in the next crop to clean the system and eliminate unwanted bacterial or fungal growth

Table 1. Protocol for prevention of various risk factors in aquaculture

Risk factors	**Example**	**Prevention**
Fish movement	New or returning fish / shrimp	• Purchase certified heathy fish

	such as broodstock, egg, grow out, restocking	(SPF broodstock that is disease free) from limited number of sources and from trusted suppliers. • Vaccinate the newly acquired ones in quarantine system with due care for resident fish
Water sources	Surface water, ground water, municipal sources	• Disinfect water supply by ozonation, UV irradiation and/ or filtration
Fish health	Disease (direct loss by death, illness and indirect loss by reduced growth rate, reduced FCR etc).	• Minimise stress - maintain appropriate stocking density, reduce transfers between units & farms, use gentle fish handling methods, follow a stable routine and keep away predators • Maintain optimum water quality and provide proper nutrition - avoid nutrient deterioration, store feed in cool and dry place; use feed within 3-6 months, keep vectors out of feed storing area, clean up spilled feed and obtain live feed from reliable sources • Monitor fish frequently - remove dead or dying fish and dispose properly, prevent predator access. • Remove and isolate ill fish (separate isolation facilities and assign employees for them).

		• Diagnostic testing (contact fish health specialist), treat/vaccinate, keep accurate record offish illness, death, growth and FCR, identify potential disease entry points
Fomites	Equipment's, nets, buckets, waders, foot dips, tanks, raceways, vehicles etc.	• Clean and disinfect: do not share vehicles between sites. Drive through areas filled with disinfectant at entrance at recommended contact time. • Vehicles to be brushed thoroughly with disinfectant after each use, washed and then properly sundried. • Place foot dip near entrance; insist on using them prior to and after leaving area. Change solution daily or when visibly soiled. • Boots/waders should be submerged and cleaned with disinfectant lodophore, Virkon@ Aquatic or Na/Ca hypochlorite solution. Allow necessary contact time.
Vectors	Animal	Minimise bird nesting sites. Implement predator and rodent management programmes
	People	Maintain a visitor log book. Employees should wear clean clothing use foot dips, wash or sanitise hands before and after contact with fish. Limit access to egg or fry facilities

Conclusion

Aquaculture industry continues to grow, the threat of infectious diseases to fish production facilities will continue. New disease pathogens are being discovered or are emerging to new locations. Biosecurity can be applied to aquaculture production systems through a variety of management strategies and by following internationally agreed upon policies and guidelines. In addition, there are a variety of risk assessments that can be used for aquatic animal diseases of fin-fishes, molluscs, and crustaceans. Disease challenge by viruses, bacteria, fungi and toxic algae presents a major threat to profitable aquaculture production.

8. Biofloc based Smart Aquaculture

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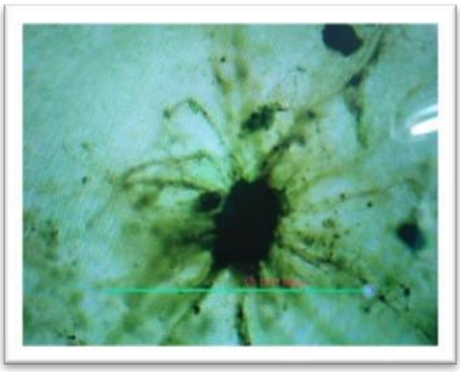
Introduction

Biofloc technology (BFT) is an innovative and eco-friendly aquaculture approach that enhances water quality, optimizes nutrient utilization, and supports sustainable fish and shrimp farming. It is also known as active suspension ponds, heterotrophic ponds and green soup.This technology integrates advanced monitoring systems, IoT devices, and artificial intelligence to improve aquaculture operations and is increasingly being referred to as "smart aquaculture."

Biofloc

Biofloc is an aggregate of algae, diatoms, bacteria, protozoans, planktons and particulate organic matter such as faeces and uneaten feed. Each floc is held together in a loose matrix of mucus that is secreted by bacteria and bound by filamentous microorganisms

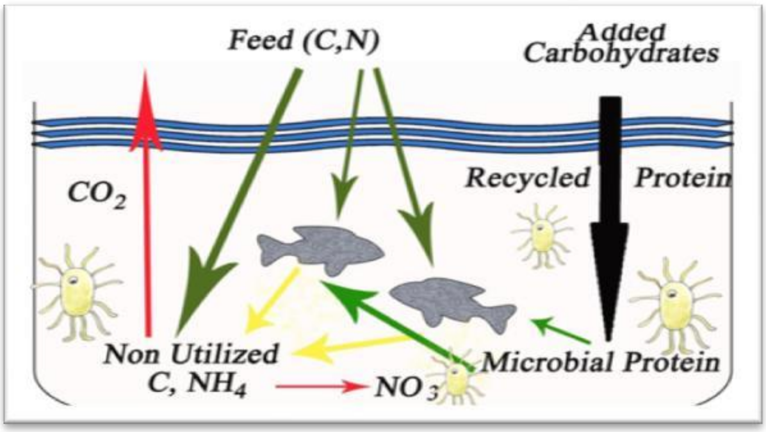


Types of biofloc system

Green water biofloc system (outdoor open culture) that are open to natural light. In this system, both algae and bacteria which control the water quality. And those that are not exposed to natural system is called brown- waterbiofloc system (indoor closed system). In this system, water quality is controlled only by bacteria.

Concept of biofloctechnology

Biofloc enhances the water quality, act as live food, reduces feed cost and increased disease resistance. Under well aerated aerobic condition, it recycles nutrients continuously by maintaining carbon/nitrogen (C/N) ratio in the water which stimulates heterotrophic bacterial growth and converts ammonia into microbial biomass. If carbon and nitrogen are well balanced, bacteria briskly utilize ammonium ion. This process is more rapid and powerful in immobilizing ammonium ion than conventional nitrification process. Moreover, heterotrophs have 10 times faster growth rate than that of nitrifying bacteria and has an ability to remove nitrogen even when organic matter and biological oxygen demand of the system are high. Selection of a carbonaceous substrate is possible to locally available and cheap sources.



Key principles of biofloc system

a. **Microbial Community Management:** Biofloc technology involves the cultivation of beneficial microbial communities in the water. These microbes convert toxic nitrogenous waste (e.g., ammonia) into microbial biomass, which can serve as a supplementary feed for fish or shrimp.
b. **Minimal Water Exchange:** BFT operates with little or no water exchange, relying on microbial processes to maintain water quality. This makes it a water-saving and environmentally friendly method.
c. **Carbon-to-Nitrogen (C:N) Ratio:** The addition of carbon sources (e.g., molasses) encourages heterotrophic bacteria to assimilate nitrogenous compounds, reducing ammonia toxicity.

Carbon source

Carbon sources like cellulose, sorghum meal, wheat flour, crushed sorghum, cassava meal, wheat, corn meal, sugar (glucose), glycerol, sweet potato, jaggery, molasses and distillery spent washare used for floc production.

