Mariculture Technologies - Recent Advancement for Sustainable Production

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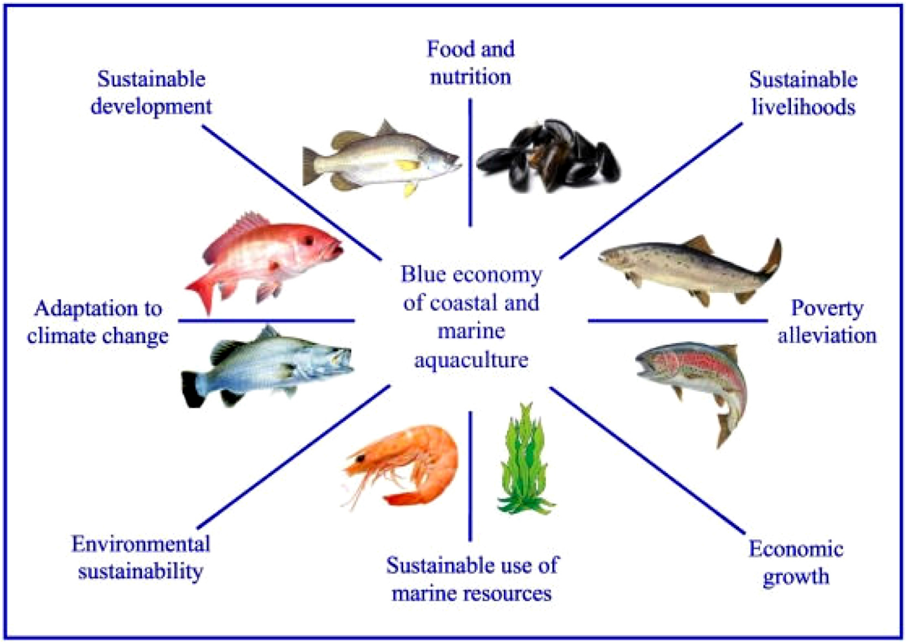
Introduction

Mariculture has been defined as the cultivation, management, and harvesting of marine organisms in their natural environment (including estuarine, brackish, coastal, and offshore waters) or in enclosures such as pens, tanks, or channels. Mariculture has become an inevitable and important producer of aquatic food in coastal areas and is one of the major sources of employment and income for many coastal communities. Well-planned and managed mariculture can contribute positively to coastal environmental integrity and enhanced production. However, mariculture's future development will occur in many areas, with increasing pressure on coastal resources caused by rising populations, and increasing competition for resources. Thus, considerable attention is necessary to improve the environmental management of aquaculture through environmentally sound technology and better management, supported by effective policy and planning strategies and legislation.

Mariculture started by catching wild juveniles and feeding them in a controlled environment. As more knowledge was gained, the degree of control with the production process increased and the farmers increased their influence on growth and reproduction. The degree of control is often categorized by the intensity of the farming operation. Traditional, extensive, semi-intensive, and intensive are the existing farming practices (Quentin et al., 2010). Mussel farming is an example of an extensive method of mariculture used around the globe, whereby the farmer provides a rope or a stake for the juveniles to attach to and undertakes to cull so that the density does not get too high, but otherwise leaves the mussels to grow without further interference. Mariculture and coastal aquaculture collectively produced 30.8 million tonnes (USD 106.5 billion) of aquatic animals in 2018. Despite technological developments in marine finfish aquaculture, marine, and coastal aquaculture produce currently many more molluscs than finfish and crustaceans.

In 2018, shelled molluscs (17.3 million tonnes) represented 56.2 percent of the production of marine and coastal aquaculture. Finfish (7.3 million tonnes) and crustaceans (5.7 million tonnes) taken together were responsible for 42.5 percent. The enhanced production through mariculture has been achieved through the development of environment friendly, cost effective, and high production technologies. Some of the noted and well-developed mariculture technologies are being followed across the world are Sea cage farming, marine finfish culture in coastal ponds, marine finfish hatcheries, fish farming in pens, bivalve culture, seaweed culture, Integrated Multi- tropic Aquaculture and Precision fish farming in mariculture(Joseph and Augustine, 2020). The different mariculture technologies adopted have helped to attain to the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of the ocean ecosystem (Fig.1)



