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SOUVENIR BOOK ON

ADVANCES IN ENVIRONMENT MANAGEMENT FOR SUSTAINABLE FISHERIES & LIVESTOCK PRODUCTION

Editors
V. P. Saini
Chandrahas
Ashutosh Kumar Singh
Tapas Paul
Abhishek Thakur
Mamta Singh

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Souvenir Book

On

Advances in Environment Management for Sustainable Fisheries & livestock production

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सम्राट चौधरी
उप मुख्यमंत्री
बिहार

बिहार सरकार

Samrat Choudhary
Deputy Chief Minister
Bihar

पत्रांक : 1130/FIN

दिनांक : 15-11-2024

Message

It is quite gratifying to note that Department of Aquatic Environment Management, College of Fisheries, Kishanganj is organizing ***National Seminar on "Advances in Environment Management for Sustainable Fisheries and Livestock Production (AEMS-2024)"*** *at College of Fisheries (BASU), Kishanganj from 18-19st November, 2024.*

The theme of this year's Seminar will focus on sustainable environment management for fisheries and livestock production. I'm aware that this Seminar is full with eminent speakers, a presentation of an innovative research study, and invited speeches. This will undoubtedly contribute to enhancing the knowledge of the participants in environmental sciences. Such a large meeting cannot be arranged without total dedication and assistance, participation of numerous individuals, including faculty, students, and sponsors.

I send my hearty wishes on the successful organization of the Seminar. I strongly believe that this Seminar will aid future research initiatives and become the impetus for the interchange of research concepts.

(Samrat Choudhary)

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Renu Devi
Minester
Animal & Fisheries Resources Department
Government of Bihar

Govt. of Bihar

Message

I am delighted to learn that Department of Aquatic Environment Management, College of Fisheries, Kishanganj is organizing **National Seminar on "Advances in Environment Management for Sustainable Fisheries and Livestock Production (AEMS-2024)"** at College of Fisheries (BASU), Kishanganj from 18-19st November, 2024.

I believe that the seminar would definitely be a forerunner towards reorienting our approach to sustain production without any harm to environment. I hope the seminar will identify and bring out new strategies and path ways to develop eco-friendly fisheries and livestock production technologies for attaining food and nutritional security.

My hearty wishes for the organizers for a great success of the seminar and congratulations to the College of Fisheries, Kishanganj for hosting the seminar, discussing the contemporary issues involved in Indian aquaculture and livestock sector.

Renu Devi

Smt. Renu Devi)

Dr. N. Vijaya Lakshmi, I.A.S., Ph.D
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Message

I am happy to note that a **National Seminar on "Advances in Environment Management for Sustainable Fisheries and Livestock Production (AEMS-2024)"** is scheduled to be held at College of Fisheries (BASU), Kishanganj from 18-19th November, 2024.Keeping in view the state of food and nutrition security in the country and the UN Agenda 2030, the theme of the Seminar is very timely and relevant.

The prospects for increasing the standard of living and achieving comprehensive food and nutritional security will rely on sustainable environmental manegement. It calls for a focussed approach on innovations, technology and planning in transformation of our social, economic, and environmental settings. A substantial part of our fisheries and animal husbandary growth thus must come through the application of innovative technologies at different segments of value chain to promote both food security and nutritional security. I believe that the Seminar will discuss these aspects in detail and come up with effective action plans for alleviating poverty and hunger through eco-friendly fisheries and livestock production.

I appreciate the efforts of the organizing committee, and all other stake holders involved in organizing this Seminar.

I wish the Seminar a great success.

(Dr. N. Vijaya Lakshmi)

बिहार पशु विज्ञान विश्वविद्यालय

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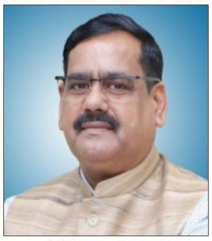


Message

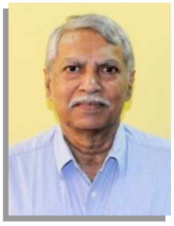
It gives me a great sense of pride to mention that the **National Seminar on "Advances in Environment Management for Sustainable Fisheries and Livestock Production (AEMS-2024)"** is being organized by the Department of Aquatic Environment management, College of Fisheries Kishanganj from 18-19th November, 2024.

Fisheries science sector is one of the principal sources of livelihood for a large section of the economically underprivileged population of the country. This sector has grown up tremendously since last decade and are supporting economic growth & prosperity of the country. However, with the increase in urbanization and population this sector is facing new challenges including environmental aspects in terms of pollution, climate change, antimicrobial resistance etc. It is the need of the hour to focus on environmentally sound aquaculture and fish production keeping in focus to emerging environmental issues.

I believe that the seminar would definitely be a forerunner towards reorienting our approach to sustain production without any harm to environment. I hope the seminar will identify and bring out new strategies and path ways to develop eco-friendly fisheries production technologies for attaining food and nutritional security.

I sincerely appreciate the academics and scientists from different regions of the nation and the dedicated organizing committee for organizing this conference for the benefit of all and the generations to come.

(D. R. Singh)



Message

I am highly pleased to know that the **National Seminar on "Advances in Environment Management for Sustainable Fisheries and Livestock Production (AEMS-2024)"** is being organized by the Department of Aquatic environment Management, College of Fisheries, Kishanganj from 18-19th November, 2024.

I am glad that the College of Fisheries, Kishanganj is planning to discuss on the diversified issues, inviting experts and students to discuss the merits and relevance of the issues on environment management for sustainable fisheries and livestock production. I look forward for the effective knowledge sharing which will help making major reforms in fisheries and livestock sectors and in the production of nutritious and energy rich food to all sections of the people.

I anticipate this conference to discuss the eco-friendly innovations in aquaculture and livestock sector for uplifting economically underprivileged population of the country. As India is a fast developing country, no future generation should be malnourished. I believe that the National Seminar would pave a path for it.

I convey my best wishes to the organizers and congratulate College of Fisheries, Kishanganj for organizing a wonderful Seminar.

Dilip Kumar

(Dr. Dilip Kumar)
Chief Technical Advisor at FAO-Myanmar
& Former Director & Vice-Chancellor, ICAR-CIFE

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MESSAGE

It gives me immense pleasure to know that Department of Aquatic Environment Management of College of Fisheries, Kishanganj, Behar, India is going to organize a 2-day National Seminar on “Advances in Environment Management for Sustainable Fisheries & Livestock Production” during 18-19th November, 2024.

The United Nations has established 17 Sustainable Development Goals, also known as SDGs, with the aim of ensuring that everyone lives well in a healthy world by 2047. Aquatic resources have directly helped nine to ten goals out of seventeen SDGs. According to World Bank projections, there will be nine billion people on Earth by the year 2050 (FAO, 2010). It shouldn't be easy to meet the demands for fisheries, crops, fuel, fiber, food, and cattle. In the near future, there will be a lot of obstacles to overcome, like starvation, malnutrition, poor health, and biodiversity loss. These difficulties also serve as roadblocks to human advancement.

The Fisheries and Livestock sector, crucial for underprivileged populations, faces environmental challenges like pollution and climate change. This seminar aims to provide a national platform for researchers to discuss "Advances in Environment Management for Sustainable Fisheries and Livestock Production (AEMS-2024)" focusing on environmental biotechnology, eco-friendly food production, health, and biodiversity conservation.

I congratulate Dr. V. P. Saini, Chairperson and Dean College of Fisheries, Kishanganj India and other members of the entire team for taking up this difficult and significant assignment. I thus have great expectations that the two days of the conference will be filled with stimulating discussion and debate that will lead to the development of preliminary answers to the issues that are now being considered.

Lastly, I hope the conference achieves its goals and fulfills its mission with great success.

(Prof. Dr. Binay Kumar Chakraborty)

Preface

It is with immense pleasure and gratitude that we present this Book of Souvenir as a part of National Seminar on “Advances in Environment Management for Sustainable Fisheries and Livestock Production (AEMS-2024)” is being organized by the Department of Aquatic Environment Management, College of Fisheries, Kishanganj from 18-19th November, 2024. Since its establishment, the College of Fisheries, Kishanganj has been at the forefront of promoting awareness and tirelessly working towards the sustainable development of fisheries in Bihar. This seminar serves as a platform for discussing crucial issues related to the advancement of the field, with a particular focus on eco friendly sustainable fish and livestock production. By exploring transformative technologies, we aim to address the challenges posed by climate change and ensure food security. We envision that this seminar will attract substantial investment and inspire technological innovations, including start-ups, to generate employment opportunities and enhance sustainable production in the face of a growing population. By improving incomes and livelihoods in the fisheries and livestock sector, we can elevate the quality of employment and living standards, thereby contributing significantly to its overall development within a limited timeframe. We extend our heartfelt appreciation to all the participants, organizers, and sponsors who have contributed their valuable insights, suggestions, and unwavering support in organizing this remarkable event. **The financial assistance received from Research and Development Fund of National Bank for Agriculture and Rural Development (NABARD) towards printing of the proceedings of the seminar is gratefully acknowledged.** We anticipate an extraordinary seminar and with the AEMS-2024 great success.

Editors

Aquaculture for Sustainable Development: Tribute to Dr V. R. P. Sinha

Dilip Kumar
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International Civil Service (FAO of UN)-Retired
Ex-Director/VC of ICAR CIFE Mumbai, India

This lecture honours the contributions of a legendary aquaculture scientist from Bihar, India, Dr V.R.P. Sinha and explores the vital role of aquaculture in sustainable development. Dr Sinha was an exceptionally decorated Scientist with long and wide-ranging experience working with the United Nations and several other highly reputed International, regional and national organizations. Some of his notable contributions have been mentioned.

Aquaculture—the farming of fish and other aquatic organisms—has emerged as a key driver in improving food security, reducing poverty, and supporting economic growth, particularly in regions with limited agricultural resources. The major key areas include:

- Unique Features of Aquaculture: Aquaculture is adaptable, scalable, and efficient in its use of land and water, making it accessible for small-scale and rural farmers. This versatility allows it to support food production in diverse environments, from rural ponds to commercial farms.
- Aquaculture's Role in Poverty Reduction: By providing reliable income and creating jobs, aquaculture empowers low-income communities and reduces poverty. In Bihar and similar regions, aquaculture offers economic opportunities that help stabilize rural economies and enhance household resilience.
- Contribution to Food and Nutritional Security: Fish and shellfish are nutrient-dense and affordable, making them critical for addressing malnutrition and improving diets in vulnerable communities. Aquaculture increases local access to these foods, supporting year-round food security.
- Economic Security: Aquaculture strengthens local economies by supporting jobs, stimulating local markets, and contributing to exports. Government and NGO support play a crucial role in sustaining these economic benefits.
- Environmental Conservation through Sustainable Practices: Sustainable aquaculture methods—such as integrated multi-trophic systems and habitat-friendly practices—align with biodiversity conservation and pollution reduction goals, proving that food production and environmental stewardship can go hand in hand.
- Future Directions: The future of aquaculture in India holds promise, with technological advancements, policy support, and community models driving sustainable growth. Embracing innovation and sustainability will position aquaculture as a leading contributor to economic resilience and environmental health.

In conclusion, sustainable aquaculture offers a pathway to healthier communities, stronger economies, and preserved ecosystems. By honouring the scientist's legacy, we underscore the importance of continued innovation and collaboration in making aquaculture a cornerstone of sustainable development in India and beyond.

Inland Open Water Fisheries Management: An Ecosystem Approach

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1. Introduction

India's Viksit Bharat vision, recognizes the significance of the fisheries sector in achieving sustainable development. India currently is third-largest fish-producing country, the inland sector, contributing 75% of the total fish production. The country stands first in inland capture fisheries globally, contributing 1.46 million tonnes to the food basket (FAO, 2022), showcasing its potential for fish production enhancement. supporting 9.45 million livelihoods.

India has a vast and numerous inland open water fisheries resources scattered in different parts of the country. These water bodies possess a huge potential for fish production. The major inland open water fisheries resources in India are rivers, wetlands, and reservoirs. The inland fisheries resources of India provide goods and services which support livelihood of many rural people. Inland open water fisheries resources in India not only support livelihood but also deliver nutritional security to many rural people. At present, inland open waters are regarded as the most suitable options for inland fish production enhancement in India.

In spite of huge potential for fish production from reservoirs and wetlands of India the present fish yield is low. Fish catch reduction and loss of fish diversity has been observed in many river systems due to several reasons. The inland open water fisheries resources are vulnerable to multiple threats of both natural and anthropogenic nature. The important factors for the low fish yield in reservoirs and wetlands and the loss of fish diversity in rivers include climate change, environmental stress, unscientific management, lack of awareness and conflict among the stakeholders, lack of infrastructure, lack of proper governance, illegal and unregulated fishing, exotic fishes etc. The untapped potential of reservoir, wetland and rivers is yet to be harnessed.

Fish production enhancement strategies should not only focus on fish but also take into consideration of whole aquatic ecosystem while managing the fisheries to maintain sustainability. Management of fisheries without considering the other component can deteriorate the aquatic environment hampering the sustainability of the fisheries and the whole ecosystem. Ecosystem based fisheries management approach has to be considered for sustainable fish production in inland open waters. Fish production through culture-based fisheries (CBF), stock enhancement and species enhancement in floodplain wetlands and reservoirs, habitat protection, closed season and mesh size regulation for conservation of fisheries resources in rivers are the most suitable ecosystem approach for sustainable fisheries development in inland open waters of India.

2. Inland open fisheries resources of India

The Inland open water fisheries resources of India are diverse and scattered in different region of the country. The major fisheries resources of inland open waters are in the forms of rivers, reservoirs and wetlands. Most of the water bodies are productive to support good fisheries.

2.1. Reservoirs

India is blessed with a vast reservoir's resources with 3.51 million ha area. Reservoirs contribute significantly to inland open water fish production. Most of the reservoirs of India are in the peninsular and central part of India. Despite having vast reservoir resources for fish production, the fish production are quite low compared to the potential production.

Table 1. Projected fish yield in reservoir through CBF and stocking enhancement

Reservoir category	Present fish yield (kg/ha/yr)	Potential yield (kg/ha/yr)
Small	190	500
Medium	98	200
Large	34	100

2.2. Wetlands

Wetlands are considered to be one of the most productive inland open water fisheries resources of India. Most of the floodplain wetlands of India are concentrated in the eastern and northern regions of India. These floodplains are mostly associated to the Ganga and Brahmaputra river systems. Most of the floodplain wetlands of India are utilized for fish production. However, ample of scope are available to increase fish production through scientific intervention using ecosystem based approach.

Table 2. Floodplain wetlands resources of India

State	Area (ha)
West Bengal	42,500
Bihar	2,40,000
Uttar Pradesh	1,52,000
Assam	1,00,000
Manipur	16,500

2.3. Rivers

The Ganga River System, the Brahmaputra River System, the Indus River System, the East Coast River System, and the West Coast River System are among India's five major river systems. The Indian rivers with 15 major rivers, 44 medium rivers, numerous minor rivers, and rivulets drained the Indian mainland. Due to habitat degradation and many other factors the fish diversity is declining.

3. Issues and challenges in inland open waters

- Wide gap between present fish yield and potential yield
- Lack of proper governance and policy
- Conflict of ownership or management with different stakeholders
- Less focus on ecosystem-based approach
- Lack of quality seeds for culture-based fisheries
- Habitat degradation due to pollution, encroachment, and other anthropogenic activities
- Lack of trained manpower
- Climate change and other extreme weather
- Lack of data driven decision making support
- Illegal fishing and unregulated fishing
- Poor adoption of technology
- Declining of fish production and loss of biodiversity

A holistic approach is needed to overcome of the above-mentioned issues and challenges. A coordinated effort from fisheries dependent communities, government sectors, research and academic institutions, and other stakeholders to implement effective ecosystem-based management practices and policies for sustainable fisheries in inland open waters.

4. Ecosystem approach to fisheries management

Ecosystem approach to fisheries management (EBFM) take into the account the entire ecosystem instead of considering a single component while formulating strategies for fisheries management. An ecosystem approach to fisheries management consider the interactions between fish and their environment including abiotic component and biotic component, as well as the activity of different stakeholders to maintain the integrity and resilience of the entire aquatic ecosystem. Several components including fish diversity and assemblage pattern and species interaction, interaction among different components, fish habitat condition, pollution and other anthropogenic stress, environmental status, and the role of other stakeholder for that ecosystem are considered in ecosystem approach to fisheries management.

Most of the inland open waters provide essential ecosystem services beyond fish production, such as water purification, flood control, and recreation. Some of the ecosystem-based fisheries management approach in inland open water fisheries management include culture-based fisheries, stock enhancement, species enhancement, habitat protection, ban season and mesh size regulation where these interventions do not have or less impact on the environment. EBFM recognizes the importance of maintaining these services while managing fisheries.

Culture-based fisheries (CBF)

The purpose of CBF is to increase fish production in natural environments by utilizing the natural productivity, rather than fish production in artificial environment and controlled life cycles. In CBF, fingerlings of selected fish species are stocked to harness the natural food availability in wetlands and reservoirs and recapture the stocked fish after attaining the harvestable size by maintaining a balance and healthy aquatic environment. In CBF artificial feeds or supplements feeds are discourage which promotes sustainability by relying on natural food sources available in the water body.

Stock enhancement

Stock enhancement aim to establish self-recruiting fish population in the natural aquatic environment. In stock enhancement fish, typically juveniles or adults, are stocked into the natural aquatic environment to supplement or rebuild existing populations. The main purpose of the stock enhancement is to improve the fisheries for a long term.

Species enhancement

Species enhancement aimed to improve the population and diversity of fish diversity within the aquatic environment. Species enhancement involve enhancing the existing fish stock or involving new fish species for improving biodiversity, enhancing fisheries, and providing recreational opportunities without disturbing the ecological balance of the aquatic ecosystem. The main purpose of stock enhancement is to provide healthier and more resilient ecosystem, benefiting both the environment and the human communities that rely on it.

Habitat protection, Fishing ban and mesh size regulation

Habitat protection of breeding grounds in rivers, wetlands and reservoirs is essential for ensuring the successful reproduction and recruitment of fish species, which is crucial for maintaining healthy and sustainable fish populations. Temporarily closing or implementing fishing restrictions in identified breeding grounds during the spawning season can help to conserve the fish diversity and, simultaneously, boost fish production. Mesh size regulation is intended to control the capture of undersized fish supporting the recruitment of young fish into the population and help in preventing overfishing.

River Ranching

The primary goal of the river ranching programmes is to restore the vulnerable and depleting native fish populations by introducing fish seed to the surrounding ecosystem. The fish seed can be obtained either by collecting wild seeds from the same river system or by artificially raising the fish. Precautions must be taken during the ranching programme to prevent genetic pollution. To ensure the greater survival of ranched fish, the ranching locations on a stretch should be identified, and fishing in the surrounding areas shall be limited.

Pollution abatement and e-flow assessment

The main sources of pollution in rivers are industrial and domestic wastes. Installation of effluent treatment plants (ETPs) and sewage treatment plants (STPs) in major cities and towns along rivers is critical for pollution control. Altering a river's natural flow regime can disrupt the entire river ecosystem, resulting in the collapse of riverine fisheries and fish diversity. Thus, proper assessment of river e-flow requirements is critical for fisheries management.

Greener enclosure culture

Greener enclosure fish culture system considers the use of eco-friendly feed, efficient feeding techniques, such as demand feeding or automatic feeders, to minimize wastage and improve feed conversion ratios, efficient water management to reduce waste and pollution, adoption of renewable energy sources, and implementation of integrated systems such as IMTA (Integrated multi-trophic aquaculture). The reduction of chemicals and antibiotics, and following environmental regulations contribute to make enclosure fish farming more sustainable and ecologically responsible. Prevention of the introduction and spread of diseases, and also to control the escape of fish species to natural systems has to be ensure through systematic biosecurity system. The enclosure culture with the greener approach would help in maintaining the balance of the increasing demand of fish production with the conservation of biodiversity and the protection of aquatic ecosystems, promoting a more sustainable and eco-friendly fish production system.

Building climate resilience

Climate change poses significant threats to ecology of inland open waters. Due to an increase of temperature and erratic rainfall pattern, fish production and fish diversity are impacted. Climate change influences fisher livelihoods through various pathways related to environmental, economic, and social factors. Understanding these pathways is crucial for implementing effective mitigation and adaptation strategies to ensure sustainability. Suggested measures to cope with the climate change impact on inland open water fisheries:

- Habitat restoration and improvement
- Development of certain measure such as deep pool in wetlands to adapt to rise in temperature and other climate change impact.
- Identifying resilient species and inclusion to CBF regime would help in climate resilience.

- Species diversification in enclosure culture in wetlands and reservoirs which are more resilient to rise in temperature and fluctuation in rainfall pattern.

Ecosystem modelling

Ecosystem model are useful in simulating the dynamics of an ecosystem which is useful for decision making for the fisheries managers to maintain fisheries and ecosystem sustainability in inland open waters. Some model like mass balance models (Ecopath with Ecosim) are among the popular model which are used for fisheries management in different water bodies. However, it is difficult to establish a reliable and accurate ecosystem model due to the high demand of high quality and long-term data sets for establishing model.

5. Recent developments and achievements in inland open water fisheries management

- **Fish catch estimation and data acquisition system:** ICAR-CIFRI had developed a suitable sampling methodology and standalone software 'Catch Assessment Survey' (CAS) (Version 2.0) to estimate inland open water resources and fish catch production at the state-level. Android based electronic data acquisition system (eMATSYA) has been developed to collect fish catch data of different inland open waters.
- **IoT based fisheries management:** An IoT based Dissolved Oxygen (DO) monitoring system has been developed which operate aerator in case of DO fluctuation. A drone-based water sampler has been developed to collect water samples from difficult area.
- **Riverine fisheries online database towards data science and bigdata application**: Institute has contemplated to create a bigdata ecosystem to develop a comprehensive database on biotic and abiotic parameters of Indian Rivers for sustainable and judicious management of fisheries system using data science and bigdata technologies.
- **Databases development:**
    - Nutritional database: A database (NutriFishIn) on nutritional composition of food fishes from India (www.cifri.res.in/nutrifishin/) has been developed.
    - Fish proteomic Database: An online fish proteomic database, "Fish Prot" has been developed for *Labeo catla*, *Labeo rohita*, *Channa striatus* and *Rita rita.*
    - Wetland information system (www.wetvoice.com) has been developed to highlight the different aspects of fisheries and ecology of floodplain wetland.
    - Database on climate change and inland fisheries (www.climcifri.com) has been developed to highlight the impact of climate change on inland open water fisheries and its mitigation measures.
- **Acoustics technology in reservoir fisheries:** Potential Fishery Zones (PFZs) was identified using acoustic technology in reservoirs. Fishing efficiency will be enhanced and at the same time the fishing cost will be reduced.

- **Climate change mitigation:**
    - **Carbon sequestration:** Assessed the carbon sequestration by floodplain wetlands of West Bengal and Assam and mangroves in Sundarbans.
    - **Vulnerability map**: Climate change vulnerability map prepared for fourteen districts of West Bengal and adaptation options suggested.
    - **Upper thermal tolerance** of the selected fishes species of Ganga River basin has been documented.
- **Development of eAtlas:** eAtlas of Inland waters bodies (>0.5 ha) for 7 states viz. Uttar Pradesh, Chhattisgarh, Himachal Pradesh, Odisha, Meghalaya, Gujarat and Rajasthan.
- **Cage culture:** Technology developed for raising table fish (*Pangasianodon hypophthalmus*) in reservoirs in cage enclosure (5m X 5m X 4m). ICAR-CIFRI has successfully demonstrated culture of diversified high value species (*Labeo rohita*, *L. bata*, *Systomus sarana*, *Puntius gonionotus*, *Ompok bimaculatus* and *Macrobrachium rosenbergii* in different parts of India.
- **Low-cost floating fish feed for cage culture**: Using agro-industry co-products, a low-cost feed with highly stable floating feed has been developed for cage culture.
- **Pen culture:** CIFRI has developed HDPE pen (113 m long, 3.05 m high net wall covering 0.1 ha circular area) for *in situ* production of advanced fingerlings for stocking in wetlands and small reservoirs.

6. Conclusion

Inland open water fishery of India is vast and provide the most important options for sustainable enhancement of fish production. These water bodies play an important in providing different ecosystem services apart from fish production fish production, which is useful for maintaining food security and livelihood development of many rural people. However, due to several reasons the fish production in inland open waters is low and the biodiversity is declining. An ecosystem approach for fisheries management is an important option to increase the fish production as well as to conserve aquatic biodiversity in inland open waters. Stock enhancement, culture-based fishery, habitat protection, mesh size regulations, greener enclosure culture system, ecosystem modelling, building climate resilient culture system are the important ecosystem approach for inland open water fisheries management. Coordination of all the government agencies, research and academic institute, local public bodies, and the fishing community is really essential to carry out the fisheries management for maintaining fisheries and ecosystem sustainability.

Indian Mariculture: Status and Prospects

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1. Introduction

Mariculture is the fastest growing sub-sector of aquaculture and has very high growth potential. In 2020, mariculture contributed around 33.0 million tonnes of food-fish, which formed about 27% of the global food-fish aquaculture production. The total mariculture production including seaweeds was 68.1 million tonnes, which constituted 55.6% of the total world aquaculture production during 2020. India with 8,119 km length of coastline encompassing nine coastal states, two union territories and two island ecosystems and possessing an Exclusive Economic Zone area of 2.372 million square km (according to MoES – Govt of India) offers immense potential for mariculture. Given the limitation of the marine capture fisheries sector of the country in increasing production, and the modest enhancement that is likely to occur from deep-sea resources along with the limited opportunities for expansion of land-based fisheries and aquaculture systems, the focus is mostly on the expansion of mariculture.

2. Finfish Cage Mariculture

Cage farming is widely recognized as the most important technology in mariculture for increasing fish production. Cage is an aquaculture production system made of a floating frame, net materials and mooring system (with synthetic mooring rope, buoy, and anchor) as round, square or rectangular shape to hold and culture a large number of fishes. Cage is an enclosure in the sea whereby the juveniles of aquatic animals are stocked, fed and grown to marketable size. Fish farming in cages ensures effective utilization of marine systems from a production perspective and is a lucrative business for poor coastal communities. Productivity (production per unit area/volume) is much higher in open-sea cages (20-25 kg/m^3) when compared to other shore-based (0.5 kg/m^3) aquaculture systems. Stock monitoring and management, in terms of observations on behaviour, feeding and growth is simple in open-sea cages and are of paramount importance in avoiding stress and disease outbreak. Feeding and harvesting are easy in open-sea cages, ensuring better feed conversions and superior quality and premium prices for the produce. Efficient feed and disease management would improve farming efficiency manifold, thereby promoting sustainability and ensuring economic growth and better use of resources. Open-sea cage farming is, therefore, a boon to landless farmers.

The indigenously designed High Density Polyethylene (HDPE) open-sea cage, which was initially 16 metre in diameter, has underwent a series of modifications and refinements and is presently standardized at 6 metre in diameter. Varying dimensions of HDPE pipe, ranging from 90 mm to 250 mm inner diameter are used for construction of the cage frame. The net cages range between 3-6 m in depth with varying production volumes. The installations and mooring are based on a single point revolving system anchored with a dead weight combination. However, for meeting the requirements of small-scale farmers in terms of reduced cost and ease of management, Galvanised Iron (GI) cage designs have become popular in recent times. These cages are attached with barrels filled with air for providing floatation to the cage frame. Mooring structures and other necessary components were modified according to the environment and requirement of the farmers.

2.1. Achievements till-date

Open-sea cage farming was conceptualized in India in 2005 and a demonstration project for the same involving four locations (Diu, Ratnagiri, Mandapam and Visakhapatnam) was funded by the Ministry of Agriculture, Government of India to the ICAR- Central Marine Fisheries Research Institute (CMFRI). Initial success on open-sea cage culture was for seabass with substantial harvest to the tune of 3 tonnes from Visakhapatnam in 2007 and Balasore in 2009. Thereafter, cage culture demonstrations for finfishes (seabass, snappers, pearl spot and mullets) and shellfishes (lobsters) were carried out, mostly with wild-caught seeds at multiple locations across most maritime states of the country (Srikakulam and Kakinada in Andhra Pradesh; Chennai, Kanyakumari and Rameswaram in Tamil Nadu; Vizhinjam and Kochi in Kerala; Karwar and Mangalore in Karnataka; Mumbai in Maharashtra and Veraval in Gujarat). However, subsequently for a few years, cage farming failed to achieve its true potential because of several issues, the most important of which was the non-availability of adequate number of quality seeds for stocking. During the last one decade, technology has been developed for consistent round-the-year seed production of 6 species *viz.*, cobia (*Rachycentron canadum*), pompano (*Trachinotus mookalee* and *Trachinotus blochii*), grouper (*Epinephelus coioides*), snapper (*Lutjanus johnii*) and sea bream (*Lethrinus lentjan*); expanding the open-sea cage farming considerably. Presently, the country boasts of more than 3800 cages. More than 12000 tonnes of finfishes are produced annually from these cages, adding to the food basket of the country. Cage-farmed fishes include mostly cobia, pompano, grouper, snapper, seabass and mullets. Their farming has been adopted in substantial numbers by private entrepreneurs and associations in all maritime states. An average production of 2.5 tonnes per cage per crop in 7-8 months is achieved from cobia, seabass, grouper and pompano. The average cost of production is around Rs. 210 per kg and the farm gate price realized is Rs. 350 per kg, resulting in net profit per unit cage of Rs. 3.5 lakh.

2.2. Latest Initiatives

- Potential cage farming sites along the Indian coastline within 3 km has been identified and geo-referenced (134 sites; 46,958 ha) with a production potential of 2.11 million tonnes/year.
- Establishment of National Brood-bank Facility for cobia and silver pompano at Mandapam and Vizhinjam Regional Centres of ICAR-CMFRI with a targeted production of 30 million cobia larvae and 48 million silver pompano larvae per year, aimed to enhance the availability of quality seeds for sea-cage farming.
- Integrated Multitrophic Aquaculture systems has been developed and demonstrated at Mandapam (cobia with seaweed, *Kappaphycus*), Visakhapatnam (pompano and grouper with seaweed, *Kappaphycus*), Veraval (lobster with seaweed, *Kappaphycus*), Kochi (pearlspot with oyster) and Mangalore (snapper with green mussel).

2.3. Challenges & Way Forward

- Seed production should be up-scaled for meeting the stocking demand of the increasing number of cages. The recommended stocking density is 7-10/m^3 for cobia and 25-30/m^3 for seabass, grouper, snapper and pompano. Keeping in view the huge demand of stockable sized seeds, multiple satellite hatcheries and satellite nursery rearing centres needs to be developed in all maritime states. A system of seed certification should also be developed to ensure consistent supply of quality seed.
- Average Feed Conversion Ratio for formulated feed in commercial open-sea cage culture varies between 1:1.5 and 1:1.8. There are no exclusive marine fish feed manufacturers in the country, presently due to lack of stable continuous requirement in substantial quantities from farming. This has negatively impacted the profitability and economic viability of mariculture operations. Thus, it is of utmost importance that if our true potential in cage farming has to be realized, then ensuring establishment of several marine fish feed manufacturing units in the country is a necessity.
- The highly perishable nature of the harvested produce makes it necessary to develop efficient value chains that ensure timely clearance of harvested produce at minimum cost. Efficient market logistics (insulated trucks/refrigerated containers, cold/chilled storage facilities, packaging) play a major role in ensuring the quality of the final product. Therefore, infrastructure requirements for mariculture produce marketing should be addressed on a priority basis. Necessary financial assistance, capacity building, technical guidance and institutional support are to be extended to the various stakeholders involved in the value chain. The involvement of middlemen or intermediaries in the marketing channel should been minimized to the extent possible, ensuring that maximum revenue is realized by the fish farmer.
- Open-sea cage farming in the country has been restricted mostly to the culture of high-value carnivorous fish species requiring feed containing high (40% and more) protein. With rapid expansion of open-sea cage farming, the removal of low-value fishes in huge amounts for producing fish feed would disbalance the stability and impair the structure and functioning of the marine ecosystem. Therefore, farming of omnivorous species in cages assumes paramount importance. Standardizing the seed production technology and farming protocols for several omnivorous species is in the process. Omnivorous species require much less protein and therefore, the use of fish meal in fish feed can considerably be reduced or replaced with plant protein (soybean) or insect protein (black soldier fly and house fly) based ingredients. Future efforts need to be directed for developing species specific feeds including microfeeds meant for larval nutrition, which

are customized to suit the growth patterns of individual prioritized mariculture species for efficient and economically viable production.

- Recent global trend in marine cage farming is to expand the culture volume by installing large off-shore submersible cages ranging in diameter from 20 m to 50 m. Such cages are purely automated in operation. Research efforts need to be strengthened for installing such huge off-shore submersible cages in India.

3. Seaweed Farming

Seaweed farming is a climate-resilient aquaculture practice. It is a sustainable, diversified livelihood option for coastal communities. It reduces the effects of oceanic eutrophication and acidification and oxygenates the seawater for a healthy ecosystem. Seaweeds are valued commercially for their cell wall polysaccharides, such as agar, algin, carrageenan etc. and for their bioactive metabolites, manure and fodder. They have a variety of commercial applications in the food, pharmaceutical, cosmetics and mining industries. Some seaweeds are also gaining importance as healthy food for human consumption. World seaweed production was 35.1 million tonnes of wet weight with the first sale value estimated at 16.5 billion USD (FAO, 2022). There are 10,000 species of seaweeds globally divided across three main types; red, brown and green seaweeds. Among the global seaweed production through farming, *Kappaphycus alvarezii* and *Eucheuma denticulatum* contribute to 27.8% of the total production (FAO, 2022). India contributes less than 1.0 % of global seaweed production, with an annual turnover of around Rs. 200 crores.

