MARICULTURE IN INDIA

UNDERSTANDING ECOSYSTEMS FOR SUSTAINABLE MARINE FOOD PRODUCTION

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Mariculture In India: Understanding Ecosystems for Sustainable Marine Food Production

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FOREWORD-I

The book "Mariculture in India: Understanding Ecosystems for Sustainable Marine Food Production" emphasizes the vital role of mariculture in global economic and community development. From the coast to the deep ocean floor, marine ecosystems represent the largest habitat system on Earth. This book provides a national forum for key information, ideas, and discussion on all aspects of mariculture.

Through a rapid, thorough, and open-access publishing approach, it presents advanced research that helps readers understand marine life, interactions among organisms, ecosystem functioning, and human interactions with the oceans. The book focuses on experimental work at all levels of biological organization, including ecological modeling and ecosystem studies, both in the laboratory and in the field.

The author has organized the book into diverse chapters, including Introduction of Global Mariculture Production and Development, Present Status, and Prospects of Mariculture, providing readers with insights into the current status, challenges, and future potential of the sector. Further chapters, such as Water Resources for Sustainable Mariculture and Mariculture Pollution and Biodiversity, expand knowledge for researchers and offer guidance for addressing ecological challenges. Chapters on Management of Sustainable Mariculture and Development of Aqua Feed for Mariculture Species present key issues in aquaculture development and offer frameworks for improving sustainability from both socioeconomic and ecological perspectives.

The final chapters, Role of Biotechnology in Sustainable Mariculture and Planning and Regulation of Sustainable Mariculture, explore how biotechnology, through nutrition, feeding stimuli, chemical signals, and the reduction of in-pond chemical oxygen demand, can support sustainable practices. All articles, including original research and reviews, have undergone peer review by subject-matter experts and esteemed editors, ensuring the highest quality for the scientific community.

It is a privilege to write the foreword for this book, which thoroughly examines the structure and development of mariculture in India. The book's wide range of topics, authored by experts in their respective fields, provides a comprehensive overview of ecosystem-based, environmentally friendly mariculture practices. I firmly believe the knowledge presented here will be highly beneficial, thought-provoking, and inspirational for the entire scientific community.

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FOREWORD-II

The rapid development of animal and plant biotechnology and the numerous researches conducted under the auspices of various organizations and private industries, both in this country and abroad, make it challenging to interpret the vast amount of information that accumulates daily.

Mariculture is the cultivation of aquatic animals and plants in marine and estuarine waters. The growth of mariculture provides many social and economic opportunities as well as challenges. Improved food security, higher incomes, and increased job opportunities are some potential benefits for local communities. This book is an effort to consolidate and present the understanding of ecosystems for sustainable marine food. It is divided into eight valuable chapters covering the introduction, global mariculture production, present status, prospects of mariculture development, water resources for sustainable mariculture, mariculture pollution and biodiversity, management of sustainable mariculture, development of aquafeed for mariculture species, the role of biotechnology in sustainable mariculture, and planning and regulation of sustainable mariculture. This work aims to provide students with comprehensive information on all aspects of mariculture to support their academic careers.

As part of the commitment to promoting a healthy environment, faculty from various colleges have compiled and collated ideas from academicians and researchers on mariculture.

I wish the editors and all authors the best of luck.

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PREFACE

The oceans have long been the cradle of life, sustaining civilizations through their vast biodiversity and invaluable resources. In an era marked by rapid population growth and increasing pressure on natural resources, the need for sustainable and responsible food production from marine ecosystems has become more critical than ever. Mariculture, as an emerging scientific discipline and expanding industry, offers a promising pathway to address food security challenges while preserving the delicate balance of marine environments.

This book, ***Mariculture in India: Understanding Ecosystems for Sustainable Marine Food Production***, has been conceived to provide a comprehensive insight into the ecological, biological, and technological foundations of mariculture in the Indian context. It presents an integrated perspective on the rich marine biodiversity of India, advances in culture technologies, ecosystem-based management approaches, and the socio-economic dimensions of sustainable marine food production. The central emphasis of this work is to bridge scientific knowledge with sustainable practices, ensuring that mariculture contributes not only to nutrition and livelihoods but also to the conservation and responsible stewardship of marine ecosystems. The chapters in this book are contributed by experts who bring together their research findings and practical experiences. Collectively, they offer a valuable resource for students, researchers, academicians, policymakers, and practitioners seeking a deeper understanding of mariculture and its pivotal role in building a sustainable future.

We hope that this volume will inspire continued research, innovation, and responsible practices in marine food production systems, while reinforcing our shared responsibility to protect and sustain the ecosystems that support life. It is our firm belief that promoting sustainable mariculture in India will play a significant role in strengthening national food security, supporting economic development, and conserving marine biodiversity.

We express our sincere gratitude to all contributors, reviewers, and supporting institutions whose cooperation made this work possible. We also thank our readers for their interest and engagement with this important field of study.

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CHAPTER 1

Global Mariculture Production

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Abstract: To date, the net contribution of global mariculture to the world's fish supplies, along with the changes in this contribution, has been briefly discussed in this chapter. Primarily, the industrial sub-sector emphasizes how mariculture is integrated into the global marine food system. However, the greatest contribution to global fish production and food security has come from inland aquaculture. Although the dependency on marine ingredients persists and the reliance on terrestrial ingredients has increased, significant improvements in aquaculture feed efficiency and fish nutrition have also been made. This has resulted in a decrease in the fish-in-fish-out ratio for all fed species. This ratio is expected to increase over the next few decades as global demand for seafood rises and fisheries catch remains stagnant. The marine and brackish subsector is of particular interest for examination, as the importance of mariculture increases due to its expanding impact on global mariculture growth, as well as its recognized detrimental effects on fish populations and maritime security. The ecological services provided by the cultivation of molluscs and seaweed are becoming more widely acknowledged. These services are being quantified, valued, and developed into a market to increase production.

Keywords: Fisheries, Global, Mariculture, Production.

INTRODUCTION

The output of aquatic flora and nutrients for fish around the world has increased dramatically over the last 50 years. Mariculture is a practice that produces food for human use. It is a process in which aquatic organisms, including both plants

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and animals, are cultivated in a controlled setting using an aquatic medium that may be entirely marine or in brackish water regions, or may be a mix of marine and freshwater. To encourage the standardization of mariculture data reports, this chapter is organized by grouping global mariculture production. Mariculture is generally considered to refer to the farming of aquatic animals and plants, such as fish, molluscs, crustaceans, and aquatic plants. To increase productivity, farming often involves some type of intervention, such as frequent stocking, feeding, and predator protection [1]. A record-breaking 214 million tonnes of fisheries and mariculture products were produced in 2020, including 178 million tonnes of aquatic animals and 36 million tonnes of algae, according to the 2022 edition of The State of World Fisheries and Mariculture (SOFIA). This growth was primarily attributed to Asia. Aquatic animal production was 30% greater in 2020 than it was on average during the 2000s and more than 60% higher than it was on average during the 1990s. These results were largely the result of the record mariculture output of 87.5 million tonnes of aquatic animals [2].