Sea cage farming

High-density, low-volume system with maximum production in unit area than in any other culture systems. Sea cage farming has been expanding in recent years on a global basis and it is viewed by many stakeholders in the industry as the aquaculture system of the millennium. Cage culture has made possible the large-scale production of commercial finfish in many parts of the world and can be considered as the most efficient and economical way of augmenting fish. The rapid growth of the industry across the globe is attributed to (i) the availability of suitable sites for cage culture (ii) well-established breeding techniques that yield a sufficient quantity of various marine fish juveniles (iii) the availability of supporting industries such and feed, net manufactures, fish processors etc. (iv) strong research and development initiatives from institutions, governments and universities and (v) the private sector ensuring refinement and improvement of techniques/ culture systems, thereby further developing the industry. Industrial marine fish farming is a relatively young phenomenon but has grown to be a major industry in many regions of the world, producing some 6.6 million tons of fish per year. The standard production units, sea-cage fish farms, are variations on a common theme, floating, surface-based structures holding large nets that contain thousands to hundreds of thousands of fish. The major species produced using the mariculture technology are the Atlantic salmon, *Salmo salar* (2.44 million metric tonnes), and 0.767 million metric tonnes of other marine fin fishes including different species of breams, snapper, seabass, grouper, pompanos, etc (FAO, 2022). In India, ICAR-CMFRI, has developed sea cage farming technology for different species such as cobia, Indian pompano, silver pompano, orange-spotted grouper, Asian seabass, and snapper, etc

Marine coastal pond culture

Coastal aquaculture plays an important role in livelihoods, employment, and local economic development among coastal communities in many developing countries. It is practiced in completely or partially artificial structures in areas adjacent to the sea, such as coastal ponds and gated lagoons. In coastal aquaculture with saline water, the salinity is less stable than in mariculture because of rainfall or evaporation, depending on the season and location. Although coastal ponds for aquaculture, modern or traditional are found in almost all regions in the world, they are far more concentrated in South, Southeast, and East Asia and Latin America for raising crustaceans, finfish, molluscs and, to a lesser extent, seaweeds. Many Asian countries, and more recently, Latin American, European and North American countries have developed their expertise and support institutions for marine and coastal aquaculture. The more popular species for culture in marine ponds are the sea bass, grouper, red sea bream, yellowtail, rabbitfish, and marine shrimps. In Asia, where the bulk of world production from aquaculture emanates, fish ponds are mostly freshwater or brackishwater, and rarely marine. In India, coastal pond farming has been well standardised for species such as Asian Seabass, Indian pompano, orange-spotted grouper, milkfish, and mullet, etc.

Marine finfish hatcheries

Hatcheries are land-based seed production units, set up in a protected environment. A fish hatchery is a place for artificial breeding, hatching, and rearing through the early life stages of animals. The output of a hatchery is normally fry, fingerlings, or juveniles. These hatcheries are used to produce seeds of marine finfish in larger quantities for a sustainable manner. The facility at the hatchery is designed to cultivate and breed a large number of fish in an enclosed artificial environment. It provides for fish eggs to develop and hatch by maintaining proper water temperature, oxygen levels, disease control, food and protection from predators. Marine finfish hatchery components is having different units, which include broodstock holding tanks, larval rearing units, Live feed culture units for mass production of phytoplankton and zooplanktons. Broodstock holding tank in the hatchery are used for various purposes such as for broodstock-conditioning, and subsequent spawning and incubation. Seawater intake system, water supply system and aeration systems are additional supporting systems helping for effective functioning of the hatchery unit. Hatchery technology has been well-standardised for different candidate species of marine fin fish and at least 130 species of marine finfish have been trialled or routinely produced in hatcheries for their regular supply in different parts of the world. Number of species and different family, the seed production technology standardised are as follows.

Family (-ies)	No. of species
Latidae, Percichthyidae, Haemulidae	11
Lutjanidae, Lethrinidae	11
Groupers	26
Sparidae	10
Sciaenidae	7
Carangidae	13
Others	52
Total	**130**

(Resource: Micheal A Rimmer, 2015)

Understanding the importance of the mariculture potential in India, ICAR research institutions, such as Central Marine Fisheries Research Institute and Central Institute of Brackish Water Aquaculture had initiated different mariculture programmes and has developed seed production and farming technologies of different species including Cobia (*Rachycentron canadum*), Orange-spotted grouper (*Epinephelus coioides*), Silver pompano (*Trachinotus blochii*), Indian pompano (*T. mookalee*), Pink-ear sea bream (*Lethrinus lentjan*), banded grunter (*Pomadasys furcatus*), John's snapper (*Lutjanus johnii*), Vermiculated spine foot (*Siganus vermiculatus*) and picnic seabream (*Acanthopagrus berda*) (Shinoj et al., 2023, Gopalakrishnan et al., 2019). Aiasnseabass, (*Lates calcarifer*), mangrove red snapper (*L. argentima culatus*) (CIBA) (Arasu et al., 2009).