India is bestowed with more than 0.26 million tonnes wet harvestable biomass of seaweeds belonging to 700 species. Of these, nearly 60 species are economically important for their polysaccharides and secondary metabolites. Nearly 47,000 tonnes wet weight of seaweeds (*Sargassum*, *Turbinaria*, *Gracilaria* and *Gelidiella*) are being harvested from natural seaweed beds. Agarophytes are red seaweeds (*Gracilaria* and *Gelidiella*) used as starting raw material for agar extraction. Though the annual demand is 4,000 tonnes, the present collection from wild is 2,000-2,500 tonnes dry weight per year. Alginophytes are brown seaweeds (*Sargassum* and *Turbinaria*) which are used as starting raw material for algin extraction. Currently, production from wild collection is 3,000-4,000 tonnes dry weight per year, albeit an annual demand of 5,000 tonnes. The carrageenophytes (*Kappaphycus alvarezii*) are typically red seaweeds used as starting raw material for carrageenan extraction. Seaweed farming in the country is being carried out with *Kappaphycus alvarezii*. Carrageenan is used in a variety of commercial applications as gelling, thickening, and stabilizing agent, especially in food products. Aside from these functions, carrageenan is also used in pharmaceutical formulations, cosmetics, and industrial applications such as mining. Farming of *Kappaphycus alvarezii* by the fisherfolk of Tamil Nadu coast was at its maximum in 2012-2013, and the highest yield of 1,500 tonnes dry weight was recorded. However, production sharply declined thereafter, due to mass mortality. Around 400-500 tonnes dry weight per year is being produced in the last few years. Whereas, taking the demand for carrageenan into account, the total annual seaweed requirement in dry weight basis is 4,500 to 6,000 tonnes of carrageenan yielding algae.

3.1. Achievements till-date

ICAR-CMFRI has been working on seaweed mariculture and seaweed utilization since 1972, and have developed the technology for commercial scale cultivation of *Gracilaria edulis* using raft, and coir-rope nets/spore method. A cottage industry for the manufacture of agar from *Gracilaria* spp. and alginic acid from *Sargassum* spp. was set up during 1980s and agar and algin production was demonstrated to many farmers and entrepreneurs. Large scale, commercial sea-farming of *Kappaphycus alvarezii* started in 2000 with financial support from PepsiCo India Holdings Ltd in the coastal waters of Tamil Nadu, Odisha and Gujarat including Daman & Diu. Approximately 1,500–2,500 families along the Tamil Nadu coast are involved in farming. The commercial farming is carried out following three techniques, namely floating bamboo raft, tube net (net sleeves), and long lines; of which the former two are widely practiced.

ICAR-CMFRI has developed 11 nutraceutical products exclusively from seaweeds, of which nine are commercialised for human well-being and to treat lifestyle diseases (Diabetes, Hypothyroidism, Arthritis, Obesity, Hypertension, Osteoporosis, NAFLD etc.). CSIR-CSMCRI, Bhavnagar has invented a technology for production of sap from *Kappaphycus alvarezii,* along with a residue that yields *kappa* carrageenan. The sap derived from fresh *Kappaphycus alvarezii* is an effective bio-stimulant. Studies showed that the foliar application of sap in dilute form resulted in yield improvement in number of crops.

3.2. Latest Initiatives

- 24,252 hectares of potential seaweed farming area has been identified and mapped in GIS based portal (a spatial map of 333 locations with geo-coordinates along the Indian coast within a 1,000 m distance from the lowest low tide line).
- Integrated Multi Trophic Aquaculture (IMTA) has been developed by integrating seaweed bamboo rafts with one cage containing farmed cobia, resulting in a better average yield of 390 kg per raft than of 250 kg per raft obtained in non-integrated rafts.
- Seaweed biomass along the Indian coast is estimated to utilize 3,017 t CO_2/day against the emission of 122 t CO_2/day, indicating a net carbon credit of 2,895 t/day.
- The average carbon content in the farmed seaweed *Kappaphycus alvarezii* is calculated at 19.92% and the specific rate of sequestration of carbon dioxide (CO_2) is estimated as 19 kg/day/tonnes of dry wt. of seaweed (= 760 kgCO_2/day/tonne dry weight/ha); therefore, their large-scale mariculture would definitely help in curbing ocean acidification.
- Seaweed farming trials on various islands of Lakshadweep has revealed a promising daily growth rate for the indigenous red algae *Gracilaria edulis* and *Acanthophora spicifera*. Farming was performed using PVC net cages, PVC rafts and bamboo rafts.

3.3. Challenges & Way Forward

- Inadequate availability of good quality seed/plantlets, and need for development of improved strains and commercial micropropagation hubs in different parts of the nation for round-the-year seed availability.
- Need for leasing policy of coastal areas in coastal states.
- Unorganized markets for raw material and its products, and no domestic acceptance of seaweed as food.
- Pilot farming trials with eco-friendly materials in potential areas identified suitable for seaweed culture.
- Exploring farming of exotic strains (*Eucheuma spinosum*) and higher agar yielding *Gracilaria* species.
- Genetic improvement of native species for faster growth and better phycocolloid yield.
- Technical know-how on the offshore seaweed culture, and scientific interventions to minimize grazing, fouling and disease incidences.
- Seaweed-based products' value chain diversification.
- Developing a seaweed associated rural enterprise comprising of farming, marketing and post-production activities.
- Enhancing the availability of credit, insurance and other logistical support for farmers.

Fish Biodiversity and its Conservation

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Introduction

Fish biodiversity plays a crucial role in maintaining the health and stability of aquatic ecosystems. Encompassing a vast array of species, fish biodiversity supports vital ecological processes such as nutrient cycling, habitat structuring, and food web dynamics. Fish species occupy a variety of ecological niches, ranging from freshwater rivers and lakes to marine environments, each contributing uniquely to the ecosystem's overall function. Conservation of fish biodiversity is essential due to its significant ecological, economic, and cultural value. Healthy fish populations support commercial and subsistence fisheries, which are a primary source of protein for millions of people globally. Additionally, fish biodiversity contributes to recreational activities and tourism, fostering economic growth in many regions.

However, fish biodiversity faces numerous threats, including habitat degradation, overfishing, pollution, climate change, and the introduction of invasive species. These challenges lead to population declines and the extinction of vulnerable species, undermining ecosystem resilience and the services they provide. Effective conservation strategies are imperative to mitigate these threats and preserve fish biodiversity. This involves the establishment of protected areas, sustainable fishing practices, habitat restoration, and the enforcement of environmental regulations. Furthermore, scientific research and community engagement are critical in developing and implementing successful conservation initiatives.

Fish biodiversity is crucial in the aquaculture and fisheries sector as it underpins the sustainability and productivity of these industries. A diverse range of fish species ensures the availability of various traits that can be harnessed for breeding programs, enhancing disease resistance, growth rates, and adaptability to different environmental conditions. Genetic improvement is a key aspect of aquaculture, where selective breeding and biotechnological interventions are employed to develop superior strains with desirable traits. By maintaining a broad genetic base, aquaculture operations can increase resilience against diseases and environmental changes, thereby improving overall yield and stability. Furthermore, conserving genetic diversity allows for the potential future development of new aquaculture species, which can reduce pressure on wild fish stocks and contribute to food security. In essence, fish biodiversity and genetic improvement are pivotal for advancing the aquaculture and fisheries sector, ensuring long-term economic viability and ecological sustainability.

Safeguarding fish biodiversity is integral to maintaining ecological balance, supporting human livelihoods, and preserving cultural heritage. Collaborative efforts between governments, organizations, and local communities are essential to ensure the sustainability and resilience of aquatic ecosystems for future generations.

Fish Biodiversity- Impact Worldwide

1. The Great Barrier Reef, Australia

The Great Barrier Reef is one of the most biodiverse marine ecosystems in the world, home to over 1,500 species of fish. However, this biodiversity is under severe threat from climate change, particularly coral bleaching, and ocean acidification. Increased water temperatures cause coral bleaching, which destroys the habitats essential for many fish species. The 2016 and 2017 bleaching events significantly reduced fish populations, affecting not only the ecosystem but also the local fisheries and tourism industries that rely on the reef. Conservation efforts, such as marine protected areas and coral restoration projects, are crucial to mitigate these impacts and preserve the reef's biodiversity.

2. Lake Victoria, East Africa

Lake Victoria, the largest lake in Africa, has experienced dramatic changes in fish biodiversity over the past few decades. The introduction of the Nile perch in the 1950s, intended to boost the fishing industry, led to the decline and extinction of many native cichlid species. The Nile perch, a voracious predator, disrupted the lake's ecological balance, causing a significant loss in fish diversity. This has had profound socio-economic effects on local communities that depend on the lake for their livelihoods. Efforts to restore the lake's biodiversity include regulating fishing practices, controlling invasive species, and promoting the conservation of native species.

3. The Mekong River Basin, Southeast Asia

The Mekong River Basin is a biodiversity hotspot, supporting over 850 species of fish. However, the construction of dams and other infrastructure projects has severely impacted this biodiversity. Dams obstruct migratory routes for many fish species, alter water flow and sediment deposition, and degrade habitats. This has led to declines in fish populations and affected the livelihoods of millions who rely on the river for food and income. Transboundary cooperation among the Mekong River countries and sustainable management practices are essential to mitigate these impacts and conserve the river’s biodiversity.

4. The Amazon River Basin, South America

The Amazon River Basin is another critical area of fish biodiversity, home to thousands of species. Deforestation, pollution, and the construction of hydroelectric dams pose significant threats to this diversity. Deforestation leads to habitat loss and increased sedimentation in rivers, while pollution from mining and agricultural runoff degrades water quality. Hydroelectric dams disrupt the natural flow of rivers, affecting fish migration and spawning. Conservation strategies include establishing protected areas, enforcing environmental regulations, and promoting sustainable development practices to balance economic growth with biodiversity conservation.

5. The Baltic Sea, Northern Europe

The Baltic Sea, with its unique brackish water ecosystem, supports a variety of fish species, including commercially important ones like cod, herring, and sprat. Overfishing, pollution, and climate change have significantly impacted fish populations in the Baltic Sea. Overfishing has led to the decline of key species, disrupting the food web and ecosystem balance. Pollution, particularly from agricultural runoff, causes eutrophication, leading to dead zones where few fish can survive. Climate change further exacerbates these issues by altering water temperatures and salinity levels. Regional cooperation through initiatives like the Baltic Sea Action Plan aims to address these challenges by promoting sustainable fishing practices, reducing pollution, and enhancing habitat protection.

Factors Responsible for Declines in Fish Biodiversity

1. **Climate Change**

   Climate change is a major driver of fish biodiversity loss globally. Rising water temperatures, ocean acidification, and changes in precipitation patterns affect fish habitats and physiological processes. For instance, warmer waters can lead to coral bleaching, which destroys critical habitats for many fish species, while acidification impairs the ability of calcifying organisms like shellfish and coral to form their shells and skeletons. Additionally, altered precipitation patterns can lead to changes in river flows, affecting freshwater fish species that rely on specific flow conditions for spawning.

2. **Overfishing**

   Overfishing is a significant threat to fish biodiversity. The excessive and unsustainable extraction of fish from marine and freshwater environments depletes fish populations faster than they can reproduce. This not only reduces the abundance of targeted species but also disrupts the entire ecosystem. Overfishing can lead to the collapse of fish stocks, loss of genetic diversity, and alteration of food webs. Bycatch, the unintended capture of non-target species, further exacerbates the problem by impacting a wide range of marine life, including endangered species.

3. **Habitat Destruction and Degradation**

   Habitat destruction and degradation, driven by human activities such as deforestation, urbanization, and agricultural expansion, significantly impact fish biodiversity. Coastal development and land reclamation destroy mangroves, seagrasses, and coral reefs, which are crucial habitats for many fish species. In freshwater systems, activities such as dam construction, river channelization, and wetland drainage alter natural water flows, fragment habitats, and reduce the availability of critical spawning and feeding grounds.

4. **Pollution**

   Pollution from industrial, agricultural, and urban sources degrades aquatic environments and poses a significant threat to fish biodiversity. Chemical pollutants, including heavy metals, pesticides, and pharmaceuticals, can be toxic to fish and other aquatic organisms. Nutrient runoff from agriculture leads to eutrophication, causing algal blooms that deplete oxygen levels in the water, resulting in hypoxic or anoxic conditions that are lethal to many fish species. Plastic pollution also poses a growing threat, as fish and other marine organisms can ingest microplastics, leading to physical harm and exposure to toxic substances.

5. **Invasive Species**
   The introduction of non-native species can have devastating effects on local fish biodiversity. Invasive species can outcompete, prey upon, or introduce diseases to native fish populations. For example, the introduction of the Nile perch in Lake Victoria led to the decline and extinction of many native cichlid species. Invasive species often lack natural predators in their new environments, allowing them to proliferate and dominate ecosystems, displacing native species and altering ecosystem dynamics.
6. **Hydrological Alterations**
   Hydrological alterations, such as the construction of dams and water diversion for irrigation, significantly impact fish biodiversity. Dams block migratory routes for anadromous fish species that travel upstream to spawn, such as salmon. They also alter sediment transport and water flow regimes, which can degrade habitats downstream. Water extraction for agriculture and urban use can reduce river flows, leading to habitat loss and reduced water quality in freshwater systems.
7. **Climate-induced**
   Changes in Water Chemistry Changes in water chemistry due to climate change, such as increased temperatures and altered salinity levels, can affect the physiology and distribution of fish species. Warmer temperatures can increase the metabolism of fish, leading to higher oxygen demand in environments where oxygen levels are decreasing due to eutrophication. Changes in salinity, particularly in brackish environments like estuaries, can disrupt the delicate balance needed for certain fish species to thrive.
8. **Ocean Acidification**
   Ocean acidification, driven by the absorption of excess atmospheric CO_2 by the oceans, reduces the availability of carbonate ions needed for calcification. This affects not only shell-forming organisms but also has broader implications for marine ecosystems. Acidification can impair sensory functions and behavior in fish, affecting their ability to find food and avoid predators, which can have cascading effects on fish populations and biodiversity.

Detection and Conservation of Fish Biodiversity

1. Environmental DNA (eDNA)

Environmental DNA (eDNA) technology involves collecting DNA from environmental samples such as water, soil, or sediment. This non-invasive method allows for the detection of fish species presence and abundance without the need for direct capture. eDNA analysis is highly sensitive and can identify rare or elusive species, providing valuable data for biodiversity assessments and monitoring programs. It is particularly useful in detecting invasive species early and monitoring the effectiveness of conservation measures.

2. Acoustic and Telemetry Tracking

Acoustic and telemetry tracking technologies involve attaching tags to fish that emit sound signals or radio waves, which are then detected by receivers placed in the environment. These technologies enable researchers to track the movement, behavior, and habitat use of individual fish over time. Understanding migration patterns, habitat preferences, and spawning behaviors is crucial for developing effective conservation strategies, such as designing marine protected areas and identifying critical habitats that need protection.

3. Remote Sensing and GIS

Remote sensing technologies, including satellite imagery and aerial drones, provide large-scale, high-resolution data on aquatic habitats. Geographic Information Systems (GIS) are used to analyze and visualize this data, helping to map critical habitats, monitor habitat changes, and assess the impacts of human activities on fish biodiversity. Remote sensing can detect changes in land use, water quality, and habitat fragmentation, informing conservation planning and policy decisions.

4. Automated Monitoring Systems

Automated monitoring systems, such as underwater cameras and sensor networks, continuously collect data on fish populations and environmental conditions. These systems can be deployed in various habitats, including coral reefs, rivers, and lakes. The data collected helps in real-time monitoring of fish abundance, behavior, and habitat conditions, enabling rapid response to emerging threats such as pollution events or illegal fishing activities.

5. Genomic Technologies

Advances in genomic technologies, such as whole genome sequencing and CRISPR gene editing, are enhancing our understanding of fish genetics and their adaptive capacities. Genomic data can identify genetic diversity, population structure, and evolutionary history, which are critical for designing breeding programs and conservation strategies. For example, genetic rescue techniques can be used to introduce genetic diversity into small, isolated populations to improve their resilience and adaptability.

6. Artificial Intelligence (AI) and Machine Learning

AI and machine learning algorithms are increasingly being used to analyze large datasets from various sources, including eDNA, remote sensing, and automated monitoring systems. These technologies can identify patterns and trends in fish biodiversity, predict the impacts of environmental changes, and optimize conservation strategies. AI can also enhance the accuracy and efficiency of species identification and population assessments, providing valuable insights for conservation management.

7. Hydroacoustic Surveys

Hydroacoustic technology uses sound waves to detect and estimate fish populations and biomass in aquatic environments. It is particularly effective in large and deep water bodies where traditional survey methods are challenging. Hydroacoustic surveys provide data on fish distribution, abundance, and behavior, which are essential for managing fisheries and conserving fish biodiversity. This technology is non-invasive and can cover large areas quickly, making it a valuable tool for ecosystem assessments.

8. Citizen Science and Mobile Apps

Citizen science initiatives and mobile applications are engaging the public in fish biodiversity monitoring and conservation efforts. Apps like iNaturalist and eBird allow users to record and share observations of fish species, contributing to large-scale biodiversity databases. These platforms provide valuable data for researchers and conservationists while raising public awareness and fostering community involvement in conservation activities.

Organizations Involved in Conservation

Numerous leading organizations around the world are dedicated to the conservation of fish biodiversity. These organizations conduct research, implement conservation projects, advocate for sustainable practices, and collaborate with governments and communities to protect fish species and their habitats. Some of the foremost organizations include:

1. World Wildlife Fund (WWF)

The WWF is one of the most prominent global conservation organizations, working on a wide range of environmental issues, including the conservation of fish biodiversity. WWF engages in marine and freshwater conservation projects, focusing on protecting critical habitats, promoting sustainable fishing practices, and addressing the impacts of climate change on aquatic ecosystems.

2. The Nature Conservancy (TNC)

TNC is a leading conservation organization that works to protect the lands and waters on which all life depends. TNC's marine and freshwater conservation initiatives include habitat restoration, sustainable fisheries management, and the creation of protected areas to conserve fish biodiversity. They work with local communities, governments, and other stakeholders to implement science-based conservation strategies.

3. International Union for Conservation of Nature (IUCN)

The IUCN is a global authority on the status of the natural world and the measures needed to safeguard it. Through its Red List of Threatened Species, the IUCN assesses the conservation status of fish species worldwide, identifying those at risk of extinction and promoting conservation actions. The IUCN also facilitates international cooperation and policy development for biodiversity conservation.

4. FishBase Information and Research Group, Inc. (Fin)

FishBase is a comprehensive database of information about fish species, maintained by Fin. It provides extensive data on fish taxonomy, distribution, ecology, and conservation status. FishBase is an essential tool for researchers, policymakers, and conservationists working to understand and protect fish biodiversity.

5. Marine Conservation Institute

The Marine Conservation Institute is dedicated to securing permanent, strong protection for the ocean's most important places. They work on identifying and advocating for the protection of critical marine habitats, establishing marine protected areas (MPAs), and promoting sustainable fisheries management to conserve marine biodiversity.

6. Oceana

Oceana is the largest international advocacy organization focused solely on ocean conservation. Oceana works to protect and restore the world's oceans through policy advocacy, scientific research, and public campaigns. Their efforts include promoting sustainable fishing practices, reducing bycatch, and protecting critical habitats for fish species.

7. Conservation International (CI)

CI works to protect nature for the benefit of people and biodiversity. Their initiatives include marine and freshwater conservation programs that focus on preserving critical habitats, promoting sustainable resource use, and addressing the impacts of climate change. CI collaborates with local communities, governments, and businesses to implement effective conservation strategies.

8. Pew Charitable Trusts

The Pew Charitable Trusts' environmental initiatives include efforts to protect ocean and freshwater ecosystems. Pew works on creating and expanding marine protected areas, promoting sustainable fisheries management, and advocating for policies that protect fish biodiversity and the health of aquatic ecosystems.

9. Environmental Defense Fund (EDF)

EDF works to create innovative solutions to environmental problems, including the conservation of fish biodiversity. Their Oceans program focuses on sustainable fisheries management, protecting critical marine habitats, and addressing the impacts of climate change on marine ecosystems.

10. International Council for the Exploration of the Sea (ICES)

ICES is an intergovernmental organization that promotes marine research and provides scientific advice for the management of marine ecosystems and resources. ICES conducts research on fish populations, ecosystems, and the impacts of human activities, providing valuable data and recommendations for sustainable fisheries management and conservation.

Conclusion

The conservation of fish biodiversity is a multifaceted and urgent endeavor that requires comprehensive strategies, including habitat protection, sustainable fisheries management, pollution control, and climate change mitigation. Collaborative efforts between governments, non-governmental organizations, local communities, and the public are crucial for the successful conservation of fish biodiversity.

By leveraging technological advancements, implementing science-based conservation practices, and fostering global cooperation, we can mitigate the threats to fish biodiversity and ensure the sustainability of aquatic ecosystems. Protecting fish biodiversity is not only essential for maintaining ecological balance but also for securing the long-term well-being of human societies that depend on these vital resources. The collective actions taken today will shape the future health of our planet's aquatic environments and the diversity of life they support.

Applications of Omics Technologies in Fisheries and Veterinary Science

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Fisheries and Animal Husbandry for preventing protein hunger and ensuring Nutrition Security

One of the World's greatest challenges is to secure sufficient and healthy food for all, and to do so in an environmentally sustainable manner. Aquaculture and Animal Husbandry are important food production sectors which significantly contribute to global food and nutritional security. Fish, a superfood, plays major role in human nutrition providing at least 20% of protein intake for a third of the world's population. It is an important component of human diet and is a rich source of quality animal proteins, essential and omega-3 rich oils (especially EPA and DHA) and micronutrients.[1] Aquaculture production has increased drastically in the recent years; global fisheries and aquaculture production in 2022 surged to 223.2 million tonnes, a 4.4 percent increase from the year 2020. Production comprised 185.4 million tonnes of aquatic animals and 37.8 million tonnes of algae. (FAO 2024).[2] Taken together, the fisheries and veterinary sector (including poultry, dairy and meat) play important role in ensuring steady supply of animal proteins thereby keeping away protein hunger and malnutrition. This augments well for our journey towards nutritional security and zero hunger by 2030.

Sustainable Development Goals

The fisheries and aquaculture as well as animal husbandry sector deliver to a multitude of Sustainable Development Goals (SDGs) (Fig. 1)[3]; it provides food for zero hunger (SDG 2), nutritional security for good health and well-being (SDG 3), and employment to millions of people thereby helping in reduction in poverty (no poverty, SDG 1). The by-products of agriculture and livestock industries are utilized in aquaculture systems for fish feed and pond manuring satisfying responsible consumption and production (SDG 12). Adoption of methods to reduce carbon foot prints and selective breeding of fishes are some of the important milestones towards climate action (SDG 13), which are being implemented. Conservation and sustainable use of fisheries and animal resources to maintain life below water (SDG 14), and life on land (SDG 15) effectively regulates over exploitation and protects the ecosystem. All this can be achieved by building liaisons with all the stakeholders such as government, scientific institutions, industry, banks and the farmers and entrepreneurs in fisheries and animal sector (SDG 17).

Fig. 1. Sustainable Development Goals (SDGs) (Source: https://www.un.org/goals)[3]

Fig. 2. One health
Source: https://www.epa.gov/one-health/[4]

Ecosystem Health under One-health

Ecosystem Health and One Health are broadly aimed at understanding the links between human, animal, and environment health. Water is a primary natural source, a basic human need and a precious asset. It is one of the most abundant compounds on earth and groundwater contributes about 95% of the freshwater on earth making it fundamental to human life and economic development. In recent times, aquatic pollution has been a serious challenge, which could make food and drinking water unsafe for consumption. This makes aquatic ecosystem health management an issue of great concern. Therefore, ecosystem health monitoring and assessment using advanced biotechnology are employed today and they are rapid and highly sensitive even at very low concentrations of chemicals, contaminants and xenobiotics. With rapid globalization, population rise and environmental degradation, health threats in aquaculture sector is becoming more frequent and complex and health management of one sector will not serve the purpose. For this reason, 'One-health', the **integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems (the triad, Fig. 2) is the approach of the day**.[4]

Omics Technologies

Omics technologies (including genomics, transcriptomics, proteomics, metabolomics, lipidomics and phenomics) have revolutionized our understanding of biology and life sciences.[5] Omics technologies employ powerful tools and techniques of biotechnology that involve wet-lab experiments, databases, in-silico analysis using bioinformatic tools and data validation by complementary and supplementary wet-lab experiments including immunoblotting, qPCR depending upon the validation needs. Proteomics is functional genomics that deals with the proteome, which is highly dynamic unlike the genome. Proteomics is both basic and applied science and is being used in many fields including disease pathogenesis, biomarker identification for disease diagnosis, forensics.

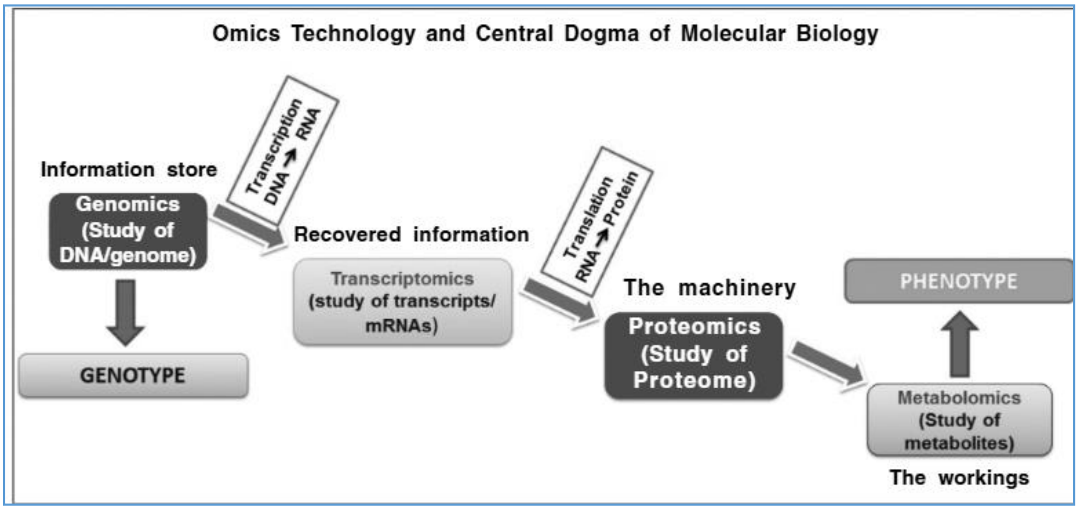

Fig. 3. Flow of Omics Technology and central dogma of molecular biology[5]

Proteomics

Proteomics is a highly powerful technology in protein analysis which supplements gene sequence data with protein information about where, in which ratio and under what condition proteins are expressed. In the last decade, proteomic technologies have been increasingly used in biological research, applied primarily to investigate the physiology, nutrition, health, quality and food safety, development biology and the impact of contaminants in model organisms, such as zebrafish (*Danio rerio*) and rats, as well as in number of non-model organisms. For example, fish species like s *Catla catla* and *Labeo rohita*, minor carp *Puntius sophore* (all belong to the Cyprinid family as the zebrafish), murrel *Channa striatus* – a hardy species, and the freshwater catfish *Rita rita* have been utilized to understand organismal response towards the altered environment.[6] Similarly, proteomics has been applied in goat mesenteric artery to better understand acidosis in small ruminants. Milk proteomics, reproductive proteomics, meat proteomics for species authentication for preventing food fraud (food forensics), development of diagnostics and vaccine candidates etc. are other applications in animal husbandry sector.

Application of proteomics in Fisheries and Veterinary Sector

The aquatic ecosystem and the aquatic organisms, especially fish species encounter variety of stress, both biotic and abiotic, during their continuous interaction with the environment from very early stages of their life and the adverse habitat condition can lead to impairment of their health, growth, fitness. When large quantities of pollutants are released, there may be an immediate impact at molecular level followed by responses at the cellular (biochemical), tissue/organ and whole-body levels. Responses that occur at individual, population and ecosystem levels are generally accepted to have ecological relevance and tend to be less reversible and more detrimental than effects at lower levels. The biotechnological tools are employed for biomonitoring and evaluation of stress that could help in better environmental management. Few such case studies on aquatic and land animals are discussed below.

Liver proteomics of *Channa striatus* for understanding thermal stress response

Temperature stress is one of the major abiotic factors that hampers the growth and productivity and is a leading cause of mortality and neurologic morbidity. An increased understanding of the distinct temporal patterns of response of gene regulatory processes to changes in temperature is needed to develop a mechanistic understanding of the effects of temperature change on the vertebrates. Identifying gene or protein markers that define the different sub lethal stress levels are useful in assessing the health of individual organisms in their environment. A study was undertaken to investigate the proteomic changes in liver of murrel *Channa striatus* exposed to high temperature stress. Fishes were exposed to 36 °C for 4 days and liver proteome changes were analysed using gel- based proteomics i.e. 2D gel electrophoresis, MALDI-TOF-MS and the results were validated by transcript analysis. The study showed, besides others, up regulation of two sets of proteins, the antioxidant enzymes SOD, ferritin, GST and chaperones HSP60, PDI. Further, gene expression analysis was also carried out in the fishes exposed to thermal stress for longer duration (30 days, in the laboratory and beyond, taking Channa collected from a hot spring runoff at a water temperature 36-38 °C); hsp60, sod and gst were found to continue to remain up regulated at 11, 8 and 3 folds, respectively in the hot spring runoff fish. Thus, the study showed that SOD, GST and HSP60 play important role in thermal adaptation and survival under chronic heat stress.[7]

Plasma proteomics of *Labeo rohita* for identification of potential biomarkers of arsenic-induced hepatotoxicity

Arsenic (As) is a toxic environmental contaminant and a potential human carcinogen. Human exposure to arsenic is caused mainly through arsenic-contaminated underground drinking water, and it is now understood that food-chain is another contributor to arsenicosis problem. Fish and other aquatic animals are naturally the worst affected ones as they feed, breed and grow in the contaminated aquatic habitat, thereby getting lifelong exposure. For understanding the molecular toxicology of arsenicosis, which might provide clues for developing mitigation measures, fish is an important model. Early detection of arsenic toxicity can provide great benefits to patients; however, toxicity detection needs to be done at the earliest and minimally symptomatic stage for which detection tools must be very sensitive and reliable. In this context, we investigated the plasma proteome changes in arsenic-exposed *Labeo rohita*, with the objective of identifying biomarkers of arsenicosis. Changes in plasma proteome were investigated using gel-based proteomics technology. The unique proteins identified include Apolipoprotein-A1 (Apo-A1), α-2 macroglobulin-like protein (A2ML) transferrin and warm-temperature acclimation related 65kDa protein (Wap65). All these highly up-regulated protein spots identified in plasma are liver-specific and indicate their utility as potential biomarkers of hepatotoxicity and chronic liver disease.[8]

Recent Approaches in Aquatic Ecosystem Health Assessment

Riverine environment is recognized as a complex ecosystem, contaminated with organic pollutants, heavy metals, xenobiotics, microbes, pesticides, which have carcinogenic, teratogenic and mutagenic effects on aquatic biota. Study of physiological response of aquatic organisms is important because it can provide information on the impact of pollution on their health, and could also be helpful in evaluation of the ecosystem health. Biomonitoring, the 'act of observing and assessing state and ongoing changes in ecosystem components of biodiversity and landscape including the types of natural habitats, population and species', helps in rapid assessment of aquatic pollution. Biomonitoring programmes usually involve the use of biomarkers, which are 'key molecular or cellular events that link a specific environmental exposure to a health outcome'.

In natural water bodies joint toxicity of multiple contaminants is very common. Synergistic effects of multiple pollutants have detrimental effect on aquatic organisms although individually these could be present at concentration within the permissible limits.

Therefore, an integrated approach with study of water quality characteristics (including heavy metals and pesticides) and response of aquatic organisms (biomolecules) both are necessary for the assessment of the health of aquatic ecosystem. Correlation analysis (Principal component analysis) with these variables are useful to identify biomarkers for biomonitoring of aquatic ecosystem health and integrity (Fig. 3). [9-12]

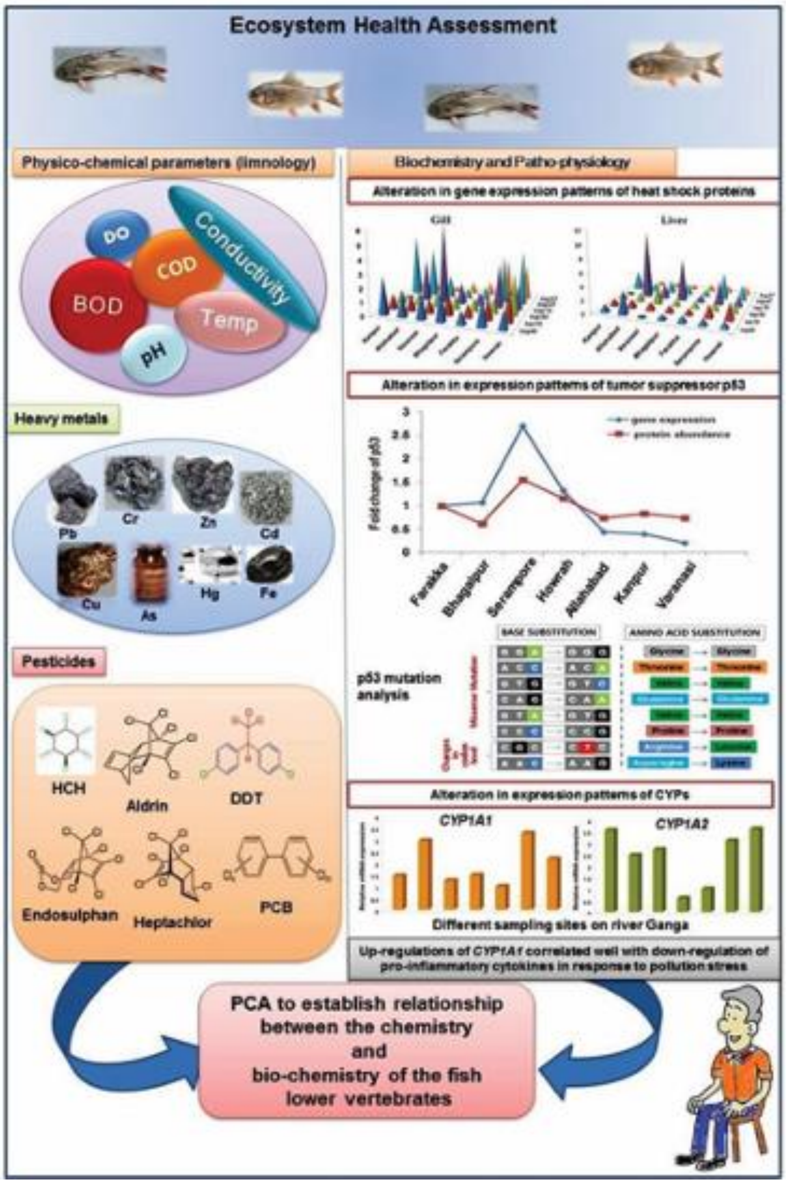

Fig 3: New approaches in aquatic ecosystem health assessment[12]

Rat Liver Proteomics for Safety Evaluation in Formaldehyde Toxicity

Formaldehyde is currently classified as a known human carcinogen by the WHO International Agency for Research on Cancer (IARC) and the National Toxicology Program (NTP) (IARC 2012). Formaldehyde (FA) is a hazardous chemical and human carcinogen. Contamination of FA in food, especially perishable commodities like fish and meat, is a major source of exposure, although it is not recommended for use in food and food products owing to its carcinogenicity. Considering the health risks associated with formaldehyde exposure, both international and national agencies have set maximum permissible limits for formaldehyde indifferent sources. The United States Environmental Protection Agency (US EPA) has set a limit of <0.20ppm/cc for indoor air; however, studies are meagre on ingestion toxicity. Effects of oral feeding of FA have been studied by evaluating general health, haematology and clinical chemistry in rat. Reports indicate that FA exposure leads to detrimental cardiovascular effects. Although FA is an established carcinogen, molecular studies on carcinogenic potential with dose dependency are meagre. Since there were reports on adding formalin (formaldehyde) in fish and possibly in other sources of meat, experimental studies were conducted to investigate toxicogenomic and proteomic alterations changes in liver of rats (*Rattus norvegicus*) fed FA through drinking water.[13] Gene ontology analysis showed that binding, catalysis, signal transduction was affected in formaldehyde-fed rats. Pathway analysis revealed that formaldehyde-exposure activated PI3K-AKT pathway that leads to inhibition of caspase activity thereby assisting cells to survive against apoptosis. Decreased abundance/down-regulation of ANGPT, eNOS, STAT3 proteins/transcripts and increased abundance of EDN1 indicated decrease in angiogenesis and vasodilatation that restricted hepatic cells from becoming tumorigenic; thus, indicating FA could be less toxic and non-tumorigenic at low concentrations.[13]

Vascular Proteomics to better understand Acidosis in Small Ruminants

Metabolic acidosis is associated with numerous pathophysiological conditions and its vasorelaxation effects have been well described in different animal and culture models; however, the molecular mechanisms of acidosis-induced vasorelaxation are not well understood. Mesenteric artery models have been used extensively to examine the vascular response to various pathophysiological conditions. Reports have suggested the vascular responses of goat mesenteric arteries and human arteries to various stimuli, including acidic stress, are highly similar. To identify the signaling molecules responsible for altered vasoreactivity in response to acidic pH, proteome profile of acid stress-induced vasorelaxation using a goat (*Capra hircus*) mesenteric artery model was studied.[14] The vascular proteomes under acidic pH were compared employing gel-based proteomics (2D-GE, LC-MS/MS, and MALDI-TOF-MS). The unique proteins identified by mass spectroscopy were actin, transgelin, WD repeat-containing protein 1, desmin, tropomyosin, ATP synthase β, Hsp27, aldehyde dehydrogenase, pyruvate kinase, and vitamin K epoxide reductase complex subunit 1-like protein. Out of five protein spots identified as actin, three were upregulated > 2-fold. ATP synthase β was also upregulated (2.14-fold) under acid stress. Isometric contraction studies revealed that both receptor-mediated (histamine) and non-receptor-mediated (KCl) vasocontraction were attenuated, whereas acetylcholine-induced vasorelaxation was augmented under acidosis. Overall, the altered vasoreactivity under acidosis observed in the functional studies could possibly be attributed to the increase in expression of actin and ATP synthase β.