AQUATIC FOOD PRODUCTION AND CONSUMPTION

Food security and nutrition are being improved more than ever by aquatic foods. Aquatic food consumption has grown globally at an average annual rate of 3.0 percent since 1961, about twice the rate of annual population growth. Consumption has more than doubled since the 1960s, reaching 20.2 kg per person. Despite the COVID-19 pandemic's impact, over 157 million tonnes, or 89 percent of aquatic animal production, were used for direct human consumption in 2020. In 2019, aquatic foods accounted for roughly 17% of the animal proteins consumed, rising to 23% in lower-middle-income countries and exceeding 50% in certain regions of Asia and Africa. Fishing and mariculture support trading, employment, and economic growth. Aquatic animal production in 2020 was projected to generate a total first-sale value of $406 billion, with approximately $265 billion from mariculture [3]. The sector employed an estimated 58.5 million individuals, of whom about 21 percent were women, according to the most recent data. It is estimated that 600 million people rely on fisheries and mariculture in some capacity for their survival. To achieve equitable and sustainable development, it is essential to build resilience [4].

INTENTIONS BEHIND THE MARICULTURE

- To increase the quantity of marine fish produced.
- Utilize open-sea cage culture, shrimp hatcheries with greater diversity, and finfish seed production.
- Molluscan farming has broadened the field of marine agriculture.

- Popularising the idea of cage culture by creating demonstration models and units, and providing traditional fishermen with training.

ASSISTANCE-PROVIDING ELEMENTS

The following elements are supported by the National Fisheries Development Board (NFDB):

FINFISH SEED PRODUCTION IN SHRIMP HATCHERIES

For various finfish species, as well as significant crustacean species, breeding and seed production technologies have been developed in response to the increased emphasis on species diversity in recent years. To meet the demand of both farmers and the market, the research institutions of the Indian Council of Agricultural Research (ICAR) have developed breeding and seed production technologies for more than 60 species of freshwater, brackish water, and marine habitats over the past six decades. The species include highly prized ones with short production cycles, system- and region-specific demand, and many are rare or unheard of by the nation's mariculture industry, making them potential farmed fish of the future. To promote species diversification in fish farming and provide avenues for increasing the income of fish farmers in response to the Doubling Farmers' Income by 2022, these technologies are documented in the current book, “ICAR Technologies for Breeding and Seed Production of Finfishes and Shellfishes.” These technological briefings were compiled using data published in several ICAR Fisheries Research Institutes as research papers and other scientific reports. It is worth noting that the individuals listed as contributors for various species may not have developed the technologies, but rather participated in their demonstration [5].

CONSTRUCTION OF AN OPEN-WATER CAGE CULTURE

One of the four culture systems—ponds, raceways, recirculating systems, and cages—can be used to raise fish. A method that confines fish or shellfish in a mesh enclosure is called a cage or net pen. By definition, the structure of a cage and a net pen differs: a net pen has a rigid frame only at the top, whereas a cage has a rigid frame surrounding the entire structure. However, the terms “cage” and “net pen” are frequently used interchangeably [6]. Despite having rigid frames, marine cages are frequently referred to as net pens and vice versa. Differences in structure have minimal impact on how these systems produce things or how they affect the environment. Fish in cage culture are kept in some sort of mesh enclosure while still utilizing available water resources, such as ponds, rivers, estuaries, and the open ocean. Fish may be fed, observed, and harvested more easily since the mesh holds the fish in place [7]. Additionally, the mesh allows

CHAPTER 2

Contemporary Status and Imminent Projections of Mariculture Advancements

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Abstract: In the contemporary world, where the demand for proteins and minerals is rapidly increasing, the need for seafood is growing substantially. However, traditional fishing methods are insufficient to meet this demand, especially with a rising population. In this context, mariculture emerges as an innovative approach that can effectively address the limitations of wild fishing. Although highly efficient, mariculture also has certain challenges that need to be addressed. This chapter discusses the current status of mariculture, with a focus on India, and the technologies that have been implemented. Furthermore, it highlights the need for further development and governance to overcome these challenges and achieve efficient mariculture practices. Beyond serving as a source of human consumption, mariculture plays a vital role in the country's economy and employment.

Keywords: Nutrition, Population, Fishing, Technology, Economy, Employment.

INTRODUCTION

Mariculture is a branch of aquaculture that involves the cultivation of food products or other commercial products in the marine environment. It can be conducted under natural conditions or through human interventions, such as cages or sea enclosures. The main products obtained through mariculture include finfishes, crustaceans, molluscs, and other non-food products, such as jewelry, cosmetics, and pharmaceuticals. Furthermore, mariculture is considered an important contributor to India's economic growth and employment. Therefore, it requires active initiatives from both government and private sectors for its further

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development. The following chapter discusses in detail its significance, methods, current status, strategies, and advancements.

MARICULTURE, THE NEED OF THE HOUR

Global demand for nutrition is rising due to a growing population. Analyses have identified that approximately 2 billion people suffer from inadequate basic nutrition, and around 1 billion lack even the minimum calorie requirements [1]. In this context, protein is a fundamental nutritional requirement, which can be obtained from grains or edible meats [2]. Marine food products are rich in protein and essential micronutrients; however, they currently contribute only about 17% of global meat consumption. Projections estimate that seafood demand will increase by 36–74% by 2050 under current scenarios [3]. Therefore, the importance of marine food products is steadily increasing.

Apart from human consumption, marine products such as seaweeds, clams, oysters, and ornamental fishes play a vital role in the production of valuable products, including pharmaceuticals, bioactive compounds, fertilizers, drugs, cosmetics, biofuels, nutraceuticals, pearls, and ornamentals [4, 5]. Given these growing demands, improved production of marine products is essential, which cannot be met through natural resources alone. Therefore, innovative technologies must be introduced to address the insufficiency of marine products and their by-products effectively. This approach has led to the development of mariculture and the implementation of advanced technologies for its further advancement.

INDIA'S GLOBAL CONTRIBUTION TOWARDS MARICULTURE

Mariculture, the practice of culturing fishes, aquatic plants, and other aquatic animals, can be carried out either in natural marine environments or in inland waters such as rivers, estuaries, lagoons, canals, and reservoirs [6]. Asia tops the list in mariculture production, with around seven countries among the top ten leading producers [5]. In particular, India, the second-largest producer after China, is highly efficient in mariculture production due to its geographical location and abundant resources.

India, which ranks among the 12 megadiverse countries, is also well known for its richness in flora and fauna [7]. Specifically, regarding marine life, it ranks at the top, comprising 3,231 species of fishes from both marine and freshwater environments, representing 9.70% of the 33,059 fish species identified worldwide [8]. Of these, 2,443 species, nearly 75.6% of the total, are classified under 230 families [9].