Carbon / Nitrogen ratio

C/N ratio calculation was quantitatively framed by Avnimelech (1999). The relationship between the addition of carbohydrates, the decrease of ammonium and the production of microbial proteins depends on the microbial conversion coefficient, the C/N ratio in the microbial biomass and the carbon contents of the added material. Goldman et al. (1987) showed that sugar as carbon source in the C: N ratio of 6:1 to 10:1, absorbs more ammonia by heterotrophic bacteria. De Schryver and Verstraete (2009) recommended that, C: N ratio within optimal range 10:1 to 15:1 was favorable to attain maximum heterotrophic bacterial growth. Asaduzzaman et al. (2008) recommend 15:1 to 20:1 C: N ratio for good floc production system. Avnimelech (2012) studied that the more efficient C: N ratios were between 15:1 and 20:1, which indicated improved productivity in ponds by 20 – 45 % and survival by 20 –30 %. Perez-Fuentes (2015) has suggested that, 10:1 C: N ratio results good survival and growth of tilapia with no water exchange. Yuvarajan (2021) stated that DSW can be used as a potential carbon source in the C: N ratio of 10:1 for the maintenance of good and stable water quality to improve the animal performance in zero water exchange system.The CN Ratio Calculation is based on Fish Feed Protein Percentage and TAN.

Candidate species for biofloc

Hargreaves (2013) stated that primary factor in designing abiofloc system based on species selection. For example, species such as tilapia and shrimp have physiological adaptations that allow them to consume floc and digest microbial protein. These species can tolerate high solids concentration in water. Based on that, tilapia and shrimp (*Penaeus vannamei*) are ideal best candidate species for biofloc system (Avnimelech, 2007). Apart from this some other species like Catfish (e.g., *Pangasius* spp., *Clarias* spp.), Carps (e.g., Common carp - *Cyprinus carpio*), Barramundi/Asian Sea Bass (*Lates calcarifer*), Milkfish (*Chanos chanos*), Snakehead (*Channa* spp.), Tiger Shrimp (*Penaeus monodon*) and Freshwater Prawns (*Macrobrachiumrosenbergii*) can be cultured in the BFT system

Floc production

Floc can be produced by following Yoram Avnimelech, Nayan taw, Conventional method. Yuvarajan (2021) used the following fertilization in the outdoor lined pond as follows(in kg/pond (100-ton capacity)) fertile soil - 10,urea - 0.11, triple superphosphate - 0.014, commercial feed - 0.8,dolomite - 1.4, wheat flour - 0.4, cornflour - 0.4 and carbon source - 3) in BFTtreatment. Aspirator type aerators can be placed at diagonal positionin pond and operated with an hour interval, alternatively, to keepthe floc in suspension.

The parameters such as Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Solids (TS), Volatile Suspended Solids (VSS), Total organic carbon (TOC) – Walkley and Black (1934), Floc volume – Imhof cone, Floc volume Index (FVI) – Mohlman method (1934), Floc Density Index (FDI) – WHO International

Reference Centre, 1978), Porosity (%) – Smith and Coakley (1984), Floc size (µm) – Binocular digital microscope, Floc settling velocity (mm/s) – Magara et al. (1976), Floc microorganisms and their structure - Binocular digital microscope - should be measured to know the quantitative and quality of floc (Table.1)

Table1. Floc parameters obtained from biofloc based tilapia culture pond (Yuvarajan, 2021)

S. No	Floc parameters	Ranges
1	Floc size (µm)	113 - 1158
2	Settling velocity (mm/sec)	0.85 – 4.15
3	Floc volume (ml/l)	5–20 (tilapia fingerlings) and 20–50 mL L−1 (juveniles and adult tilapia)
4	Floc volume index (ml/g)	70 - 120
5	Floc density index (g/100g)	0.5 – 1.5
6	Porosity (%)	90 – 98
7	Total solids (ppm)	200 – 1300
8	Total suspended solids (ppm)	100 – 600
9	Total dissolved solids (ppm)	100 - 750
10	Volatile suspended solids (ppm)	40 - 250
11	Biological oxygen demand (ppm)	4 - 8
12	Total organic carbon (%)	0.5 – 1.72

The water quality parameters such as Dissolved oxygen(DO) - mg/l, Temperature – ^{0}C, pH, Carbon dioxide (CO2) – mg/l, Alkalinity – mg/l, Hardness – mg/l, Calcium – mg/l, Magnesium – mg/l, Ammonia-nitrogen (NH3- N) – mg/l, Nitrite-nitrogen (NO2- N) – mg/l, Nitrate-nitrogen (NO3- N) – mg/l and Phosphate (PO4) – mg/l should be measured to maintain the water quality of biofloc system (Table.2)

Table.2. Water quality ranges from BFT (Emerenciano et al., 2016)

S. No	Parameters	Ideal and/or normal observed ranges
1	Dissolved oxygen (DO)	Above of 4.0 mg L^{-1} (ideal) and at least 60% of saturation
2	Temperature	28–30° (ideal for tropical species)
3	pH	6.8–8.0
4	Salinity	Depends on the cultured species
5	TAN	Less than 1 mg L^{-1} (ideal)
6	Nitrite	Less than 1 mg L^{-1} (ideal)

7	Nitrate	0.5–20 mg L^{-1}
8	Orthophosphate	0.5–20 mg L^{-1}
9	Alkalinity	More than 100 mg L^{-1}

Growth performance in BFT

Growth performance parameters such as survival rate influence cost returns and profitability. Scientific studies have demonstrated the positive impact of BFT on the growth performance of tilapia. Research shows that tilapia raised in biofloc systems exhibit improved growth rates, feed conversion ratios (FCR), and survival rates compared to those in traditional systems. The presence of biofloc provides an additional protein source, reducing dependence on formulated feeds and lowering production costs. A study by Avnimelech et al. (2015) reported that biofloc-fed tilapia exhibited a 15–20% increase in weight gain, attributed to the bioavailable nutrients in the microbial aggregates.

Similarly, vannamei shrimp thrive in biofloc systems due to their ability to consume biofloc particles directly. Case studies, such as those by Krummenauer et al. (2014), indicate that vannamei raised in biofloc systems achieve higher growth rates and better FCR compared to shrimp in conventional pond systems. The biofloc also enhances water quality by maintaining optimal ammonia and nitrate levels, which is critical for shrimp health. Moreover, BFT reduces disease outbreaks by promoting a balanced microbial community and minimizing pathogen proliferation.

Table Common growth parameters for shrimp grown in indoor biofloc systems. From Ray et al. (2014) and Samocha (2010).

Stocking rate	250-500/m^2
Stocking size	PL 11+, 1+g/individual
Feed rate	3–6% body weight
Feed conversion	1.2–1.8:1
Growth rate per individual	1.3–2.0 g/week
Rearing period	80 days
Final weight	22 g (20/lbs., 20 count)
Survival	85–95%
Production	5–9kg/m^3

Feed and feeding management in BFT

Effective feed and feeding management is crucial for the success of biofloc systems, which rely on a balance between nutrient input and microbial activity. Biofloc systems utilize organic matter, uneaten feed, and excreted nitrogenous waste to cultivate microbial flocs that serve as a supplemental feed source for cultured species like tilapia and vannamei shrimp.

Managing feed inputs optimally is essential to maximize growth performance, reduce feed costs, and maintain water quality.

Scientific studies highlight the need for reduced protein levels in formulated feeds when using biofloc systems. The microbial flocs, rich in protein and essential amino acids, can replace a portion of dietary protein. Avnimelech (2009) suggested that reducing dietary protein levels by 20–30% in biofloc systems can maintain or improve growth rates without compromising health. This is due to the microbial flocs providing bioavailable nutrients, thus lowering the dependence on high-cost commercial feeds.