Epilogue

The combined omics technology (genomics-transcriptomics-proteomics-metabolomics-phenomics), in fact, have a greater scope of application in fisheries and aquaculture and animal science sector. It can certainly help in achieving the objectives of SDGs; leading to quantum jump in high quality fish, meat, dairy and poultry production and ensuring food safety, at the same time, thereby contributing towards the SDG Goals and a healthy planet.

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Influence of Livestock Waste on Climate Change and Animal Welfare

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1.1 Introduction

Climate changes include major variations in temperature, precipitation or wind patterns, among other effects, that occur over several decades or longer. The key indicators of climate change are fluctuations in carbon dioxide concentration, global air temperature, Arctic sea ice, land ice and seas level. The main cause of current global warming trend is human expansion of the "greenhouse effect' warming and also includes livestock activities.

Livestock and poultry production plays a crucial role in India, providing food security and financial stability for more than two-thirds of the population. Animal-sourced foods like meat, milk, and eggs are highly valued for their nutritional content. In the 2021-22 fiscal year, India produced 9.29 million tonnes of meat. According to FAOSTAT (2019), India ranks first in water buffalo population, second in cattle and goat population, and fourth in sheep population. The 20th livestock census reported a growth rate of 4.06%, with all species showing growth except for pigs, which experienced a 12.03% decrease. Cattle account for 35.94% of the total animal population, goats for 27.80%, buffaloes for 20.45%, sheep for 13.87%, and pigs for 1.69%.

Waste is inevitable from livestock and poultry establishments. It is defined as anything that is no longer useful and needs to be disposed-off. Technological advancement in livestock and poultry production system has resulted in the production of various type of solid and liquid wastes on a larger scale. The solid waste consists of bedding material, dung/excreta, leftover feed and fodders, feathers, hatchery waste, shells, sludge, abattoir waste, mortalities, etc. The liquid waste includes urine and wastewater results from washing and disinfection of livestock and poultry houses and abattoirs. Waste management may be correlated with conservation of energy according to which "Energy can neither be created nor be destroyed but only can be transformed from one form to other form". During rearing process of various livestock and poultry species, we supplement feed and fodder as a source of energy. Digestible portion of feed and fodder is utilizable source of energy. However, indigestible portion as well as residues of feed, fodder, slaughter houses etc., which is still a source of energy remained idle as waste and there is no utilization of valuable sources of dumped energy. Therefore, for balancing the energy flow system, the waste, from any source, should be properly utilized.

In terms of Gross Value Added (GVA) to the Indian Economy from livestock and poultry sector, third level of economic gain after milk and meat group is from livestock waste especially dung (about 6-7% of total), which is even higher than eggs. Even though it is most neglected aspect till date. Proper waste management planning and economic prioritization can fetch 2-5 times higher income. This may further make livestock enterprise especially from indigenous, less productive groups, more viable, eco-friendly and sustainable. Waste from cattle and buffalo has proved to be most efficient for augmenting economic gain in form of bio-gas, compost, vermin-compost mainly due to optimum C:N ration. However, poultry and piggery waste is still posing challenges towards its economic utilization. Higher nitrogen, sulphur and lower fibre content in the excrement of these species is the most challenging aspect and has polluted both air (as ammonia) and ground water (N percolation). Furthermore, these excrements can't be applied directly as FYM due to caustic effect of ammonium hydroxide on plants.

1.2 Volume of livestock and poultry waste generated

Average waste output from large ruminants is about 40kg/day/adult animal which includes dung, urine, bedding materials, left over feed and fodder, etc. Estimated daily manure outputs from lactating and growing bovines are about 9.4 and 4.6 %, respectively. Respective output of dung and faeces (kg) from Indian cattle, buffalo, horse, sheep & goats and pigs is about 16-24 (20), 22-38 (30), 10-16 (13), 1.2-2.4 (1.8) and 3-7 (5). The daily manure production of a laying hen and broiler is about 120-140g/day (with 25% dry matter) and 60-90 g/day (with 40% dry matter), respectively. This results in production of about 12.0-18.0 kg dry excreta per layer and 1.5-2.0 kg per broiler per cycle. Average excreta output from an adult turkey is about 400g/day.

1.3 Environmental effect of livestock and its waste

Huge livestock population has both positive and negative impact on environment. The livestock production system contributes to global climate change directly through production of GHG emissions and indirectly through the destruction of biodiversity, degradation of land, and water and air pollution. The main contributors of GHG emission from livestock production system are enteric fermentation, waste products and production of feed and fodder. Worldwide, livestock emits around 7.1 Gt CO2-eq GHGs per year which makes 15% of human induced GHGs emissions. Additionally 5.7Gt CO2-eq GHGs also emitted from the ruminant supply chain, wherein large and small ruminant production contributes 81, 11 and 8%, respectively.

The major adverse effect of livestock on environment is through the production of the potent GHG, methane production. Enteric fermentation in ruminants annually contributes about 90 Tg methane to the atmospheric pool, while about 25 Tg comes from the excrements. Emission of enteric methane resulted in loss of biological energy (6-12% of intake), which otherwise would have been utilized by the host animal for different productive functions. India with current livestock population, methane emission comes around 9-12 Tg per year. As per the second official Indian inventory of GHGs carried out in 2000 showed that India's contribution in this was 216517 Gg/year (3% of global), of which 97.65% is from enteric fermentation and the remaining from manure management. Methane emissions from excrement in India are very little as the disposal system does not support anaerobic conditions for methanogens except lower layer of manure heaps. In contrast, in developed world, excrement stored as lagoons is one of the major sources for methane emission.

Among Indian livestock, Buffalo, Yak and Mithun contribute maximum (55 kg methane/head/year); however, sheep and goat contribute only 5 kg/head/year. The enteric methane emission from crossbred cattle is much higher than that of the indigenous cattle (46 vs 25 kg/head/year). Cattle and buffaloes together emit bulk, sheep and goat together around 7.7%, pigs about 0.57% of the total enteric methane emission from livestock in the country. The positive impact of livestock is through its contribution in the form of manure, saving natural resources through bio-fuel production, replacing fire woods, recycling agricultural by-products, reducing emission from vehicles by replacing draught animals etc.

1.4 Impact of climate change on livestock welfare

The GHG produced from livestock including waste has detrimental effects on livestock welfare. Some effects include:

- Heat stress on livestock due to global warming with variety of detrimental effects like significant effect on growth, milk production and reproduction.
- Due to failure of thermoregulatory mechanism of livestock under heat stress, their feeding behaviour is further affected and has negative impact on their welfare.
- Indirectly, there will be reduction in the quantity and availability of feed and water and prevalence of many livestock parasites, pests and disease vectors will increase and will deteriorate the welfare state of livestock.
- Livestock welfare will be further affected due to accumulation of anti-nutritional factors like HCN, nitrates, nitrites etc.; lower concentration of essential elements; and impaired digestibility of fodder especially during drought season.

Livestock welfare will be further affected by biological changes due to effects of heat stress like

- Elevated body temperature, pulse and respiration rate and related adverse impacts.
- Increased maintenance energy requirements, elevated metabolism and immunosuppression.
- Increased losses of minerals like sodium and potassium, acid-bas balance shift and metabolic alkalosis.
- Reduced dry matter intake.
- Reduced productivity e.g. milk production.
- Decreased reproductive performances like reduced length and intensity of oestrous period, decreased conception rate, decreased follicular development, increased embryonic mortalities and decreased foetal and calf size.
- Higher disease incidences due to global warming is another welfare issues for livestock. This is due to immune-suppression of livestock, increase in number of disease vectors and parasites etc.

1.5. Livestock and Poultry waste utilization

There is an urgent need to formulate strict regulations governing the safe disposal and handling of livestock and poultry waste in order to minimise the environmental impact. Many systems and approaches, as mentioned below, can be successful if properly adopted and judiciously applied.

1.5.1 Excrement as FYM

FYM is partially composed dung, urine, bedding and straw. Dung contains about 50 per cent of the nitrogen, 15 per cent of potash and almost all of the phosphorus that is excreted by animals. FYM contains approximately 5 - 6 kg nitrogen, 1.2 - 2.0 kg phosphorus and 5 - 6 kg potash per tonne. Though FYM is the most common organic manure in India, the farmer, in general, do not give adequate attention to the proper conservation and efficient use of the resource. For preparing better quality FYM, the use of pit method for areas with less than 1000 mm precipitation and heap method for other places is recommended.

1.5.2 Composting

Composting is defined as a method of biological degradation of organic residues under aerobic condition resulting in end products consisting largely of water, carbon dioxide, ammonia, heat and humus, consisting of microorganisms, non bio-degradable inorganics, and organic compounds resistant to rapid biodegradation (Glanville and Trampel, 1997). The benefits of compositing are manifold. It reduces the bulkiness of the waste and yields a stabilized product suitable for handling and land application. Compositing has the ability to reduce livestock and poultry litter, disposal of carcasses, stabilize trace minerals and reduce odours (Turnell et al., 2007). There are four general methods of producing compost i.e. static pile, standard windrow, improved windrow and in-vessel and agitation. Static pile, the simplest, involves mixing the poultry litter with a carbon source (most often sawdust) and putting it into a pile that is aerated from below. Windrow methods involve laying out the livestock and poultry litter/sawdust mixture in long piles that form tall rows. The rows are turned periodically to increase aeration and thus speed the composting process. Improved windrow is similar to standard windrow but involves greater capital expenditure on equipment and facilities that increase production efficiencies and reduce production time. In-vessel and agitation systems involve putting the input mixture into trough bays or large drums that mechanically agitate the product. This system has the shortest production cycle but involves the greatest expenditure on equipment, facilities, and operation. It is a relatively fast biodegradation process, taking typically 4–6 weeks to reach a stabilised material (Kelleher et al. 2002).

1.5.3 Vermicomposting

It is a simple process of composting in which animal and farm waste harbour earthworms and micro organisms which are used to enhance and accelerate the process of waste conversion into value added organic products viz. vermicompost, nutriwash or vermiwash and high quality of animal protein. The soil nutrients and microbial population are higher in vermicompost which can be used as a fertilizer (Jayakumar et al. 2011).

1.5.4 Animal feeding

Especially, poultry excreta has this potential. As per various scientific studies, nutrients and energy from poultry waste by-products can be safely recycled as a component of ruminant and poultry diets when pathogens are neutralized. Poultry litter proved to have as much as three times more valuable as a feedstuff than as a fertilizer for crop nutrients. In recent years, poultry nutritionists have explored the possibility of recycling poultry waste as a feed for poultry, rabbits and ruminants. Ruminants are able to utilise the urea nitrogen (uric acid) of poultry manure. It is important to maintain low ash content. When large quantities of soil are removed with the litter, the ash content increased dramatically. It is recommended that poultry litter with ash contents exceeding 28% should not be fed to cattle (Williams et al. 1999).

1.5.5 Gasification

Gasification technology is a way of producing bio-energy that is receiving renewed interest for small on-farm systems and central electric power stations in some regions. The process involves incomplete combustion in a limited-oxygen environment. As noted for both anaerobic digester technology and incineration units, economic costs and returns, operational feasibility and emission issues have an impact on the implementation of this technology. However, increasing energy costs, environmental policy related to mandated renewable energy production goals in some regions, and the evolving carbon credit market are stimulating interest in all technologies for processing poultry and other waste products that yield bio-energy and reduce greenhouse emissions.

1.5.6 Treatment of heavy metal contaminated water

Utilization of poultry litter as a precursor material to manufacture activated carbon for treating heavy metal-contaminated water is a value-added strategy for recycling the organic waste (Guo et al., 2010). Poultry litter-based activated carbon possesses a significantly higher adsorption affinity and capacity for heavy metals than commercially activated carbons derived from bituminous coal and coconut shell and does not pose secondary water contamination risks.

1.5.7 Rendering and Biodiesel production

There is great potential for producing biodiesel from animal fats near major commercial slaughterhouses, rendering factories, and areas with a high animal population. Animal breeding for meat and biodiesel might be future production goals. This approach has the potential to transform the animal production industry. Pigs and poultry may make significant contributions due to their good characteristics such as prolificacy, short generation intervals, and rapid body weight increase for slaughter. At the same time, this proposal has the potential to address the societal issue of disposing of dead birds and slaughter waste. The rendered chicken oil can be used for biodiesel production by the process of transesterification. The solvent extraction method was cheaper compared to the mechanical centrifugation method to produce biodiesel from rendered chicken oil. A total of sixteen dead birds of average 1.25 kg weight were required to produce one litre of biodiesel and whereas only six birds of the same body weight were to produce one litre of biodiesel by solvent extraction (Abraham *et al.* 2014).

1.5.8 Anaerobic digestion and bio-energy production

Anaerobic digestion is a relatively efficient conversion process for livestock excreta and poultry litter producing a collectable biogas mixture with an average methane content of 60%. The methane produced by this process can be used as a fuel for boilers, as a replacement for natural gas or fuel oil and can also be fired in engine-generators to produce electricity for on-farm use or sale to electricity companies (Kelleher et al 2002).

1.5.8.1 'DAC' technology for biogas production exclusively from poultry excreta

ICAR-Central Avian Research Institute, Izatnagar, developed a novice technology for all-weather biogas production (DAC technology) exclusively from poultry excreta. The poultry biogas burns like LPG with blue flame. The methane (%, V/V) content of poultry biogas was 60.02 which is equal to or better than biogas available from other methods and substrate. The signifying point of this technology is that only poultry excreta are required for biogas production and there is no need to add cow dung which is commonly being mixed for biogas production from poultry excreta in other methods. This technology also helps in conservation of water as used slurry of digester is reutilized again and again as dilutor for poultry excreta. Round the year i.e. both during summer and winter biogas production is possible from this technology. It is pertinent that, in India, most of the biogas plants become non-functional during winter season due to lower ambient temperature. In our technology, about 12-13 to 19-20 kg poultry excreta is required for production of about one cubic meter of biogas during summer and winter seasons, respectively. This quantity of biogas is sufficient for cooking 3-times meals of an average family comprising 4-5 members. This can also be used as heat source at poultry farm. Spent slurry of poultry biogas has good manure value and germination potential and can be easily applied in agricultural fields for organic crop production without burning effect on plants which is a common problem with crude poultry excreta. This technology has enormous positive impact on environment by drastically reducing pollutants, bad odour and flies thereby also helping in accomplishing the Sawachch Bharata Mission.

1.5.9 Azolla, fodder and mushroom cultivation

Livestock waste can also be used for cultivation of certain minor components like fodder, mushroom, medicinal plants etc. Azolla and fodder produced can be fed to dairy animals, so that the feeding cost can be reduced. This system has potential to provide long term sustainability, reduce environmental impacts and also to achieve food and nutritional security at farm level itself.

1.5.10 Alternate use of dung and urine

In Ayurveda, Panchagavya is a necessary and valuable ingredients. It is prepared by mixing cow milk, cow urine, cow ghee, cow butter milk and cow dung. Cow urine also has many alternate uses like insect repellent, as cosmetics, medicines etc. Therefore, it is a very good alternative of dairy waste management and sustainability of dairy farm.

1.5.11 Larvae from livestock and poultry waste

The black soldier fly (*Hermetia illucens*) is a widely used insect as its larvae provide a great source of protein and fat. The use of black soldier fly (BSF) larvae can also help manage slaughter waste. These larvae are efficient feeders and can quickly consume and eliminate organic substances thanks to their strong digestive systems and effective mouthparts. Additionally, the larvae contain natural antibacterial defensin-like peptide 4 (DLP4), which can inhibit the growth of harmful infections such as *Salmonella* and *E. coli* (Erickson *et al.*

2004; Li *et al.* 2017). The larvae are an abundant source of protein (35-40%) and fat (30%), depending on the stage of harvest and substrate used. They can be added to poultry feed as a protein source, and the oil extracted from the larvae can be used in biodiesel production. Using BSF larvae has multiple benefits, and specialized facilities are not required. The ease of operation and minimal space requirement are additional advantages. This method is an excellent example of the circular economy model and has great potential for future use (Gadekar *et al.* 2022).

1.5.12 Poultry feather

Chicken feathers are waste products of the poultry industry create a serious solid waste problem. Typically, as each bird has up to 125 grams of feather, the weekly worldwide production of feather waste is about 3000 tons. Disposal of this bulk waste is a global environmental problem accounting to the pollution of land and underground water resources. Poultry feathers are abundantly available and have wide applications for the preparation of diversified products like bio-fertilizer, films, absorbents, bio-composites, flame retardants, keratinases, thermoplastics, textile yarn sizing agents, and regenerated protein fibers (Reddy, 2015).

1.6 Conclusions

There is a serious threat of climate change due to livestock waste. Major climate change includes release of GHGs, global warming, heat stress on livestock and poor livestock welfare. It is, therefore, imperative that animal husbandry practices and the welfare of animals must be considered when developing climate change policies and programmes, both as potential victim and causes. Such policies and programmes that minimize the impact on animal production on environment should not be at the expense of animal welfare. As livestock is playing very important role in rural economy, it is necessary to find suitable solution to reduce the ill effect of climate change on livestock production. One of the main problems of livestock industry is curbing Green House Gases and recycling the wastes in an environment friendly and sustainable way for improving environment vis-à-vis animal welfare. There are tremendous opportunities for utilization of livestock waste as FYM, compost, vermicullture, bio-energy by the development of small-scale biogas plants, etc. This needs to be translated into sustainable action, such as improved information dissemination regarding the benefits of biogas plants, composting, vermi-composting etc. for the use of end users and stakeholders. A comprehensive understanding of the wide array of livestock waste disposal technologies will facilitate the identification and implementation of effective disposal strategies for protection of environment and animal welfare.

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Climate Change Impacts on Fisheries: Pathways to Sustainable Resource Management and Policy

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Climate Change has significant impact on the fisheries sector. Impacts of climate change such as rising temperatures, ocean acidification, sea-level rise, and shifting marine ecosystems are changing fish population dynamics and habitats, particularly, the Bay of Bengal, where millions of people directly or indirectly depend on fisheries and aquaculture. To address these challenges, it is essential to implement adaptive and sustainable management strategies that can mitigate climate impacts and promote resilience in this sector.

Several studies have observed the decline in fish stock and catches across the Bay of Bengal region, rising the sea temperature and increased the frequency of the cyclones and heatwave in this region disrupted the marine ecosystem and altered fishing migration pattern. These changes have reduced near-shore catches, lowering the yield for fishing communities. In coastal Odisha, fishers report decreased catches linked to altered fish movements, which adversely affected the local fishing community. Due to low fish stock availability, fishers often end up catching juvenile fish.[1] Declining fish stocks lead to reduced incomes, potentially driving fishers toward poverty or compelling them to migrate in search of other livelihoods. To further control the depletion of the fish stock, governments often impose seasonal fishing bans, which, although essential for stock recovery, can disrupt local economies—especially where alternative income support options are limited.

A recent FAO[2] report highlights the long-term impacts of climate change on marine ecosystems and fisheries worldwide. Under a high-emission scenario (SSP5), global temperatures are projected to rise by 3 to 4°C by the end of the century, which could lead to a 10–30% decline in global fish biomass. India, as one of the world's largest fish producers, is expected to experience significant losses, putting livelihoods and seafood demand at risk. This emphasizes the urgent need for climate-resilient management practices in the fisheries sector to safeguard food security and economic stability.

A comprehensive economic valuation of climate change impacts on fisheries can help policymakers and stakeholders assess the monetary value of these effects, supporting improved resource management and policy decisions. This valuation framework examines the marine ecosystem through four main services: provisioning, recreational, regulatory, and supporting services. Each service is analyzed for its direct and indirect benefits and costs. Economic valuation methods: Contingent Valuation assesses how much individuals would pay to prevent or mitigate damage; for example, the study by Mohammed et al. (2016)[3] employed the CV method to examine community willingness to pay for the conservation measures of the Hilsa in Bangladesh, recognizing the fish's cultural importance and the ecosystem benefits households expressed their willingness to pay for its conservation, the study estimated that improved fishery in the region would increase Hilsa fish value by US 8.3 – 17.7 million (2016 prices), further the study estimated that better management of the Hilsa fishery would have an over value US 167 to 355 million per annum. The results of CV method highlights that understanding community values can guide sustainable management practices and policy development for Hilsa in the Gangetic region of India and Bangladesh. Similarly, studies have been examined the direct and indirect value of the Sundarbans mangrove ecosystem services, particularly in supporting fisheries and protecting against climate-driven flooding. Economic assessments of mangrove conservation highlight its cost-effectiveness for maintaining fisheries, reducing disaster risks, and supporting local livelihoods. Studies have examined sustainable aquaculture practices in Gujarat using CBA, revealing that aquaculture's resilience to climate variability offers a viable alternative to traditional fishing, which is increasingly vulnerable to climate-induced changes.

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[1] https://www.downtoearth.org.in/climate-change/odisha-s-fish-stocks-are-depleting-courtesy-warming-seas-here-s-how-89139

[2] https://www.fao.org/family-farming/detail/en/c/1698073/

[3] https://digitalarchive.worldfishcenter.org/server/api/core/bitstreams/a50295e1-755b-4d25-89b7-09ebb2eec36e/content

Adopting diverse economic valuation techniques is crucial to fully assess climate change impacts on fisheries, these techniques helps for effective policy responses. These valuations not only highlight current economic losses but also demonstrate the importance of sustainable practices for the resilience of fish stocks and local economies. An integrated approach, combining fishery science, economic, social, and environmental factors, supports holistic resource management and ensures sustainable and resilient future for India's fisheries, benefiting communities and conserving marine resources for generations.

Climate Change in Fisheries and Livestock System

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Livestock and fisheries play an important role in achieving food and nutrition security apart from providing a source of income and livelihood to millions of people across the globe. In the last few decades, both these sectors have continued to expand in terms of area, quantity and production, making these sectors the fastest-growing agricultural production sectors in India. These sectors also play a significant role in generating gainful employment in the rural sector, particularly among the landless, small and marginal farmers and women, besides providing cheap and nutritious food to millions of people. The livestock and fisheries sector plays an important role in the national economy and also in the socio-economic development of millions of rural households. The contribution of the livestock sector in Gross Value Added (GVA) during 2022-23 was about 30.23% of the agricultural and allied sectors and 5.50 % of the total GVA. In the same time, the share of the fisheries sector in the total GVA was about 1.09 % of the total national GVA and 6.72 % of agricultural GVA. About 20.5 million people depend upon livestock for their livelihood. It provides livelihood to two-thirds of rural communities and employs about 8.8 % of the population in India. Similarly, fisheries sector provides livelihood to about 16 million fishers and fish farmers at the primary level and several lakhs along the value chain (AR 2023). Globally at present, more than 80% of global aquaculture production is contributed by small to medium-scale fish farmers, nearly 90% of whom live in Asia (Subasinghe *et al,* 2012). Hence, for sustainable production and incessant growth in aquaculture special attention in the aquaculture sector has to be given to the small and marginal farmers. With this large population directly and indirectly depending on livestock and fisheries including aquaculture, any drastic change in the sustainable production structure will not only create a significant impact on their income and livelihood security but also will hamper their nutritional security.

Climate change is impacting agriculture and allied sectors adversely across the globe. It is now widely accepted that it is no longer a potential threat, but slowly becoming an unavoidable reality. This is anticipated that climate change in the long run will significantly affect aquatic ecosystems, livestock and fisheries productivity, income and ultimately food availability and livelihoods. In recent times impact of climate change has already been encountered by drastic changes in weather conditions, changes in precipitation, hydrological regimes as well as in water flow, heavy wind and storm as well as cloud bursts, increased incidence of flood and drought, etc. These effects have resulted in changes in the primary productivity of the water, fish production and productivity, increase in disease infestation etc.

The effect of climate change is more impact-oriented, especially for developing countries predominantly due to limited capabilities and restricted resources to address climate related issues. Droughts and floods are regularly visited in India and thus nation exhibits a significant susceptibility to climate-related disasters. It is reported that around 68% of the area in India has been categorized as “drought-prone”, and about 12% of its area faces frequent floods. Moreover, about 8% of the coastal area is also prone to cyclones (Deshpande 2022). As agriculture is the mainstay of the Indian economy, hence, vagaries of this climate-sensitive sector can significantly affect the Indian population and economy.

Globally, the Earth's average surface temperature has risen by over 1.1°C between 2011 and 2020, with more gain over land (1.59 °C) than the ocean (0.88°C) (IPCC, 2023). Contrary to popular belief that climate change is simply the world is getting hotter, it is more than that. It is not a single parameter that directly influences or impacts on organism level or the environment. But it acts as a cascade of stimuli to the environment and there-by causes various indirect effects on organisms and associated systems (Sarma and Jaspreet, 2022). We are already experiencing widespread changes across the atmosphere, land, ocean and ice regions.

There are several reasons responsible for global warming. Human-induced greenhouse gas (GHG) emissions are the most important drivers of global climate change. Nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4) are primarily accountable for GHG. The global emissions of greenhouse gases have consistently risen, primarily due to unsustainable use of fossil fuels (coal, oil, and gas) for energy purposes (electricity generation, transportation, industrial use); deforestation and forest degradation; changes in land use patterns; changes in lifestyles; consumption, and production patterns; intensive agriculture, etc., and are widely acknowledged for climate change (IPCC, 2023). As per the Government of India database energy sector contributed around 75.8% of GHG followed by 13.44% from the agriculture sector with a total of 3.13 Gt CO_2 eq in 2019. Global net anthropogenic GHG emissions have been estimated to be 59 ± 6.6 Gt CO_2-eq in 2019. Approximately 79% of global GHG emissions came from the sectors of energy, industry, transport, and buildings together, and 22% from agriculture, forestry and other land use (IPCC, 2023). Globally the livestock sector is responsible for about 14.5% of total anthropogenic GHG emissions (Downing *et al.*, 2017). The most important greenhouse gases from animal agriculture are methane and nitrous oxide. Methane is mainly produced by enteric fermentation and manure storage while nitrous oxide, arising from manure storage and the use of organic/inorganic fertilizers, affects global warming 28 times and 265 times higher than carbon dioxide (Grossi *et al.,* 2019). Aquaculture accounted for approximately 0.49% of anthropogenic GHG emissions in 2017 (MacLeod *et al.,* 2020).

Climate change and impact on fisheries

Climate change can significantly affect not only the loss of biodiversity, frequent occurrence of drought and floods, excessive and persistent heat conditions, low fish production etc. but it will have a cascade of different potential effects that work together directly and indirectly and ultimately whole ecosystem system will suffer which will intern affect the food security and livelihood, especially for the poor and underprivileged people. Climate change encompasses the production and composition of aquatic ecosystems in terms of physical, chemical, and biological features that serve as crucial sources of sustenance and refuge for fish. In general, fishes have an adaptive mechanism through which they try to maintain homeostasis develop inside the organism itself. However, when the adverse condition persists or goes beyond the tolerance limit, fish respond in the form of biochemical, physiological and immunological alterations which in turn leads to behavioural change, suppression of immune response and susceptibility to diseases causing organisms, breeding and reproduction-related issues, decreased growth rate, and these ultimately lead to decrease in production and economic loss. During the last few years, unprecedented floods have caused severe loss to the aquaculture production and facilities amounting to several crores. Apart from this, the escape of culture species can cause ecological disturbance and contribute to a reduction in the genetic diversity of wild stock as well as a threat to the endemic native species.

As such higher temperature has many adverse impacts. It is well established that higher temperatures decrease the dissolution capacity of water and at the same time increase the demand for dissolved oxygen by the fishes (hypoxia) and microbiota present in the fish pond. It can also significantly affect fish migration pattern & distribution; breeding, metabolism, osmoregulation & reproductive behaviour; fish interaction with the environment; disease susceptibility and parasitic infestation; fish growth and ultimately production. Similarly, climate change may influence the sea level rise and change in salinity. This in turn shall have issues related to migration, metabolism, osmoregulation etc. It is estimated that the Global mean sea level has already risen by 0.20 [0.15 to 0.25] m between 1901 and 2018. It will be more severe when the temperature will further increase to 2^0 C or more (IPCC, 2023). Higher temperatures reduce the glacial cover around the globe and many low-elevation and small glaciers around the world will lose most of their mass or disappear within decades to centuries. Similarly, climate-induced nutrient distribution can also affect reproductive behaviour, metabolism, growth and production, fish breeding etc. It also significantly affects biodiversity. In terrestrial ecosystems, 3 to 14% of species will likely face a very high risk of extinction at a global warming level of 1.5°C. Coral reefs are projected to decline by a further 70–90% at 1.5°C of global warming (IPCC, 2023). The above-mentioned impacts caused by climate changes are interrelated, interact with one another and can combine or singly influence the target organism and thereby the whole system becomes vulnerable. Handisyde *et al.* (2017) from their analysis found that Asia is expected to have the most vulnerability in freshwater aquaculture, with Vietnam being the most vulnerable country, followed by Bangladesh, Myanmar, and China. Similarly, the countries Ecuador, Vietnam, Belize, Egypt, and Taiwan have shown the most vulnerability in brackish water aquaculture. Likewise, Norway, Chile, China, and Vietnam have shown the highest vulnerability in mariculture aquaculture.

Aquaculture production systems in India mostly are outdoor activities, dependent mostly on local environmental and climate conditions, with the possible exceptions of indoor recirculating systems and biofloc systems. To tackle climate change-related variability the concept of Climate-Smart Agriculture (CSA) is nowadays gaining importance. CSA is an approach to develop the technical, policy and investment conditions to achieve sustainable agricultural development for food security. It integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges (FAO, 2013). Similarly, climate-smart aquaculture also aims to support food security and reduce vulnerability taking into account the need for adaptation and the potential for mitigation (Onada and Ogunola, 2016). Though there is large-scale human control in aquaculture, unprecedented floods, rain, run-off, etc. can have a catastrophic impact on production and economic return. Hence, adaptation and mitigation are two important aspects that have to be taken care of for climate-smart aquaculture.

Climate change and impact on livestock

Similar to fisheries, climate change can affect livestock production and consequently food security. The impact of climate change on livestock can be numerous and multifaceted (Downing *et al.,* 2019). It can severely affect the production and quality of feed and forage crops, water availability, animal production, reproduction and health, heat stress, animal growth and milk production, diseases, reproduction and biodiversity. These impacts are primarily due to an increase in temperature and atmospheric CO_2 concentration, precipitation variation, and a combination of these factors. For example, forage quantity and quality generally depend on the season they are grown and area specific. It has been reported that an increase of 2°C will produce negative impacts on pasture and livestock production in arid and semiarid regions and positive effects in humid temperate regions. The length of the growing season is also an important factor for forage quality and quantity because it determines the duration and periods of available forage. A decrease in forage quality can increase methane emissions per unit of gross energy consumed (Benchaar *et al.,* 2001). Water availability issues will also influence the livestock sector. Water is required for drinking, feed and fodder production as well as processes of livestock products. The livestock sector accounts for about 8% of global human water use and an increase in temperature may increase animal water consumption by a factor of two to three (Nardone *et al.,* 2010). To address this issue, there is a need to produce crops and raise animals in livestock systems that demand less water (Nardone *et al.,* 2010) or in locations with water abundance. Animal health can be affected by climate change. Higher temperatures can increase the potential for morbidity and death of the animal, while indirectly may have immune depression effects and host resistance, and become susceptible to microbial communities (pathogens or parasites), food-borne diseases, etc. Climate change has a significant impact on reproduction, health and production sector in livestock. It has been reported that reproduction efficiency can be affected by heat stress. Heat stress due to higher temperature can affect in lowering sperm count, pregnancy rate, oocyte growth and embryo development and thereby can compromise fertility in the livestock sector. Production also can be affected by reducing body weight gain, feed intake, carcass weight, meat quality etc., and as per report one of the major causes of decreased production in the dairy and beef industry in USA.