Approximately 10% of the global fish diversity is found in India, due to its extensive water resources from Himalayan lakes, rivers, the deep sea [10], and the Western Ghats. More significantly, the central part of the Indian Ocean is advantageous as it connects three distinct marine regions: the Indian Ocean, the Arabian Sea, and the Bay of Bengal [7]. Furthermore, India's coastline, Exclusive Economic Zone (EEZ), and continental shelf, which cover approximately 8,129 km, 2.02 million km^2, and 0.5 million km^2 respectively, contribute to an impressive fisheries yield of 3.93 million tonnes [11]. According to Lakra and Gopalakrishnan (2021), this production has further increased globally to 13.4 million tonnes in 2018–2019, including 3.7 million tonnes from marine sources and 9.7 million tonnes from inland waters. At present, the most commonly cultured species in mariculture include fishes, crustaceans, molluscs, seaweeds, and some other less common species [5]. To produce these valuable products more efficiently, various initiatives have been implemented, both technologically and through governance, schemes, and policies. However, it is widely acknowledged that all fields of innovation and implementation have their own advantages and limitations, which must be addressed to further enhance the status of mariculture.

RECENT STATUS OF INDIA IN MARICULTURE

Recently, CMFRI (2020) reported an overview of the marine fisheries status for 2020, in comparison to 2019, which is further discussed in detail.

Fish Landings of Marine Fisheries

Fish landings reflect the growth and development status of fisheries and mariculture. "Marine fish landings" refers to the quantity of fish captured, post-harvest, and brought to either international or domestic ports. In 2020, Tamil Nadu led marine fish landings, contributing 20.51% (5.59 lakh tonnes) of the total. Gujarat and Karnataka ranked second and third, with 19.51% (5.32 lakh tonnes) and 13.75% (3.75 lakh tonnes), respectively. A decline of 23.45% was observed in 2020 (2.73 million tonnes) compared to 2019. The COVID-19 pandemic was a major factor in this reduction, as marketing, sales, and distribution were severely disrupted, and fresh fish were not easily available. Marine fish landings by coastal states and the number of species are summarized in Table **1**, comparing recent years.

CHAPTER 3

Integrated Multi-Trophic Aquaculture Systems (IMTA): A Pathway Towards Achieving Sustainability

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Abstract: Sustainable mariculture is the practice of utilizing marine resources in an integrated method using technologies with economic and environmental sustainability without exploiting the natural resources needed for future generations. The growth of mariculture is doubling every decade, but the management and responsibility of those undertaking the activity to ensure sustainability are declining. The development of culture technology for marine organisms under controlled conditions in open ocean environments, beyond significant coastal influence, is a topic of the hour in mariculture. A new approach in mariculture that invites much-focused research on ensuring sustainability includes seed production technology, cost-effective feed, grow-out culture technology, and the social responsibility of stakeholders. Mariculture is the fastest-growing food-providing sector for the global population, with a minimal focus on environmentally sustainable practices regarding the degradation of coastal environments and the management of coastal resources. Integrated mariculture combines various farming methods, including Integrated Multitrophic Aquaculture (IMTA) and aquasilviculture, which involves combining mangrove planting with aquaculture. Modern integrated mariculture should be developed to facilitate the sustainable expansion of this sector in coastal and marine ecosystems, thereby addressing the global increase in seafood demand with a new paradigm of more efficient food production systems. Hence, mariculture as a whole must focus its growth on harnessing coastal resources more effectively by ensuring sustainability and the responsible use of marine resources.

Keywords: Fish production, IMTA, Mariculture, Marine resources, Sustainability.

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INTRODUCTION

With a global production of 178.5 million tonnes, the fisheries sector remains a significant contributor to the global economy. It remains a major source of food, nutrition, income, and livelihoods for millions of people worldwide [1]. The contribution of total marine fisheries production in 2018 reached its highest record at approximately 65 percent (115.2 million metric tonnes), reflecting a 3.6 percent increase over the previous year, and 63.3 million metric tonnes in global inland fisheries. It is evident that capture fisheries account for around 73 percent of the total marine production and play a vital role in meeting current demand. However, global marine fisheries production has been showing a declining trend since the 1980s, with 31 percent of stocks being overfished and 58 percent fully exploited [2], which will significantly affect the livelihoods of millions of people who depend on the sector for food, nutrition, and income. Overexploitation of resources, induced by improvements in technology, juvenile fishing, bycatch, discards, and pollution, is a major challenge in the marine fisheries sector and threatens sustainability [3]. The increase in global demand for fish protein and vulnerabilities in livelihoods and the economy have driven the discovery and adoption of coastal aquaculture and mariculture techniques and technologies for candidate species to expand marine production, offering large potential for future sustainable growth [4]. Currently, mariculture and coastal aquaculture together contribute approximately 27 percent of the total marine production (30.8 million metric tonnes) and generate USD 106.5 billion [1]. Despite the development of many production technologies for marine finfish, a lion's share of 56.2 percent (17.3 million metric tonnes) of the total production is mainly dominated by mollusks, followed by finfish (7.3 million metric tonnes) and crustaceans (5.7 million metric tonnes), which underscores the immense scope for finfish mariculture.

Asian countries are dominant players in aquaculture production, and India, with its varied resources and potential, enjoys a prominent position as the second-largest producer of fish in the world, contributing approximately 6 percent of the total production [1, 5]. However, the stagnant phase of the country's marine capture fisheries sector poses a challenge in meeting the increasing demands of the fish-eating population, which has an annual per capita fish consumption of 8-10 Kg [6]. This also threatens the livelihoods and employment of 5 million fishers [7]. Mariculture can be a viable alternative for increasing seafood production, thereby meeting the country's demand and ensuring the livelihood security and income source for coastal communities. Blessed with a coastline length of 8,118 km, a continental shelf area of 0.5 million square kilometers, and a brackish water resource of 1.16 million hectares [5], the tropical country of India offers immense potential for the expansion of mariculture activities, which could become a flourishing sector shortly. However, the country is still in its early stages when compared to the global scenario. Furthermore, in the wake of the Pradhan Mantri Matsya Sampada Yojana (PMMSY) under Atma Nirbhar Bharat, with a 20 crore package to revive the blue economy [8], offers immense potential for the expansion of mariculture activities in the country.