Feeding strategies in biofloc systems often emphasize frequent, smaller feedings to minimize waste and optimize nutrient utilization. Studies, such as those by Kuhn et al. (2010), recommend feeding 3–5 times daily to ensure efficient feed conversion and to synchronize nutrient release with microbial uptake. Overfeeding should be avoided, as excessive feed input can disrupt the system's microbial balance and deteriorate water quality.Biofloc nutrition reduce up to 30% of conventional feeding ration consumption in shrimp and 20% in tilapia

Sludge management in BFT

Sludge management is a critical component of biofloc systems to maintain water quality and system efficiency. Sludge primarily consists of uneaten feed, fish or shrimp waste, and dead microbial biomass that accumulates over time. If not properly managed, excessive sludge can disrupt microbial activity, reduce dissolved oxygen levels, and release toxic compounds like ammonia and hydrogen sulfide. Studies, such as those by Hargreaves (2013), emphasize the importance of periodic sludge removal to prevent overloading of organic matter. Common methods include mechanical siphoning or settling tanks, which separate sludge from the water column without disturbing the biofloc. Properly managed sludge removal not only improves water quality but also facilitates nutrient recycling, as the sludge can be used as fertilizer or in biogas production. Effective sludge management, therefore, is essential for maintaining the ecological and economic sustainability of biofloc systems.

On the other hand, type of aerator and aerator position/direction also influence the waste recycling process in BFT which helps to reduce the sludge accumulation and nutrient discharge.

Advantages of BFT

1. Environmental Benefits

Reduced Water Pollution: The system minimizes nutrient discharge, reducing environmental impacts.

Water Conservation: Minimal water exchange is required, conserving water resources.

2. **Economic Advantages**

Feed Cost Reduction: Biofloc serves as a natural feed supplement, reducing dependence on commercial feeds.

Increased Yield: Enhanced water quality and nutrient recycling support higher growth rates and survival.

3. **Sustainability**

Promotes sustainable aquaculture practices by reducing the carbon footprint and reliance on external water bodies.

Disadvantages of BFT

- Need continuous aeration
- Need technical knowledge to maintain C/N ratio and water quality
- Need continuous electricity
- Suitable for limited species

Need of smart technology in Biofloc system

- Biofloc fish farming is productive as well as sensitive. It needs to be concisely monitored, since a minor mistake may lead to the mortality of fish on a large scale, and the setup may undergo loss.
- IoT can help with real-life problems, and it will be beneficial in solving this problem as well

Integration with Smart Aquaculture

Biofloc technology becomes smarter when integrated with modern technologies, including:

a. Internet of Things (IoT)

- **Real-Time Monitoring**: IoT devices like sensors measure critical water parameters such as dissolved oxygen (DO), temperature, pH, salinity, ammonia, and nitrate levels.
- **Data Collection and Analysis:** These devices send data to centralized platforms for real-time analysis, allowing precise adjustments in biofloc systems.

b. Artificial Intelligence (AI)

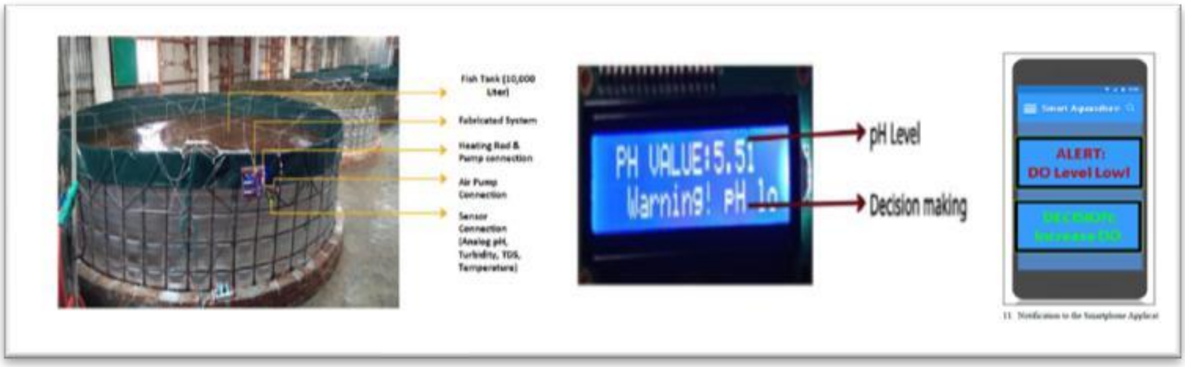
- **Predictive Analytics:** AI systems analyze trends in water quality and provide predictive insights, helping farmers prevent system failures.
- **Automated Decision-Making:** AI-powered algorithms can control aerators, feeders, and other equipment based on water quality data.

c. Automation

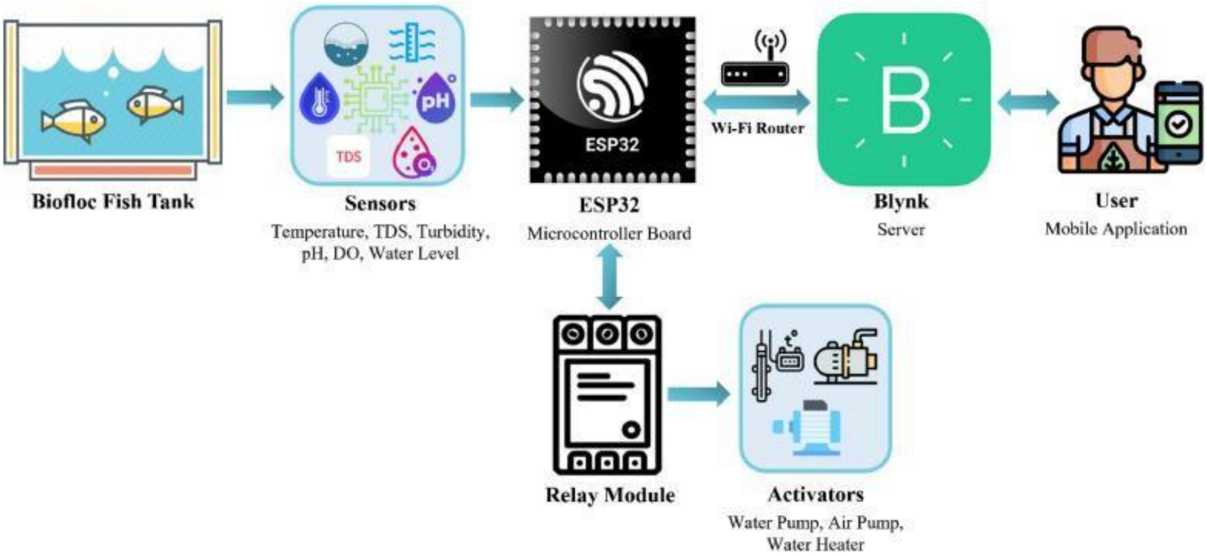
- **Feeding Systems:** Automated feeders optimize feeding schedules, preventing overfeeding and reducing organic waste accumulation.
- **Aeration Control:** Smart aerators adjust oxygen supply based on microbial and stock requirements.

d. Remote Management

Mobile and web-based applications allow farmers to monitor and manage biofloc systems remotely, enhancing convenience and efficiency.



IoT system that collects data using sensors, analyzes them using a machine learning model, generates decisions with the help of Artificial Intelligence (AI), and sends notifications to the user



Real-time monitoring of crucial parameters such as temperature, pH, turbidity, TDS, and dissolved oxygen ensures continuous improvement in water quality management for controlled fish farming. It provides ideal conditions for fish growth fosters increased productivity within aquaculture operations. It helps the stakeholders for monitoring aquaculture systems via mobile devices or computers remotely, which gives them a sense of control and facilitates efficient oversight and management (Al mamun et al., 2024). In addition, it can be easily installed and located inside water. The smart system proficiently analyses and monitors the water quality data in real time while decreasing production costs and human reliance, enhancing productivity and sustainability. Also, the controlling device controls the air pump and temperature in accordance with the requirement. The entire system functions by an IoT based platform via a wireless network and send the monitored data very fast by analyzing the received data, users can take action immediately.