Adaptation and Mitigation

Agricultural production is the mainstay of the Indian economy. Hence, adaptation of the agricultural sector to the adverse effects of climate change will be imperative for protecting and improving the livelihoods of the poor and ensuring food security (FAO, 2012). Hence, increasing adaptive capacity through resilience and sustainable production strategies, reducing the sector's vulnerability through an integrated approach and reducing and removing greenhouse gas (GHG) emissions significantly from within the sector (FAO, 2013) are some of the recent adaptive mechanisms. Development of climate-smart sustainable production system for livestock and fisheries, the ready availability of quality seed materials for livestock and fish, shifting to less vulnerable or more resilient livestock and fish species, and promotion of their selective breeding programme, system diversification for more climate resilient aquaculture, Integrated nutrient management in soil and water, efficient recycling and reuse of organic waste generated within a system; enhancing the effective management of capture fisheries through an integrated approach involving PPP mode, promotion of insurance schemes among the producers especially small-scale farmers are some of the approaches and practices which can contribute to climate change adaptation.

Various approaches for mitigation are being adopted. Technological intervention to reduce the utilization of resource inputs and GHG emissions per unit of output can be an ideal approach for mitigation. Integrated management practices can create optimal physical and biological conditions for sustainable agricultural production (Kochewad *et al* 2022, FAO, 2013). Management practices to increase organic carbon in soil through application and recycling of organic matter, improve capacity to retain, replenish and recycle nutrients in soil and water, enhance biodiversity of soil and water, use of fewer chemicals in the system, judicious use of fertilizer and pesticide, development of more energy-smart food production systems, crop rotating and diversifying crops to reduce crop pests and disease occurrence, minimum disturbance and maximum per unit production from unit area, etc. are some of the methods to reduce impact. Location-specific and resource-based livestock-based fish farming can be an important avenue for improving livelihood and income for mainly marginal and poor farmers in the climate change scenario (Sarma and Jaspreet 2022). Hence, decision-makers need to adopt a long-term view to make the needed paradigm shift to food systems that are energy-smart and contribute to climate change mitigation and adaptation as well as food security (FAO, 2013). The Indian economy and population rely heavily on climate-sensitive sectors such as agriculture, forests, tourism, livestock and fisheries. Hence, both short-term and long-term management strategies have to be formulated for possible ramifications of climate change including GHG emission strategies. Making livestock and fisheries sectors a climate-smart through an integrated way involving policymakers, scientists and common people can an ideal approach to ensure the food and nutrition security of the growing global population.

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Application of Advance Tools in Fisheries Research with Reference to Bioactive Compounds and Nutraceuticals

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In recent years, there has been a growing interest in functional foods and nutraceuticals, which are enriched with natural ingredients and have demonstrated significant health benefits. Particularly, marine-derived functional foods contain bioactive components with various therapeutic properties. These marine secondary metabolites have attracted attention as potential alternatives to synthetic drugs, which are often associated with toxic side effects, sparking a demand for new marine compounds with pharmaceutical applications. Marine organisms represent an underexplored resource for bioactive compound discovery. While there are approximately 391,000 species of vascular plants known to science, with 20,000 species exhibiting medicinal properties, the exploration of marine species—estimated at about 212,000—is still in its early stages. The chemical diversity and unique bioactivity of marine species make them promising candidates for developing new drugs to combat major diseases like cancer, AIDS, malaria, and neuromuscular disorders. Marine autotrophs, such as algae, have shown greater chemical diversity than their terrestrial counterparts, making them key targets for research over the past few decades. Bio-prospecting has led to the discovery of new secondary metabolites from these organisms, many of which display novel structures with potential applications in nutraceuticals and therapeutics. Despite the increasing interest, only a small number of these natural compounds have progressed to clinical trials. Nevertheless, efforts to explore marine environments for structurally diverse and chemically unique metabolites have intensified. Researchers have studied a wide range of marine organisms, including sponges, mollusks, tunicates, corals, algae, microorganisms, and more, isolating numerous bioactive compounds like terpenes, polyketides, peptides, and alkaloids with varied pharmacological properties. The contribution of marine natural products to drug discovery and pharmacology has been significant. Between 1984 and 2014, the number of new compounds isolated from marine organisms rose from 332 to 1,378, highlighting the potential of marine habitats to yield novel therapeutic agents. These marine organisms often produce bioactive compounds as chemical defenses, making them ideal candidates for human medicinal use. Among marine organisms, macroalgae (seaweeds) have gained particular attention for their nutraceutical potential. Marine macroalgae contain valuable nutrients and diverse secondary metabolites, such as phlorotannins, sulfated polysaccharides, and polyphenols, which exhibit anti-cancer, anti-inflammatory, and anti-diabetic properties. These compounds have shown promise in treating metabolic disorders, including diabetes and hypertension, by modulating glucose-induced oxidative stress and regulating digestive enzymes. One of the key drivers behind the growing interest in marine nutraceuticals is the demand for natural, bioactive ingredients to replace synthetic drugs, which often cause harmful side effects. Marine macroalgae, sometimes referred to as "ocean herbs," have drawn attention due to their bioactive metabolites and their ability to address lifestyle diseases. The harsh environments in which these marine organisms thrive may contribute to the potency of their bioactive compounds. Research conducted by institutions such as the ICAR-Central Marine Fisheries Research Institute has advanced the exploration of marine species for their bioactive potential. This research has led to the identification of compounds that combat oxidative stress-induced diseases, including diabetes, hypertension, and inflammation. Protocols developed for functional food supplements enriched with these bioactive molecules have demonstrated their therapeutic potential for lifestyle diseases. Additionally, marine macroalgae are fast-growing and renewable, making them attractive for pharmaceutical and nutraceutical applications. The global nutraceutical market, including functional foods, beverages, and dietary supplements, has been expanding rapidly, with a market value of approximately $250 billion in 2014, projected to grow to around $385 billion by 2020. The Indian nutraceutical market has seen significant growth, with a compound annual growth rate (CAGR) of 20%, fueled by rising disposable incomes, increased awareness of lifestyle diseases, and the government’s efforts to streamline regulatory protocols for nutraceutical products. India's nutraceutical market is projected to reach $18 billion by 2025.

The COVID-19 pandemic has further accelerated demand for nutraceutical products, particularly those that boost immunity. As consumers become more health-conscious, the demand for natural, bioactive ingredients from marine sources, especially marine macroalgae, is expected to rise. These organisms offer sustainable sources of functional ingredients for nutraceutical and pharmaceutical applications, and their rich biodiversity holds immense potential for drug discovery and development. The commercial seaweed market is also growing rapidly, valued at USD 14.8 billion in 2020 and projected to reach USD 24 billion by 2027, with a CAGR of 7.1% during this period. Asia-Pacific, particularly led by China, dominates the market, with North America and Europe also showing strong growth. In India, seaweed utilization is a priority under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), which aims to support seaweed cultivation, processing, and marketing with significant investments.

Nutraceutical Products of ICAR-CMFRI

Commercial large-scale microalgae cultivation began in Japan in the early 1960s with the culture of Chlorella. Over the subsequent four decades, the microalgae industry expanded significantly in both production and diversity. Today, the global microalgal biomass market produces around 5,000 tons of dry matter annually, generating approximately U.S. $1.25 billion per year. Chlorella, particularly Chlorella vulgaris and Chlorella pyrenoidosa, is rich in chlorophyll, proteins (40–60%), and carotenoids. It is reputed to have anti-carcinogenic, immunomodulatory, hypolipidemic, gastric mucosal-protective, and detoxifying properties. Key producers of Chlorella include Cyanotech (Kailua-Kona, Hawaii) and Earthrise Nutritionals (Ishigaki Island, Japan). Another notable microalga, Spirulina platensis, is one of the few plant sources of vitamin B12 and offers immune system enhancement and protein supplementation (65–71% by weight). Its health benefits include potential prevention of anemia, hypocholesterolemic effects, antioxidant activity, hepatoprotection, and anti-allergic properties. Producers of Spirulina include Cyanotech, Earthrise Nutritionals (Irvine, California), and Parry Nutraceuticals (Chennai, India). Dunaliella salina is a primary source of ß-carotene, a powerful antioxidant with reported benefits such as immune enhancement and anti-aging effects. This alga also produces bioglycerol. Cognis Nutrition and Health (Tullamarine, Australia), now part of BASF, is a prominent manufacturer of Dunaliella salina products. Crypthecodinium cohnii is valued for its high DHA content (> 30%), which is primarily used in infant formula alongside arachidonic acid (ARA). DSM-Martek Biosciences is a major supplier of Crypthecodinium cohnii. Similarly, Schizochytrium sp. produces DHA (> 35%) and DPA (13.5%), making it useful in nutritional supplements and as an ingredient in poultry feed. DSM-Martek Biosciences also supplies this species. Nitzschia laevis produces eicosapentaenoic acid (EPA), an omega-3 fatty acid with pharmaceutical applications, particularly for cardiovascular health. Photonz Corp. has developed a pharmaceutical-grade EPA manufacturing process from Nitzschia biomass, utilizing supercritical fluid extraction (SFE) technology from Separex S.A. (Champigneulles, France). Haematococcus pluvialis is renowned for its high astaxanthin content (7% of dried weight), an antioxidant 500 times more potent than vitamin E. Astaxanthin protects membrane phospholipids and other lipids from peroxidation more effectively than ß-carotene and lutein. Leading producers of Haematococcus pluvialis include Cyanotech, Mera Pharmaceuticals (Kailua-Kona, Hawaii), Valensa International, Parry Nutraceuticals, Astareal (Gustavsberg, Sweden), and Algatechnologies (Kibbutz Ketura, Israel).

In conclusion, marine ecosystems offer an untapped reservoir of bioactive compounds with immense potential for the development of nutraceuticals and pharmaceuticals. Marine-derived metabolites, particularly from macroalgae, represent promising alternatives to synthetic drugs, with numerous applications in addressing lifestyle diseases and promoting human health. The continued exploration of marine species for these compounds will not only support new therapeutic developments but also contribute to the growing global market for natural, sustainable health-promoting products.

Advances in Fish Disease Diagnosis: Aiming for High Specificity and Sensitivity

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Introduction

Aquaculture represents a rapidly expanding sector in food production. Recently, in 2023-24, global aquaculture production achieved a new record high, surpassing that of capture fisheries for the first time in history (FAO, 2024). This sector underscores the substantial evolution in recent decades. Despite its growth, the aquaculture industry confronts significant challenges, particularly disease outbreaks, which can lead to substantial mortality and economic losses. Factors such as climate change and the intensification of stocks are primary contributors to disease outbreaks (Pulkkinen et al., 2010). These diseases are a major concern due to their high mortality rates, varied patterns, uncontrolled spread, risks to food safety, and implications for global health. Prevention and control measures always rely on early and precise diagnosis. Numerous methodologies and platforms have been developed to enhance the sensitivity, specificity, rapidity, and effectiveness of pathogen detection in aquaculture.

Spectrum of Fish Diseases and Management Strategies

Fish are highly susceptible to a variety of diseases, both infectious and non-infectious, which pose significant challenges in aquaculture. Infectious diseases caused by viruses, bacteria, fungi, and parasites can spread through direct contact, contaminated water, or food, resulting in substantial economic losses and potential risks to human health. Treatment strategies vary: parasitic infections affecting gills and skin are controlled by chemicals like potassium permanganate and formalin, while fungal infections, often secondary to parasitic infestations, are treated with fungicides like copper sulfate. Bacterial infections necessitate antibiotics for symptoms such as hemorrhagic spots and ulcers. Viral diseases, such as channel catfish virus disease, require expert consultation due to diagnostic complexities. Non-infectious diseases start from environmental factors, nutritional deficiencies, and genetic abnormalities, necessitating effective management approaches like water quality control and adjusted feeding regimes. Overall, effective disease management is critical for ensuring fish health and sustainable aquaculture practices. Addressing infectious diseases in aquaculture requires rigorous epidemiological studies, animal health surveillance, and robust biosecurity measures. Rapid and accurate diagnostic methods, including microbiological, immunological, and molecular techniques, play a crucial role in disease prevention, screening, quarantine, and pathogen confirmation.

Current level diagnostics

Significant advancements have been made in the diagnostic methodologies for identifying diseases in fish and shrimp, encompassing the combination of conventional and cutting-edge approaches. Initially, disease diagnosis relied on gross observations, visual inspections, and empirical knowledge (Noga, 2010). Subsequent progress in molecular microbiological sciences led to the discovery of diverse pathogens and their mechanisms, enabling the development of highly sensitive diagnostic tests and therapeutic interventions for numerous diseases. The Food and Agriculture Organization (FAO) and European Union have categorized diagnostic techniques into three levels: Level 1 involves gross observation, Level 2 includes microscopy and histology, and Level 3 integrates advanced techniques such as molecular assays, immunoassays, and electron microscopy (Dong et al., 2023).

While traditional methods like microscopy and histology remain widely employed due to their simplicity and cost-effectiveness, recent advancements in molecular techniques such as PCR-based assays, DNA sequencing, and other sophisticated methods have revolutionized pathogen detection capabilities. These advanced techniques offer advantages over traditional approaches, including enhanced sensitivity, specificity, and rapid detection of a broad spectrum of bacterial, viral, parasitic, and fungal pathogens. They have been instrumental in identifying significant diseases such as koi herpes virus (KHV), Tilapia Lake virus (TiLV), white spot syndrome virus (WSSV), and the oyster parasite Bonamia (Cunningham et al., 2002; Rajendran et al., 2005; Abdelsalam et al., 2023). Additionally, DNA microarrays and nucleotide sequencing aid in pathogen characterization and understanding disease transmission, which is crucial for developing targeted control strategies. Monitoring pathogen levels in the environment allows for proactive disease outbreak management.

Limitations

Despite their high sensitivity and specificity, current diagnostic methods are not without limitations, necessitating the development of more advanced diagnostic technologies (Li et al., 2022). Challenges include the requirement for sophisticated equipment, prolonged assay durations, impracticality in on-farm conditions (point of care), varying temperature range dependencies, difficulties in targeting multiple pathogens simultaneously, and lack of standardized protocols (Li et al., 2022; Moreira et al., 2021). Addressing these challenges is crucial for further enhancing diagnostic fidelity, accuracy and applicability in aquaculture settings.

Advanced fish diagnostics

In response to these challenges, novel advanced diagnostic techniques have emerged, including CRISPR/Cas-based systems, Image-Based Diagnosis, and Electrochemical Genetic Sensors (Li et al., 2022). Image processing enhanced by advanced computer vision technologies enables intelligent diagnosis, offering non-destructive, rapid, automated, and real-time capabilities. Recently, machine learning algorithms such as Support Vector Machines (SVM) have been successfully applied for the accurate detection of salmon diseases (Li et al., 2022). Electrochemical biosensors utilize reactions to detect specific genetic markers or biomarkers associated with fish health and disease (Mahari et al., 2022). CRISPR/Cas-based diagnostics have rapidly evolved due to their speed, high sensitivity, and precision in targeting. They have shown promise for point-of-care applications, employing isothermal amplification (RPA) techniques, Cas enzyme-mediated precise target cleavage and simplified endpoint detection. Simple modification of Cas enzymes and guide RNAs enables the targeting of diverse fish and shrimp pathogens. This platform has demonstrated high sensitivity in detecting diseases such as RGNNV, SDDV, TiLV, GCRV, Large yellow croaker iridovirus (Chaijarasphong et al., 2019; Sukonta et al., 2022a, 2022b; Li et al., 2023; Zhang et al., 2024), and shrimp diseases including WSSV, AHPND, EHP, TSV, YHV genotype 1, *Vibrio parahemolyticus*, and *V. vulnificus* (Kanitchinda et al., 2020; Huang et al., 2022; Liu et al., 2023; Xiao et al., 2021; Aiamsa et al., 2023). These CRISPR-based fluorescent assays have paved the way for field-based disease detection, eliminating the need for sophisticated instruments, particularly with the advent of lateral flow kits.

Important fish diagnostics developed at ICAR-CIFE

ICAR-CIFE is the recognized National Reference Laboratory for Fish and Aquatic Animal Health Diseases. The well-developed infrastructure and laboratory facilities underscore the institute's expertise in diagnosis and managing diseases in aquatic environments. Notably, ICAR-CIFE excels in diagnosing OIE-listed pathogens, which pose significant concerns due to their rapid transmission, adaptability to hosts and environments, emergence of new strains, and complex pathogenicity. ***To address these issues, ICAR-CIFE mainly focuses on the research activities of developing effective non-invasive diagnostics and detecting pathogens at subclinical, asymptomatic, and carrier stages down to low copy number levels, which can be feasibly performed at the point of care (POC).*** Several diagnostic platforms have been successfully developed for significant pathogens.

An indirect enzyme-linked immunosorbent assay (iELISA) was developed with high specificity and sensitivity for detecting TiLV. This non-destructive method, which can be performed on mucus samples, showed a high positive rate of 92.3%. Its sensitivity is comparable to molecular assays and is less time-consuming. This technique, being highly sensitive, is helpful for extensive examinations of TiLV infections and monitoring disease status even in apparently healthy samples using a non-invasive technology. Additionally, a highly sensitive molecular assay, such as real-time PCR, was developed for the quantitative detection of TiLV with high diagnostic sensitivity and specificity, with the lowest detection limit of 10 copies and 100% absolute specificity towards the TiLV, proved highly reliable with limiting the false positives and false negatives. Moreover, this quantitative method aids in diagnosing fish at subclinical or asymptomatic levels, which are significant concerns in farm conditions. To enhance feasibility at the farm level, advanced molecular assays, specifically CRISPR-based fluorescent assays, were developed for both WSSV and TiLV. These assays exhibit high sensitivity comparable to real-time PCR, with a detection limit of around 10-20 copies and absolute specificity for the target pathogen. These assays can be performed on the farm without requiring sophisticated instruments and have short assay durations. Furthermore, they are designed to detect pathogens in their early stages, including the latent stage of WSSV and the subclinical or asymptomatic stage of TiLV, helping farmers implement effective prevention and control strategies.

The primary goal of ICAR-CIFE is to transfer these technologies to farm levels to enhance the aquaculture sector. Ongoing research aims to develop new methods to make these assays more feasible and reliable, ultimately benefiting farmers.

Conclusion

The most effective way to control any pathogen is through an effective diagnostic platform that offers early, rapid, and precise diagnosis. These developed diagnostics have made disease detection significantly more accessible, more feasible, and applicable at the farm level. However, this does not mean that these are without limitations. One primary concern is the cost-effectiveness of these chemicals. Additionally, pathogen morphology and genetic changes often occur in aquatic conditions due to their adaptability to the host and environment, mainly seen in RNA viruses, which have been extensively studied. Therefore, diagnosing diseases is crucial and requires consideration of all aspects when designing and implementing methods against specific pathogens. Despite these challenges, modern diagnostic tools have not stopped at the above-mentioned level; they continue to develop towards more precise and feasible solutions. These coming developments will eliminate the limitations and enable effective disease management and control in aquaculture.

Species Diversification in Mid hill Aquaculture

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The Northeast region of India comprising the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura are blessed with rich biodiversity and fisheries resources. Fish being one of the cheapest and easily digestible proteins can ensure the nutritional requirements and alleviate malnutrition especially in the hilly states of the region. The altitude in the region varies from almost sea-level to over 7,000 metres (23,000 ft) above MSL. Barring Assam and Tripura, other six states are predominantly in hilly region which are mostly inhabited by different tribes. The fish culture in the lower altitude (less than 400 m above msl) records the highest production while the high altitude aquaculture (>1200 m above msl) produces very little fish. The mid altitude region which cover a large part of NE hill states provide immense potential for aquaculture. However, promoting mid altitude aquaculture (400-1200 m above msl) to farmers in the hill states of the Northeast is a major challenge due to several reasons. One of the important bottlenecks in promoting mid hill aquaculture is the non-availability of suitable fish species for culture. There is therefore an urgent need to find alternate fish species which can grow in lower water temperature or grow to marketable size within short period of time (7-8 months).

The fishery resources of the North eastern region fall within all three types of climate i.e. Tropical, Sub-tropical and Temperate and represent a strong biodiversity. The region harbour several important fish species of both food and ornamental value. In fact the Northeast India is considered as one of the hot spots of fresh water fish biodiversity in the world.

Goswami et al in 2012 listed 422 fish species from northeast India, belonging to 133 genera and 38 families. Since, water temperature in the hills falls below 20°C, the exotic carps (common, grass and silver carps), mahseers and other such coldwater fishes that can grow and survive at lesser temperature than IMCs are more suitable for use in hill aquaculture. Thus, the fish production technologies being practiced in plain areas are less viable in the Northeast hill areas primarily due to cold climatic conditions and lack of appropriate infrastructure facilities. Hence, for the sustainability of aquaculture, more species need to be brought into the culture system although we all know that each species has a unique set of biological factors that influence its culture potential. Further water quality, growth variations, food conversion rates, predation, and disease problems should also be anticipated.

Aquaculture in the region is basically carp based polyculture. Among all the fish species available in the Northeast, only three Indian major carps (Rohu, Mrigal and Catla) and three exotic carps (Silver, grass and Common carp) are the most common and widely cultured fish species in farmer's ponds. Most of these fishes are warm water species and perform better in plain areas at lower altitude although the Chinese carps withstand relatively colder temperature considered suitable for hill aquaculture.

In the Northeast, fish seeds about 11-12 various fish species are commonly produced mostly by the farmer seed producers in the private sectors. In addition, the state of Tripura produces seeds of Pabda, Ompok pabda, Macrobrachium rosenbergii (Fresh water giant prawn), Manipur and now Meghalaya (ICAR NEH) produce seeds of an endemic minor carp, Pengba, Osteobrama belangeri in limited quality. Among all the cultured species; Silver carp, Grass carp and Common carp are reported to perform better in composite culture system in the mid altitude conditions. Common carp plays an important role in augmenting fish production especially in the hill states of the region. However, the local existing stock of common carp has several demerits, resulting in poor growth. To address the problems of early maturation and poor growth of the existing local stock of Common carp (Cyprinus carpio var.communis), a maiden effort was made by the ICAR NEH which is located at about 900 meter above mean sea level (MSL) in 2010 to introduce the genetically superior breed/variety of Common carp-Amur (Hungarian strain, Cyprinus carpio haematopterus) in Meghalaya after thorough on-station & on-farm trials .Later the new variety was popularized for improving the fish production and productivity from the rural ponds in all the states of the Northeast India . The fish breeding season in mid hill region is restricted to only few months (June to August), July being the peak. The ICAR NEHR, Meghalaya has been successful in breeding of all the exotic and India major carps. In addition, minor carps, *Labeo gonius, Labeo bata, Barbonymus gonionotus* and recently *Cirrhinus reba* have also been reared and induced bred for promotion of these species in mid hill aquaculture successfully. Further, one more fish species which is highly esteemed- *Pengba, Osteobrama belangeri* (- an endemic & endangered fish species of Manipur) has also been introduced after evaluating it's growth and reproductive performances in Meghalaya. In recent times, the combination of Amur common carp and minor carps such as *Labeo gonius* is observed to be the best suited for mid hill aquaculture. Thus, there is always a growing demand for the quality seeds of especially Amur common carp and *Labeo gonius* by the farmers of mid hill region. Under mid hill condition both the species attain marketable size within one year of rearing unlike the Indian major carps. We also standardized and introduced combination of two and three fish species pond aquaculture with *Cyprinus carpio, Labeo gonius*, and *Barbonymus gonionotus*. This combination of fish species in poly culture systems yielded encouraging results and disseminated to the farmers through the KVKs.

There is great potential for utilizing indigenous fish species for aquaculture in the mid hill region. The potential candidate species for mid hill aquaculture in North east region are *Tor putitora* (Golden mahseer), *Neolissochilus hexagonolepis* (Chocolate mahseer), *Amblypharygodon mola*, Chagunius spp, *Cirrhinus reba*, *L. pangusia*, *Labeo dyocheilus, Labeo dero, Semiplotus semiplotus* etc. Breeding and culture of these important indigenous fish species shall not only improve the fish production scenario in the hilly states of the region but also shall help in conservation of these valuable fish species. Although there are reports on induced breeding of some theses species, at the moment there are no farmer friendly technologies available for mass- scale production of their seeds to promote aquaculture in ponds, tanks and in other water bodies especially in the mid hill areas. In recent years, the culture of alien fish species such as Thai magur (*Clarias gariepineus*), Tilapia, hybrid Kawoi (*Anabas testeduneus*), Roop chanda (*Colossoma macropomum*), Bighead carp (*Arichthicthys nobilis*) Pangasius sutchi etc. have triggered great threat to native fish species and gene pool that may lead to loss of bio-diversity. Therefore, adequate measures are required to eliminate these species from culture system or culture with do's and dont's as prescribed by the ICAR- NBFGR, Lucknow, UP, India for enhancing fish production from confined environment in the mid hill region.

In general the cold water fish farming has been largely overlooked due to lack of appropriate fish species, lack of suitable technology, poor growth of fish and inadequate infrastructures. The Northeast hill states are predominantly tribal states. It is assumed that knowledge of scientific fish farming is yet to reach majority of fish farmers for expansion and intensification of aquaculture activities. Most tribal farmers of the region are resource poor and possess small to medium sized fish ponds for aquaculture. Therefore, there is tremendous scope for increasing productivity through introduction of suitable fast growing fish species appropriate to the region. The Government should take a policy decision to establish brood bank of suitable fish species for quality fish seed production in order to provide quality brood stocks to the selected farmer fish seed producers of the mid hill region.

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Shape-Shifting Fish Erythrocytes: An Emerging Biomarker for Fish Health Assessment

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Aquaculture has drawn significant attention because of its rapid growth over other food animal-producing sectors. The intensification of aquaculture techniques has led to frequent disease outbreaks and huge economic losses. Fish health assessment is, therefore, essential for upholding sustainable aquaculture and ensuring the well-being of fish stocks. Fish haematology offers valuable insights into disease processes in teleosts and elasmobranchs. Fish erythrocytes, vital for oxygen transport and maintaining balance, are often assessed through quantitative parameters, overlooking intricate morphology. Fish erythrocytes are nucleated cells with an elliptical to oval shape. Their cytoplasm is eosinophilic, and the nucleus is centrally located and deeply basophilic. The size and life span of the erythrocytes range from 102 to 800 fl and 13 to 500 days, respectively. The number of erythrocytes in the peripheral blood depends on many factors such as fish activity, age, sex, nutritional and reproductive status, water temperature, dissolved oxygen concentration, as well as other environmental factors. They also show significant seasonal variability and may differ between populations of the same species. It typically ranges from 0.5-1.5 × $10^6/mm^3$ in less active species to 3.0–4.2 × $10^6/mm^3$ in more active species.

As in other vertebrates, fish erythrocytes contain tetrameric haemoglobins, but with different oxygen affinities. It is lower in species living in well-oxygenated water than in those exposed to hypoxia. The main erythropoietic organ in teleost is the anterior kidney. The multifunctional nucleated fish erythrocytes not only transport oxygen and carbon dioxide but also transport 50% of the ammonia waste to the gills for excretion. In addition, fish erythrocytes respond to pathogens. The barrier between the hematopoietic tissue and the circulatory system is weak and, therefore, many immature erythrocytes are found in the circulating blood, often constituting >10% of all erythrocytes. Immature erythrocytes are round rather than oval, their cytoplasm is blue-stained, and their nucleus is larger and heterochromatic. Fish erythrocytes are also an important site to produce reactive oxygen species (ROS) due to the presence of mitochondria and due to auto-oxidation reactions of oxyhaemoglobin. As a result, alterations appear in erythrocyte morphology and erythrocytes undergo premature destruction in the circulation either due to natural complement activation or due to superimposed or underlying structural pathology. Erythrocytes of all organisms are capable of stereotypic responses to a variety of environmental perturbations, and modifications in shape and size of the erythrocytes represent the most common morphological abnormalities under pathological conditions. Though haematological parameters are crucial indicators of fish health, erythrocyte morphology is emerging as a fundamental marker with significant diagnostic value.

Microscopy analysis is the most common way to study alterations in erythrocyte morphology. In stressed fish, abnormal erythrocytes exhibit various forms like flat, elongated, teardrop, or crescent-shaped, indicating underlying disease pathology. Referred to as shape-shifting erythrocytes (poikilocytes), poikilocytosis can result from internal damage, external stress, or genetic abnormalities. Fish poikilocytosis is linked to conditions such as microbial infections, anaemia, and oxidative stress, making it an early biomarker and a valuable tool in fish health assessment. It is also induced by foreign particles, heavy metals, pharmaceuticals, and antibiotics, leading to poikilocytes and anaemic conditions. Most studies have focused on xenobiotics, but the etiological induction of poikilocytosis in fish health has been overlooked. Its usefulness is, however, gaining attention in aquaculture and fisheries management in recent years. In aquaculture, the use of veterinary medicinal products such as florfenicol, oxolinic acid, enrofloxacin and emamectin benzoate reportedly cause erythro-morphological alterations in healthy fish. Shape-shifting erythrocytes such as acanthocytes, echinocytes, dacrocytes, schistocytes, spherocytes, and codocytes are common in fish. Often, the poikilocytes provide insights into fish pathophysiology, indicating environmental stressors, infection with infectious agents, nutritional deficiencies, anaemia, inflammatory diseases, toxic exposures, etc. The poikilocytes have diverse characteristics, but not all distorted erythrocytes imply poikilocytosis. An accurate diagnosis of acquired poikilocytosis is vital, highlighting its suitability as a fish health indicator. By quantifying poikilocytic changes, fish health specialists can differentiate normal variations from pathological conditions, facilitating targeted interventions and treatment strategies. It provides diagnostic information and delves into the complex realm of fish haematological health, aiding advancements in fish health management and conservation practices. Ongoing research may enhance our understanding of shape-shifting erythrocytes, and their molecular mechanisms, and facilitate progress in assessing fish health, management and conservation.

Harnessing Genetics and Genomics Potentials of Indian Major Carps

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Introduction

The human population is expected to reach 10 billion people by the year 2059, which will have immense impacts on the aspiration of achieving food & nutrition security. In addition, other stressors, such as climate change, and limited natural resources, are further complicating efforts to achieve food security. Increased demand for urban development will coincide with the increased demand for high-quality protein, creating competition for agricultural and allied sector land use. This competition will drive more efficient and sustainable animal production systems. As a result, aquaculture is expected to play an important role in meeting future nutrition demands. Aquaculture genetics shows immense potential for enhancing production. Aquaculture is a fastest-growing food production sector globally (Maulu et al., 2021) and contributes considerably to the economic development. In India, compared to the economic growth of about 8% per year, the aquaculture sector witnessed an annual average growth of more than 10% (Singh and Simlai, 2021). During 2020-21, the total inland fish production of the country stands at 12.12 million tonnes (Handbook on Fisheries Statistics, 2022) with about 52% contribution from Indian Major Carps (IMCs). The fisheries sector contributes 1.1% of the total Indian economy and about 6.72% share of agriculture GVA in 2020-21 (Handbook on Fisheries Statistics, 2022). The major bottlenecks for enhancing aquaculture productivity are the unavailability of quality seeds of major cultivable species in required quantities at right time. During 2020-21the total fish seed production of the country was 54.06 billion fries which is insufficient to meet the projected target production of 22 million tonnes by 2025 (Handbook on Fisheries Statistics, 2022).

One of the major ways to increase aquaculture production and generation of quality seeds is through selective breeding of potential aquaculture species. Genetic selection has been a very successful tool for the long-term improvement of livestock populations. Breeding programs seek to identify genetically superior parents of the next generation, typically as a function of an index that combines information about many economically important traits into a single number. During the last 50 years it has been shown that well planned family-based breeding programs yield high rates of genetic improvement for aquatic species. The genetic gain has been greater than 12% per generation for growth rate and for disease resistance. The main reasons for the large genetic gains observed for aquatic species are their relatively high fertility and the natural existence of broad genetic variation for economically important traits, both of which allows a very high selection intensity to be applied. However, the genetic improvement of species grown in aquaculture is far behind that achieved for animals and plants. Less than 10% of aquaculture production was based on genetically improved stocks.

Global Initiatives

Production of “quality fish seed” is the primary goal of aquaculture sustainability (Gjedremet al., 2012). The role of selective breeding in significantly enhancing the production of selectively bred species has been well-established and documented in crops, poultry and other farm animals. Today the high-yielding crops and terrestrial farm animals comprise genetically improved and domesticated strains/breeds. However, proper exploitation and utilization of genetic potential are lacking in the aquaculture sector. Less than 10% of the total output of global aquaculture production is derived from genetically improved breeds (Gjedremet al., 2012). The last few decades have witnessed the success of selective breeding programmes in improving economically important traits viz. growth, survival, disease resistance, improved carcass quality, etc. through genetic selection in Atlantic salmon in Norway, Channel catfish in USA, Nile tilapia in the Philippines, and Rohu and Freshwater Prawn in India. Selectively bred individuals with improved performance in growth have the added advantage of being produced in a comparatively shorter time with an enhanced growth rate. This would contribute to cost-efficient production, feed efficiency (Thodesenet al., 1999) and reduction of mortality because less time will be required to attain marketable size. Selective breeding targets the additive genetic variance of the desired trait in the population by which improvement in one generation is retained with an addition in genetic gain in the following generations.

ICAR CIFA Iniative -Global Perspectives

Genetic Improvement Program

Indian Inland aquaculture is one of the most attractive and demanding food supplying sectors as human diets. Indian major carp, Labeo rohita has long been domesticated and farmed with the help of artificial hormonally-induced breeding protocol. Keeping in view its paramount importance in delivering animal food and nutritional security, selective breeding programmes were undertaken to improve growth and enhance disease resistance. However, following more than two decades of research, progress is limited by the heritability of the trait and generation interval of the species. ICAR-Central Institute of Freshwater Aquaculture, the premier research institute in the country working on various aspects of freshwater aquaculture, started a genetic improvement program in 1992 for improving harvest body weight and disease resistance of Indian major carp, Labeo rohita in collaboration with the Institute of Aquaculture Research (AKVAFORSK), Norway. The genetically improved rohu, popularly known as Jayanti, was developed using six different stocks as founder populations and recorded 18 %average genetic gain per generation after twelve generations of selection. Later from the year 2004, disease resistance against Aeromonas hydrophila was added as a second trait for selection. At least 50 percent economic gain in aquaculture practices as it takes 56 days less time to attain marketable size in comparison to local rohu framing. After the success and wide acceptance of Jayanti rohu by farmers across many states of India. The next selection programme on IMC was commenced in 2010 to improve the harvest weight of catla (Labeo catla) at ICAR-CIFA from a base population of nine strains (Mahapatra et al., 2018). In addition to the above programs, UAS Bangalore has continued the selective breeding program of Amur carp brought from Hungary (Amur and P3), Vietnam (SV) and Indonesia (RJ), and produced new generations of Amur carp having higher growth performance and delayed maturity.