Marine aquaculture is a specialized branch of aquaculture that involves the cultivation of economically important marine plants and animals in the sea or other natural water bodies with tidal effects, and includes onshore facilities such as brood banks, hatcheries, nursery rearing, and growing systems using seawater [9]. Mariculture plays a crucial role among coastal communities in many developing countries, contributing significantly to livelihoods, employment, and economic growth. The earliest attempts to establish saltwater fish farms were made by the Department of Fisheries, Tamil Nadu, on Krusadai Island and in the Adyar estuary [10]. Further significant interventions and contribution from several institutes like Central Marine Fisheries Research Institute (ICAR-CMFRI), Central Institute of Brackishwater Aquaculture (ICAR-CIBA), Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), National Institute of Ocean Technology (NIOT) and the Marine Products Export Development Authority (MPEDA) have developed the mariculture of fishes, prawns, mussels, pearl oysters and sea weeds. Currently, seed production and culture technologies for a variety of finfish and shellfish species have been developed. The candidate fin fish species for mariculture includes John's snapper (*Lutjanus johnii*), Cobia (*Rachycentron canadum*), Silver pompano (*Trachinotus blochi),* Orange spotted grouper (*Epinephelus coioides*), Indian pompano (*Trachinotus mookalee*), Asian sea bass (*Lates calcarifer*), Greasy grouper (*Epinephelus tauvina*), Milk fish (*Chanos chanos*), Grey mullet (*Mugil cephalus*), and Silver moony (*Monodactylus argenteus*). The crustaceans include Indian white shrimp (*Penaeus indicus*), Green tiger shrimp (*Penaeus semisulcatus*), Mud crab (*Scylla serrata*), (*Portunus pelagicus),* Blue swimmer crab, Shovel-nosed lobster (*Thenus unimaculatus*) [11, 12]. Apart from this, the culture of seaweeds like *Gracilaria edulis, Gelidiella acerosa, Sargassum wightii, Acanthophora spicifera, Ulva lactuca*, and *Kappaphycus sp*. has developed in India. Major species of molluscs include mussels like *Perna indica* and *Perna viridis,* and clams like blood clam *(Anadara granosa)* and short neck clam (*Paphia malabarica),* Asiatic hard clam (*Meretrix meretrix) and* fertile venus *(Marcia opima), and* the edible oysters include *Crassostrea madrasensis, Crassostrea cucullata,* and *Crassostrea gryphoides* [13]. Marine pearl culture and ornamental fish culture are other potential sectors in mariculture, which could serve as a valuable source of foreign exchange. Some important species include *Pinctada fucata* and *Pinctada margaritifera*, whereas ornamental fish families include Pomacentridae *(Clownfishes and damselfishes)*, Labridae *(Wrasse)*, Scaridae *(Parrotfishes)*,

CHAPTER 4

Mariculture Pollution and Its Impacts on Biodiversity

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Abstract: Mariculture is an activity primarily focused on producing aquatic food, and many people living along the coast depend on it for their livelihood and income. Due to population growth and rising demand for seafood products, it has rapidly expanded. Maricultural activities discharge particulate organic matter, nitrogen, phosphorus, antibiotics, and hormones into the marine ecosystem. Large areas of mangrove and coastal regions have been converted into shrimp and fish ponds. It also has unintended predation impacts on non-target species. These have the potential to alter, destroy, or disrupt habitat, trophic structures, disease transmission, and genetic capabilities. As a result, mariculture affects biodiversity, which will be reflected in the supply of ecosystem services. Mariculture development must be sustained to promise economic and environmental benefits.

Keywords: Mariculture, Biodiversity, Habitat modification, Pollution.

INTRODUCTION

Mariculture is the practice of cultivating marine organisms in their natural habitats for commercial purposes. Mariculture contributes to the production of protein-rich foods, providing a source of income for millions of coastal communities. It is one of the fastest-growing food-producing sectors, offering high-quality food and being more efficient than many other food-production systems around the world.

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The nutritional importance of fish has been acknowledged since the dawn of humanity. Humans can get plenty of protein from fresh fish, which contains all of the important amino acids, minerals, and vitamins in the amounts that humans require. It also has a pleasant taste and flavor and is simple to digest.

Mariculture is dominated by unfed aquaculture of aquatic plants, bivalves, and mollusks, as well as fed aquaculture of marine finfish and shrimp. The potential interaction and conflict between mariculture activities and marine ecosystems have been a long-standing concern, with aquaculture-derived effluents being one of the most significant factors contributing to negative environmental consequences [1]. Mariculture systems generate significant volumes of effluent that may have negative environmental implications due to the recurring input of feeds, fertilizers, and chemicals required to sustain the health and growth of the culture [2, 3]. The effluent contains large amounts of organic wastes, nutrients, and chemicals, which are discharged into receiving waters, then carried through the water column and deposited on the bottom, affecting the nearby area and beyond [4, 5]. Hypoxia, eutrophication, heavy metal contamination, and habitat destruction are just a few of the problems that they can create [6]. As a result, to manage the discharge of mariculture effluents and their repercussions, adequate and rigorous regulatory measures are required [7, 8]. Habitat degradation, the collapse of wild populations, the introduction of non-indigenous species, biological pollution, and genetic effects on target species are among the most significant consequences. Additionally, social repercussions include health difficulties and the loss of employment and income for traditional fishermen.

It is well acknowledged that all forms of mariculture harm biodiversity at the species, genetic, and ecological levels. There are several viable options for avoiding the negative consequences of mariculture on biodiversity. These include effective site selection, proper environmental assessment, proper feeding protocols, improved effluent and waste control measures, enhanced genetic resource management, the establishment of seed hatcheries, reduced wild seed collection, and the enhancement of the positive effects of mariculture to reduce pressure on capture fisheries [9].

Mariculture Pollution

Due to advances in technology, the development of formulated feeds, and a deeper biological understanding of farmed species, as well as improvements in water quality within closed farm systems, rising demand for seafood products, site development, and increased government attention, mariculture has experienced rapid growth over the past two decades [10 - 12]. As a result, there has been some debate about the social and environmental consequences of mariculture [13, 14].

The degree of environmental impact, like most farming activities, is determined by factors such as the size of the farm, the species being cultivated, stock density, type of feed, the site's hydrography, and husbandry practices [15].

Cage Culture's Waste

Waste products from cage aquaculture operations in freshwater are discharged directly into aquatic habitats. These wastes can take the form of particulate debris (*e.g*., feces and uneaten feed) that fall to the benthic habitat beneath the cage arrays, or dissolved wastes that are discharged directly into the water column from fish feed, feces, and metabolic excretions. Several factors may influence the amount of waste produced, including fish size, water temperature, and aquaculture practices (*e.g*., feed composition, diet, and feeding methods). Phosphorus is typically the most limiting nutrient for algal growth in freshwater ecosystems; therefore, its release into the environment is of particular concern. Excessive phosphorus input into lakes can stimulate algal blooms, leading to harmful or nuisance growth, shoreline fouling from attached algae, and reduced oxygen levels in deeper waters.

Finfish farming may necessitate a high-protein food supply. Due to inefficient feeding regimes and poor digestibility of formulated diets, a large amount of fishmeal is wasted, resulting in low feed conservation ratios. Overfeeding primarily results in increased debris deposition on the bottom in coastal fish farms, whereas excess food goes to waste in hatcheries and land-based farms, potentially impacting the adjacent catchment and local coastal ecology. This effect is highly dependent on the settling velocity of the waste feed, as well as the current velocity and depth [16, 17].