Benefit of Biofloc-Based Smart Aquaculture

Management of water quality parameters and C/N ratio in BFT can be possible with IoT based system which helps to operate BFT system.

Challenges and Limitations

- **High Initial Investment:** Setting up smart aquaculture systems involves significant costs for IoT devices, software, and infrastructure.
- **Complexity:** Managing biofloc systems requires technical expertise, especially with smart technologies.
- **Power Dependence:** Continuous aeration and monitoring systems require a reliable power supply.
- **System Maintenance:** Sensors and other IoT devices need regular calibration and maintenance.

Applications in Aquaculture

- **Fish Farming:** Suitable for species like tilapia, catfish, and ornamental fish.
- **Shrimp Farming:** Widely adopted in shrimp culture to enhance survival and growth.
- **Urban and Small-Scale Aquaculture:** Ideal for urban aquaponics and small-scale farming due to its resource efficiency.

Future Trends in Biofloc-Based Smart Aquaculture

- **Integration with Blockchain:** For traceability and transparency in aquaculture supply chains.
- **Machine Learning Models:** Advanced algorithms to optimize feeding strategies and predict system failures.
- **Renewable Energy Integration:** Solar or wind-powered systems to reduce operational costs.
- **Hybrid Systems:** Combining biofloc with other aquaculture systems, such as Recirculating Aquaculture Systems (RAS), for improved efficiency.

Conclusion

Biofloc-based smart aquaculture represents a revolutionary step toward sustainable and efficient fish and shrimp farming. By merging biofloc technology with cutting-edge digital tools, aquaculture systems can achieve higher productivity, resource efficiency, and environmental sustainability. Despite challenges, ongoing research and technological advancements promise a bright future forthis innovative approach.

9. Integrated Multi Trophic Aquaculture System- A Solution for Sustainability

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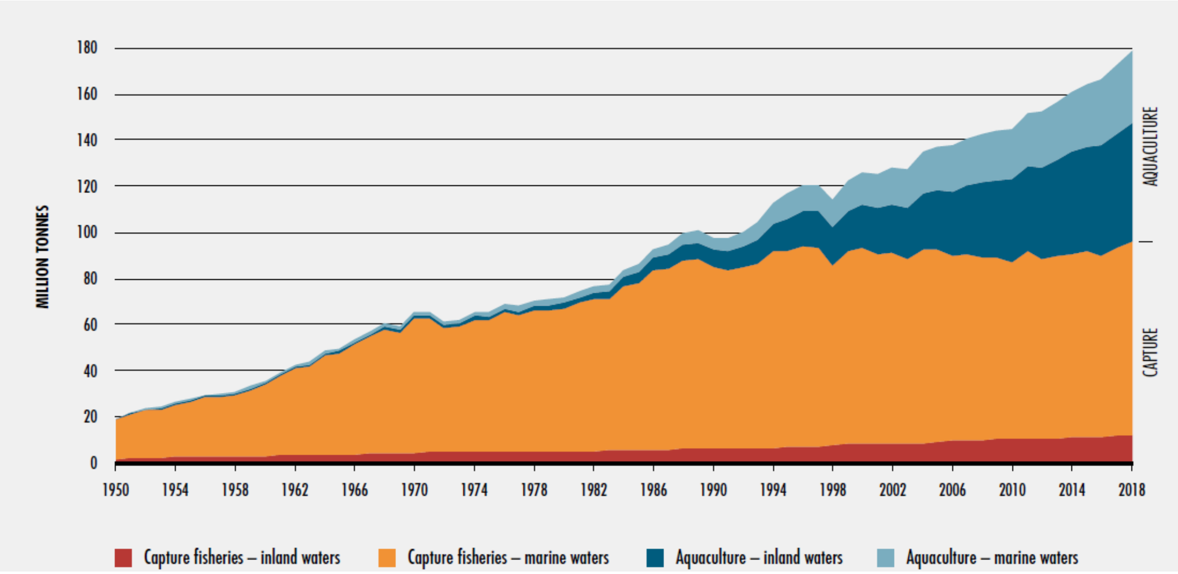
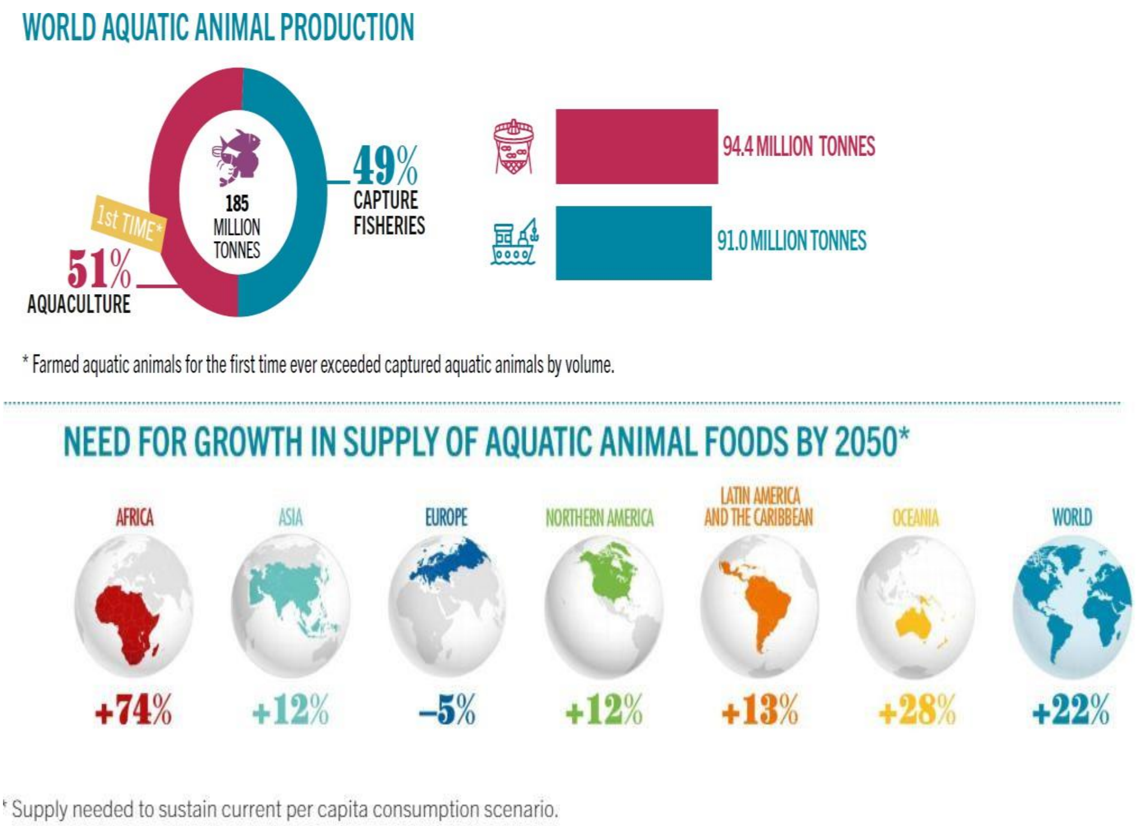
Global Fish Production



World Aquatic Animal Production



Sustainability

Meeting needs of present without compromising the ability of future generations to meet their own needs.The potential to increase aquaculture production by expanding the present pond area and raising water consumption is limited. Consequently, the most sustainable way to increase aquaculture production is through intensification of existing aquaculture systems. (Bosma et al., 2011)

Table 2. Water requirements of Indian Major Carps for production of one Kilogram fish under different production technologies.