Genomic Selction Program

Genomic selection involves selecting individuals based on estimated breeding values derived from genotypic (genome-wide genetic markers) and phenotypic information. Recently available genomic resources, including high-quality reference genomes and genome-wide markers, have facilitated the implementation of genomic selection in important aquaculture species. The discovery of SNP arrays and genotyping methods has enabled their integration into genomic selection programs for candidate species. These methods offer significant potential for enhancing genetic gain and improving the accuracy of predicting breeding values, especially for qualitative traits like disease resistance and stress tolerance, as highlighted in various review articles (Houston et al., 2020, Yanez et al., 2023). Several studies suggested that marker panels could be used for the evaluation of underlying genetic variation of intricate traits using genome-wide association studies (GWAS). Molecular markers are widely utilized in aquaculture and fisheries to answer several biological questions. Single nucleotide polymorphism (SNP) markers are the marker of choice due to their abundance, presence in all region of the genome, bi-allelic in nature and amenable to high throughput. Advancement in the sequencing technology and surfacing of next generation sequencing platforms revolutionized identification of SNPs in non-model organism such as aquaculture species. The most important application of next generation sequencing is identification of SNPs used for various purposes such as linkage mapping, QTL identification, genome wide association study, marker assisted selection and genomic selection etc. Carp genome re-sequencing reveals millions of SNPs associated with growth or disease resistance. Rohu species, through whole genome sequencing and re-sequencing of 10 wild populations, identify 4.95 million SNPs (380,991 to 679,963 in each population (Das et al., 2020c). A total of 9157 SNPs were found in rohu breeding populations from Halda, Jamuna, and Padma rivers. Among them, 1985 SNPs exhibited slight genetic divergence between the river populations (Hamilton et al., 2019b). Recent rohu genome data and transcriptome resequencing identified 39,158 high-quality coding SNPs. Among these, 12 SNPs were associated with cellular growth and proliferation genes, including myf 6, fgf, gfr-bound protein 10-like, IGF-1-like, and TGF β, among others (Nandanpawar et al., 2023). Implementation of gene-edited assisted selection (GEAS) in aquaculture breeding schemes needs to be efficient and economically feasible to ensure sustainability. Among other factors, editing efficiency determines the feasibility of gene editing in aquaculture breeding. Even though, studies on the optimal number of edits required in aquaculture breeding schemes are lacking, simulation results from livestock schemes demonstrated the potential of genome editing technologies in combination with genomic selection to increase genetic gain in many folds for traits of interest compared with genomic selection alone.

Genome Editing Program

To further support selective breeding program and genomics selection, researchers have witnessed revolutionary progresses in the field of reverse genetics with the development of novel genome editing technologies, including ZFN, TALEN, and CRISPR/Cas9, which all adopt an engineered sequence-specific nuclease for DNA cleavage. These newly emerged genomes editing technologies for the first time allow for gene targeting or editing in a wide range of species including fishes with great efficiency (Gaj et al., 2013). So far, more than 40 fish species have had their genomes sequenced, including model species such as the zebrafish (Howe et al., 2013). These studies show great potential for the application of genome editing in aquaculture for breeding new varieties with valuable traits. Compared with traditional transgenesis, genome editing normally does not introduce foreign DNA into the genome of target species, therefore alleviating public concerns on the safety of genetically modified organisms (GMOs). Recently, a gene coding for myostatin (mstnba) (an inhibitor of skeletal muscle growth) was mutated by CRISPR/Cas9 in the common carp, which showed increased muscles in F0 founders (Zhong et al., 2016). In contrast, disruption of mstna with ZFN (Dong et al., 2011) and mstnb with TALEN (Dong et al., 2014) in the yellow catfish displayed no significant phenotype in muscle growth in either F0 or F1 generation. Based on the evidence in other species, recent advancement in gene-editing technology such as CRISPR/Cas9 has the immense scope to expedite sustainable genetic improvement/gain in Indian major rohu carp and generate model rohu carp. It would be interesting to undertake studies for major traits like growth, reproduction, disease resistance, etc. Species-specific optimization of editing methods with better efficiency and lesser off-target effects with reduced mosaicism in the F0 generation is also required.

Conclusion

The aquaculture industry is expected to play an integral role in meeting future nutrition demands and addressing global food security. Achieving sustainable aquaculture production depends on utilizing a diverse range of genetic and genomic resources. The selective breeding program in carp has successfully improved traits like growth rate and disease resistance. However, maintaining a balance between high selection intensity and low inbreeding rates poses a long-term challenge. Some breeding programs failed due to a weak base population or limited stocks involved, leading to inbreeding and loss of genetic viability. To ensure successful selective breeding, it is crucial to generate a complete set of heritability values and genetic correlations for important traits in carp species. Genotype-by-environment interactions, often overlooked, result in varied phenotypes, leading to genetically selected carps not exhibiting desired performance. Therefore, selection strategies should consider GxE interactions during carp breeding programs. The incorporation of genomic technologies to better assist selective breeding decisions has led to major improvements within broodstock breeding values in a much shorter period of time compared to standard selective breeding techniques. The incorporation of gene editing within aquaculture production is currently at the research stage and incorporation within aquaculture breeding programs remains within its infancy. Research still needs to focus on further developing methods to disseminate gene edits into fish production. The incorporation of gene editing technologies within the aquaculture industry has shown to have great potential for identifying specific genes related to commercially desirable traits as well as expediting genomic improvement through the rapid fixation of selected alleles.

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Impacts of Climate Change on Fisheries, Aquaculture and Live Stock

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Abstract
Aquaculture continues to significantly expand its production, making it the fastest-growing food production sector globally. The sustainability of the sector is at stake due to the predicted effects of climate change that are not only a future but also a present reality. Various elements of a changing climate, such as rising temperatures, sea-level rise, diseases and harmful algal blooms, changes in rainfall patterns, the uncertainty of external inputs supplies, changes in sea surface salinity, and severe climatic events are burning issue. Increased extreme weather events may increase escapes, but regulating non-native aquatic germplasm, certifying equipment, modifying pond systems, and developing farmers minimize impacts. Climate change impact aquaculture, leading to increased competition among water users. Technological innovations and stakeholder involvement are crucial for effective decision-making. The effects of climate change in fisheries sector are loss of habitat, change in habitat conditions, disease outbreak, obstacle in migration routes, obstacle in reproduction and reduced production. The same for livestock sector are – reduced grazing area, fodder crisis, less growth and stresses and decrease in production of milk, egg and meat. All these will lead to loss in rural household income, unemployment and supply of dietary nutrition. Climate change effects and implications on aquaculture production sustainability are to be both negative and positive. But the negative effects outweigh the positive ones. Adapting to the predicted changes in the short-term while taking mitigation measures in the long-term could be the only way toward sustaining the sector's production.

Keywords: Fisheries, Aquaculture, Livestock, Production, Climate change, Ecosystem, Biodiversity.

Introduction

Aquaculture is a technique for producing aquatic products in a sustainable manner. To meet the growing demand for aquatic goods worldwide, capture fisheries are thought to be the sole viable option (AskarySary et al., 2012; FAO, 2020). Aquaculture's share of the world's fish production has been steadily increasing, accounting for 82.1 million tons (46%) of the expected 179 million tons produced worldwide, according to FAO (2020). Additionally, by 2030, the proportion of fish produced in aquaculture worldwide is predicted to increase from 46% to 53% (FAO, 2020). But the most pressing question is whether the industry is expanding effectively and quickly enough to satisfy the anticipated demand in the future, which will be made worse by a rapidly expanding population and a changing environment. According to Myers et al. (2017), climate change is currently regarded as a serious danger to both the quantity and quality of food produced worldwide. Climate change's expected effects are posing a growing danger to food security, especially availability to dietary protein (Kandu, 2017).

A straight forward example of how GHG emissions will impact aquaculture production and the role that agriculture, aquaculture, and capture fisheries play in climate change is shown in Figure 1. Aquaculture's dependence on fisheries for seed and feed is decreasing due to high risks from disease and inhibited farmed strain development. Shrimp farming is increasingly reliant on hatchery-raised stock, and climate change fears may reduce natural spatfall. Sea weed culture relies on clones, and culture-based fisheries can compensate for shortfalls in wild recruitment. Climate change is likely to change ecosystem services, forcing changes in fisheries, agriculture, and economic activities. Increased storm frequency and droughts may prioritize sheltered coastal areas for fishing and aquaculture sites. With the rapid growth of aquaculture and intensification of production practices has come an increased use of feeds for finfish and crustacean aquaculture (Tacon, Hasan and Metian, 2011). Among the feedstuffs used are fishmeal and fish oil derived from fisheries vulnerable to climate change, raising concerns about the resilience of aquaculture to climate change.

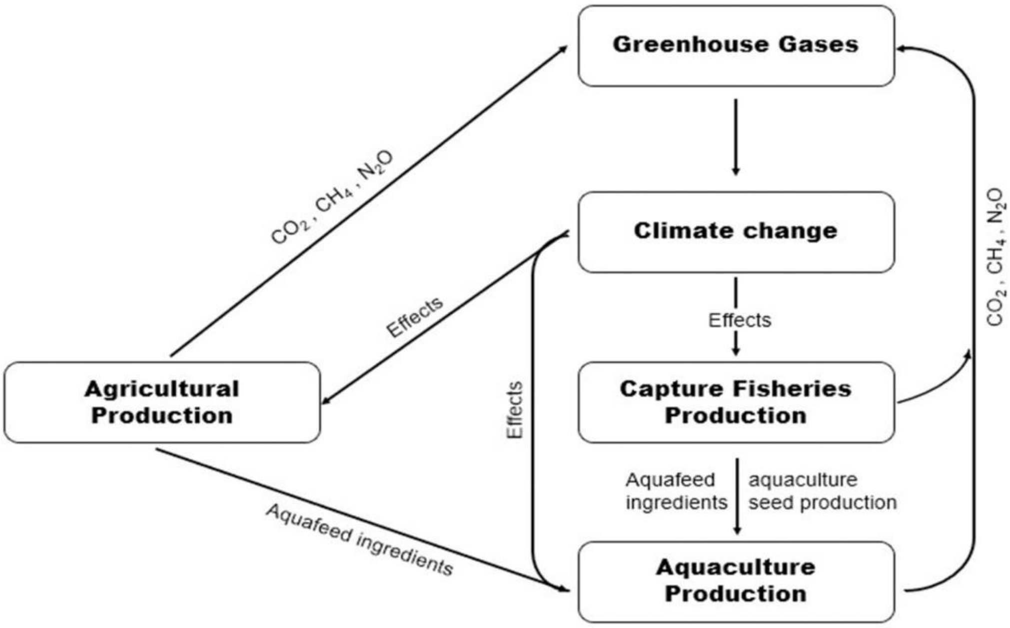

Fig. 1. Provides an overview of the direct and indirect impacts of climate change on aquaculture.

Frequent cyclonic occurrences, coastal and inland flooding, low water flows and droughts, saline intrusion, sedimentation-induced changes in river bed level, and morphological changes are some of the main effects of climate change. As a result, many rivers and streams have reduced minimum allowable surface water levels, endangering the current aquatic ecology as well as fisheries and cattle. These subsectors may be impacted by the emergence of new diseases and pests brought on by climate change. The productivity of livestock, fisheries, and agriculture are all significantly impacted by the physical and quality degradation of productive land. Understanding how domestic animals react to climate stressors has attracted a lot of attention.

1. Effects of climate change on aquaculture and fisheries

Around 11 percent of the global population, including 767 million people living in extreme poverty is marginalized in small-scale fishing and fish farming communities. The impact of climate change on these communities is significant, affecting individuals and communities dependent on their livelihoods. To increase resilience, efforts to adapt to climate change must be human-centered. This requires multi-dimensional and multi-sectoral adaptation strategies, addressing power imbalances and inequities, and empowering people to participate effectively in co-management arrangements. Active support at national, regional, and local levels is also needed, emphasizing the contribution of fisheries and aquaculture to poverty reduction and food security.

2. Demand and supply for fisheries and aquaculture products

Fishery and aquaculture products are crucial for protein, nutrients, and micronutrients, with 36% of total fish production exported globally. The production tends to be concentrated in certain regions, particularly in Asia due to favorable ecosystem. Climate change is expected to impact availability and trade, potentially impacting food security and livelihoods. Human population growth is expected to increase demand and potentially increase prices, potentially leading to a decrease in global fish consumption.

3. Water, land, and rival industries

Climate change is expected to significantly reduce renewable surface and groundwater resources in dry subtropical regions, impacting freshwater ecosystems. Aquaculture, a water-efficient method, faces indirect losses due to rainwater harvesting, costly groundwater development, and water quality issues.

4. Effects of climate change on marine capture fisheries

The projections between now and the end of the 21st century are based on two models: a species-based dynamic bioclimate envelope model and a dynamic size-based food web model. Both models are driven by earth system models from the fifth phase of the Coupled Model Intercomparison Project (CMIP5). Under two scenarios of greenhouse gas emissions, the total maximum catch potential in the world's exclusive economic zones (EEZs) is expected to decrease by 2.8% to 5.3% by 2050 under RCP 2.6 or 7.0% to 11.1% under RCP The projections are not reflecting potential changes from current catch levels but rather changes in the ocean's capacity to produce fish in the future.

5. Impacts, vulnerability, and adaptability of marine capture fisheries to climate change

5.1 Ocean impacts, both observed and anticipated

Ocean biodiversity is influenced by environmental conditions, fisheries diversity, social and economic development stages, governance capacity, and dependence on fisheries. Climate change impacts, such as ocean temperature warming, are consistent with global projections. North Atlantic, Australia's mid-latitudes, and Western Indian Ocean's lower latitudes are experiencing rapid warming.

5.2 Effects on ecosystems and fisheries

Coral reef bleaching, acidification, and climate change are major ocean issues causing species loss and reduced coral cover, while tuna abundance and distribution in the North Atlantic and Central Pacific are also affected.

5.3 Vulnerabilities and responses

Climate change impacts small-scale fishers in Northeast Tropical Pacific, requiring adaptation and sustainable use. FAO Voluntary guidelines emphasize community-based approaches, flexibility, alternative livelihoods, capacity-building, and institutional adaptation.

6. Impacts of escape on biodiversity, social capital, and economic

Climate change increases the likelihood of escapees from aquaculture farms, potentially causing adverse impacts on biodiversity. Freshwater and coastal ponds account for most farmed fish production, with the rest being produced in floating cages. Losses of farmed aquatic organisms occur through floods, extreme weather events, and changes in currents. Much aquaculture depends on the farming of non-native aquatic germplasm (De Silva et al., 2009).

Aquaculture often uses non-native aquatic germplasm, leading to domestication and genetic diversity loss. This can damage ecosystems, displace wild fish, and alter infectious disease dynamics. Convention on Biological Diversity aims to protect biodiversity.

7. Inland fisheries

Climate change is causing freshwater resources to be depleted, affecting inland fisheries, a vital global sector, and increasing population growth and development threatens their sustainability.

Climate change is causing significant changes in freshwater ecosystems, affecting inland fishery resources, global hydrological cycles, species assemblages, abundance, biomass, fish yields, and fishing methods, with potential future stressors.

Economic development, agriculture, deforestation, and habitat modification in water bodies and fisheries are causing climate change stress. Aquaculture adaptation requires ecosystem approaches, improved farm management, and holistic watershed management.

8. Culture-based fisheries

Culture-based fisheries (CBF) are fisheries that rely on regular stocking of hatchery-raised progeny or broodstock to support fisheries or aid in ecosystem rehabilitation. CBF is a climate-smart fish production system, as it doesn't require feed or care. It's already widespread in response to recruitment-limited water bodies like man-made reservoirs, but may have future potential in systems with water scarcity, seasonal temperature fluctuations, and other impacts. CBF provides essential protein for coastal communities, especially when food sources are affected by external factors like climate change. Hatchery-produced seed may help address climate change impacts on coastal CBF.

9. Impacts of Climate-Driven Extreme Events and Disasters

Extreme events, causing significant impacts on people, the environment, and infrastructure, are increasing due to anthropogenic climate change. Existing methods for assessing damage and loss from climate-related disasters in fisheries and aquaculture need improvement.

10. Hazards in food safety and aquatic animal health

Climate change, causing changes in water temperature, pH, salinity, and extreme weather, increases pathogenic bacteria in marine environments, influencing parasites and food-borne viruses. Aquaculture development increases animal health risks, necessitating effective biosecurity plans, collaboration, and responsible animal movement.

11. Adaptation in fisheries and aquaculture

Climate change impacts the viability and sustainability of socio-economic and ecological systems in fisheries and aquaculture. "Methods and tools for climate change adaptation in fisheries and aquaculture," provides guidance on identifying and selecting tools to facilitate and strengthen adaptation. Each fishery or aquaculture enterprise has unique risks and vulnerabilities, and decisions must consider uncertainties. Adaptation should be an ongoing, iterative process, with flexibility, monitoring, and correction of measures. The impacts of climate change do not respect human-made boundaries, and transboundary issues must be anticipated and addressed with suitable measures.

12. Measures and tools to reduce energy use and Greenhouse Gas emission (GHG) in Fisheries and Aquaculture

Fishing vessels and aquaculture contribute to 0.5% of global emissions, but efficient engines, larger propellers, and vessel modifications can reduce fuel use by 10%-30%.

Reduced emissions from fishing gears, multi-rig gear, LED lights, renewable energy systems, and aquaculture can be achieved through improved input efficiency and integration with agriculture.

13. Aquaculture depended on fishmeal and fish oil

The proportion of finfish and crustacean aquaculture production reliant on feeds, including fishmeal and fish oil, is increasing (Tacon, Hasan and Metian, 2011). High prices are driving feed manufacturers to decrease inclusion rates and explore cheaper alternatives like fish processing wastes. Fish processing wastes will represent 38% of world fishmeal and oil production by 2025 (FAO, 2015). Climate change's impact on aquaculture diets is considered minor in the medium to long term.

Livestock

Few economic analyses are conducted on the climatic effects on the livestock sector globally, with developed countries showing less vulnerability due to protected environments and supplemental feed.

1. Grass land changes:

Dry weather and salinity increase in grass land restricts livestock grazing, reducing weight gain and milk production.

2. Temperature and growth:

High temperatures increase body metabolism, leading to less growth in livestock.

3. Rainfall and humidity:

Increased flooding, particularly in low-lying areas, poses significant risks to animal mortality and poultry productivity due to increased rainfall and humidity.

4. Extreme hot weather:

Stress from excessive heat reduces the amount of meat, milk, and eggs produced by cattle and fowl. Assessing the economic importance of breeds is crucial. For example, in Bangladesh, the Black Bengal goat is considered a temporary animal crop. It is renowned for its breed characteristics, which include high-quality meat and skin, illness resistance, and high productivity. This breed is also seen by many in Bangladesh as a way to combat poverty. It can therefore be considered a flagship species as well.

Technology and Research

Limited research on fisheries and livestock, particularly in the livestock sector, necessitates enhancement of climate change impacts and adaptation options, requiring government grants and technology development incentives.

- Establishment of small-scale aquaculture in open water and flood zones using cages and pens;
- The advancement of salt-tolerant fish culture technologies;
- Establishment of cages and pens for small-scale fish aquaculture in the open water and flood zone area;
- The advancement of technologies for the growth of salt-tolerant fish species;
- Preservation of native fish biodiversity by creating sanctuaries for fish locations;
- Introduction of livestock, poultry, and fodder crops that are climate resilient;
- Development of low cost weather controlled housing for livestock;
- Strengthening animal disease surveillance facilities.

Conclusion

Climate change is a major threat to the survival of affected target species, human health, ecosystems and the financial sustainability of fisheries livestock production systems. Stormy weather, cyclones, and tidal surges are expected to disrupt fish trading, reducing fishing time, and causing livelihood loss, emphasizing the need for effective adaptation to mitigate climate change. Climate change impacts aquaculture, fisheries, and livestock, necessitating adaptation across sectors to maintain productive aquatic ecosystems, reduce poverty, and achieve economic, environmental, and social objectives. Competition for freshwater will intensify, with increased use of surface and groundwater for agriculture. Water allocation decisions require stakeholder involvement in policy, legal, and regulatory frameworks. New fishing technologies, including pond flooding protection, boat mechanization, alternative fish species aquaculture, livelihood support, and climate-resilient fodder crops, are needed to mitigate climate change's impact on cattle and fisheries industries.

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Synergistic Impacts of PFAS and Microplastics in Environmental Matrices: Implications for One Health and Sustainable Development Goals

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The growing prevalence of contaminants of emerging concern (CECs) presents a critical challenge to the 'One Health' initiative and the global efforts toward achieving Sustainable Development Goals (SDGs). Among these CECs, per- and polyfluoroalkyl substances (PFAS) stand out due to their extreme persistence and environmental stability, making them "forever chemicals." Compounds such as perfluorohexane sulfonate (PFHxS), perfluorooctanoic acid (PFOA), and perfluorooctane sulfonic acid (PFOS) are classified as persistent organic pollutants (POPs) under the Stockholm Convention, which restricts their usage due to their enduring toxicity. In parallel, deeply integrated into daily life, plastics have emerged as an environmental concern, marking the Anthropocene era and impacting ecosystems worldwide. Microplastics (MPs)—tiny particles derived from the breakdown of plastics—affect even remote marine environments, including the deep sea and polar regions. Additionally, personal care and cosmetic products (PCCPs), a significant source of microplastics, introduce microbeads and endocrine-disrupting compounds (EDCs) into ecosystems, further compounding environmental risks.

The combined persistence of PFAS and MPs, along with EDCs, is reshaping environmental matrices such as soil, sludge, and water bodies. This co-occurrence highlights a pressing need to understand the synergistic interactions between these compounds, especially given their collective potential to influence human health. MPs act not only as carriers of chemicals from their composition but also form "ecorona" biofilms on their surfaces. These biofilms facilitate the sorption of hazardous chemicals, such as PFAS and EDCs, which makes MPs effective transporters of pollutants into various ecological receptors. Moreover, the shared characteristics of PFAS and MPs namely, their resilience against degradation and their omnipresence across environmental media intensify their coexistence and interactions at multiple ecological interfaces.

Despite some progress in studying PFAS-MP interactions, a significant gap remains in understanding how these interactions might impact critical areas like groundwater vulnerability, pollutant transport in rivers, and toxicological risks to wildlife and humans. Existing studies have sporadically addressed these interactions, but there is limited clarity on how PFAS and MPs may interact with additional micropollutants like antibiotics, hormones, and other EDCs, which often coexist in aquatic environments. These complex interactions could elevate the risks of environmental contamination and toxicity, raising concerns for the One Health approach, which underscores the interconnectedness of human, animal, and environmental health.

Addressing these gaps, this study aims to provide a comprehensive understanding of the co-occurrence and interaction dynamics of PFAS, MPs, and EDCs in environmental systems. Our study will explore the interactions between PFAS and MPs across various environmental matrices, including soil, sludge, surface water, and groundwater, with an emphasis on understanding how the unique properties of these contaminants shape their behavior and impact. This work also examines how water matrices influence the interactions of PFAS and MPs in diverse settings, assessing the potential 'hotspot' areas where these contaminants might concentrate and pose heightened risks to ecosystems.

Our study's findings could contribute to a more refined understanding of how the synergistic effects of persistent contaminants affect health and environmental quality, potentially guiding regulatory measures. Specifically, this research could inform strategies that limit the adverse impacts of PFAS, MPs, and EDCs in line with SDG goals and the One Health framework. By mapping the environmental behavior and interactions of PFAS and MPs, this paper aims to support efforts to reduce exposure to harmful pollutants and mitigate potential antimicrobial resistance (AMR) consequences associated with such contaminants.

This study emphasizes the urgent need to deepen scientific understanding of the PFAS cycle on a global scale and its interactions with MPs. Filling this knowledge gap is essential to advancing policy development and regulatory frameworks that support environmental and public health. Through this work, we aim to enhance SDG and One Health initiatives, contributing to a holistic approach to environmental resilience by addressing the persistent risks posed by emerging contaminants.

Antimicrobial Resistance: The Strategies to be Prioritized for Mitigation in Livestock Sector

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Abstract
Zoonoses become more complicated due to transmission of antimicrobial resistance (AMR) determinants along with the infection. Over prescription and over- the- counter sale of antimicrobials are the major causes of AMR in human, but use of antimicrobials in food animals, and environmental resistance gene pool also plays important roles. AMR leads to enormous financial losses associated with high morbidity, mortality, man-day loss etc. It is estimated that two-third of the antibiotics produced is consumed by the livestock sector globally. Other than direct way the livestock are also exposed to the resistant bugs through the exposure to the contaminated environment. Few strategies like construction of a 'National AMR Task Force' for monitoring and surveillance of antimicrobial use, prevalence of antimicrobial resistance rate and detection of antibiotic residues in livestock, and foods, strengthening the disease prevention in food animals, maintenance of good herd health etc. should be prioritized for mitigation of AMR in livestock sector.

Introduction

Human and animal population are at risk of cross-transmission of zoonotic bacteria via direct contact due to close proximity with food animals, companion animals, live wildlife market, environmental contamination, and intake of contaminated animal origin food items. The situation becomes more complicated due to cross-transmission of antimicrobial resistance (AMR) determinants along with the infection. In human, over prescription of antimicrobials is the major source of selection for antimicrobial resistant bacteria but use of antimicrobials in food animals, and moreover, environmental resistance gene pool ('resistome') also play important roles in this complex multi-factorial state of affairs.

AMR leads to enormous financial losses associated with high morbidity, mortality, man-day loss, hospital length of stay (LOS), direct health-care costs and social costs of infection (Wozniak et al., 2019). About 700,000 deaths per year were attributed to AMR alone that is more than the toll caused by malaria, acquired immunodeficiency syndrome (AIDS) and tuberculosis (O'neill, 2014). World health organization (WHO) identified eight pathogens relevant to AMR, among them five are pathogenic or commensal bacteria (*Klebsiella pneumoniae*, *Escherichia coli*, *Staphylococcus aureus*, *Neisseria gonorrhoeae*, *Mycobacterium tuberculosis*) (WHO, 2018). The third-generation cephalosporin-resistant and carbapenem-resistant *Enterobacteriaceae* (CRE, e.g. *Escherichia coli* and *Klebsiella pneumoniae*) alone were reported to cause 6.4 million bloodstream infections and 50.1 million serious infections worldwide in a year (Temkin et al., 2018). A recent estimate suggested 33,000 annual deaths due to AMR in European Union and European Economic Area (Cassini et al., 2019). Additional treatment cost and loss due to methicillin-resistant *Staphylococcus aureus* (MRSA), third-generation cephalosporin-resistant and ESBL-producing *Enterobacteriaceae* ranged between 1732-9726 USD and 2.54-6.8 days per case, respectively (Wozniak et al., 2019). For the United States alone, average national health care expenditure was estimated at around 2.2 billion US Dollar due to AMR (Thorpe et al., 2018).

Addressing AMR in developing countries was considered crucial by the United Nations to attend sustainable development goals (SDGs) associated with poverty and hunger alleviation and improvement of health and economic growth. In low-and-middle-income countries (LMICs) such as India, the current rate of AMR related infections is high and is projected to grow more rapidly than the developed countries. A substantial portion (40-60%) of human bacterial infections in Brazil, the Russian Federation and India is associated with resistant bugs in comparison to developed countries (17%) (OECD, 2018). In LMICs the direct and prominent effects of AMR includes increased mortality in addition to higher morbidity and economic losses (Okeke et al., 2005). The recent projection about the financial vulnerability of LMICs revealed that additional 19 million people are going to fall into great poverty by 2030 due to AMR producing direct impacts on labour productivity (neat GDP produced by one hour labour) and increased health care costs (Ahmed et al., 2017).

Exposure of livestock to the antimicrobials

Rearing of food animals including poultry is dependent on usage of medically important antibiotics (MIA) for therapy, prophylaxis and growth promotion. Recently world health organization (WHO) recommended complete cessation of MIA use in healthy animals for prophylaxis or growth promotion (WHO, 2019). The European Centre for Disease Prevention and Control, European Food Safety Authority and European Medicines Agency joint report revealed more average annual antibiotic consumption in animals than human (ECDC/EFSA/EMA, 2017). It is estimated that two-third of the antibiotics produced is consumed by the livestock sector globally (CDDEP, 2015), which is expected to increase by 67% in 2030 specially in BRICS group of countries including India to meet the increasing animal protein demand (Van Boeckel et al., 2015). The data for antimicrobial usage in livestock in LMICs including India is scarce but it is evident that use of antibiotics varies with the farming practices. The backyard poultry farmers mostly use ethno-veterinary medicine based on indigenous technical knowledge and in more severe cases with the lower generation and cheaper antibiotics available in the local retail shop (Samanta et al., 2018). The antimicrobial usage for growth promotion of livestock and poultry was not detected among the Indian backyard farmers.

Other than direct way the livestock are also exposed to the antimicrobials by means of indirect ways such as exposure to the contaminated environment. Antibiotics treated human or animal waste, effluents from antimicrobial production units are found responsible for contamination of the environment with the resistant bugs or the 'resistome'. In India, effluent from water-treatment plant was found to contain high concentration of fluroquinolone (ciprofloxacin) causing contamination of surface, ground, and drinking water (Larsson et al., 2007). Our studies found more exposure to the environment presumed to be contaminated might be the probable reason for higher occurrence of beta-lactamase producing bacteria in backyard pigs, kuroilers and ducks than the farmed counterpart, although not directly exposed to the antimicrobials (Samanta et al., 2015; Mahanti et al., 2018; Banerjee et al., 2019).

Transmission

The transmission of antimicrobial resistance from animals to humans takes place through contaminated animal origin food, direct contact between animals and humans, and release of antibiotic residues from food-animals and birds into the environment mainly through the manure.

Areas to be focused for mitigation

Social studies

Antimicrobial resistance cannot be categorized as a scientific problem only but it is also considered as a social menace. The spread of AMR is largely dependent on human behaviour, influenced by cultural, social, political, and economic factors (Wood, 2016). Hence it is needed to join the hands with social scientists to find out the solution for the problem.

Substitution of antimicrobial use (AMU)

AMU is the single most important driver for AMR; therefore, attempts are on to slowly reduce or phase out the antimicrobials in veterinary medicine, if not possible in one go. However, substitution of the antimicrobials has short-term economic implications resulting from substantial loss of production, higher morbidity or mortality. In any case, if such measures compromise food security, that may have devastating impact in poor, highly populous and resource-deprived countries. An early warning system based on local epidemiological database and regular health check-up of the animals may allow us to detect the disease early and thereby preventing its spread to the other animals in the herd or adjoining areas. Various alternative ways like reducing meat consumption, capping of amount of antimicrobials per year per kilogram of animal product and making the antibiotics expensive by taxation were proposed to cut down AMU in food animals (Van Boeckel et al., 2017). Making the meat from antibiotic treated animals more expensive and labelling such meat packages mentioning its source (from antibiotic treated animals) is another way to discourage consumers and to indirectly reduce AMU (Giubilini et al., 2017). The alternative anti-infective strategies such as nano-material based anti-infective particles, enzymes, antimicrobial peptides, quorum sensing quenchers, efflux pump inhibitors, clay, predatory bacteria, teat sealants, and antimicrobial photodynamic therapy are in pipeline to be evaluated at field level. The supplementation of essential oils and spices as alternative to antimicrobials was reported to have beneficial health effect in poultry (Pathak et al., 2017; Chowdhury et al., 2018).

Raising awareness among farmers

FAO referred the farmers as "important frontline defenders" for the vital role they can play in stemming the spread of AMR by adopting good hygienic farm operations. Increasing awareness among the farmers by imparting basic knowledge may help reduce the unnecessary and indiscriminate AMU in food animals (Ferdous et al., 2019). Changing the farmers' behaviour or increasing their awareness for appropriate AMU in food animals require multiple supportive measures, like incentive to the farmers raising livestock without antibiotics, subsidized insurance to make up losses, implementation of strict drug regulation, and establishment of a strong network of veterinary healthcare facilities accessible to rural farmers in LMICs. The mobile veterinary clinic was introduced by Government of India to reach out to the country's remote corners.

Implementation of Government legislation

FAO identified strong government legislation as the most important component in addressing the overuse, misuse or abuse of antimicrobials. Such legislations are essential for defining the responsibilities and duties of all the stakeholders, and for sustainability of the policies and technical objectives aiming for reducing AMR. Any kind of regulatory endeavour is still at infancy in many of the LMICs, only a few to successfully implement such regulations or advisories given the prevailing socio-economic scenario, public administrative constraints and absence of political commitment/goodwill in these countries. Therefore, emphasis on education, awareness and training of the all stakeholders, particularly the end users might be a more effective in LMICs (Caudell et al., 2020).

Surveillance of AMU and AMR

Many of the developed countries such as Norway, Japan, Denmark, Canada, the USA, Finland, the Netherlands, and France have articulated national surveillance programme (NORM-VET, JVARM, DANMAP, CIPARS, NARMS, FINRES-VET, NethMap-MARAN, ONERBA- RESAPATH and SWEDRES-SVARM) and the policies on AMU in animals are tailored based on the data generated from their networks. Most of the LMICs have no surveillance in place to monitor the antimicrobial consumption in animals. Government of India adopted the National Action Plan (NAP) on AMR and strongly recommended need for strong regulatory framework for restricting the AMU in animals. The Pan-India Network – ICAR-Indian Network for Fisheries and Animal Antibiotic Resistance (INFAAR) was initiated by Indian Council of Agricultural Research in collaboration with FAO to cater the objectives laid down in India's NAP on AMR. Lack of robust infrastructural support crippled by financial constraints remains the most pressing challenge for establishment and proper functioning of a robust surveillance system on AMR/AMU in LMICs. Ashley et al. (2019) proposed to tap the large amount of data generated by the academic institutes, private laboratory to indirectly and passively monitor the problem in these areas for the time being.

Conclusion

Following strategies may be prioritized for mitigation of the antimicrobial resistance in livestock sector.