Farm Escapees

Escapees from aquaculture operations have a negative impact on local ecosystems by causing hybridization and loss of genetic diversity in native populations, as well as increasing negative interactions such as predation, competition, disease transfer, and habitat alteration. Farmed mollusks become prominent predators and competitors in molluscan farming, potentially spreading infections and parasites [18].

Disease, Parasite Transfer, and Genetic Pollution

One of the most serious issues with mariculture is the risk of disease and parasite transmission. Aquaculture stocks are frequently selectively bred to enhance resistance to diseases and parasites, improve growth rates, and increase product quality. However, if these cultured organisms escape, they may introduce

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Disease Management for Sustainable Mariculture

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Abstract: In the fisheries sector, mariculture serves as a growing backbone for the nutritional animal producing industry. Despite the progression in the farming practices for production maximisation, loss occurs through diseases by a variety of pathogens. Hence, disease management is an important criterion that must be implemented at the proper time for the prevention of diseases and also to protect cultured organisms from pathogens. Aquatic health management requires adequate knowledge to overcome the practical problems encountered in the mariculture sector. The important pathogens are categorised into major groups such as viruses, bacteria, fungi, and parasites. The viral diseases in the mariculture environment predominate with the iridoviral disease, lymphocystis disease, nervous necrosis virus disease, and rhabdoviral disease. The major bacterial diseases encountered include vibriosis, winter ulcer, photobacteriosis, and furunculosis. One of the leading causes of other infections in the saline aquaculture practices is parasites, especially in cage cultures. Disease clearance requires some practical prophylactic and therapeutic actions to eradicate them. Disease treatments using chemicals cause various problems to the fish by settling as residues in the body, polluting the environment or harms the other organisms in the surrounding environment. To avoid this and to effectively eradicate the problematic organisms, some new environmentally friendly measures can be taken to control the pathogens from the mariculture environment. Therefore, the drawbacks of using chemicals for treatments can be reduced, and better results can be expected to ensure a sustainable mariculture environment.

Keywords: Bacteria, Disease management, Parasites, Pathogen, Therapeutics.

INTRODUCTION

Globally, the disease occurrence in the mariculture environment is continuously increasing with an immediate downward effect on the wellness of the culture organisms [1]. The causative agents of the diseases are broadly categorised as bacteria, viruses, fungi, and parasites (Fig. **1**). Though fungal disease outbreaks

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are not well documented in the mariculture environments, the sporadic occurrences of significant oomycete outbreaks are unavoidable in the natural settings, which require additional research insight in the field to gain a better understanding [2]. Bacterial pathogens are one of the significant causes of production loss in the culture systems along with viral disease outbreaks. The acute viral outbreaks may result in total crop loss by causing sudden mortality of the culture organisms. Hence adequate management and preventive strategies must be employed to prevent and to overcome the disease outbreak situation. Parasitic infestations are a significant problem encountered in all the marine cage cultured areas [3]. Parasites have found the culture environment as a suitable place of attachment [4], and the severity of the infestation compels the aquaculturist to use chemical remedies which need to be chosen carefully after consideration, as this may affect the surrounding environment and the associated organisms [5]. Proper discarding of the used products, other chemicals, and wastes must be ensured to avoid future issues with the environment and ecosystem thereof.

The condition of disease is regarded as the outcome of a complex interaction between the host, pathogen, and the environment as these components interplay among themselves [6]. The factors of the pathogen contributing to disease severity include the ability to persist, zoonotic nature, host specificity, host range, virulence, attachment, colonisation, presence of toxins, and variance of infectivity of the genotype. Various environmental factors contribute to the predisposition of diseases such as water quality parameters, climate, and meteorology. The host-associated factors of disease occurrence include life stage, genetic factors, immune impairment, incorrect diet, and stress [7]. Production costs are found to be high due to disease outbreaks. Disease outbreaks are challenging to be avoided entirely in mariculture but can be inhibited, and incidence can be minimised. There are two broad classifications of diseases based on the cause, such as infectious diseases caused by pathogenic organisms and non-infectious diseases. Various stress factors depress the fish's immune system, which in turn encourages the numbers of opportunistic pathogens [6].

Stress can have apparent effects on the health of fishes. Stress can appear in many forms such as dietary stress due to inappropriate diet and feeding schemes, environmental stress, and physical stress attendant to handling, or confinement. The environmental stress factors can be categorised as physical, chemical, procedural, and biological [7]. The unfavourable environmental conditions which cause severe stress in fish include overcrowding, sub-lethal levels of toxic materials, temperature fluctuations, low dissolved oxygen, salinity fluctuations, high concentrations of obnoxious gases like hydrogen sulfide and ammonia, excessive or rough handling, *etc* [7]. Crowding is the most important predisposing factor for disease as it creates plenty of communal pressure among the competing fish species for dissolved oxygen, food, and space. Massive crowding facilitates the horizontal transmission of contagious diseases by various means. These types of pressures are inescapable in concentrated fish farming. Long-lasting experience of stress or even very brief stressful situations can lower specific cellular and humoral aspects of the immune system, thereby lowering resistance to pathogens [7]. Once stress is experienced, a flow of neuroendocrine actions occurs, leading to the rise of the steroid stress hormone, cortisol. The cortisol along with another stress hormone such as catecholamines can reduce the performance of the immune system which is carried out by reducing the number and distribution of circulating leukocytes, depressing the macrophage activity, and reducing the number of immunoglobulin-producing cells [7].

BACTERIAL DISEASES

Bacterial diseases in the marine environment are caused by various pathogens [8], such as *Renibacterium salmoninarum, Lactococcus, Streptococcus* [9], *Piscirickettsia salmonis, Pasteurella piscida, Yersinia ruckeri, Staphylococcus epidermis, Nocardia asteroids, N. campuchi,* and *Clostridium* sp [10, 11]. The most significant bacterial diseases, like vibriosis [12], winter ulcer, photobacteriosis [13], furunculosis, marine flexibacteriosis, pseudomonadiasis, edwardsiellosis, and mycobacteriosis [14] are described briefly.

Vibriosis

Vibrio spp. are the most important bacterial pathogens [15], ubiquitously distributed in the marine and estuarine culture systems causing 'salt-water furunculosis' with seasonal dynamics in population [14]. There are numerous species which are associated with pathogenicities such as *V. harveyi* [16], *V. anguillarum, V. spendidus, V. penaecida, V. alginolyticus* [17], *V. parahaemolyticus,* and *V. vulnificus* [12, 18]. The Vibrio infected fish show clinical symptoms [19], such as pale gills, dark skin, slow growth, necrosis of skin and appendages, haemorrhages at the base of fins, skin ulcers, exophthalmia, corneal opacity, internal organ liquefaction, body malformation, enteritis, blindness, muscle opacity, and splenomegaly [10].