Farming in pens

Inexpensive pen structures for farming the milkfish are constructed in shallow natural creeks, swamps, lagoons, lakes, and bays, ranging in depth from 1 to 3 m. The bottom in pen culture site should be of firm clay or mud so that poles and posts can be driven sufficiently deep to make them support the pen structure. Traditionally pens are made up of wooden planks, split bamboo etc. But in recent times, nets materials made of synthetic materials such as nylon, polypropylene, polythene etc are used commonly. A part of the vertical net barrier is buried inside the mud or ground with the aid of a footrope and small weights, secured to a chain link between concrete sinkers. At the upper level, floats are provided. Fingerlings stocked are usually fed on the natural food in the lagoon or lake and no artificial food is provided. The principal fish species cultured in Southeast Asian countries is milk fish (*Chanos chanos*)

Bivalve culture

Marine bivalves are also a sustainable type of food production. As herbivores, they are low in the trophic chain. Due to decreasing seed resources and environmental issues with the seed fishery, more and more of the seed resources for marine bivalve aquaculture are produced within land-based hatcheries. The aquaculture production of marine bivalves increased from 1.18 million tonnes per year in the period 1970–1974 to 13.47 million tonnes per year in the period 2010–2015. Raft culture is the most popular method in which seeded ropes are suspended from a raft set in a desirable site and depth in the inshore area. The ropes are set 0.5 to 1.0 m apart and care is taken to ensure that the end of the rope is about 2.0 m above the water bottom. Cultivation of marine bivalves accounts for a high percentage of total aquaculture production of aquatic animals, contributing 17.7 million tonnes of molluscs (USD 29.8 billion) mostly bivalves. These countries include New Zealand (86.9 percent), France (75.4 percent), Spain (74.8 percent), the Republic of Korea (69.7 percent), Italy (61.6 percent) and Japan (51.8 percent), against a world average of 18.4 percent (FAO, 2022).

Seaweed farming

Seaweed mariculture is believed to have started during the Tokugawa Era (AD 1600–1868) in Japan. At present, 92% of the world's seaweed supply comes from cultivated species. Depending on the selected species, their biology, life history, level of tissue specialization, and the socioeconomic situation of the region where it is developed, cultivation technology can be low-tech (and still extremely successful with highly efficient and simple culture techniques, coupled with intensive labour at low costs) or can become highly advanced and mechanized, requiring on-land cultivation systems for seeding some phases of the life history before growth-out at open-sea aquaculture sites. Global cultivation of algae, dominated by marine macroalgae known as seaweeds, grew by half a million tonnes in 2020, up by 1.4% from 34.6 million tonnes in 2019. Some major producing countries including China and Japan experienced growth in 2020, while seaweed harvests decreased in Southeast Asia and the Republic of Korea. Globally, 13 different culture methods have been employed for different species of seaweed farming, and adopting a particular method lies with the suitability of the method to the sea climatic conditions. Despite several methods available, few methods like off-bottom monoline, broadcast, floating bamboo, net system, and tubular net are common for shallow waters, whereas multiple raft long line, spider web, hanging basket, and free swing methods are suitable for deeper waters (Hurtado et al., 2014; Hurtado et al., 2015).

Integrated Multitrophic Aquaculture (IMTA)

Recently, mariculture practices have been dominated by intensive monocultures which have led to sustainability problems, environmental degradation, and consequent disease problems. Thus, the integrated multi-trophic aquaculture (IMTA) concept was developed as a way to increase the sustainability of intensive aquaculture systems, using an ecosystem-based approach. IMTA combines in appropriate proportions of the cultivation of fed aquaculture species (E.g. fin fish/ shrimp) with organic extractive aquaculture species (e.g. shell / herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems for environmental stability (biomitigation), economic stability (product diversification and risk reduction) and social acceptability (better management practices). IMTA is well recognized as a mitigation approach against the excess nutrients / organic matter generated by intensive aquaculture activities, especially in marine waters, since it incorporates species from different trophic levels in the same system. Besides being a form of balanced ecosystem management, this approach prevents potential environmental impacts from fed aquaculture. It also provides exciting new opportunities for valuable crops of seaweeds (Hossain et al., 2022). The seaweed IMTA component may include species of *Porphyra*, *Laminaria*, *Undaria*, and *Gracilaria. I*n addition, it is also relevant in the implementation of an ecosystem approach to aquaculture (EAA) propagated by FAO. IMTA can also increase the production capacity of a particular site. The main potentials of IMTA are thus environmental neutrality, economic viability, and social sustainability, although IMTA can improve the long-term viability of aquaculture by generating environmental, economic, and social benefits.