1. Construction of a 'National AMR Task Force' for monitoring and surveillance of antimicrobial use, prevalence of antimicrobial resistance rate and detection of antibiotic residues in livestock, and foods and food products of animal origin

2. Strengthening the disease prevention in food animals to minimize the use of antibiotics

(a) Maintenance of good herd health by employing best management practices suitable to the local climate

(b) Implementing strict biosecurity measures in the farms

(c) Vaccination of all animals in the herd

3. The instructions for antibiotic dosage, frequency, route of administration and milk withholding time should be followed by the farmers

4. Slaughter of animals only after the completion of recommended withdrawal periods

4. Maintenance of good treatment records and periodical checking of records

6. Screening of antibiotic residues in foods and food products of animal origin and restriction on use and distribution of foods containing antibiotics above the prescribed limit

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Technological Innovations for Biodiversity Conservation

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Abstract
Biodiversity conservation refers to the protection, management and restoration of biological diversity, including the variety of species, ecosystems and genetic diversity within them. Biodiversity is essential for ecosystem health, human survival and the functioning of natural processes. Aquatic ecosystems support a substantial source of the earth's biological diversity. Both freshwater and marine habitats are experiencing a persistent decrease in aquatic biodiversity due to overexploitation of some species, the introduction of exotic plants and animals, pollution from cities, industry and agricultural areas as well as changes and loss of ecological niches. To safeguard the aquatic biodiversity, they must be conserved, managed and monitored globally through the use of bioregional management, bio reserve sites and global monitoring. The integration of innovative technologies into conservation efforts has significantly improved the ability to protect biodiversity. While these technologies like geographic information systems (GIS) and remote sensing help identify critical habitats, detect illegal activities like poaching and deforestation, and guide conservation efforts. AI and machine learning are being used to analyze large datasets, predict biodiversity trends, and optimize conservation strategies. Furthermore, biotechnologies such as DNA barcoding aid in identifying species, even from environmental samples, which enhances our understanding of biodiversity. They must be coupled with strong policy measures, community involvement and sustainable practices to effectively combat biodiversity loss and ensure the long-term health of ecosystems.

Keywords: Biodiversity conservation, Technological Innovations, remote sensing and DNA barcoding

1. Introduction

The term biodiversity (from "biological diversity") refers to the diversity of life on Earth at all scales, including genes, ecosystems, and the ecological, evolutionary, and cultural processes that keep life possible. Biodiversity encompasses more than just species richness; it also refers to genetic diversity and the many environments and habitats that support plant and animal life. Living things (plants and animals) and inanimate objects (soils, sunshine and water) coexist in ecosystems. On Earth, there are already about 1.7 million known species and every year, scientists describe new ones.

Biodiversity provides multiple benefit to humanity in several ways importantly, such as economic, recreational, cultural, scientific and ecological manner. Furthermore, pollination, seed dispersal, climate regulation, water purification, nutrient cycling, supply oxygen, clean air and water and control of agricultural pests are important for ecological services in ecosystem.

The preservation of biodiversity is vitally important right now, not only because its very diversity is in danger of disappearing or being lost, but also because it may benefit humanity directly or indirectly. The use of plants and animals in horticulture and agriculture, the creation of pharmaceuticals and the crucial functions that species play in the operation of all natural ecosystems are just a few of the ways that biodiversity helps humanity. In addition, biodiversity is beneficial for moral, artistic and recreational purposes.

- Conserving biodiversity and safeguarding a broad array of habitats upholds the numerous advantages that this variety affords to every species.
- The conservation of biodiversity is crucial for the upkeep of healthy ecosystems, a consistent supply of food and a host of other advantages including aesthetics, recreation and ecological services.

Identification of species as well as tracking, locating and identification of individual plants and animals are necessary for conservation. These techniques have improved in terms of speed, quality, ease of use and cost. These techniques are only a few examples of the wide range of approaches that may be used to monitor individuals and species. They are especially promising for species that are threatened and may not be allowed to use invasive methods. They share a significant amount of the biological production of the planet and serve as an essential reserve. Aquatic resources serve a multitude of purposes are vital and necessary for the survival of biotic groups and are correlated with biodiversity. The present manuscript illustrated the innovative technologies for biodiversity conservation in general application and aquatic ecosystem.

2. Technological innovations in biodiversity conservation

Innovative technologies have emerged as transformative tools in biodiversity conservation, helping to monitor, protect, and restore ecosystems with unprecedented precision and scale. Advances such as remote sensing, artificial intelligence (AI) and genetic technologies are reshaping how we understand and respond to the complex challenges facing biodiversity. Remote sensing technologies, including drones and satellite imagery, provide critical data on habitat changes and species distributions, detect illegal activities like poaching, deforestation and enabling conservationists to track environmental shifts in real time. AI and machine learning algorithms are increasingly employed to analyze large datasets, offering insights into patterns of species behaviour, migration and threats. In the realm of genetics, techniques such as environmental DNA (eDNA) and CRISPR offer new approaches to understanding species diversity, monitoring populations and even aiding in the revival of endangered or extinct species. These technologies are creating opportunities for more effective, data-driven conservation strategies, crucial to safeguarding biodiversity in the face of climate change, habitat loss and other global pressures.

2.1 Satellite Image Processing and GIS Techniques Used to Measure and Model Biodiversity

Three categories may be distinguished among the current works on biodiversity conservation utilising GIS and remote sensing:

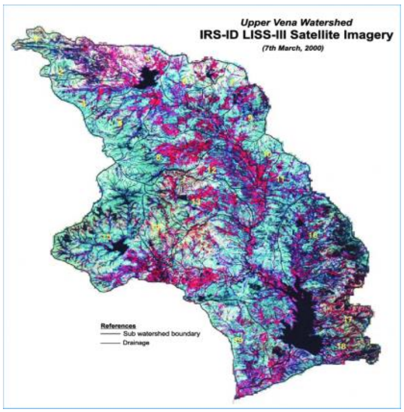
- Biodiversity mapping (individual species, species assemblages and habitats)
- Biodiversity monitoring
- Biodiversity modelling.

The most common methods for obtaining data on species distribution are habitat maps derived from remote sensing and information on the relationships between different habitat types. According to Kerr *et al.* (2001) and Scribner *et al.* (2001), habitat boundaries and biophysical traits of species may be identified by combining satellite data with field-based habitat data, landscape structure, and species abundance information. The categorisation of satellite data has long been used to establish a connection between species distributions, plant types, and the corresponding habitat preference (Nagendra 2001; Gottschalk *et al.* 2005; Leyequien *et al.* 2007).

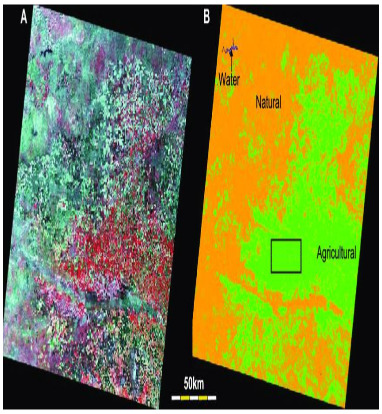
Geographic Information Systems (GIS) allow for the integration and analysis of spatial data related to biodiversity. GIS platforms facilitate the mapping of ecosystems, species distributions, and habitat corridors, helping conservationists understand spatial patterns of biodiversity and prioritize conservation efforts.

Table 1: Some important biodiversity conservation studies, techniques employed and data sources

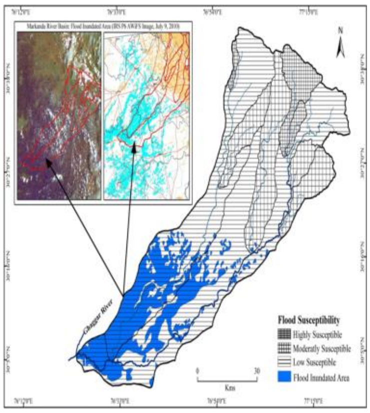
Issues addressed	**Technique used**	**RS data used**	**References**
Biodiversity mapping	Individual species mapping, species assemblage mapping	IRS LISS-III, QuickBird MSS	Franklin *et al.* (1994)
	Habitat mapping	IRS LISS-III, Landsat ETM+	Ravan *et al.* (1995)
Biodiversity monitoring and assessment	Monitoring habitat modification/ degradation	IRS LISS-II, LISS-III, Landsat TM/ETM/MSS, SPOT MSS	Nagendra and Gadgil (1999)
	Monitoring human induced habitat threat	LISS-III, Landsat TM/ ETM/MSS, IKONOS, DMSP-OLS, IRS P6-AWIFS	Roy and Tomar (2001)
	Monitoring vegetation versus climate change	IRS LISS-III, LISS-IV, Landsat TM/MSS	Panigrahy *et al.* (2010)
Biodiversity modelling	Species distribution modelling	NA	Engler *et al.* (2004)
	Species diversity modelling	MODIS, QSCAT, SRTM	Gould (2000)



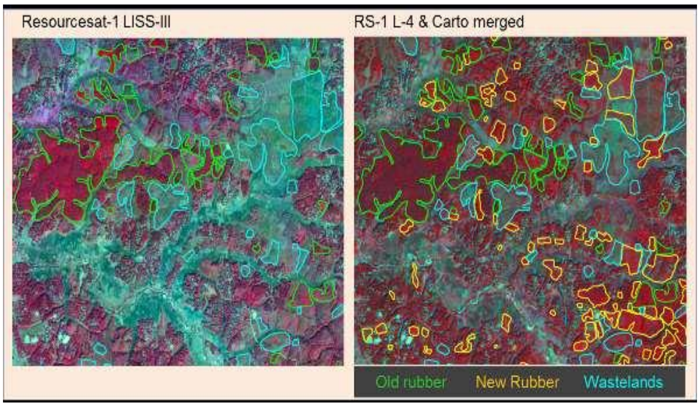
IRS LISS-III



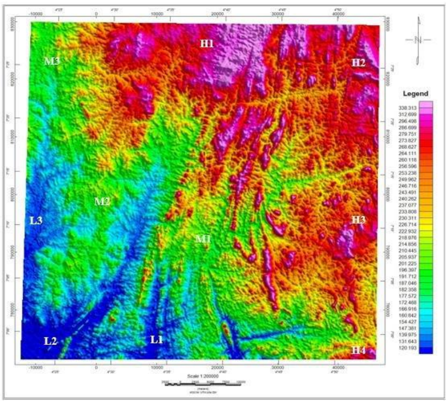
Landsat ETM+



IRS P6- AWIFS



LISS-IV



SRTM

Figure 1: Some techniques for biodiversity conservation by using Remote sensing data

2.2 Artificial Intelligence (AI) and Machine Learning in Biodiversity Conservation

The recent advancement in data science coupled with the revolution in digital and satellite technology has improved the potential for artificial intelligence applications in the forestry and wildlife sectors. Artificial Intelligence (AI) and machine learning algorithms are increasingly being important role in biodiversity conservation for tasks such as species identification, habitat mapping and threat assessment. It can automatically identify species in photos or videos from camera traps, reducing the need for human analysis.

AI models can analyze sounds in the environment, identifying bird songs, bat echolocation calls or whale vocalizations to track populations. Detect changes in land use, deforestation, habitat fragmentation or illegal activities such as logging and mining. Map ecosystems and habitats, allowing conservationists to identify critical regions that need protection. Forecasting the future changes in biodiversity by analyzing large datasets related to climate, land use and human activity. Predict how species distributions will shift due to climate change, informing conservation planning. Assess the risk of species extinction by analyzing ecological data and identifying key threats. Monitoring the spread of invasive species through remote sensing data and predicting where an invasive species may spread next, allowing conservationists to take preventative measures. In conservation genomics, AI is used to analyze large-scale genomic data from endangered species. This can inform strategies like captive breeding, genetic diversity monitoring and population viability analyses.

AI-powered mobile apps like iNaturalist, PlantSnap use image recognition algorithms to help users identify plant and animal species, contributing to citizen science efforts. Moreover, AI models trained on large datasets can predict species distributions, assess climate change impacts on biodiversity and optimize conservation strategies by identifying priority areas for protection. For instance, AI models have been used to predict the habitats of endangered species, such as tigers and elephants, based on environmental variables and human activity patterns. By automating time-consuming tasks, providing more accurate predictions and enhancing real-time monitoring, AI has the potential to transform biodiversity conservation efforts worldwide.

iNaturalist

PlantSnap

Figure 2: AI powered app used for biodiversity conservation

Big data is a scientific framework that can help solve the global conservation crisis by providing a way to document patterns across scales. Within the context of biodiversity, big data is defined as a "techno-political tool to manage the distribution of biological species" and as "the intensive data accumulation of digitized information on biodiversity, corresponding to a spatial and temporal description of species distribution".

Big data offers powerful tools for biodiversity conservation by providing insights into species behaviour, ecosystem health, and environmental changes at scales and resolutions that were previously impossible. When combined with AI and predictive analytics, big data allows conservationists to make more informed decisions, track progress, and adapt to changing conditions more effectively.

2.3 DNA Barcoding and Environmental DNA (eDNA)

Genetic technologies such as DNA barcoding and environmental DNA (eDNA) have emerged as transformative tools for species identification and monitoring. DNA barcoding uses short genetic sequences from a standardized region of the genome to identify species, which is particularly useful for monitoring biodiversity in regions with incomplete taxonomic inventories.

eDNA, which refers to the genetic material shed by organisms into the environment (e.g., in soil or water), allows for the detection of species without the need for direct observation or capture. This non-invasive approach has been highly effective for monitoring elusive or rare species and detecting invasive species. A notable example is the use of eDNA to monitor amphibian populations, including endangered species, in various freshwater ecosystems.

2.4 Drones for Wildlife Monitoring

Drones or Unmanned Aerial Vehicles (UAVs), have proven to be highly effective in wildlife monitoring, providing a cost-effective and less invasive way to survey large areas. Drones equipped with cameras or thermal imaging technology can monitor animal populations, track poachers, and even assess the health of ecosystems.

In marine environments, drones have been used to monitor coral reef health, providing detailed images that help in assessing the impact of bleaching events caused by climate change. In terrestrial ecosystems, drones have been used to monitor elephant and rhino populations, offering real-time data that aids in anti-poaching operations.

2.5 Blockchain for Transparency in Conservation Efforts

Blockchain technology has emerged as a tool for increasing transparency and accountability in conservation efforts. By creating immutable records of transactions and actions, blockchain can ensure that funds allocated for conservation are used effectively. For example, blockchain has been applied to track the certification of sustainable fisheries, ensuring that seafood labelled as sustainable comes from verified sources.

Additionally, blockchain platforms are being developed to allow communities to manage and trade carbon credits, offering incentives for preserving forests and other carbon sinks.

2.6 Citizen Science and Mobile Applications

Citizen science platforms and mobile applications have brought the general public into biodiversity conservation efforts. Apps such as eBird and iNaturalist allow individuals to record and share sightings of birds and other wildlife, contributing valuable data to large biodiversity databases.

These platforms not only engage the public but also provide researchers with extensive data on species distributions, migration patterns, and population dynamics. For example, data from eBird have been used in several studies to assess bird population trends across different regions, providing insights into the impacts of climate change and habitat loss.

3. Biodiversity Conservation in Aquatic Ecosystem

Aquatic ecosystems which include marine, freshwater and brackish environments, are among the most biologically diverse habitats on Earth. They provide critical ecosystem services, such as oxygen production, climate regulation, and food supply, while supporting the livelihoods of billions of people. However, these ecosystems face significant threats from human activities, including overfishing, habitat destruction, pollution, climate change and invasive species. Biodiversity conservation in aquatic ecosystems is essential to maintaining their ecological integrity and the services they provide.

This review explores the importance of conserving aquatic biodiversity, the key threats to aquatic ecosystems, conservation strategies, and technological innovations that aid in protecting these ecosystems.

Technological Innovations in Aquatic Biodiversity Conservation

Technological innovations have significantly enhanced efforts to conserve biodiversity in aquatic ecosystems, addressing the challenges of monitoring vast and often inaccessible underwater environments. The advancement of technologies such as remote sensing, environmental DNA (eDNA), artificial intelligence (AI) and unmanned systems have provided researchers and conservationists with new tools to monitor and protect marine and freshwater species. This review examines key technological innovations and their roles in conserving aquatic biodiversity. Recent technological advancements have improved the ability to monitor and protect biodiversity. These innovations include:

3.1 Remote Sensing and Satellite Imagery

Remote sensing technologies, including satellite imagery and sonar systems, have revolutionized aquatic ecosystem monitoring. Satellites like NASA's Aqua and Terra provide high-resolution data on ocean surface temperatures, chlorophyll concentrations and ocean currents. These metrics are crucial for identifying changes in marine habitats, such as coral bleaching events, harmful algal blooms and shifts in oceanic biodiversity caused by climate change.

Researchers are able to gather ever-increasing amounts of data on the spatial ecology of marine megafauna in the context of global change because to satellite remote sensing and animal monitoring. Emerging the realm of big data science is to create the whole new frameworks for gathering, storing, exchanging, analysing, visualising and distributing data is made possible by information technology. The use of big data in protecting marine megafauna by providing in-depth understanding of the spatial ecology of these fascinating, endangered species.

For example, satellite-based data have been used to monitor coral reefs globally, detecting bleaching events and changes in water temperatures that threaten coral ecosystems. Sonar technologies, such as multibeam echosounders, have also been deployed to map underwater topography, providing detailed images of sea-beds that support habitat assessments and biodiversity studies.

3.2 Artificial Intelligence (AI) and Machine Learning

AI and machine learning technologies have become critical in processing large datasets collected from aquatic ecosystems. For instance, AI algorithms can analyze underwater video footage or sonar data to automatically identify and classify marine species, reducing the time and effort required for human observation.

AI models have been applied in fisheries management to predict fish population dynamics based on environmental data, allowing for more sustainable harvesting practices. AI-driven platforms are also being developed to model marine ecosystem responses to climate change and predict the spread of invasive species, enhancing the ability to pre-emptively mitigate threats to biodiversity.

3.3 Acoustic Monitoring

Acoustic technologies have enabled the non-invasive monitoring of aquatic species, especially those that produce sound for communication, navigation or foraging. Passive acoustic monitoring systems can record sounds produced by marine mammals, such as whales and dolphins, allowing researchers to track their movements and population densities.

In addition to marine mammals, acoustic technologies have been applied to monitor fish populations, identifying spawning sites and migration routes. This data has been essential in creating marine protected areas (MPAs) and informing policies to minimize the impact of human activities, such as shipping and fishing, on sensitive species.

3.4 Environmental DNA (eDNA) in Aquatic Ecosystems

Environmental DNA (eDNA) has emerged as a game-changing tool in aquatic biodiversity monitoring. As organisms interact with their environments, they shed DNA into the water through skin, scales and waste products. By collecting water samples and analyzing the eDNA, scientists can detect the presence of species without physically capturing them.

This non-invasive approach is particularly valuable in aquatic ecosystems, where many species are elusive or difficult to monitor. eDNA has been used extensively in detecting invasive species, such as Asian carp in U.S. freshwater systems, and monitoring endangered species like the critically endangered vaquita porpoise in the Gulf of California. Additionally, eDNA is used in monitoring fish populations, amphibians and other aquatic organisms, making it an essential tool in marine conservation.

3.5 Drones and Autonomous Underwater Vehicles (AUVs)

Drones and Autonomous Underwater Vehicles (AUVs) are increasingly used in aquatic biodiversity research, providing real-time data on marine life and ecosystems. Drones equipped with high-resolution cameras and thermal imaging technology can survey coastal areas, monitor marine species such as sea turtles and sharks, and even assess coral reef health.

AUVs, such as gliders and remotely operated vehicles (ROVs), are capable of exploring deep-sea environments that are otherwise inaccessible to humans. These vehicles can be equipped with a range of sensors to measure water temperature, salinity and pH levels as well as cameras to capture images of deep-sea species. AUVs have been instrumental in documenting previously unknown species in deep-sea ecosystems and assessing the impacts of human activities, such as deep-sea mining, on biodiversity.

3.6 Marine Protected Area (MPA) Management and GIS Tools

Geographic Information Systems (GIS) play an essential role in the creation and management of Marine Protected Areas (MPAs), helping conservationists map critical habitats, monitor human activities and assess biodiversity within protected zones. GIS tools allow for the integration of spatial data from various sources, such as satellite imagery, oceanographic data and species distribution models, to identify areas that are most in need of protection.

In the Great Barrier Reef, for example, GIS has been used to monitor coral bleaching events and design conservation strategies that protect vulnerable areas from further degradation. Additionally, GIS-based models have helped create migratory corridors for marine species and improve the management of fishing activities within MPAs.

3.7 Blockchain for Sustainable Fisheries and Transparency

Blockchain technology is being explored for its potential to improve transparency and sustainability in the fishing industry, a critical factor in marine biodiversity conservation. Illegal, unreported and unregulated (IUU) fishing is a major threat to marine biodiversity. Blockchain can help track seafood products from catch to consumer, ensuring that they come from sustainable sources.

Blockchain has been successfully piloted in sustainable fisheries projects, where it helps verify that fish are harvested in compliance with environmental regulations and fair labour practices. This technology provides consumers with the information needed to make informed choices, while also holding fisheries accountable to environmental standards.

3.8 Robotics for Coral Reef Restoration

Robotic technologies have shown promise in aiding coral reef restoration efforts. Robots like “Coralbots” are designed to identify damaged coral fragments and help restore them by attaching healthy coral fragments to substrates. These robots can work autonomously in environments that are difficult for human divers to reach, offering a scalable solution to restoring degraded coral reefs.

For example, the Coralbots initiative has deployed small autonomous robots to assist in coral transplantation efforts in areas affected by bleaching events or physical damage. These robots improve the efficiency and success rate of coral restoration projects, which are vital to maintaining biodiversity in reef ecosystems.

3.9 Hydrological Modelling and Decision Support Systems

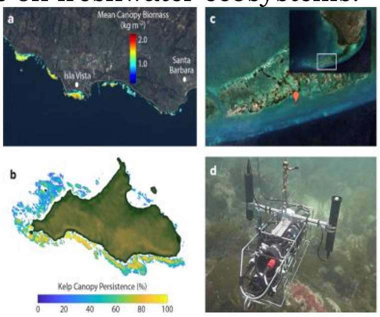
Hydrological models and decision support systems are important tools for managing freshwater ecosystems and ensuring the sustainable use of water resources. These models simulate the flow of water in rivers, lakes and wetlands, helping conservationists understand the relationships between water quantity, quality and biodiversity.

In freshwater ecosystems, hydrological models have been used to assess the impacts of water extraction, climate change and land-use changes on biodiversity. For example, in the Murray-Darling Basin in Australia, hydrological models have been used to predict the effects of water diversions for agriculture on wetland biodiversity. These models provide valuable insights for managing water resources in a way that supports both human needs and biodiversity conservation.

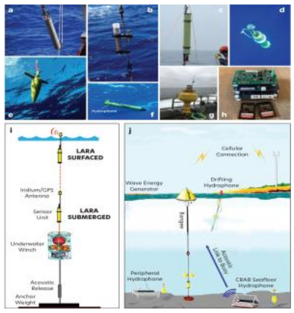
3.10 Restoration Technologies and Bioremediation

Technologies used in ecosystem restoration, such as bioremediation, are vital for freshwater biodiversity conservation. Bioremediation involves the use of microorganisms or plants to remove pollutants from water, helping to restore degraded aquatic ecosystems. Floating wetlands, which consist of artificial islands with plants that absorb excess nutrients and contaminants, have been deployed in various freshwater systems to improve water quality and support biodiversity.

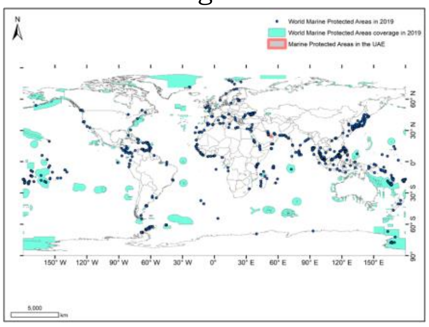
For example, bioremediation has been used in polluted lakes and rivers, such as China's Tai Lake, to reduce nutrient pollution and restore the aquatic habitat for fish and other species. These technologies help to mitigate the impact of industrial and agricultural pollutants on freshwater ecosystems.



Remote Sensing and Satellite Imagery

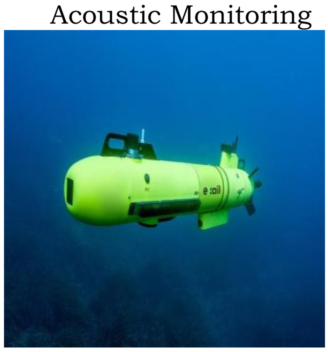


Acoustic Monitoring



MPA Management and GIS Tools

eDNA



Autonomous Underwater Vehicles

Figure 3: Technologies in aquatic biodiversity conservation

4. Internet of Things (IoT) for biodiversity conservation

The Internet of Things (IoT) is playing a growing role in biodiversity conservation by enabling real-time, remote monitoring of ecosystems, species and environmental changes. Through interconnected sensors, devices and systems. IoT technology allows conservationists to gather detailed data across vast areas and difficult terrains, contributing to more efficient and proactive conservation efforts.

IoT devices, such as GPS collars, radio tags and bio-logging devices, are used to monitor the movement, behaviour, and health of animals in real-time. These devices provide critical data for conservationists to track the migration patterns, home ranges, and movements of endangered species like elephants, rhinos or marine animals and also helps to identify key habitats and migration corridors for protection. Sensors can track activity levels, body temperature and even heart rates in animals to study their behaviours and stress levels in response to environmental changes associated with climate change, such as rising sea levels, increasing temperatures or shifts in precipitation patterns or human interference. IoT sensors placed in forests, wetlands or marine environments can monitor temperature, humidity, soil moisture, water quality and pollution or pollutant levels such as chemical runoff or plastics in water bodies, which may affect species and ecosystems.

IoT-based camera traps and acoustic monitoring devices are critical for biodiversity surveys and monitoring species in hard-to-reach areas. By integrating IoT with AI, drones and big data analytics, conservationists can gather actionable insights more quickly, respond to threats more effectively and engage local communities in the process. Despite challenges, IoT has the potential to significantly enhance conservation efforts and protect biodiversity in a rapidly changing world.

5. Conclusion

Technological innovations are increasingly integral to conserving biodiversity offering new ways to monitor, protect and restore ecosystems. Advances in satellite imaging, drones, artificial intelligence, genetic analysis and data modelling enable researchers to gather precise data on species populations, track habitat changes and assess the impacts of human activities on biodiversity at unprecedented scales.

From remote sensing and eDNA to AI and autonomous vehicles, these tools offer new capabilities for monitoring species, detecting environmental changes, and managing human impacts. However, their success depends on integration with traditional conservation efforts, global cooperation, and sustainable resource management. As technology continues to evolve, its role in the preservation of aquatic ecosystems and the diverse species they support will only grow more significant.

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Hi-Tech Aquaculture Practices: Researchable Issues to Enhance Production and Sustainability in view to Climate Change Adaptation

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Abstract
Climate change is already affecting various food production methods globally, with countries like India, which has a large population dependent on agriculture, facing significant challenges. This situation places immense pressure on natural resources and highlights inadequate coping strategies. Among the various food production sectors, fisheries and aquaculture are particularly crucial. Climate change risk factors, including rising temperatures, sea-level increases, cyclones, storm surges, ocean acidification, and related ecological shifts, are leading to numerous challenges within the fisheries industry. The aquaculture sector is particularly vulnerable to these climatic changes, necessitating a new perspective for enhancing production. It is essential to comprehend the socio-economic impacts of climate change on aquaculture and its communities to implement sustainable and environmentally friendly farming practices. In light of evolving environmental conditions, the emphasis should be on developing climate-resilient fisheries as part of a climate-smart aquaculture strategy to ensure nutritional security for the increasing population. A viable approach involves adopting an integrated farming system. Furthermore, scientific advancements in integrated farming have led to the development of several innovative technologies, including partitioned aquaculture systems, Integrated Multi-Trophic Aquaculture (IMTA), aquaponics, biofloc technology, and recirculating aquaculture systems (RAS). These practices not only enhance production but also mitigate the impacts of climate change and reduce contributions to it. However, aquafarming practices are limited to developed countries due to lack of expertise, higher initial investment, and high operating costs. Scientists are researching to minimize costs and find suitable species for production, while understanding the micro ecosystem is crucial for future challenges.

Keywords: Sustainable Aquaculture, Climate change, innovative farming practices, operation constraints.

Introduction

Climate change manifests both direct and indirect impacts on aquaculture production, influencing the sector in both the short term and long term (Maulu *et al.*, 2021). The outcomes such as rising temperature, ocean acidification, harmful algal blooms, etc. can directly affect the physical and physiological characteristics of finfish and shellfish (Handisyde *et al.*, 2006; De Silva and Soto, 2009). These changes may exhibit lower productivity, sudden deaths, and shifts in spawning seasons and quantities among the effects of climate change on aquaculture (McIlgorm *et al.*, 2010; Ho *et al.*, 2016). Moreover, the lack of space for expansion and new sites (due to competition with other uses and interests), limited fresh water availability, and concerns over pollution are considered as key obstacles for further expansion of conventional cage-based and flow-through aquaculture systems. Thus, in relation to more production in limited area with less impact of climate change further intensification is needed for sustainable and innovative aquaculture (Godfray *et al.*, 2010). Therefore, major aquaculture producing countries including India have promoted various hi-tech aquaculture systems viz. Recirculating Aquaculture Systems (RAS), Integrated Multi-Trophic Aquaculture (IMTA), aquaponics, biofloc technology, and raceways as one of the possible solutions and opportunities to further develop aquaculture.

New Technologies for Climate Adaptive Integrated Aquaculture

Subsequent innovations over scientific interventions and climate-resilient aquaculture strategies aimed at strengthening the adaptive capacity of aquaculture practices. Some widely established solutions include Recirculating Aquaculture Systems (RAS), Integrated Multi-Trophic Aquaculture (IMTA), aquaponics, Bio floc technology (BFT).

Re-circulatory Aquaculture System (RAS)

The Recirculatory Aquaculture System (RAS) is a sustainable method for aquafarmers to produce more food while reducing environmental impacts. It requires limited resources and maintains optimal water quality conditions, making it crucial for indoor tank-based fish production. RAS uses biofiltration to reduce ammonia levels and isolates stock from the external environment. It uses clean water, dissolved oxygen, and optimal temperatures for growth and sustainability. In contrast with the conventional method of growing fish outdoors unit, this system rears fish at very high densities in indoor tanks with a "controlled" environment.

Figure: Backyard Re-circulatory Aquaculture System (RAS)

Table 1: Major design parameters to benefit RAS

Parameters	Comments
Biosecurity	A risk assessment needs to be carried out that considers factors such as species, potential pathogens, disease susceptibility, location and potential routes of infection. This will lead to decisions on disinfection and other biosecurity measures.
Salinity	This will depend on the requirements of the species, but marine systems have inherently more complex water chemistry and less efficient biofiltration.
Production plan	The use of multiple batches involving staggered stocking and harvesting schedules is normal in RAS to optimise use of resources and maintain reasonably stable biomass
Water flow rates	These may be calculated in relation to biomass has been stocked as to provide a consistent supply of water per minute per kg or stock. Consideration of water velocities in relation to body length can be a useful design parameter
Water quality targets	Typical parameters include suspended solids, dissolved oxygen and carbon dioxide, ammonia, nitrite and nitrate, pH, alkalinity, salinity and temperature need to be set at the design stage to help define performance requirements for treatment equipment
Waste treatment and disposal	The major waste stream from RAS is organic solids which frequently need dewatering and other treatment prior to disposal

However, the technology is very dependent on the life stage of the cultured animal, e.g. it is different to manage newly hatched or small size animals; this is why on-growing and hatchery are considered separately, from here onwards. The major issues include: wrong system approach (i.e. inaccurate parameter design calculations, and being too optimistic); inappropriate management (including lack of training); maintenance issues (poor water qualities achieved); and poor system designs (e.g. equipment selection). Likewise, the lack of response to unforeseen circumstances is also a common issue.

Despite the fact that RAS systems were developed as a technology for intensive fish farming and used mainly when water availability is restricted: they enable up to 90–99% of the water to be recycled, through the utilization of many different components. These systems allow the operator greater control over the environmental and water quality parameters, thus enabling optimal conditions for fish culture (Heinen *et al.*, 1996). In contrast, high capital and operational costs as well as the requirement for a very careful management and difficulties in treating the diseases (Schneider *et al.*, 2006), are the main limitations. Moreover, having water in continuous reuse, constant pumping of new intake water is needed, leading with elevated electricity costs i.e. the higher the water reuse, the more elevated will be the costs (Shepherd and Bromage, 1988). Thereafter, RAS systems are not simple systems; they are technology–biology interaction systems, requiring performance monitoring (Lekang, 2007). They have benefited from continuous development (from the simplest path of water treatment until the most sophisticated process) (Muir, 1982; Rosenthal, 1993); nowadays, they are considered "high-tech" methods.

Aquaponics

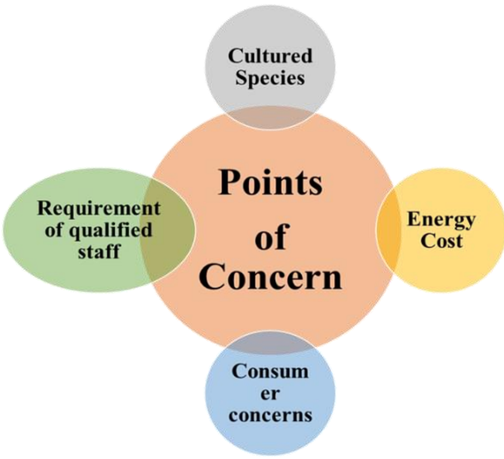
Aquaponics is an integrated multi-trophic system that combines elements of recirculating aquaculture and hydroponics, wherein the water from the fish tanks that is enriched in nutrients is used for plant growth. It is a soil-free down-sized natural process that can be found in lakes, ponds and rivers. Using fish waste as fertilizer for crops is an ancient practice.