Winter Ulcer

Characteristics of the disease include skin ulcers confined to scaled body surfaces and often petechial bleeding in internal organs [10]. Although mortality is limited, the market price of the affected fish is reduced [18]. The disease is caused by a psychrotrophic bacterial species referred to as *Moritella viscosa*. The bacterium has the thread-forming ability with adherent colonies in culture media [14].

CHAPTER 6

Developmental Trends in Aquafeed for Mariculture Species

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Abstract: Fish play a crucial role in ensuring global food security, particularly in developing countries, where the demand for additional protein sources continues to rise alongside population growth. Aquaculture, the fastest-growing sector in food production, focuses on the breeding and rearing of fish and other aquatic species. Within this industry, fish nutrition and feeding are critical for sustainable growth and overall productivity. The use of feed ingredients that support growth while providing a balanced supply of essential nutrients is fundamental to maintaining healthy fish and, by extension, healthy consumers. Scientific research has significantly advanced the development and efficacy of aquafeeds, ensuring that both farmed and wild fish receive optimal levels of essential nutrients, including vitamins, fatty acids, and amino acids, to maximize growth, health, and survival. Freshly formed resources include macroalgae, transgenic-raised, HUFA-producing plants, and microorganism biomass. Newly explored feed resources include herbivorous zooplankton, such as Antarctic krill, and various plant-based ingredients. Incorporating these resources can help shift carnivorous species toward lower trophic-level diets, thereby enhancing production efficiency and product quality. While these ingredients contribute, to some extent, to human nutrition, the long-term goal of mariculture in the 21st century is to rear carnivorous fish primarily on plant-based resources. The aquaculture industry has significant potential to reduce its reliance on conventional fishmeal. Improvements in feed composition and nutritional efficiency can lead to higher fish yields, lower feed costs, and reduced waste, ultimately decreasing the environmental nutrient load associated with intensive fish farming.

Keywords: Aquaculture, Aquafeed, Fish farming, HUFA, Mariculture.

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INTRODUCTION

Aquaculture is expanding rapidly worldwide, driving increased interest in the use of compound aquafeeds and alternative external feed inputs. Changes in feed ingredients, marketing strategies, and production technologies represent key structural developments necessary for the sustainable growth of the aquaculture industry [1]. The conversion of agriculturally derived raw materials into feed is primarily managed by the aquafeed sector, which plays a critical role both nutritionally and economically. These feed units serve as the main source of animal and plant proteins essential for the proper growth of cultured species. A wide range of professionals is involved in this sector, including process engineers, economists, marketing specialists, aquaculture scientists, regulatory experts, quality control technicians, and logistics personnel. Since feed accounts for 50-60% of the total production cost in aquaculture, even small reductions in feed prices can significantly impact overall costs and profitability. Most feed ingredients have inherent nutritional and functional limitations and cannot be used in isolation at high inclusion levels for most cultured species. Therefore, aquafeed formulation requires the careful combination of multiple ingredients. To maintain profitability, farmers often rely on locally available raw material substitutes when preparing aquafeeds. However, factors such as ingredient availability, seasonal production, market prices, and processing capabilities present challenges to feed formulation. As a result, designing an optimal aquafeed formula is a critical step in the successful development of the aquaculture sector.

Since 1950, the human population and global food demand have increased dramatically. Agricultural production expanded from over 3,000 million metric tonnes in 1961 to roughly 7,000 million metric tonnes in 2010, growing at a rate slightly faster than population growth. However, land use for agriculture increased by only about 10%, from approximately 4,500 million hectares in 1961 to around 5,000 million hectares in 2010, with the primary driver of production growth being agricultural intensification [2]. Fisheries play a critical role in the global food system, providing about 2% of the world's protein consumption. As the global population continues to rise, so does the demand for fish products. Overfishing has become a major concern, and production from global capture fisheries has fluctuated annually without showing significant growth since the mid-1980s.

Currently, 8-9% of the global human protein intake from animal sources is supplied by aquaculture, which also provides nearly half of the world's fisheries production for human consumption. By the end of the century, the global population is projected to exceed ten billion, up from the current estimate of approximately 7.2 billion, with most of this growth occurring over the next forty years. As capture fisheries are not expected to expand—and may even decline—aquaculture production will need to meet the increasing demand for fish and other aquatic products. In its simplest form, animal aquaculture produces shrimp, fish, or other aquatic species that rely on naturally available food sources. However, natural productivity in these systems is often limited, so industrial chemical fertilizers or organic waste by-products are commonly used to enhance the availability of food for cultured animals.

The use of high-quality, formulated feed that is readily consumed by cultured animals can substantially increase productivity. When mechanical aeration is applied to supplement existing sources of dissolved oxygen, both feed utilization and overall production are further enhanced. For example, penaeid shrimp yields in unfertilized ponds are typically 200-300 kg/ha, whereas yields in fertilized ponds can range from 400 to 800 kg/ha. Feeding alone can increase shrimp yields to 1500-2000 kg/ha, provided dissolved oxygen levels do not become limiting. In ponds equipped with both feeding and mechanical aeration, yields can reach up to 10,000 kg/ha [3, 4]. Aquaculture often faces limitations in land and water availability, which has driven a trend toward intensification, similar to practices observed in terrestrial agriculture. For instance, farm yields of ictalurid catfish in the southern United States averaged around 1,500-1,800 kg/ha in the 1960s, gradually increasing to approximately 5,000 kg/ha by 2012. This growth has been driven by improved feed formulations, higher feeding rates, and the development of more efficient aeration systems [5].

A feed input was employed in approximately one-third of aquaculture production systems in 2012, up from about one-third of systems in 1980, according to the UN (2012). The production of aquaculture feeds reached 34.4 million tonnes in 2012 [6]. Although this is small compared to ruminant and poultry feed, which totaled 418 million tonnes, global production of fish through aquaculture and capture is significant. Feed production for aquaculture (34.4 million tonnes) and for even-toed ungulates (218 million tonnes) represents an important industry with substantial potential for future growth. Aquaculture feed contains similar components to feed for other animals, with the majority of ingredients derived from capture fisheries or agriculture, which are then processed before being sent to a feed mill for aquafeed production. Additionally, some ingredients are by-products or leftovers from fishing and agricultural activities.