Production (Ton/ha/year)	Water requirement at CIFA Study Site in m^3/kg
3 - 4	7.65
6 - 8	3.82
10 - 12	2.43

Major inputs in aquaculture:

Seed

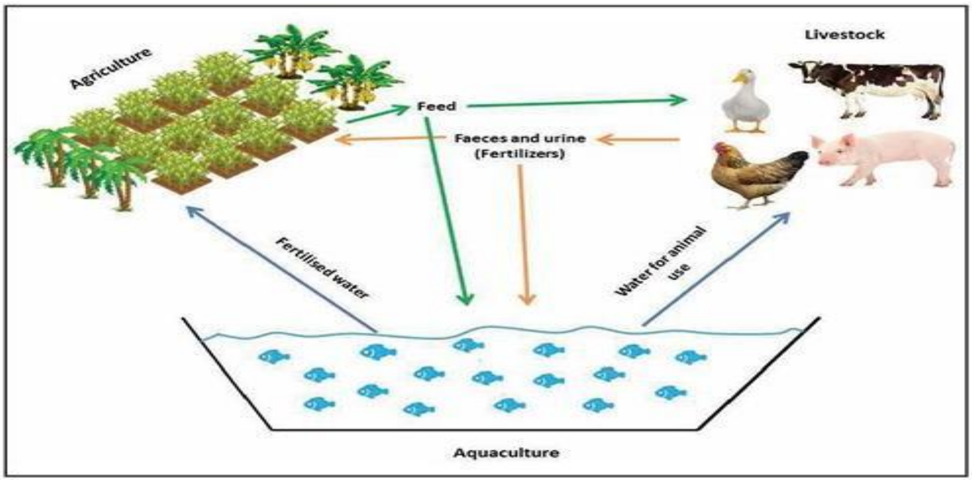
Feed

Water - Intensive yet sustainable aquaculture technologies

Land

Waste management by Integration:

Integrated fish farming (IFF) is a sustainable system of aquaculture where sequential linkages between two or more farming activities are utilised with fish farming as the major component.



IMTA

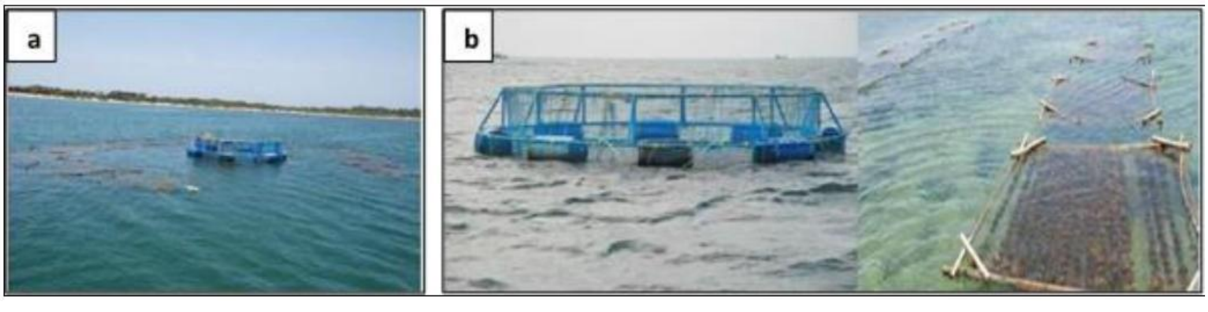
- **Integrated -**Cultivation of the different species in proximity of each other connected by nutrient and Energy transfer throgh water.
- **Multi -**More than one component.
- **Trophic** -Incorporation of species from different trophic or nutritional levels in the same system
- **Aquaculture** -Rearing of aquatic plants and animals under controlled or semi controlled condition.

History of IMTA

Brief History of IMTA		
2200-100 B.C.	*You Hou Bin* detailed integration of fish with aquatic plants and vegetable production in China.	
1975-780 B.C.	Fish culture in rice paddies in China.	
1550-070 B.C.	Earliest representations of tilapia grown in drainable agriculture-aquaculture ponds in Egypt.	
1330-100 B.C.	Development of polyculture in China.	
889-904	Lin Xun published *The Curious Lingbiao Region* in China. It described the theory of mutualism in grass carp/rice paddies culture and integration of fish and fruit production.	
1500	Pond culture in East Java.	
1600	Chateau de Fontainebleau in France, a self-sufficient castle with King Henri IV's royal carp pond.	
1639	Xu Guangqi published The Complete Book on Agriculture, describing irrigation rotation of fish and aquatic plant production and integration of fish with livestock.	
1975	John Ryther *et al.*	Integrated waste recycling marine polyculture systems.
1979	Marilyn Harlin *et al.*	Seaweeds in closed-system fish culture.
1987	M. E. McDonald	Biological removal of nutrients in algal-fish systems.
1991	Amir Neori	Seaweed biofilters for intensive mariculture.
1991	Muki Shpigel *et al.*	Oysters in fish aquaculture ponds.
1994	Alejandro Buschmann *et al.*	Seaweed cultivation with land-based salmon effluents.
1999	Max Troell *et al.*	Aquaculture ecological engineering
2004	Thierry Chopin, Jack Taylor	Integrated milti-tropic aquaculture.

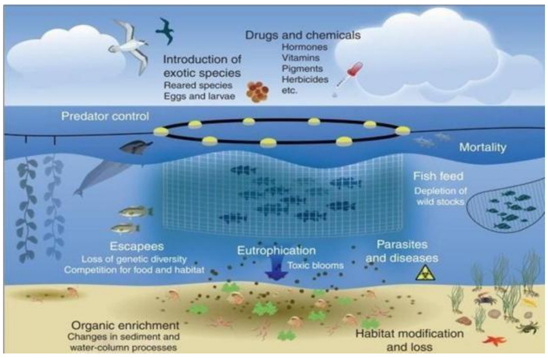
IMTA in India

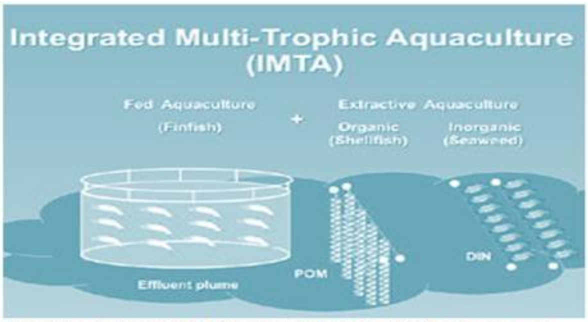
ICAR-Central Marine Fisheries Research Institute (CMFRI) was the pioneer behind the adoption of IMTA farming in India in the year 2013-14 under participatory mode with fisherman groups in coastal area. Palk Bay in the Ramanathapuram district of Tamil Nadu. This trial involved the integration of seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadam*).



IMTA as a concept

IMTA was designed and developed to reduce the environmental impact on marine cage farming (Troell, 2009).





Conceptual diagram of an integrated multi-trophic aquaculture (IMTA) operation including fish, shellfish and seaweeds.

Components of IMTA : b

1. Fed aquaculture species (e.g. finfish/shrimp)
2. Extractive Aquaculture -organic extractive aquaculture species (e.g. shellfish)
3. Inorganic extractive aquaculture species (e.g. seaweed).