The system design and application for aquaponics can be considered a highly multidisciplinary approach drawing from environmental, mechanical and civil engineering design concepts as well as aquatic and plant related biology, biochemistry, and biotechnology. System specific measurements and control technologies also require knowledge of subjects related to the field of computer science for automatic control systems. This high level of complexity necessarily demands in-depth knowledge and expertise of all involved fields. The biggest challenge in commercial aquaponics is its multi-disciplinarity, needing further expertise in economics, finance and marketing. Thus, a high degree of field-specific insight in terms of both practical and in-depth theoretical knowledge is required. This leads to an increasing level of complexity, which directly affects the efficiency factors of the running system. In the interest of highest efficiency and productivity, some challenges include pH stabilization, nutrient balance, phosphorus, and pest management. Moreover, Energy cost and fertilizer prices are constantly rising and governmental policies encourage reduction of emitted pollution (e.g., tax incentive schemes), so this cost margin benefit of aquaponics is expected to rise. These challenges, therefore, need to be resolved with the aim to establish fully controlled and standardized aquaponic systems that will be easy to handle and economically viable.

Biofloc Aquaculture System

Recirculating aquaculture systems (RASs) use significantly less water than traditional flow-through farming systems (Martins *et al.*, 2010). However, the RAS systems are not preferred by many farmers due to their high installation and operating costs as well as management issues (Badiola *et al.*, 2012). The BFT, due to its working principles, focuses on the welfare of the heterotrophic bacterial community in the environment to keep the water quality within the optimum ranges for fish or shellfish being cultivated. Therefore, BFT strongly influences harvest yield by providing suitable water quality over the culture period (Crab *et al.*, 2010) reducing the feed cost.

Figure: Biofloc System for Aquaculture



Thus, BFT has emerged as a promising and sustainable aquaculture technique with significant economic and environmental benefits. However, there are still challenges and opportunities for improvement in BFT systems. One area of future research is the optimization of carbon sources for biofloc production. Specific carbon sources can stimulate particular microbial populations, affecting the nutritional properties of the biofloc and fish performance. Therefore, developing strategies for selecting and managing carbon sources are necessary to improve biofloc quality and quantity. Another critical challenge is managing microbial populations. Imbalances in the microbial community can lead to the accumulation of toxic compounds like nitrate and ammonia, leading to negative impacts on fish health and water quality. Therefore, controlling microbial populations and maintaining a balanced community is essential for the successful implementation of BFT. Effective monitoring tools for BFT systems are also necessary to ensure stable and consistent production. Currently, there are limited techniques available to monitor the microbial community in real-time and detect changes in water quality. Developing accurate and reliable monitoring tools is essential for the successful implementation of BFT. Finally, scaling up BFT systems to commercial production levels is another challenge. Optimizing system design, management practices, and developing economically viable production models are necessary for the successful commercialization of BFT systems.

Integrated multi-trophic Aquaculture (IMTA)

Climate change causes ocean acidification that creates a deleterious impact on Mollusca (shellfish) such as forming thin shells in oysters resulting in low market value and a negative impact on growth, survival, and calcite biomineralization. So IMTA implementation is the way to longer adaptation of bivalve culture. It is suggested that bivalves use a combination of IMTA and genetic breeding strategies to achieve trans-generational acclimatization and increase their resilience to climate change (Tan & Zheng, 2020).

It is however noteworthy that if background levels of dissolved nutrients are too low, overall seaweed production will be limited regardless of local nutrient enhancement from fish farms (Troell *et al.*, 2003). The same situation would affect particulate matter availability for bivalves as well. Hydrodynamics, including current strength and direction will affect the success of IMTA systems, as this influences the distribution of nutrients and organic particles from the point sources. As the distribution of farm effluents could determine the appropriate orientation and location of the extractive species within the IMTA systems, any offshore IMTA enterprise, especially when natural dissolved nutrient concentrations and particle load are limited at the particular site, should be carefully located. In general, sites with (1) anthropogenic-induced eutrophication through larger river inputs, (2) atmospheric depositions, (3) upwelling, as well as (4) locations presenting natural eutrophication should be sought after. All these influences can increase nutrient concentrations in offshore waters, stimulating growth of bivalves and seaweeds, i.e., independently from fed aquaculture nutrient enrichment (Buck and Buchholz, 2004; Buck, 2008). For example, the offshore test site for mussel and seaweed cultivation in the vicinity of the estuaries of the rivers are therefore, influenced by the river-run nutrient load (Buck, 2007). However, it is important to also understand how such environments may affect fed species, as these may not be optimal for fish growth.

Conclusion

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. Aquaculture being one among the topmost contributor and fastest-growing food sector; the scientific interventions in the concept of integrated farming has resulted in many viable advanced technologies such as Integrated multi-trophic aquaculture (IMTA), aquaponics, biofloc technology, recirculatory aquaculture systems (RAS) and raceways so as to adopt the best method of culture, taking into account the need as well as the sustainability.

In spite of several advantages, the system of aquafarming practices likely BFT, RAS, aquaponics etc. is yet to reach to the large section of the people mostly because of lack of expertise, higher initial investment and high operating cost of running. Most of the systems are limited to developed countries currently using for either brood stock management or in nursery rearing. Researches are being carried out by the scientists to minimize the operational cost and find suitable species for production. Thorough research and deeper understanding are required to understand the micro ecosystem of the practices and interaction of various component of this species to face the challenges in the future.

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Sustainable Livelihood through Fish Farming with Institutional Credit Support in Bihar

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1. Introduction

Fishery is one of the prominent allied activities in India that not only ensures food and nutritional security to its population but also contributes to the national income, agricultural exports and employment generation from the allied activity. Fisheries sector is instrumental in sustaining livelihoods of around 30 million people in India, particularly from the marginalized and vulnerable communities. With a record fish production of 175.45 lakh tons in FY 2022-23, India is the third largest fish producing country in the world accounting for 8% of global production and contributing about 1.09% to the country's Gross Value Added (GVA) and over 6.7% to the agricultural GVA (GoI 2023).

2. Inland fisheries production and potential

Fishery is an important ancillary employment and a fishermen community-based livelihood activity. The sector remains under slow growth trajectory for centuries due to its un-organised, scattered and diffused nature, traditional ways of catching, limited to natural water resources, and mainly dependent on public sector for development involvements. The first institutional development initiative was taken by establishing the Fish Farmers Development Authorities (FFDAs) to provide a package of technical, financial and extension support to fish farmers. With a view to bring in new areas and regenerate existing water bodies for improved ways of fish farming, credit support fro banking sector for capital investments and operational expenses, sub-vented credit, subsidies, etc. were provided for excavation of new ponds, renovation of existing fonds for fish and prawn cultivation. For a faster growth of production and export of the sector, incessant efforts were made by both central and state governments by launching the Blue Revolution in 7th Five Year Plan (1985-1990), Intensive Marine Fisheries Program during 8th Five Year Plan (1992-97), established a series of fisheries research institutes and extension and training centres across the states. In order give focussed attention for a rapid growth, fisheries development has separated from Ministry of Agriculture at Centre and a separate ministry i.e. Ministry of Fisheries, Animal Husbandry and Dairying has been created on 31 May 2019. As a result of various initiatives, fish production in India increased from 7.52 lakh MT in 1950-51 to 175.45 lakh MT in 2022-23. During the said period marine fish production increased to 8.3 times while inland fish production has increased by 60.0 times. The share of inland fisheries in total fish production of the country has increased from 29% in 1950-51 to 75% in 2022-23 (Table 1). The inland fish production has shown a rapid growth during recent years. The total inland fish production increased from 66.87 lakh MT in 2014-15 to 131.13 lakh MT in 2022-23. Inland fish production however remained highly skewed across states. States like Andhra Pradesh and West Bengal together account for almost half of the inland fish production in the country whereas Uttar Pradesh, Bihar and Odisha account for another 20% (Table 2).

With concerted efforts for enhancing fish production, the demand for consumption, marketing and export of fish and fishery related products have been increased. The total value of export of marine fish and related products from India has been steadily increasing over the years. The value of exports from India far exceeds the value of its imports. The year-wise details of import of marine fish and related products in recent years is given Table 3.

Table 1: Trends and Progress of Fish Production in India (`000 Tons)

Year	Inland			Marine			Total	
	Prod-uction	Share in Total Production (%)	Decadal CAGR (%)	Prod -uction	Share in Total Produc-tion (%)	Decadal CAGR (%)	Prod uction	Decada l CAGR (%)
1950-51	218	28.99		534	71.01		752	
1960-61	280	24.14	2.5	880	75.86	5.1	1160	4.4
1970-71	670	38.15	9.1	1086	61.85	2.1	1756	4.2
1980-81	887	36.32	2.8	1555	63.68	3.7	2442	3.4
1990-91	1536	40.04	5.6	2300	59.96	4.0	3836	4.6
2000-01	2845	50.30	6.4	2811	49.70	2.0	5656	4.0

2010-11	4981	60.52	5.8	3250	39.48	1.5	8231	3.8
2015-16	7162	66.55		3600	33.45		10762	
2016-17	7806	68.29		3625	31.71		11431	
2017-18	8902	70.71		3688	29.29		12590	
2018-19	9720	71.61		3853	28.39		13573	
2019-20	10437	73.69		3727	26.31		14164	
2020-21	11248	76.39	8.5	3477	23.61	0.7	14725	6.0
2021-22	12121	74.60		4127	25.40		16248	
2022-23	13113	74.74		4432	25.26		17545	

Source: Handbook of Fisheries statistics 2023, Government of India

Table 2: Inland Fish Production in major states of India

Name of state	Production (000 Tons)			
	2019-20	**2020-21**	**2021-22**	**2022-23**
Andhra Pradesh	3610 (34.6)	4070(36.2)	4219(34.8)	4506(34.4)
West Bengal	1619(15.5)	1669(14.8)	1652(13.6)	1856(14.2)
Uttar Pradesh	699(6.7)	746(6.6)	809(6.7)	915(7.0)
Bihar	641(6.1)	683(6.1)	762(6.3)	846(6.4)
Odisha	660(6.3)	701(6.2)	789(6.5)	839(6.4)
Chhattisgarh	572(5.5)	577(5.1)	591(4.9)	652(5.0)
Karnataka	229(2.2)	261(2.3)	485(4.0)	495(3.8)
Assam	373 (3.6)	393(3.5)	417(3.4)	443(3.4)
All India	10437(100)	11248(100)	12121(100)	13113(100)

Source: Handbook of Fisheries statistics 2023, Government of India

Table 3: Export and import of fish and related products in India

(in Rupee crore)

Financial Year	Export Value	Import Value	Export Surplus	Import as % of Exports
2019-20	46,663	1,271	45,392	2.7
2020-21	43,721	1,656	42,065	3.8
2021-22	57,586	1,662	55,925	2.9
2022-23	63,969	1,950	62,020	3.0

Source : PIB, Ministry of Fisheries, Animal Husbandry & Dairying, Posted on 19 Dec 2023

3. Fisheries in Bihar

Bihar is one of the prominent states so far as inland fish production is concerned. Fish production in the state has increased from 6.02 lakh tonnes in 2018-19 to 8.40 lakh tonnes in 2022-23, at an annual growth rate of 8.91 per cent during the said period (GoB 2024). The state has vast water resources like rivers, canals, reservoirs, ponds, tanks and wetland water resources that include about 1125 ha of chaurs, 619 ha of lakes, and 2011 ha of oxbow lakes suitable for fisheries (GoB 2023). Though currently these water bodies are used for capture fisheries, they can be developed for intensive fish cultivation to exploit their optimum potential. However, fish farming in private ponds is yet to be developed in the state in a massive scale because of geo-climatic challenges. A major part of north-Bihar gets inundated during monsoon, and large territories in south Bihar is water-stressed, which makes maintaining water level in ponds for fish farming a difficult task. Moreover, the average landholding of farmers in the state is less than one acre and this is a major deterrent for dedicating land for fish farming.

Table 4: Fish Production and Targeted Production in Bihar

Financial Year	Production (000 Tons)	Year on Year Growth (%)
2020-21	683	6.55
2021-22	762	11.57
2022-23	846	11.02
2023-24	889	5.08
2024-25	950	6.86
2025-26	1020	7.37
2026-27	1160	13.73
2027-28	1270	9.48

Source: 4th Bihar Agriculture Roadmap 2023-2028.

4. Livelihood and Income Opportunities

Catching fish from natural waterbodies and marketing of fish are age old livelihood activities for the fishermen community. This has been giving livelihood to more than six lakh fishermen in Bihar. Gradually fishing from large waterbodies and intensive fish farming has evolved as an income generating activity. Planning and development Initiatives have been taken in more organized and scientific way with application of modern technologies and practices for fish capture, fish production, packaging and marketing fish in local, domestic and export market. Fish farming has been proven as a profit-making investment opportunity. It has been estimated that modern fish farming in Bihar can earn an approximate income ranging between Rs.2.27 lakh to 7.49 lakh per annum (Table 5)(SLBC 2024).

Table 5: Net income from fish farming

Type	Unit	Annual Gross Income	Annual Net Income
Carp culture	1 Ha	7.20	2.82
Tilapia culture	1 Ha	6.75	2.27
Magur culture	1 Ha	11.49	7.49
Pangasius Culture	1 Ha	24.20	5.94
Pen culture	1 – 2 Ha	9.60	6.10

Source: Scale of Finance of Bihar 2024-25, SLBC

5. Initiatives for Development of Fisheries Development

5.1 Initiatives of State Government

The state government has come up with a number of promotional schemes that provide financial, subsidy and technical support for development of fisheries sector and improve fish production as well as productivity in the state. A few important government schemes are Mukhyamantri Samekit Chaur Vikas Yojana, River Ranching Programme, Pradhan Mantri Matsya Sampada Yojana, Mukhyamantri Matsya Vipnan Yojana, Jalashay Matsyiki Vikas Yojana. These schemes not only create employment and income generating opportunities for fishermen communities and others engaged in fish production and marketing, but also maintains the quality of waterbodies and conserve biodiversity. The state government makes adequate budgetary provisions under each scheme and has been scouting for suitable proposals from fish farmers under various schemes.

5.2 Fish Farming through Bank Credit

Commercial fish farming requires medium to large investments depending on the size and nature of the unit for development and maintenance as well as for other operational expenses of the unit. Even capture fishing from large water bodies needs investments in infrastructure for catching and transportation of the catch. In recent years, ornamental fish farming has been coming up on a wider scale. In this perspective, institutional credit plays a crucial role by providing medium term loan for various investment activities and short-term loans for meeting the operational expenses pertaining to modern fish farming. NABARD in consultation with a Unit Cost Committee fixes the unit costs (NABARD 2024) every year to facilitate the banks for providing medium and long-term loans to fish farmers and traders for development of inland fisheries and aquaculture, development of ornamental and recreational fisheries, and for infrastructure and post-harvest management. Similarly, Department of Agriculture, Government of Bihar every year fixes the Scale of Finance (SoF) in consultation with the State Level Technical Committee to facilitate the banks to lend short term institutional credit to fish farmers for meeting operational expenses. The Unit Cost and SoF are being reviewed every year taking into consideration the anticipated escalation in costs for establishing and maintaining a fish farm. The unit costs and SoF fixed in Bihar have taken into account all types of possible investments and have seen a regular improvement over the years in order to ensure adequate bank loan is available to the fish farmers. A few of investments for which SoF and Unit Costs have been fixed are indicated in Table 6.

Table 6 : Unit Cost and Scale of Finance in Bihar

Particulars	2024-25	2023-24	2022-23	2021-22
I. Scale of Finance (Rs. Lakh/ha)				
Carp culture	4.00	4.01	4.00	1.50
Catfish & others	7.00	6.75	4.00	1.50
Pangasius culture	6.00	5.50	4.00	5.00
Fish seed production	5.00	5.00	4.00	2.80
Carp hatchery	8.00	7.00	4.00	2.50
Pen culture	3.50	3.50		
II. Unit Cost				
Construction of fish rearing new pond	7.90	7.00	7.00	7.00
Construction of nursery pond (0.5 acre)	2.13	1.87	1.78	1.70
Renovation of rearing tank	1.10	0.95	0.41	0.40
Soil & water testing kit	0.60	0.50	0.50	0.50
Bio-flock Pond construction	15.80	14.00	14.00	14.00
Fish processing plant unit	125.00	100.00	80.00	80.00
Ornamental fish rearing unit	13.50	12.14	12.00	8.00

Source : Scale of Finance, various years, Unit Cost of Bihar, Various Years, SLBC, Bihar

With a view to provide a hassle free and adequate short term credit access to fish farmers, government of India in 2019 has extended KCC scheme for fish farmers. Under this scheme, working capital requirements for culture of fish, shrimp, other aquatic organisms, capture of fish, etc. are made available with interest subvention up to the fixed credit limit. In Bihar, during 2023-24 Rs.24.44 crore short term bank loan was disbursed to 795 fish farmers under Fisheries-KCC and another Rs.41.25 crore of term loan has been disbursed to 7614 fish farmers for various investment activities. NABARD every year estimates the credit potential for various sectors. The credit potential for 2024-25 for fisheries sector has been estimated at Rs.2105 crore, which signifies that there is huge untapped credit potential under fisheries sector.

6. Challenges in Fisheries Sector in Bihar

Small landholding is the major challenge for expansion of fisheries sector in the densely populated state of Bihar. The average size of land holding in the state is 0.39 ha and 97% of land holders are small or marginal. This leaves little scope for dedicating land for fish farming ahead of cultivating staple crops like paddy and wheat. Further, a large tract of North Bihar gets inundated during the monsoon. On the other hand, the south Bihar has issues of low rainfall and water-stress which make fish farming difficult, costly and economically unviable. Keeping in view the challenges, especially in North Bihar, integrated fish farming can be a technically feasible and economically viable option. Integrated fish farming can go along with makhana cultivation in low lying and waterlogged areas of North Bihar.

7. The Way Forward

The 4th Bihar Agriculture Roadmap 2023-2028 has set the vision to make Bihar a “Fish Surplus” state. Fish production in Bihar in 2023-24 was 8.89 lakh tonnes whereas the estimated demand during the year was 9.56 lakh tonnes, which exceeds the production by 7.5%. The roadmap has set a target to enhance the fish production to 12.70 lakh tonnes by 2027-28 against the estimated demand of 9.91 lakh tonnes (Bihar 2023). The potential of the fish seed production in the state has been targeted to almost double during the five-year period, from about 1800 million fries in 2023-24 to about 3500 million fries in 2027-28. This needs a concerted efforts from the government departments, financing institutions, Universities and research agencies, fish farmers and entrepreneurs, etc. for achieving the target set in Agricultural Road Map.

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Addressing Emerging Contaminants: Innovative Remediation Technologies for Water Safety

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Contaminants of Emerging Concern (CECs) are pollutants that can cause the deleterious effect on aquatic life and human health but are not yet included in routine monitoring programs. CECs include persistent organic pollutants, pharmaceuticals and personal care product, veterinary medicines, endocrine-disrupting chemicals, nanomaterial, and antibiotic-resistant bacteria and genes. CECs are pervasive in the environment and have gained more prominence over the past few years. CECs such as pharmaceuticals, personal care products, endocrine disrupting compounds, and their active congeners, are increasingly being detected in wastewater effluents around the world. The word "emerging" which is frequently used in environmental debates, refers to new health risks that emerge as a result of micro level exposure to existing pollutants. Emerging contaminants have a variety of physicochemical characteristics that influence their exposure, fate, persistence, and toxicity in the environment. Their occurrences at trace levels in wastewater are detrimental to human health and the natural biota.

The search for these chemicals' origins has frequently led to wastewater treatment facilities as a portal of entry for pollutants into the environment. Discharges from various sources such as hospitals, pharmaceutical industries, and municipal wastewater contribute to the release of PPCPs into the environment, with concentrations ranging from ng/L to µg/L. CECs enter wastewater via a variety of routes, including hazardous spills, farm runoff, excretion via urine and feces, and consumer product disposal and usage. Another source could be items like shampoo, toothpaste, soap, and disinfection washes which contain biologically active components that, when used, release these pollutants into the sewage system and are subsequently transferred to a wastewater treatment plant. Since these contaminants were introduced or detected relatively recently, there is an existential knowledge gap about their fate, impacts, and behaviors, as well as treatment strategies for their effective removal.

Conventional wastewater treatment facilities are often ineffective in fully degrading these substances, leading to partial degradation and the release of antibiotic-resistant genes (ARGs) and bacteria, posing serious health risks to humans and animals. To develop efficient treatment technologies, it is important to understand the processes of various removal methods, the characteristics of pollutants, and the variables which influenced removal efficacy.

This talk will provide a brief overview of emerging pollutants, their main categories, occurrences, points of discharge, and toxicity in natural and engineered systems, followed by an illustration of physicochemical properties and detected micropollutant concentrations that have raised concerns in recent years. The talk will also focus on existing research that provides credible and quantitative information on ECs in various water sources, as well as the removal efficacy of different treatment techniques for different emerging contaminants. Perspectives of various biological and advanced treatment technologies developed to address the challenge of removing CECs especially PPCPs, ARGs and ARBs from wastewater will be discussed. The objective of this talk is to summarize the importance, drawbacks and feasibility of a range of methods that have been used for the remediation of CCECs from aqueous systems. It aims to discuss the applications of traditional treatment technologies (physical, chemical & biological), advanced oxidation processes (AOPs) including membrane filtration, adsorption, electrochemical oxidation, ozonation, fenton and photo-fenton processes, catalytic oxidation and photocatalysis, combined processes, and heterogeneous photocatalysis including combined utilization of AOPs on mitigation of the CCECs from aquatic environment. This chapter also provides a comprehensive assessment of various treatment technologies and their future perspectives for CCECs removal.

Plastic litters and Marine micro plastics: Impact and Governance to the Indian Ocean Ecosystem

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Summery

In the existing times plastics are the blanket that are covering the planet blue and have started to unravel the journey towards the arctic circle. Plastics have become a household name and their presence is quite evident in almost all the trash bins. The global production of plastics reached 360 million tons in 2018 [Plastic Europe, 2019]. It is estimated that by 2050 the production will increase to a colossal 33 billion tons [Horton et al., 2017; Free et al., 2014], with 10% ending up in the oceans [Cole, 2011]. The residence time of plastic when released in the environment has been estimated in the range of tens to hundreds of years [Zbyszewski et al., 2011]. High resistance leads to extremely low degradation and long halflife of plastics under environmental conditions [Eubeler et al., 2009]. Thus, the durability of plastics carry a devil side in the face of long half lifes. Therefore, the proper disposal of plastic litter is attracting concerns globally. Generally, Plastics are classified as mega-debris (100 mm), macro-debris (20 mm), meso-debris (20–5mm), and micro-debris (<5 mm) [Barnes et al. 2009; Cozzolino et al., 2020]. The term microplastics (MPs) has been in use since 2004 and can be defined as a heterogeneous mixture of particles ranging in size from a few microns to several millimetres produced as a result of anthropogenic activities. [Bergmen et al., 2015]. In simple words the term 'microplastics' is used to describe plastic particles which are less than 5 mm in size [Arthur et al., 2008]. Depending upon the source of origin these particles can occur in different shapes and composition (Blair, 2017).

Microplastics are usually classified into two categories: primary microplastic and secondary microplastics. Primary MPs are those which are manufactured in the micrometre size range and find usefulness in industrial activities from the production of air-blasting media to the production of boat hulls [Syberg et al.,2015] and in personal care and cosmetic products such as scrubs, toothpastes soaps and lotions [Carr et al., 2016; Murphy et al.,2016]. While, secondary MPs are formed as the result of fragmentation of meso- and macro-plastic litter due to physical abrasion, mechanical degradation and prolonged exposure to UV light [Barnes et al., 2009], as the UV radiation causes oxidative reactions which leads to degradation [Zepp et al., 2011].

As an emerging menace, microplastics (MPs) have received widespread attention, yet we have scarce knowledge of their accumulation profile and changing trends in and around the Indian Ocean. In India, we have been focusing on the seasonal distribution, characterization, and source determination of MPs in different environmental matrices (e.g. surface water, water column, sediment, biota, sewage wastewater, beach sediments, aerosols, sediment from different depths and microbial degradation of plastics) covering the west coast of India (Indian Ocean) and major riverine system (Ganga and Yamuna). Moreover, research investigations have also been carried out on the chemicals adsorbed on the surface of plastics (POPs and metals) and chemicals leached from the plastics (Plastic additives) from their production till the consumption stage and after they discard into the natural environment. The extraction of MPs from surface water (using plankton net), water column (using Niskin sampler) sediments (using van veen grab), and biota samples are followed by acid digestion (H_2O_2 & KOH) and density separation (NaCl). For MPs identification and characterization, a stereo microscope is used for different shapes, sizes, and color determination. Polymer type of MPs is examined by FTIR instrument (micro-FTIR & ATR) with mid-IR range 750-4000 cm-1, in reflection mode. The chemical concentration of MPs is tested by Gas chromatography-mass spectrometry (GC-MS) and direct probe analysis (micro TOF). In our MP studies, mainly fibre and fragments are dominating in shape, size ranging from 20µm-5mm, varying in distinct colors (black, transparent & colored) has been observed. A diverse variety of polymers (~33 types) have been detected in FTIR analysis wherein polyacrylamide, polyamide, polyvinyl chloride, polyvinyl alcohol, ethyl vinyl alcohol and poly methacrylate are predominant ones. The source of found MPs could be originated from the various activities in coastal areas (fishing, shipping, outfall of sewage wastewaters, and numerous land-based activities). Therefore, mapping of MPs is needed to understand their sources and accumulation in the Indian Ocean region which is now a hot spot of a huge garbage patch.

In addition, the miniscule spheres could harm aquatic animals that mistake them for food. Perhaps more ominously, they worry that the plastic balls could help transfer toxic pollutants from the Great Lakes to the food chain, including fish that people eat. Further, a 2017 literature review from the UN's International Maritime Organization concluded that 89 species of fish have ingested microplastics. Of those, 49 species are favourites on our dinner plates, including bluefin tuna, albacore, Atlantic herring, and anchovies. The studies on fish have been limited to examining microplastics in the gut and have not evaluated how long the plastic stays in the stomach or whether it is transferred to tissues that people like to eat (Lusher et al., 2017). In our study also we found MPs in water, sediment and fishes and shellfishes in western coast of India (Saha et al., 2021).

A very recent research of us highlighting MPs accumulation in the internal organs and tissues of Adelie Penguin from Antarctica have also been investigated which further attenuates the long range transport of MPs to pristine environments. Thus, it is very important to work on the mitigation/removal of these smaller sized MPs from the environment. Along with this, we are also working on the microbial biodegradation of the plastics which offer promising eco-friendly alternatives for plastic waste degradation. Our study will aid in establishing policies and legal limits for the use of plastics along with recommendations for management actions and long-term strategies. Therefore, the study is essential to address the knowledge gap regarding the status of Indian Ocean MP pollution and overall the transport and fate of MPs on the global scale.

The Role of Fisheries Industries in Overall Development of India

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Background: India's fisheries and aquaculture sectors play a crucial role in the nation's economy, contributing significantly to food security, employment, and livelihoods. As the second-largest producer of fish in the world, India boasts a diverse range of freshwater and marine resources, with total fish production reaching around 14 million metric tons annually. The sector not only supports millions of families but also serves as a vital source of nutrition, particularly in coastal and rural communities (FAO, 2020).

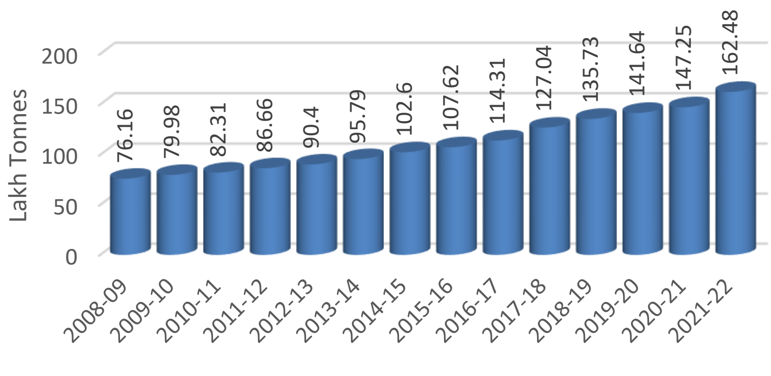

Fig.1: Trend in all India Fish Production (in lakh Tonnes): ***Source NFDB***

In recent years, aquaculture has emerged as a key driver of growth, particularly in shrimp farming, which has become a major export product. Government initiatives, such as the Pradhan Mantri Matsya Sampada Yojana, aim to enhance production while promoting sustainable practices (Government of India, 2020). However, challenges such as overfishing, habitat degradation, and environmental concerns remain pressing issues. As India navigates the complexities of this sector, balancing growth with sustainability will be essential for ensuring its long-term viability and contribution to the economy.

technological innovation, policy and regulation, education and awareness, and climate change mitigation, the industry has a significant impact on the overall well-being of the nation. In this article, we will explore the various roles and contributions of the fisheries industry and examine the challenges and future directions for sustainable development.

Sustainable fishing practices not only preserve the marine ecosystem but also secure the income and livelihoods of those involved in the sector. This approach aligns with the broader global efforts towards environmental conservation and responsible resource management. The importance of the fisheries sector goes beyond its economic contributions. It also serves as a source of food security, providing essential protein sources for millions of people globally. As such, sustainable fisheries management is vital in ensuring that future generations can continue to benefit from the resources provided by our oceans and water bodies. Efforts to promote responsible fishing practices and to support the growth of the fisheries sector can lead to a more robust and sustainable economy. Governments, industry stakeholders, and local communities The fisheries industry in India plays a crucial role in promoting sustainable development within the fisheries and aquaculture sector. With its contributions to economic development, food security and nutrition, environmental sustainability,

must work together to strike a balance between economic development and environmental preservation (Ghosh & Khatun, 2017. Through collaborative efforts, it is possible to harness the full potential of the fisheries sector while safeguarding the well-being of current and future generations.

Food Security and Nutrition: Fish is a rich source of high-quality protein, essential fatty acids, vitamins, and minerals, making it an essential component of the diet (Fig.4). Sustainable fisheries practices ensure a steady supply of these important nutrients to the population, particularly in regions where fish is a primary dietary component. By focusing on sustainable practices, the industry helps to maintain fish stocks and aquatic biodiversity, ensuring a reliable food supply. In today's world, food security is a pressing issue, with many regions facing challenges in providing an adequate and nutritious food supply for their populations. One crucial aspect of addressing food security is ensuring the sustainability of fisheries, as fish is a vital source of nutrition for millions of people around the globe. Sustainable fisheries practices play a significant role in maintaining food security and nutrition. By adopting methods that protect the long-term

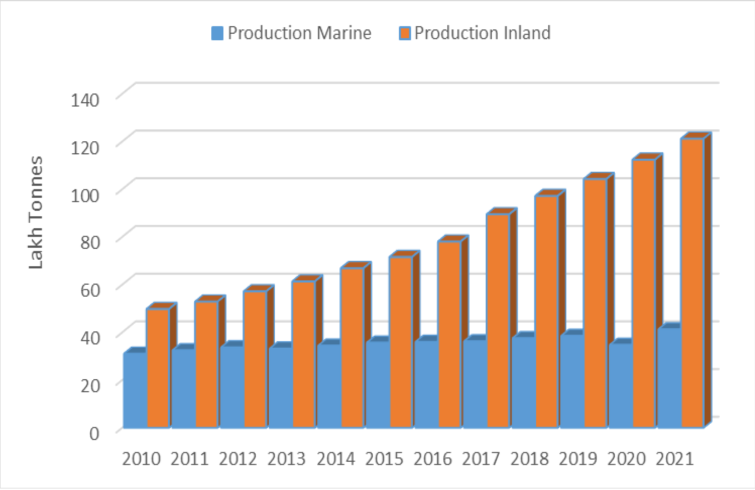

Fig.2: Number of people engaged in fishing and aquaculture. ***Source Deptt of Fisheries, Govt. of India***

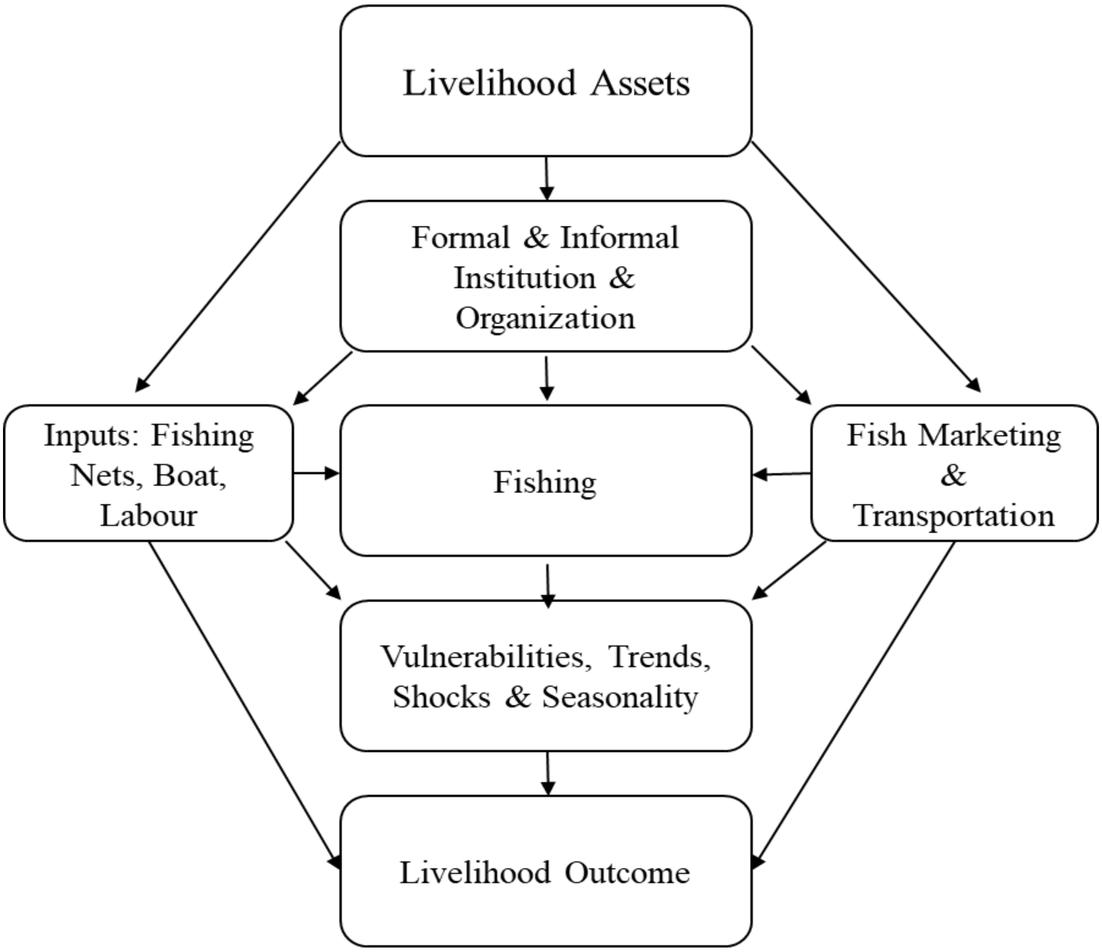

Fig.3: Livelihood outcomes of fisheries. ***Source- https://www.researchgate.net/profile/Atiqur-Sunny***

health of marine ecosystems and fish populations, the fisheries industry can ensure a consistent and reliable supply of fish for consumption. This is especially important in regions where fish is a primary dietary staple and a crucial source of essential nutrients. Furthermore, sustainable fisheries practices contribute to the overall health of our oceans and aquatic ecosystems. By preventing overfishing and minimizing the impact of fishing activities on marine habitats, these practices help maintain fish stocks and preserve biodiversity. This not only supports the long-term sustainability of fisheries but also helps to safeguard the health of our oceans for future generations. It is essential for governments, industry stakeholders, and local communities to work together to promote and implement sustainable fisheries practices. This includes establishing and enforcing regulations that prevent overfishing, minimizing bycatch, and protecting important marine

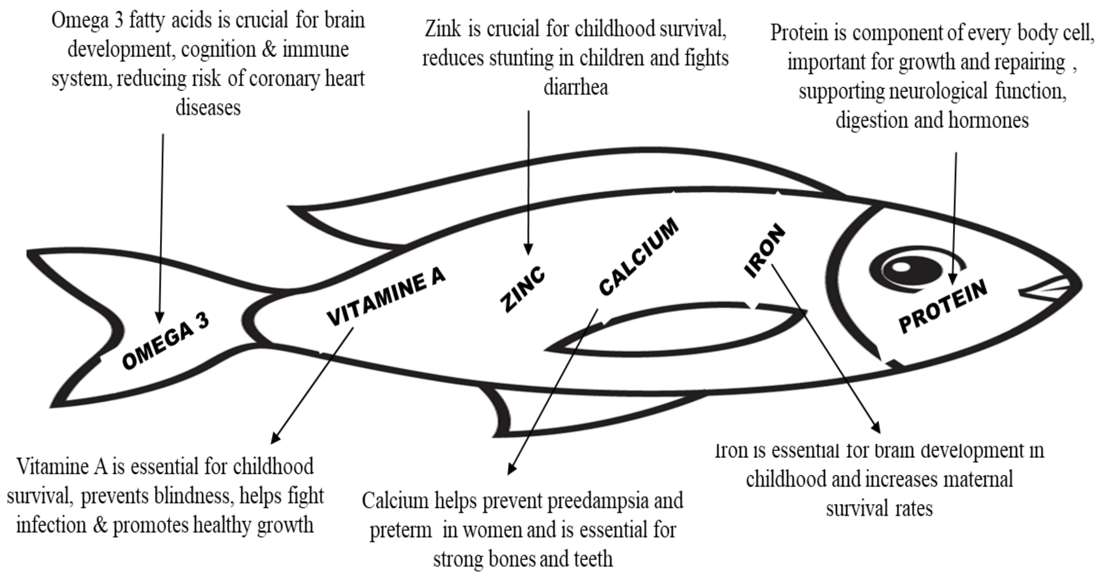

Fig.4: Fish important source of protein and micronutrients. **Source: - https://www.researchgate.net/publication/335397522**

habitats. Additionally, promoting aquaculture and fish farming practices that adhere to sustainability principles can further enhance food security by providing an alternative source of fish while reducing the pressure on wild fish populations. By prioritizing sustainable fisheries practices, we can address food security and nutrition challenges while also protecting the environment and supporting the livelihoods of those who depend on fisheries for their sustenance. Ultimately, a commitment to sustainability in the fisheries industry is vital for ensuring a secure and stable food supply for current and future generations (Raja & Kora, 2018).