FEED INGREDIENTS

Utilizing locally available raw materials as ingredients in aquaculture feed enhances resource efficiency and supports the potential for increased aquaculture

CHAPTER 7

Role of Biotechnology in Sustainable Mariculture

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Abstract: Marine biotechnology in pharmaceutical and food industries is a growing sector supported by expanding reach and financial resources worldwide. This study evaluates 620 publications and 29 projects, identifying the most promising technologies and business trends to advance materials development and improve performance. Omics, drug evaluation, and bioinformatics technologies are driving medical research and are considered essential tools to develop novel materials and candidate organisms for commercial applications. Techniques to optimize living conditions, harvesting, and purification methods, combined with recombinant technologies, are important to maximize commercial and industrial use, particularly in food and nutraceutical programs. Growth in this sector has been driven by increasing consumer demand for healthy ingredients that provide sustained health benefits, along with less stringent regulations compared to pharmaceutical products. Although this review has several limitations—particularly the author's subjectivity in classifying publications and an imperfect selection of projects analyzed—it offers insights into trends most relevant in Europe. It does not provide a fully quantitative assessment of the current literature in drug and food applications, but it highlights the development of basic research and its implementation during the period. As such, promoting evidence-based strategy creation is the primary recommendation for overcoming barriers that limit seafood commercialization.

Keywords: Aquaculture, Biotechnology, Food security, Public health, Sustainable development.

INTRODUCTION

Biotechnology is an important tool for the sustainable use of marine resources, as a series of cognitive and technological limitations hinders its full potential. Using a modern systematic approach that combines meta-analysis of 620 globally published items with 29 TRL (Technology Readiness Level) assessments from

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EU-funded projects, this study focuses on evaluating the development opportunities of marine biotechnologies for pharmaceutical and nutraceutical applications, with an emphasis on technologies that address the major challenges in the commercialization of seafood products. The results show a trend of significant quality improvement, with rates more than doubling between 2010 and 2019. Biochemical and molecular characterization, represented in 150 studies, is a well-established technology. Emerging technologies in fundamental research include omics, drug evaluation, and bioinformatics, each of which has doubled in application over the last five years.

In contrast, technologies to optimize cultivation, harvesting, and extraction conditions are crucial for maximizing commercial potential, with 65% of the high TRL projects targeting immediate industrial exploitation, particularly in food and nutraceutical applications. This chapter provides preliminary guidance for studies aimed at overcoming restrictions that limit the marketing of organism-derived products. General trends in the development of aquaculture include (Subasinghe, 2007): (i) Continuing intensification of aquaculture production, (ii) Continuing diversification of species used, (iii) Continuing diversification of production structures and practices, (iv) Increasing market influence and consumer demand, (v) Enhancing regulations and governance in the sector, and (vi) Growing interest in higher control over production environments.

Aquaculture production is expected to increase, but the question remains whether it will grow sustainably and rapidly enough to meet demand while maintaining fish stocks. Biotechnology plays a key role in addressing this global challenge by supporting sustainable aquaculture development, economic and social progress, and environmental security worldwide. The application of biotechnology to the production of aquatic species has significant potential to improve aquaculture and meet the growing demand for aquatic food. As production of aquatic products increases, environmentally friendly strategies must be implemented to enhance productivity and improve product quality. At the same time, biotechnology contributes significantly to disease resistance and the rising value of aquatic species. By using disease-resistance genes, biotechnology reduces dependence on chemicals, particularly antibiotics, promoting sustainable aquaculture. It also provides effective tools to improve the health and safety of wild and farmed aquatic species, especially by increasing the proportion of fish suitable for commercial aquaculture.

Additionally, biotechnology allows the production of species in larger batches per unit area, reduces costs, supports biodiversity and critical ecosystems, and mitigates environmentally harmful aquaculture practices. However, the development of marine biotechnology in new areas faces challenges. Although several marine-derived products have been successfully commercialized through established technologies, the field remains marginal and underdeveloped in European and global markets. For the purposes of this chapter, the main challenges for advancing this industry and promoting new products are divided into three categories: discovering novel products, achieving sustainable production, and enhancing product performance and characteristics.

SUSTAINABLE PRODUCTION

When using marine organisms to produce valuable materials and biofuels, the vulnerability of marine ecosystems must be considered. Ready-to-use materials from marine organisms are often unsustainable for commercial applications due to the limited availability of some species. Many species are threatened, and overexploitation can destabilize fragile ecosystems, highlighting the need for alternative approaches. Traditional chemical and microbiological methods, including chemical combination or semi-synthesis, often have significant ecological impacts, particularly due to the use of toxic solvents and generation of large amounts of waste. Researchers and industrial operations in marine biotechnology must overcome these challenges by developing greener technologies [1].

Sustainable aquaculture strategies, including the cultivation of marine organisms such as corals and sponges, represent eco-friendly approaches, as these organisms provide important raw materials without further destabilizing marine ecosystems [2]. The environmental impact of producing bioactive compounds from marine organisms is often exacerbated by traditional production methods. For example, conventional microalgae production is energy-intensive, generates significant waste, and can account for up to 80% of total production costs. Expanding downstream capabilities through marine biotechnology provides a solution to these challenges [3].

Sustainable production can also leverage fishery waste to obtain high-value materials. Fish processing byproducts create significant waste—often exceeding 1,000 tons annually—which raises environmental and disposal concerns. The biochemical richness of this waste allows its conversion into valuable products through biotechnological methods, including protein hydrolysates with antioxidant properties or biomaterials such as collagen [4]. This approach reduces waste while providing a direct source of bioactive materials.

Moreover, the integration of green enzymatic processes in food production aims to reduce the use of toxic chemicals and synthetic reactions. Recently, nanoparticles have been developed for chemical, physical, and biomedical applications. Using algae or microorganisms as a production platform offers a

CHAPTER 8

Planning and Regulation of Sustainable Mariculture

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Abstract: India is viewed as a promising landscape for expanding mariculture and addressing the numerous challenges faced by the food industry. Despite the many benefits of India's green, blue, and silver revolutions, intensive aquaculture techniques have raised environmental concerns in aquatic environments, causing significant concern. Improved farm management practices, integrated farming, selective chemical usage, proper disease management, the development of low-cost and novel technologies, technology transfer for feed management, and other methods could help mariculture achieve long-term sustainability.

Keywords: Mariculture, Planning, Regulation, Sustainability.

INTRODUCTION

Aquaculture is a specialized form of farming that involves the controlled or semi-controlled cultivation of marine organisms for food and other purposes in coastal and offshore waters. Potentially cultivated species in India include fish, crustaceans, molluscs, algae, and ornamental fish. The development of aquaculture in India is gaining significant momentum, thanks to innovative technologies. However, environmentally friendly approaches must be adopted when striving to improve and expand the field. Aquaculture should be practiced as part of sustainable development. Sustainable polyculture is the technique of raising two or more compatible aquatic species in a single pond or lake, with the aim of increasing production by utilizing organisms with different feeding habits or spatial distributions [1]. Traditionally, mariculture has taken place at the interface of land and sea, in tidal flats, estuaries, and sheltered bays. Although

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calm waters and easy access make nearshore mariculture attractive, environmental impacts and conflicts with other uses have increased in these increasingly populated coastal areas. Advances in technology and farming methods have allowed farms to be established far from the coast and in harsher ocean conditions, opening up new potential aquaculture areas [2, 3]. Offshore aquaculture promises to increase seafood supply and serve as a new source of economic development.