1. The IMTA concept is very flexible. IMTA systems can be land-based or open-water systems, marine or freshwater systems, and may comprise several species combinations (Neori et al., 2004).
2. The aim is to increase long-term sustainability and profitability per cultivation unit (not per species, as is practiced in monocultures), by recapturing some of the nutrients and energy that are lost in finfish monocultures, and transforming them into additional crops with commercial value.
3. The recycling of waste nutrients from higher trophic-level species into production of lower trophic-level crops of commercial value.

Genera of particular interest

- Fishes : *Salmo spp, Oncorhynchus , Scophthalmus , Dicentrarchus , Gadus, Anoplopoma, Hippoglossus, Melanogrammus, Paralichthys, Pseudopleuronectes* and Mugil (fish)
- India :Cobia, Pearlspot, Mullet (*Mugil cephalus, Liza parsia*), Milkfish, Rohu .
- Seaweeds : *Laminaria, Saccharina, Sacchoriza, Undaria, Alaria, Ecklonia, Lessonia, Durvillaea, Macrocystis, Gigartina, Sarcothalia, Chondracanthus, Callophyllis, Gracilaria, Gracilariopsis, Porphyra, Chondrus, Palmaria, Asparagopsis* and *Ulva* (seaweeds)
- India : *Kappaphycus alvarezii, Enteromorpha spp., Wolffia globosa.*
- Bivalves: *Haliotis, Crassostrea, Pecten, Argopecten, Placopecten, Mytilus, Choromytilus & Tapes.*
- India- Green mussel *(Perna viridis), Crassostrea madrasensis, C. cuttackensis, Lamellidens marginalis*
- Echinoderms: *Strongylocentrotus, Paracentrotus, Psammechinus, Loxechinus, Cucumaria, Holothuria, Stichopus, Parastichopus, Apostichopus and Athyonidium*.
- Crustaceans : Shrimp and lobsters.

Species Combinations Criteria in IMTA

Combinations of co-cultured species to be carefully selected

- complementary roles with other species in the IMTA system.
- Their adaptability in relation to the habitat.
- The culture technologies and site environmental conditions .
- Their ability to provide both efficient and continuous biomitigation.
- The market demand for the species and pricing as raw material or for
- Their derived products.
- Their commercialization potential .
- Their contribution to improved environmental performance.
- Ideally in IMTA system, the biological and chemical processes should be balance.
- Appropriate selection and proportions of different species providing different ecosystem functions.
- The co-cultured species should be more than just bio filters; they should also be harvestable crops of commercial value (Chopin, 2006).
- A working IMTA system should result in greater production for the overall system, based on mutual benefits to the co-cultured species and improved ecosystem health, even if the individual production of some of the species is lower compared to what could be reached in monoculture practices over a short term period (Neori et al., 2004)

- On the East coast of Canada,

  -Atlantic salmon (Salmo salar),

  - (Saccharina latissima and Alaria esculenta)

  - mussel (Mytilus edulis)
- Growth rates of kelps and mussels cultured in proximity to fish farms have been 46 and 50% higher, respectively, than at control sites.

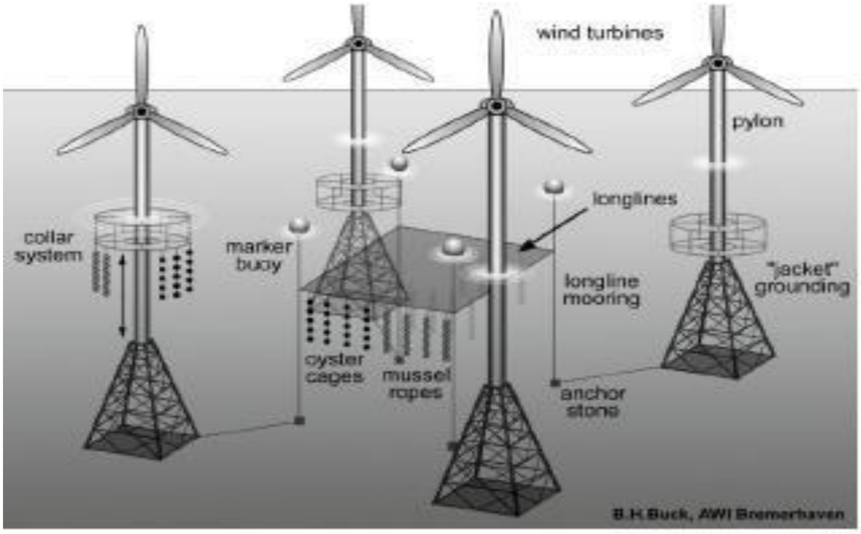
  This reflects increase in nutrients and food availability from the finfish cages (Chopet al., 2004).

Research findings

- Holothurians can consume up to 70% of the organic material that accumulates, eliminating significant quantities of waste nitrogen and organic carbon from fish production (Ren et al., 2012; Shinde et al., 2024) .
- The integration of sea urchin (Strongylocentrotus droebachiensis) with mussels (Mytilus spp.) in IMTA resulted in 40-45% less fouling of nets and did not impair the mussel growth in the system (Chopin et al., 2012).
- Co-culturing seabream and grey mullet enhanced total biomass output by 5.6-7.3%, decreased FCR by 12-15%, and reduced the quantity of sludge in IMTA by 98% (Shipgel et al., 2016) .
- Kibira and Haque (2018) potential of IMTA in freshwater ponds as a sustainable food security option for poor pond farmers and found that the stinging catfish, carp, snail and water spinach .
- The IMTA farming was found to be an efficient biomitigator of the culture environment showing a reduction efficiency of 58% phosphate, 48% nitrite, 61% ammonia, 47% nitrate (Huo et al., 2012)
- 30% reduction in surface phytoplankton and 35% increase in bottom dissolved oxygen (DO) (Zhang and Kitazawa, 2016)
- Poli et al. (2019) found that the indoor based IMTA application for shrimp rearing in biofloc system increased the yield upto 21.5% for Lithopenaeus vannamei, Oreochromis niloticus and Sarcocornia ambigua.
- Brackishwater IMTA using halophytes as extractive species in Penaeus monodon and Chanos chanos culture (Kumara et al., 2023)

OFFSHORE MULTI-USE PLATFORMS

- Offshore windfarms with mussel farming
- Less ―fights for space‖ .
- Maximizing return



Current status

- At present, the countries that have IMTA systems near commercial scale, or at commercial scale, are Canada, Chile, China, Ireland, South Africa, the United Kingdom of Great Britain and Northern Ireland (mainly Scotland) and the United States of America.
- The IMTA farming in India is still in infancy stage when compared to other countries (Sukhdhane et al., 2018).

Advantages of IMTA

- Nutrient recycling (especially in closed systems)
- Reduced demand for feed
- Ecologically sound
- Increased farm productivity
- Application to a variety of environments (e.g., land-based or marine-based),
- Species diversification.
- Healthy food (protein, Omega-3)
- Improve environmental condition.

Disadvantages

- Lack of thorough understanding of environmental impacts
- Shifts nutrients flows in the environment to reduce natural Production
- Complex in operations, risks: structural, disease, operations, seed supply
- Site-specific criteria (because of multiple species): salinity, current, temperature.

Expansion of IMTA

1. Establishing the economic and environmental value of IMTA systems and their co-products.

2. Selecting the right species, appropriate to the habitat, available technologies, and the environmental and oceanographic conditions, complementary in their ecosystem functions, growing to a significant biomass for efficient biomitigation.
3. Promoting effective government legislation/regulations and incentives to facilitate the development of IMTA practices and the commercialization of IMTA products
4. Recognizing the benefits of IMTA and educating stakeholders about this practice.