Recirculating Aquaculture System

Recirculating aquaculture systems are indoor, tank-based systems in which fish are grown at high density under controlled environmental conditions. Generally, farmers adopt a more intensive approach (higher densities and more rigorous management) than other aquaculture production systems. Recirculating aquaculture systems are indoor, tank-based systems in which fish are grown at high density under controlled environmental conditions with different levels of filtration systems (Espinal&Matulic, 2019). Recirculation is growing rapidly in many areas of the fish farming sector, and systems are deployed in production units that vary from huge plants generating many tonnes of fish per year for consumption to small sophisticated systems used for re-stocking or saving endangered species. It has always been recommended to use recirculation systems to produce expensive fish because a high selling price leaves room for higher production costs. A good example is the eel farming business where a high selling price allows relatively high production costs. The suitability of rearing specific fish species in recirculation depends on many different factors, such as profitability, environmental concerns, and biological suitability. It should be mentioned that for small fish the use of recirculation is always recommended, because small fish grow faster and are therefore particularly suited to a controlled environment until they have reached the size for growing. Some of the saltwater fish species cultured worldwide in RAS based culture system are Atlantic salmon, smolt (*Salmo salar*), Grouper (*Epinephelus spp)*; Rainbow trout (*Oncorhynchus mykiss*), Seabass/ Seabream (*Dicentrarchus labrax/ Sparus aurata*), Yellowtail amberjack (*Seriolala landi*), Cobia (*Rachycentron canadum),* Indian pompano *(Trachinotus mookalee)*

Precision Fish Farming (PFF)

Precision Fish Farming (PFF), has developed from the concept of Precision Livestock Farming (PLF) to pisciculture. PFF uses hardware (e.g., sensors), observers, and intelligent software to improve animal health and welfare while increasing productivity, yield, and environmental sustainability. In contrast to livestock production, intensive fish farming methods are more recent, crop is largely determined by environmental conditions and monitoring methods are more expensive and complex at aquatic ecosystems. The majority of components proposed to be included in PFF in mariculture systems are already developed (e.g., hydrophones, sonars, acoustic telemetry systems, cameras) but in many cases, they need to be adapted for mariculture activities. For example, smart sediment traps will greatly improve knowledge of particle settling flux data, oceanic nutrient cycles, and food efficiency through online monitoring and detection of temporal changes of sedimentation rates. Fish farming monitoring knowledge is required to understand the complex interactions between growing methods and farmed fish in the aquatic environment. An increase on the knowledge of behavioral and physiological responses may help reach sustainability (by reducing feed loose, disease and parasitic outbreaks, enhancing animal vital development, etc.) but it seems that the general aim is to improve intensive fish farming conditions from a production perspective instead of an environmental approach (carrying capacity, feed alternative, etc.). To apply a more sustainable concept of PFF, predictive models should include the information supplied by the application of technological advances to monitor other ecosystem parameters potentially affected by crops.

To be of industrial value, a precision fish farming (PFF) method must positively affect the day-to-day farming situation. PFF methods must therefore be evaluated to test their contributions to improving fish welfare and health, reducing fish losses (e.g. through handling, escapes and disease), improving production efficiency and product quality, and/or reducing environmental impacts of the farming operation, prior to launching innovative actions with the intent of commercialization.

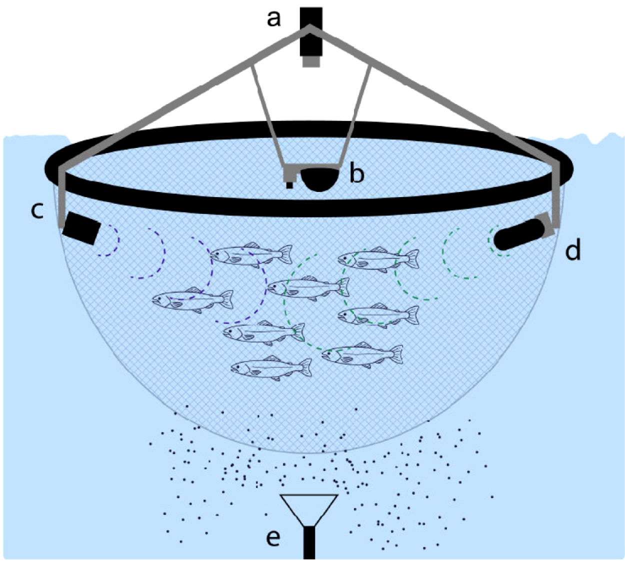


Fig. 2. Example of precision fish farming system including (a) surface camera, (b) underwater camera with multiparameter water probe, (c) sonar, (d) acoustic telemetry system with hydrophone, and (e) smart trap.

Suggested readings

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