ENVIRONMENTAL MONITORING PLANS

This plan outlines the mitigation, management, and monitoring methods to be applied during project development and operation to reduce or eliminate negative environmental impacts to a manageable level. By allocating the necessary funds, it ensures that environmental factors are safeguarded throughout various activities in the production process. It also provides for periodic monitoring of vital parameters, employee health, and all required safety and environmental measures. The committee ensures that management communicates relevant environmental factors and impacts to the implementation teams and members of the Environmental Health and Safety (EHS) unit in a clear and organized manner, without omitting any important information. This process helps clarify and streamline the EHS unit's role.

INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA)

Integrated Multitrophic Aquaculture (IMTA) involves farming species at different trophic levels in close proximity, with complementary ecosystem functions. In this system, the food, waste, nutrients, and by-products of one species are utilized and converted into fertilizer, feed, and energy for other species. It also takes advantage of synergistic interactions between species while providing biological attenuation. Algae and aquatic plants, which remove dissolved inorganic nutrients, along with shellfish and other invertebrates, which remove organic particulate nutrients for growth, are examples of extractive species cultivated alongside fed species such as shrimp and fish. The aim is to design hydroponic systems that extend natural organic management, support economic stability by increasing production, reducing costs, diversifying products, minimizing risks, and creating new job opportunities, as well as promoting social acceptance.

SUSTAINABLE FEED MANAGEMENT

The goal of food management in aquaponic systems is to provide fish and plants with appropriate nutrition while controlling input costs and minimizing pollutants. Effective food management involves determining when and how often to feed, how much to provide, and the most efficient feeding methods. While nutrition is a key factor in feed planning, optimal feed management also has a substantial impact on production costs and the overall health of the system. Feed costs and environmental impacts are therefore critical considerations in dietary management.

SUSTAINABLE USE OF CHEMICALS

The use of chemotherapy, synthetic compounds, and various drugs has been introduced in Indian aquaculture. Numerous products are employed for diverse purposes, including soil and water treatment chemicals, disinfectants, piscicides, herbicides, natural and synthetic fertilizers, food additives, therapeutic drugs, and sedatives. Methods involving synthetic materials carry potential hazards and impacts associated with the use of these compounds. Various disease management strategies—such as habitat planning, vegetation density control, and effective treatment frameworks—are reviewed, along with public guidelines on the safe use of these compounds. Research on aquaculture systems and chemical applications in India is ongoing. Suggestions for improved and responsible use of synthetic compounds in Indian aquaculture are being sought by breeders, government agencies, aquaculture organizations, the chemical industry, local and international bodies, and recognized research institutions.

PRECISION FISH FARMING

This type of fish farming utilizes various sensors to collect data on the farm's environmental conditions, enabling informed decisions that enhance fish welfare, growth, and financial performance while mitigating climate-related risks. These technological advances have also influenced horticulture, where sensors and related innovations enhance knowledge of plant health and receive government support for agricultural development [4]. Traditionally, many of these processes have relied heavily on human intervention and farmers' expertise to make the right decisions and take appropriate action. However, as farm sizes grow and operations expand, automation becomes essential for maintaining economic viability. Wireless communication systems are particularly important, as fish farms often include extensive chains, ropes, anchors, and other submerged equipment. Additionally, the industry's fragmented structure—characterized by numerous small-scale aquaculture companies and sensor suppliers—creates challenges in integrating diverse and sometimes proprietary data sets into a unified edge-fog-cloud ecosystem.

DISEASE MANAGEMENT

Successful fish health management begins with disease prevention rather than treatment. Effective prevention requires proper water quality management,

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G. Chelladurai

Dr. G. Chelladurai is an Assistant Professor of Zoology, St. Joseph's College (Autonomous), Tiruchirappalli, TamilNadu, India. He has a strong background in molluscan culture and conservation research. He has analysed and reported on the biodiversity of the mollusan population (Endangered and Endemic species) available in the Gulf of Mannar Bioreserve (GOMBR). Furthermore, his doctoral research focuses on the immunostimulatory activity of certain medicinal mushrooms in inducing an immune response in lab-reared economically important marine mollusks to combat aquatic pathogens such as Aeromonas hydrophila. He has also contributed to marine species conservation, especially molluscan species (Gastopods) by using the sea ranching strategy. He worked on an Indian National Centre for Ocean Information Science (INCOIS) project related to monitoring and locating fishing rich areas and a satellite mediated tsunami warning system by a wave rider buoy system. He has coordinated numerous awareness programs for students, researchers, and fishermen about marine ecosystem conservation and management. He has published 80 research papers on aquaculture, molluscan research, and the development of immunostimulants for molluscs and aquaculture species, as well as 12 books with ISBNs and 22 book chapters. He serves as a journal reviewer such as the Journal of critical reviews, International Journal of Arts and Science, Fisheries Open access, Journal of Biochemistry Research and the African journal of Microbiological Research. He possesses membership of the Indian Science Congress, the Ocean Future Society, the International Society of Zoological Science and the Tamil Nadu Environmental Council. He recently received three Young Scientist awards from national organizations. He has received two research projects funded by TNSCST, the government of Tamil Nadu, and five research grants received from the government and private organizations.

M. Paripooranaselvi

Dr. M. Paripooranaselvi is an Assistant Professor in the Department of Zoology at St. Mary's College (Autonomous), Tuticorin, TamilNadu. She holds M.Sc., M.Phil., B.Ed., Ph.D., and SET qualifications, with a specialization in Ascidian Pharmacology. Her research includes studies on ascidian-derived nanoparticles and their potential pharmacological applications. She has actively participated in and presented numerous national and international seminars, conferences, and faculty development programmes. Her scholarly contributions include 34 research publications in reputed journals and 8 book chapters on marine pharmacology and environmental sciences. Dr. Paripooranaselvi has organized and guided several training programmes, field visits and student research initiatives in marine biology. Her teaching blends academic rigor with practical exposure, inspiring young minds to explore science with creativity. She is committed to promoting sustainable marine resource utilization and eco-friendly innovations. She has received a research project funded by the Tamil Nadu State Council for Science and Technology. With her dedication to research, teaching, and community service, she continues to contribute meaningfully to science and society.

B. Makesh Kumar

Dr. B. Makesh Kumar Associate Professor of Botany and Director at G.Venkataswamy Nadu College (Autonomous), Kovilpatti. TamilNadu, India. He brings with him 18 years of rich teaching experience and over 25 years of dedicated research experience in the field of Botany. A committed academician and administrator, Dr. Makesh Kumar has played a key role in advancing academic quality and institutional effectiveness. His contributions to both research and higher education have been instrumental in nurturing young minds and promoting academic excellence.