Sustainable fisheries practices are crucial for protecting marine and freshwater resources: Measures such as regulated fishing quotas, gear restrictions, and seasonal closures help prevent overfishing and allow fish populations to replenish. Responsible aquaculture practices also play a significant role in reducing the impact on wild fish stocks and marine ecosystems. Innovations like integrated multi-trophic aquaculture (IMTA) and recirculating aquaculture systems (RAS) aim to minimize waste and environmental impact. These efforts are essential for the preservation of marine and freshwater resources for future generations. Moreover, technological innovation has become increasingly important in the sustainability of fisheries and aquaculture (Kumar & Singh, 2021). Investments in research and technology have led to the development of better fishing gear, disease-resistant fish breeds, and more efficient feeding techniques. Advances in technology, such as satellite tracking and data analytics, enhance monitoring and enforcement of fishing regulations, ensuring compliance and sustainability. The combination of environmentally responsible practices and technological advancements is critical for the long-term health and sustainability of fisheries and aquaculture. These efforts not only benefit the environment but also support the livelihoods of those involved in the industry. It is essential for stakeholders to continue prioritizing environmental sustainability and embracing technological innovations to ensure the responsible management of aquatic resources.

The Role of Government Policies and Programs in Promoting Sustainable Fisheries: India's rich coastal areas and vast marine resources have long supported a thriving fishing industry. However, overfishing and unsustainable practices have threatened the long-term viability of these vital resources. In response to these challenges, the Indian government has implemented several policies and programs aimed at promoting sustainable fisheries. One of the key aspects of the government's approach is the focus on sustainable practices, infrastructure development, and financial support within the fishing industry. By prioritizing sustainability, the government aims to ensure that fisheries resources are managed in a way that meets the needs of the present without compromising the ability of future generations to meet their own needs. Crucially, the government has recognized the importance of engaging local communities in the management of fisheries resources. By involving those directly involved in fishing, the government ensures that sustainability efforts are more effective and that the unique needs and knowledge of local fishers are taken into account. This community-centered approach helps to foster a sense of ownership and responsibility among the people who depend on these resources for their livelihoods. In addition to community engagement, the government has also prioritized education and awareness programs for fishers and aquaculture operators. These training programs and workshops are designed to promote best practices in sustainability, resource management, and conservation. By equipping industry professionals with the knowledge and tools they need to operate sustainably, the government is laying the groundwork for a more sustainable fishing industry as a whole. Furthermore, educating consumers about sustainable seafood choices plays a critical role in driving demand for responsibly harvested or farmed products. By raising awareness and promoting responsible consumption, the government aims to encourage industry-wide adherence to sustainable practices. This consumer-driven approach has the potential to create a market for sustainable seafood, thereby incentivizing industry players to adopt more sustainable methods. Overall, the Indian government's multifaceted approach to promoting sustainable fisheries encompasses policy implementation, community engagement, industry training, and consumer education. By addressing these various aspects, the government is working to ensure the long-term sustainability of India's fisheries while supporting the livelihoods of those who depend on them. Through these initiatives, the Indian government is demonstrating its commitment to safeguarding the country's aquatic resources for future generations.

Climate Change Mitigation: Sustainable fisheries and aquaculture can contribute to climate change adaptation by promoting resilient ecosystems and practices that mitigate the impacts of climate change on aquatic resources (Kumar & Kumar, 2020). By adopting the following practices that promote ecosystem resilience, we can protect biodiversity and maintain healthy aquatic environments:

- **Ecosystem-Based Management**: Focusing on the entire ecosystem rather than just target species helps maintain balance and resilience.
- **Energy Efficiency**: Implementing energy-efficient technologies in aquaculture systems can significantly reduce greenhouse gas emissions. This includes optimizing feeding practices and using energy-efficient pumps and aerators.
- **Renewable Energy**: Transitioning to renewable energy sources, like solar or wind, for aquaculture operations can drastically lower carbon footprints.
- **Sustainable Feed Practices**: Using alternative, sustainably sourced feeds can lessen the demand on wild fish stocks and reduce the carbon impact associated with feed production.

- **Habitat Restoration**: Protecting and restoring coastal and freshwater habitats, such as mangroves and wetlands, enhances carbon sequestration and supports biodiversity.
- **Adaptation Strategies**: Developing adaptive management strategies to cope with changing environmental conditions ensures the long-term viability of fisheries and aquaculture.

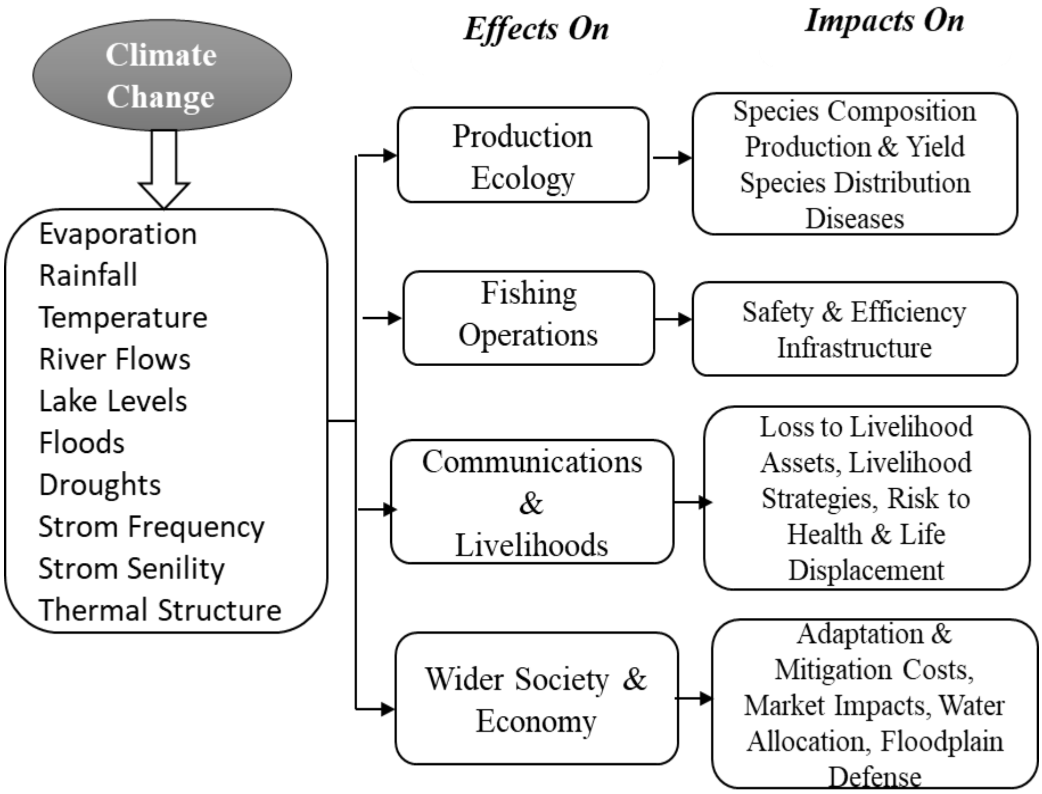

Fig.5: Potential impacts of climate change on the fisheries sector. ***Source: - Badjeck et al. (2010)***

Challenges and Future Directions in Sustainable Fisheries Management: The fisheries industry plays a crucial role in sustainable development, providing a vital source of food, income, and livelihoods for millions of people around the world (World Bank ,2019). However, the industry faces significant challenges that require continuous attention and concerted efforts to ensure its long-term sustainability. One of the most pressing challenges is overfishing, which has led to the depletion of fish stocks in many parts of the world. Overfishing not only threatens the viability of fish populations but also undermines the economic and social well-being of communities that depend on fisheries for their livelihoods. Addressing overfishing requires effective fisheries management strategies, such as the implementation of science-based quotas and the establishment of marine protected areas to allow fish stocks to recover. Habitat degradation is another major concern for sustainable fisheries management. Destructive fishing practices, coastal development, and pollution have resulted in the loss of critical fish habitats, such as coral reefs, mangroves, and seagrass beds. Protecting and restoring these habitats is essential for maintaining healthy fish populations and ensuring the resilience of marine ecosystems. Pollution, including marine litter, chemical contamination, and nutrient runoff, poses a significant threat to the health of marine environments and the sustainability of fisheries. Addressing pollution requires comprehensive regulatory frameworks, effective monitoring and enforcement mechanisms, and public awareness campaigns to reduce the sources of pollution and minimize its impact on marine ecosystems (Nath,. et al. 2018). Furthermore, climate change is altering ocean conditions and posing new challenges for sustainable fisheries management. Rising sea temperatures, ocean acidification, and changing currents are affecting the distribution and abundance of fish species, leading to shifts in fishing patterns and impacting the livelihoods of fishers and coastal communities. Adapting to these changes and building the resilience of fisheries and fishing communities will be critical for ensuring the long-term sustainability of the industry. Looking ahead, future efforts should focus on enhancing international cooperation for sustainable fisheries management. Collaborative initiatives and agreements are essential for addressing cross-border challenges, such as illegal, unreported, and unregulated (IUU) fishing, and promoting the conservation and sustainable use of shared fish stocks. Strengthening the enforcement of regulations and policies is also crucial for combatting illegal fishing activities, ensuring compliance with fishery management measures, and deterring harmful practices that undermine the sustainability of fisheries. Supporting small-scale fishers and aquaculture operators in adopting sustainable practices is essential for promoting inclusive and equitable development in the fisheries sector. Providing access to training, technology, and financial resources can help small-scale producers improve their productivity and environmental performance while contributing to poverty reduction and food security. Investing in research and innovation is paramount for addressing emerging issues and improving the sustainability of fisheries. Developing new technologies, such as alternative fishing gear and aquaculture systems, as well as advancing our understanding of the ecological, social, and economic dynamics of fisheries, can drive positive change and foster innovation in the industry. In conclusion, the challenges facing the fisheries industry require a multifaceted and integrated approach that addresses the complex interplay of ecological, social, and economic factors. By enhancing international cooperation, strengthening regulatory frameworks, supporting small-scale producers, and investing in research and innovation, we can work towards a more sustainable and resilient future for fisheries and the communities that depend on them.

Considering the above, it is concluded that the fisheries industry in India has pivotal in advancing sustainable development through its contributions to the economy, food security, environmental stewardship, and technological progress. By addressing challenges and promoting sustainable practices, the industry can continue to support both economic and environmental goals.

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Heat Stress: The interactome and Systems Biology

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Cattle being homoeothermic, modulate their internal body temperature in sync to environmental temperature by equilibrating the amount of heat produced within the body and dissipating it to the ambient environment. The stress that arises due to disproportionate thermodynamic behavior between cattle and its surrounding environment is termed as heat stress. Environmental induced hyperthermic stress lowers feed intake, which in turn reduces growth, milk production and reproductive efficiency, thereby negatively affecting the economics of livestock keepers. Heat stress has been associated with reduced fertility through its deleterious impact on oocyte maturation and early embryonic development5. Increased morbidity and mortality was observed in animals due to immune depressive effect of heat stress.

India has a wide variety of indigenous cattle breeds distributed throughout its agro-climatic zones. These are known for their natural tolerance to tropical heat. To meet the growing demand for milk and to combine the heat tolerance and tick resistance of zebu with the productivity of temperate dairy breeds9 several crossbreeding programs were taken up in India. Every state had its own crossbreeding policy, which is agro-climatic and breed-specific. Though the zebu crosses with European breeds produced more milk than zebu, they were found not withstanding heat/solar radiation. Crossbreds are susceptible to tropical diseases and require a constant input of good management conditions8. Antagonism exists between heat tolerance and milk productivity. The adaptive capacity to heat stress varies between species and genetic groups within species. Explaining the difference between the genetic groups (Crossbreds and Indigenous cattle) to address the physiological responses vis – a – vis heat stress can be best done through transcriptome analysis

Transcriptome analysis

1. Experimental considerations for an RNA-seq experiment

The change in biological function that can be reflected by the dysregulation of the transcriptome not only involves mRNA, but also other RNA types such as lncRNAs , miRNAs and circRNAs. The interplay among them influences RNA metabolism and in turn the biological and pathological conditions. Different types of strategies are being employed to profile the global change in different types of RNA. Considering the fact that rRNA accounts for 85% of total RNA level, under-representation of mRNA , lncRNAs , miRNAs and circRNAs is inevitable when whole transcriptome sequencing (total RNA sequencing) is carried out. To overcome this caveat, two strategies are followed - 1. Isolating the mRNA using oligodT probes attached to beads as all the mRNAs have a Poly (A) tail, and 2. Using a Ribozero Kit initially, to eliminate all the rRNA from the total RNA before sequencing. However, both the strategies have their own limitations. In the former, though all the differentially expressed mRNA could be identified, identification of differentially expressed lncRNAs is beyond the scope of this strategy. This is because some of lncRNA would not have a polyA tail (Zhang et al., 2014). This makes the later strategy an ideal choice, though, the Ribozero kits available in the market are only 60 - 70 % efficient. This strategy has enabled researchers to identify mRNA and lncRNA using appropriate tools for analysis.

In general, the integrity of RNA is critical for total RNA sequencing. The RNA integrity can be evaluated by carrying out denaturing or nondenaturing agarose gel electrophoresis. Many instruments viz. Bioanalyzer, Tapestation, Femto pulse systems, etc. based on capillary gel electrophoresis are currently in vogue to evaluate RNA integrity. RNA integrity is evaluated by a parameter called RIN (RNA Integrity Number). RIN greater than 7 is considered ideal for downstream processing and sequencing (Jahn et al., 2008). For miRNA sequencing specialized kits are used to recover pure miRNAs compatible for sequencing.

2. Data generation and platforms available for data generation

For an RNA–Seq experiment, advances in sequencing technology have led to the production of millions of relatively short reads. Illumina platforms are most commonly used for generation of RNA - Seq data. However, the introduction of BGI sequencers in the market has put forth a tough challenge. Different read lengths generated by different platforms are given in Table 1. The ideal read length for mRNA and lncRNA sequencing varies from 75bp - 150bp and for miRNA sequencing varies from 25 bp - 50 bp.

Table 1. Sequencing platforms with read length(s)

Sequencing Platform	Read lengths	Maximum Output (Million Single Reads)*
iSeq™ 100	1 × 36 bp,1 × 50 bp,1 × 75 bp, 2 × 75 bp and 2 × 150 bp	4
MiniSeq™	2 × 150 bp,2 × 75 bp,1 × 75 bp,1 × 100 bp	25
MiSeq™	2 × 25 bp, 2×150bp,2×250bp, 2×75bp,2×300bp and 2×150bp	25
NextSeq™ 500	2×150bp, 2×75bp and 1×75bp	130
NextSeq™ 550	2×150bp and 2×75bp	400
NextSeq 1000	2 × 50 bp,2 × 100 bp and 2 × 150 bp	400
NextSeq 2000	2 × 25 bp, 2 × 50 bp,2 × 100 bp and 2 × 150 bp	1100
HiSeq™ 1000	1 × 36 bp,1 × 50 bp,1 × 75 bp,2 × 75 bp and 2 × 150 bp	3000
HiSeq™1500	1 × 36 bp,2 × 50 bp and 2 × 100 bp	1000
HiSeq™ 2000	1 × 35 bp,2 × 50 bp, 2 × 100 bp and 2 × 150 bp	1500
HiSeq™ 2500	2 × 36 bp,2 × 50 bp,2 × 100 bp, and 2 × 125 bp	3000
HiSeq 3000	1 × 50 bp,2 × 75 bp, and 2 × 150 bp	2500
HiSeq 4000	1 × 50 bp,2 × 75 bp, and 2 × 150 bp	5000
HiSeq X	2 × 150 bp	6000
NovaSeq™ 6000	1 × 35 bp,2 × 50 bp, 2 × 100 bp, 2 × 150 bp and 2 × 250 bp	20000
BGI500	2 x 100 bp, 2 x 150bp	2000

*The output (Reads passing filter) varies from kit to kit used for the same platform. The output given here is the maximum output got with high output kit used on the platform

However, the main question in hand is the quantum of data that needs to be generated for an RNA seq experiment. As the quantum of data generated increases, the cost incurred per sample increases. Therefore, it is important to understand the minimum required data for proper inferences to be made from an experiment. For e.g. Assuming 2% of the genome is transcribed to mRNA, the number of bases that correspond to this 2% would be 6×10^7 bp (3×10^9 bp × 0.02). The thumb rule for a transcriptome experiment is to have a coverage of at least 50X. This means that we should have at least 3×10^9 bases (6×10^7 bp × 50) sequenced. This accounts to 3Gb (3 giga bases) of data to be generated. If the read length is 1 × 100 bp then a total of 30 million reads of 100bp each would cover 3 Gb of data ((3×10^9 bases) / 100). Therefore, it is mandatory to generate at least 3 Gb of data per sample for mRNA sequencing. However, for whole transcriptome data generation it is recommended to generate 60 million reads per sample as from the same data both the mRNA and lncRNA are identified for their differential expression. The number of samples to be considered for differential expression should be at least six for an in vitro experiment and at least 15 for an in vivo experiment.

3. Data quality check and considerations

Once the data is generated for each sample, the data needs to be checked for quality and uniqueness. The quality of the data can be checked by using the FASTQC tool (Andrews, 2010). This tool gives the basic statistics (viz Total number of reads,Read length and GC content), per base sequence quality (quality in phred score), per sequence quality score, per base sequence content, per sequence GC content, sequence length distribution, overrepresented sequences (viz. Adapter sequences), duplicate sequences and overrepresented Kmers. The uniqueness of the data is checked by calling the checksum value. This value is used to verify the validity of data, typically to make sure that any two data sets are not the same. The data so checked is then trimmed using tools like prinseq-lite or trimmomatic to remove either the adapter sequences or the bases with poor quality at the ends of the reads.

4. Differential expression analysis

The major goal of an RNA-Seq experiment is to determine which genes are differentially expressed between the treated and control. The reads generated in an RNA-Seq experiment can be used for transcript quantification, differential expression testing, reference-based gene annotation, and de novo transcript assembly. The tools for RNA-Seq analysis are categorized into, those for mapping the reads; those for assembly of transcripts and annotation of the genome; and those for quantification of transcripts and genes to arrive at differentially expressed genes (DEGs) across conditions. HISAT2 (Kim et al., 2015) in combination with Cufflinks packages (Trapnell et al., 2010) takes care of all these and gives a list of differentially expressed genes. RSEM (RNA-Seq by Expectation Maximization), is another user-friendly software package for quantifying abundances of genes and isoforms, from the data generated (Li and Dewey, 2011). The counts obtained from RSEM can be used for identifying DEGs in an RNA-Seq experiment using DEpackages viz. DESeq (Love et al., 2014), edgeR (Robinson et al., 2010), baySeq (Hardcastle and Kelly, 2010), BBSeq (Zhou et al., 2011) , EBSeq (Leng et al., 2013) etc.. The counts obtained are normalized for factors like gene length, library size and transcript composition bias to yield metrics like FPKM (Fragments per kilobase of gene length per millions of reads)/ RPKM (Reads per per kilobase of gene length per millions of reads), CPM (counts per million), TPM (Transcripts per million) and TMM (Trimmed Mean of M Values). FPKM is a term used for paired end reads and RPKM for single end reads. The detail on these metrics is given in Table 2.

Table 2. Metrics used in RNA-Seq data analysis*

Metric	Normalization	Remarks	Package that gives the parameter
RPKM/ FPKM	Library size (Sequencing depth) and gene length	• Should not be used for between sample comparisons and DE analysis • Should be used only for comparison of genes within a sample	Cufflinks and RSEM
TPM	Library size (Sequencing depth) and gene length	• Should not be used for between sample comparisons and DE analysis • Should be used only for comparison of genes within a sample	RSEM
CPM	Library size (Sequencing depth)	• Should not be used for between sample comparisons and DE analysis • Should be used only for comparison of genes within a sample	CLC genomics workbench
Size factor (Median of ratios)	Library size (Sequencing depth) and transcript composition bias	• Should not be used for comparison of genes within a sample • Should be used for between sample comparisons and DE analysis	DESeq2
TMM	Library size (Sequencing depth), transcript composition bias and gene length	• Should be used for between sample comparisons, DE analysis and for comparison of genes within a sample	EdgeR

* The ideal workflow (Figure 1) for identifying differentially expressed genes is by choosing the common differentially expressed genes (DEGs) identified across packages.

Functional annotation of differentially expressed genes (DEGs)

The first step after identification of DEGs is functional annotation of the DEGs. Gene Ontology refers to categorizing the genes into the biological processes in which they are involved; into the basic molecular function, they determine, and; into the cellular component that they are localized in. For eg., DNA polymerase is involved in the biological processes – replication; molecular function - polymerization and ; cellular component – nucleus. The functional enrichment of the differentially expressed genes in different categories (i.e Biological processes, Molecular function and Cellular component) would help in identifying the pathways and networks that are dysregulated. This functional annotation/enrichment can be done by using the DAVID (Dennis et al., 2003), g:Profiler (Reimand et al., 2007), AmiGO 2 (Carbon et al., 2009), PROSITE (Sigrist et al., 2002), PRINTS (Attwood et al., 2003), Pfam (Finn et al., 2007), ProDom (Bru et al., 2005), SMART (Letunic et al., 2006), TIGRFAMs (Haft et al., 2003), PIR superfamily (Nikolskaya et al., 2006), SUPERFAMILY (Wilson et al., 2007), Gene3D (Yeats et al., 2007), PANTHER (Mi et al., 2007), BLAST2GO (Conesa et al., 2005) and HAMAP (Lima et al., 2009), etc.

Interactome analysis

The study of interactions between the biological molecules on a comprehensive scale in the cell is otherwise called Interactome analysis. This analysis involves high-throughput mapping of protein interactions to construct protein-protein interaction networks. The topology of these networks reflects the functionality of the interacting genes thus helping the researcher to place the genes identified in microarray/RNA-seq experiments in a broader biological context. This functional grouping of interacting or coordinately induced/repressed genes, help in deciphering the roles of the subsets of co-expressed genes. This would result in framing biological hypotheses with increased confidence. The molecular interactions between transcription factors (TFs) and the genes that they regulate can also be mapped for identifying cell or tissue-specific regulatory networks.

The Biological General Repository for Interaction Datasets (BioGRID) is a curated biological database of protein-protein and genetic interactions (Stark et al., 2006). It provides a comprehensive resource of protein-protein and genetic interactions for all major model organism species. BioGRID currently holds 2005220 interactions curated from both high-throughput data sets and individual focused studies derived from over 75988 publications in the primary literature. In this repository, protein-protein interactions in humans are well defined to construct the protein-protein interaction network with the differentially expressed genes. For any other species in question, the orthologs of the DEGs in humans can be considered to fish out the interactions using customized Perl scripts. The other alternative for identifying the protein-protein interaction networks is the STRING database (Szklarczyk et al., 2019). The interactions thus obtained can be visualized in Cytoscape 3.8.2 (Shannon et al., 2003).Refer to **figure 2**.

Identification of Transcription factors, miRNA

Prediction of transcription factors binding to upstream regions of important differentially expressed genes would help in establishing a strong hypothesis for the biological question(s) in hand. As transcription factors bind upstream to the genes, the first major step towards identifying the TFs is the extraction of all the upstream regions of the genes in question. For this extraction of sequences, Ensembl database forms a very strong resource. Ensembl is a comprehensive database that provides access to an ocean of data to decode eukaryotic genomes. The upstream regions extracted from Ensembl can be fed into MEME (Multiple EM for Motif Elicitation) suite to identify common motifs across the upstream regions of the DEGs (Bailey et al., 2006). These motifs are then put into TOMTOM tool in the MEME suite that allows identification of transcription factors that bind to these motifs. TOMTOM compares the identified motif to a database of motifs in JASPAR (Fornes et al., 2020), JOLMA, Uni-PROBE (Newburger et al., 2009), etc., and finds matches.

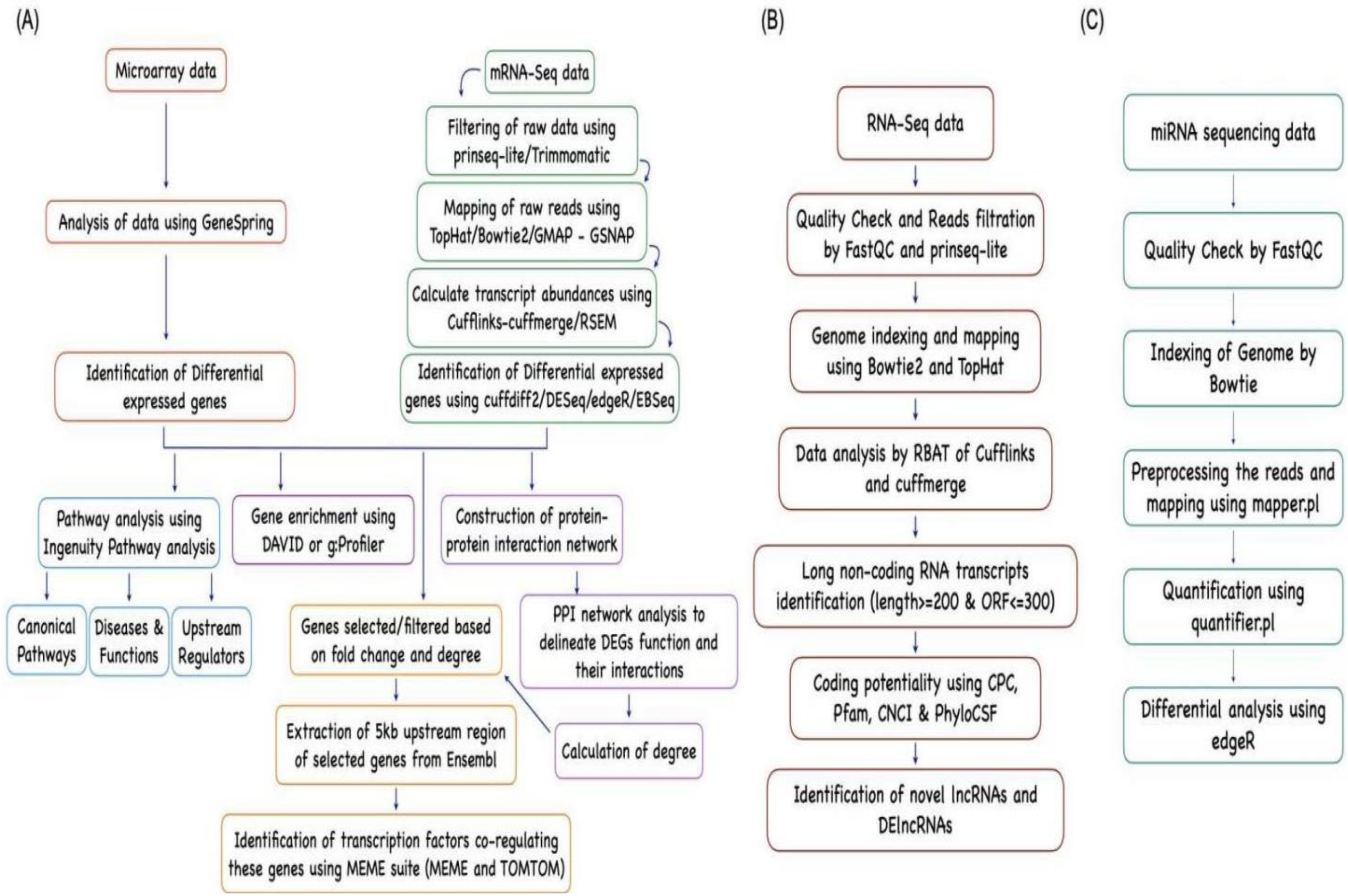

Figure 1: Workflow for the analysis of data from Microarray and RNA-Seq. (A) Data analysis pipeline for analyzing microarray and RNA-Seq data to identify dysregulated genes (B) Data analysis pipeline for analyzing RNA-Seq data to identify the dysregulated lncRNAs (C) Data analysis pipeline for analyzing miRNA-Seq data to identify the dysregulated miRNAs

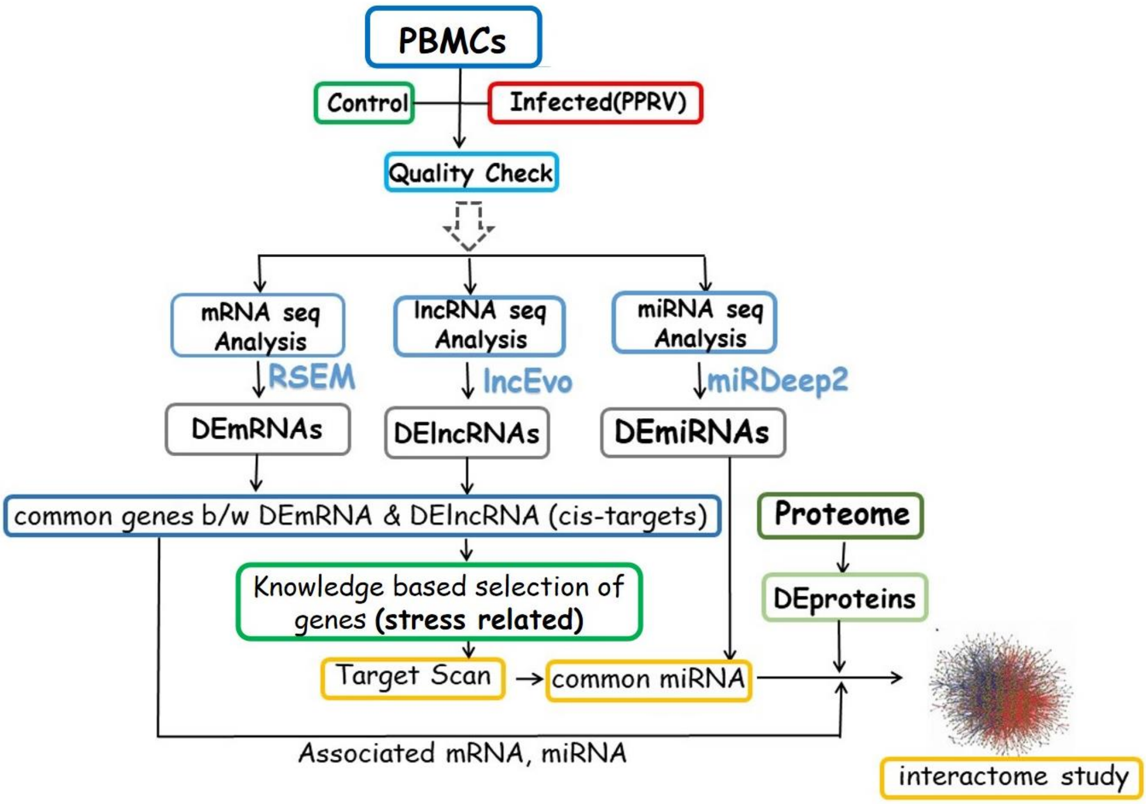

Figure 2. Interactome analysis

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