IMTA and sustainability

- The practice which combines, for

  -Environmental sustainability (biomitigation)

  -Economic stability (product diversification and risk reduction)

  -Social acceptability (better management practices).

10.Integrated fish farming system a possible climate adoption

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Definition

- Integrated farming system is a sustainable agricultural system that integrates livestock, crop production, fish, poultry, tree crops, plantation crops and other systems that benefit each other.
- It is based on the concept that _there is no waste‘ and _waste is only a misplaced resource‘ which means waste from one component becomes an input for another part of the system.

Challenges

Challenges	Current status	Rate of changes (per year)
Population – World	7.2 billion	+0.9%
India	1.3 billion	+0.8%
Food insecure population	194 million	1.0%
Soil degradation	120.40 mha	5-10 Mha
Desertification	105.19 mha	6 Mha
Irrigated Area/person	0.245 ha	-0.3%
Grain harvested area per person	0.22 ha	-0.55%
Forested area per capita	0.59 ha	-0.78%
Atmospheric concentration of GHGs		
CO2	370 ppm	+0.5 %
CH4	1.74 ppb	+0.75%
N2O	311 ppm	+0.25%

Requirement of balanced diet as per norms of ICMR

Crops/item	Requirement (gm/capita/day)	Requirement in million tons		
		2000	2010	2020
Cereals and millets	420	198.70	234.40	280.99
Pulses and legumes	70	18.92	22.61	26.76
Fats and oils	22	10.41	12.44	14.72
Vegetables	125	91.66	109.52	129.62
Roots and tubers	75	35.48	42.39	50.18
Fruits	50	36.66	43.81	51.85
Milk	250	70.96	84.79	100.35
Sugar	30	14.19	16.36	20.07
Egg	45	21.29	25.44	30.11
Fish	25	11.83	14.13	16.73

Indian Agriculture

- **Highest Arable Land (159.7 m ha)-** 47% of total land against Avg. 11 % in the world
- **Round the Year Cultivation -** Agro - climatic regions and 46 soil types suited for round the year cultivation
- **Ranks first** in production of Pulses, Tea, Jute and allied fibers
- **Second largest producer** of Rice, Wheat, Groundnut, Sugarcane, Fruits and Vegetables,
- **Third largest** producer of Mustard, Potatoes, Cotton lint, etc.
- **102.8 Million Farmers,** over 7.5% owns > 4 ha. Avg farm land size <2 ha

Farming Scenario of Tamil Nadu

- Geographical area - 13 m ha
- Cultivable area - 7 m ha
- Rainfed land - 3.1 m ha
- Soil types - red, black and alluvial
- Predominant crops – Rice, Maize, Sorghum, Cotton, Groundnut, Sunflower, Sugarcane
- Fodder crops – Sorghum, BN grass, Lucerne, Desmanthus & Cenchrus
- Livestock – 15.8 million - Milch cow, Buffalo, Goat, Sheep
- 60 % livestock population – dry lands
- Purpose – Draught, milk & mea

Problems of present agriculture

- Decline in agriculture growth rate
- Decline in factor productivity
- Static or decline in food production
- Increasing malnutrition
- Shrinkage in net cultivable area
- Increasing environmental pollution
- Depleting ground water table
- Increasing cost of production

Integrated Farming System

Introduction

- In recent years, food security, livelihood security, water security as well as natural resources conservation and environment protection have emerged as major issues worldwide. Developing countries are struggling to deal with these issues and also have to contend with the dual burden of climate change and globalization.
- It has been accepted by everyone across the globe that sustainable development is the only way to promote rational utilization of resources and environmental protection without hampering economic growth.

- Developing countries around the world are promoting sustainable development through sustainable agricultural practices which help them in addressing socio- economic as well as environmental issues simultaneously.
- Within the broad concept of sustainable agriculture ―Integrated farming systems‖ hold a special position as in this system nothing is wasted, by-product of one system becomes the input for other.
- It is an integrated approach to farming as compared to existing monoculture approaches.
- It refers to agricultural systems that integrate livestock and crop production. Moreover, the system helps poor small farmers, who have very small land holdings for crop production and a few heads of livestock to diversify farm production, increase cash income, improve the quality and quantity of food produced and exploitation of unutilized resources.

What is Integrated farming system ?

- Integrated farming systems (IFS) are agricultural production systems that involve the integration of various components, such as crops, livestock and fish farming in a single unit.
- IFS is a well-accepted sound strategy for harmonizing joint management of land, water, vegetation, livestock and human resources.
- Integrated farming systems revolutionized conventional farming of livestock, aquaculture, horticulture, agroindustry and allied activities. It is sometimes called as Integrated Biosystems or Integrated Agriculture.
- It is a system which comprises of inter related set of enterprises with crop activity as base, will provide ways to recycle produces and ―waste‖ from one component becomes an input for another part of the system, which reduces cost and improves soil health and production and/or income.

Objectives of IFS

- **To integrate** different production systems like dairy, poultry, livestock, fishery, horticulture, sericulture, apiculture, *etc.* with agricultural crops production as the base.
- **To increase farm resource** use efficiency (land, labour and production/by-products) so as to increase farm income and gainful employment opportunity.
- **To promote multi-cropping** (out of the total cropped areas of 2,65,816 ha only 46,697 ha (18%) is sown more than once), for multi-layered crops of economic value so as to sustain land productivity.
- To maintain **environmental quality and ecological stability**.

Scope of Integrated Farming System

Integrated Farming enterprises include crop, livestock, poultry, fish, tree crops, plantation crops, *etc.*

A combination of one or more enterprises with cropping, when carefully chosen, planned and executed, gives greater dividends than a single enterprise, especially for small and marginal farmers.

1. Soil and climatic features of the selected area.
2. Availability of resources, land, labour and capital.
3. Present level of utilization of resources.

Goals of Integrated Farming System

- **Maximization of yield** of all component enterprises to provide steady and stable income.
- **Rejuvenation of system's productivity** and achieve agro-ecological equilibrium.
- **Avoid build-up of insect-pests, diseases and weed population** through natural cropping system management and keep them at low level of intensity.
- Reducing the use of chemicals (fertilizers and pesticides) to provide **chemical free** healthy produce and environment to the society.

Ideal situation for the introduction of IFS

- The farmer wishes to **improve the soil quality**
- The farm household is struggling to buy food or *below the poverty line*
- Water is stored on-farm in ponds or river-charged overflow areas
- **Soil salinity has increased** as a result of inorganic fertilizer use
- The farmer is **seeking to maximize profits** on existing holding
- The **farm is being eroded** by wind or water
- The farmer is looking **to reduce chemical** control methods
- The farmer wants **to reduce pollution or waste disposal costs**

Elements of IFS

- Watershed
- Farm ponds
- Bio-pesticides
- Bio-fertilizers
- Bio-gas
- Solar energy
- Vermicompost making
- Green manuring
- Rain water harvesting

Factors determining IFS

❖ **Physical factor** (Climate, soil, topography)

❖ **Economic factor**

- ✓ Marketing cost
- ✓ Labour availability
- ✓ Capital
- ✓ Land value
- ✓ Consumer demand
- ✓ Prevalent pest and diseases

❖ **Social factor** (type of community, easy transport, marketing facilities)

❖ **Objective** (income, production, minimizing cost *etc.*)

❖ **Environment** (availability of resources and components)

Components of IFS

- Crop husbandry
- Livestock production
- Poultry
- Duckery
- Horticulture
- Aquaculture
- Apiculture
- Sericulture
- Mushroom cultivation
- Agro-forestry
- Biogas plants
- Piggery

Feasible Components

Wetland	Irrigated up land	Rainfed land
Crop	Crop	Crop
Fishery	Milch cows	Goat
Poultry	Buffalo	Agroforestry
Pigeon	Biogas	Horticulture
Goat	Spawn production	Pigeon
Duck	Mushroom	Rabbit
Pig	Homestead garden	Farm pond
Mushroom	Silviculture	Apiculture
Homestead garden	Sericulture	Homestead garden
Apiculture	Apiculture	

Goals of Integrated Farming System

- Maximum utilisation of land and water resources.

- Enhancing productivity per unit area
- Proper waste management.
- Generation of continuous income round the year
- Reducing use of chemicals
- Maximization of yield of all component enterprises
- Soil health management
- Provide employment opportunity.
- Double the farmer income
- Prevent loss to the farmer (Mono cropping system)

Components of Integrated Farming System (IFS)

- Piggery
- Poultry
- Duckery
- Fishery
- Plantation crops
- Apiary
- Mushroom Cultivation
- Vermicomposting
- Fruit cultivation

Requirements for IFS farming

- Land
- Water resource
- Seed requirement for agriculture and horticulture crops
- Availability of cheap source of animal and birds.
- Availability of fish seeds.
- Availability of cheap cost feed for animal, birds and fish

Land requirement and construction of IFS Pond

- Land required : 1 Acres
- Depth : 2 M
- Pond side Slope :1.5
- Land side slope :1 M
- Bund (walking area) : 2 M
- Water spread area : 4000 M
- Length of the pond : 100 M
- Breadth of the pond : 40 M
- Bund slope (water side) : 420 M

- Bund slope (land side : 280 M

Poultry Rearing in IFS

- Size : 10X10X8 (LXBXH)
- Stocking density : 100 chicks
- Harvesting period : 90 - 100 days
- FCR : 1:3
- Survival (%) : 80 - 90%
- Expected production : 80/kg
- Sale price : Rs.300/kg
- Total income : Rs. 24,000/-
- Total expenses : Rs. 15,000/-
- Net return / Year : Rs. 9,000/-X3= 27,000/-

Japanese Quail Rearing in IFS

- Size : 10X10X8 (LXBXH)
- Stocking density : 200 chicks
- Harvesting period : 30 days
- FCR : 1:2.5
- Survival (%) : 90%
- Expected production : 36/kg
- Sale price : Rs.160/kg
- Total income : Rs. 5760/-
- Total expenses : Rs. 2880/-
- Net return / Year : Rs. 2880X10= **28,800/-**

Duck Rearing in IFS

- Size : 10X10X8 (LXBXH)
- Stocking density : 25 Nos.
- Egg laying period : 180 to 200 days
- FCR : 1:2.5
- Survival (%) : 90%
- Egg production/duck : 300/Nos./year
- Sale price of egg : Rs.10/ egg : (15X300=4500x10=45000)
- Total income : Rs. 45000/-
- Total expenses : Rs. 10,000/-
- Net return / Year : Rs**. 35,000/-**

Goat Rearing in IFS

- Size : 10X10X8 (LXBXH)

- Stocking density : 5 Nos. (one male with 4 female)
- Harvesting period : 1 year
- Survival (%) : 90%
- Meat production : 5X15= 75 kg/year
- Sale price of Goat : Rs. 350/kg
- Total income : Rs. 26,250/-
- Total expenses : Rs. 6250/-
- Net return / Year : Rs**. 20,000/-**

Cropping in the Land side bund

- Coconut trees
- Banana trees

Vegetable cultivation in Pond Middle bund

- First side – Tomato cultivation
- Second side – Brinjal
- Third side - Bhendi
- Fourth side : Chilli

Climbers cultivation (water side bund)

1. East side bund Edge 2. West side bund Edge
3. South side bund Edge 4. North side bund Edge

Fish stocking Ratio

Fish ratio			
Catla	Catla	Catla	Catla
Rohu	Rohu	Rohu	Rohu
Mrigal	Mrigal	Mrigal	Mrigal
	Silver carp	Common carp	GIFT
	Grass carp		Murrel
	Common carp		

Fish production details

S.No.	**Fish Composition**	**Ratio**	**SD**	**Yield /kg/ha**
1.	Catla:Rogu	1:10	10000	9 to 11 tonnes
2.	Catla:Rogu:Murrel	1:9.5:0.5	10000	9 to 11 tonnes
3.	Rohu Catla Mrigal		5000 500 250	8 to 10 tonnes/ha

Income generation from IIFS

S. No.	Culture techniques	Annual Income/acre
1.	Carp culture 2 tones x120 = 2,40,000	1,00,000
2.	Murrel culture 400 Nos. = 360 kgx400- 1,44,000/- (Feed 60,000 + seed 50x 400=20,000)	65,000
3.	Poultry	27,000
4.	Japanese quail	28,000
5.	Goat	17,500
6.	Duck	30,000
7.	Vegetables cultivation	25, 000
8.	Total	2,92,500
9.	Monthly income	25,000

11. Nursery rearing of vannamei in Biofloc based system

Mr.Bakthavathalu

Progressive farmer

Andhra Pradesh

INTRODUCTION

- Nursery is one of the methods used in aquaculture to assist in the growth of shrimp larvae into juveniles.
- Nursery plays a crucial role in helping shrimp adapt to pond environments.
- Vannamei shrimp naturally inhabit brackish waters and shrimp larvae often struggle to adapt and have higher mortality rates.
- The main aim is to increase the survival rate of post larvae released into ponds. Additionally, nursery helps farmers obtain uniformly sized and high-quality shrimp.

SHRIMP NURSERY TECHNIQUES:

PREPARATION OF RESERVOIR POND

- The tank should be cleaned, dried, and equipped with aeration systems and blowers for oxygenation.
- Reservior should be developed and water to be treated with bleaching powder and hydrogen peroxide before pumping into the nursery tank
- Reservoir capacity – 450 tonnes
- Bleaching – 3kg per tank for 48 hrs
- Hydrogen peroxide – 3 litre per tank

PROCESS OF NURSERY TANK

- Tank capacity of 50000 litres.
- Cylindrical tank with HDPE sheet has been installed.
- The water has pumped into the tank, with the help of blowers the air is passed through pipeline for the oxygenation purpose.
- Application of minerals, sugar and water probiotic before seed stocking.

SUGAR DOSE FORMULA:

AMMONIA + NITRITE × VOLUME OF WATER ×15PPM = SUGAR DOSE

COMPOSITION

- FOOD COLORS
- GLUCOSE
- ELECTROLYSIS MINERALS

COMPOSITON

Water probiotic phage formulated medicine

CONTROL

Vibriosis reduce running mortality luminescent bacteria white gut white faecal disease

KEY CHARACTERS FOR SEED SELECTION

- Above PL 10 or 12 will be selected for the nursery stocking
- Seed should be active, with full gut and ready to accept the feed
- The colour of the hepatopancreas should be the feed colour
- Seed should be free from WSSV,IHHNV, EHP, VIBRIO.

MICROSCOPIC OBSERVATION OF PL HEPATOPANCREAS ON 4X

Weekly observation through microscope

- Hepatopancreas
- Intestine
- Gills

Advantage of nursery

- Growth and survival will be more
- Chance of white faecal infection is less when compared with normal
- If white faecal infection occurs recovery will be faster