CMFRI Training Manual Series No.72/2026

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All India Network Project on

Mariculture

Training Manual

Training Programme on

Marine Fish Hatchery Management and Culture

8-10 July 2026

ICAR-CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
(Department of Agricultural Research and Education, Government of India)
PB. No.1603, Ernakulam North P.O Kochi-682 018
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FOREWORD

Global aquaculture production (including algae) has expanded steadily since the start of this millennium, tripling from 43.1 million tonnes in 2000 to 141.6 million tonnes in 2024 with estimated farm-gate value of USD 391.5 billion. During the same year, global mariculture produced nearly 27 million tonnes of aquatic animals, with production dominated by molluscs followed by finfish, crustaceans and other aquatic animals. In addition to aquatic animals, 38.8 million tonnes of seaweed were also produced in marine environment.

Despite India's estimated mariculture production potential of 4–8 million tonnes annually, the current production remains only about 0.1 million tonnes, highlighting the vast untapped potential for expanding mariculture and driving blue economic growth. India's vast coastline of over 11000 km offers immense opportunities for the sustainable development of mariculture. The success of mariculture largely depends on the consistent availability of high-quality seed, making scientifically managed marine fish hatcheries the cornerstone of sustainable mariculture development.

The rapid advancement of hatchery technologies for commercially important species has significantly improved the development of mariculture sector in India. ICAR-Central Marine Fisheries Research Institute, Kochi have been in the forefront of mariculture research and development in India as early from the year 1970's. The institute has successfully developed seed production technology of 13 species of finfishes and 5 species of shellfishes along with the establishment of standardized culture systems like cages, ponds, pens, rafts, RAS, seaweed culture and Integrated Multi Trophic Aquaculture (IMTA).

The training manual, 'Marine Fish Hatchery Management and Culture' has been prepared to serve as a comprehensive resource for farmers, entrepreneurs, students, researchers, fisheries professionals, extension personnel and other stakeholders. The manual brings together the fundamental principles and practical aspects of hatchery, broodstock management, live feed production, larval rearing, nursery management, health management, water quality monitoring and different culture systems.

Well-trained manpower equipped with scientific knowledge and practical skills will play a pivotal role in achieving self-reliance in quality seed production and expanding marine fish farming. I wish every success to the training programme and trust that this manual will inspire more people to the mariculture sector. I congratulate all the contributors of this training manual.

Grinson George
Director
ICAR-CMFRI

Contents

Overview of Mariculture in India

Imelda Joseph and Anuraj A
Mariculture Division, ICAR-CMFRI, Kochi

Aquatic food systems play a vital role in ensuring healthy diets, sustaining livelihoods, enhancing global food security and nutrition, and conserving aquatic ecosystems and biodiversity. Global production of aquatic animals reached a record 195 million tonnes (live weight equivalent) in 2024, representing a 5.1% increase over 2022. Aquaculture production exceeded the landmark 100 million tonnes for the first time, reaching 102.7 million tonnes and accounting for 52.8 % of total aquatic animal production, further reinforcing its position as the primary source of aquatic food globally. Marine production contributed 118 million tonnes (61% of the total), with capture fisheries accounting for 67% and marine aquaculture for 33%. Inland waters produced 77 million tonnes (39% of the total), of which aquaculture contributed 84% and capture fisheries 16%. Additionally, global algae production reached 40 million tonnes in 2024, with 97% originating from aquaculture, reflecting a 5.8% increase compared to 2022.

Source: SOFIA, 2026

	1990s	2000s	2010s	2022	2023	2024
	Average per year					
	(million tonnes, live weight equivalent)					
Production						
Aquaculture						
Inland	12.6	25.6	44.9	59.2	61.6	64.3
Marine	9.4	18.0	26.8	35.5	37.2	38.3
Total aquaculture	**22.0**	**43.6**	**71.7**	**94.7**	**98.8**	**102.7**
Capture fisheries						
Inland	7.1	9.3	11.3	11.4	12.1	12.3
Marine	81.9	81.6	79.7	79.0	78.4	79.6
Total capture fisheries	**88.9**	**90.9**	**91.1**	**90.4**	**90.4**	**91.9**
Total world fisheries and aquaculture	**110.9**	**134.4**	**162.7**	**185.1**	**189.3**	**194.6**

Global aquaculture production (including seaweeds) has expanded steadily since the start of this millennium, more than tripling from 43.1 million tonnes in 2000 to 141.6 million tonnes in 2024 with estimated farm-gate value of USD 391.5 billion. About 770 aquatic species are cultured all over the world in a variety of farming systems and facilities of varying input intensities and technological sophistication. China, the world's largest aquaculture producer, derived 81.6 percent of its national aquatic animal production from aquaculture. In countries like India, Viet Nam and Bangladesh, as well

as in Egypt, Ecuador, Brazil, Türkiye, Colombia, Saudi Arabia and Uzbekistan, aquaculture shares represented 57 percent of total production or higher. This shows the important role of aquaculture in meeting the increasing demand for aquatic animal foods.

Mariculture is a specialized branch of aquaculture involving the cultivation of economically important marine plants and animals in the sea or any other natural water bodies having tidal influence and includes onshore facilities like brood banks, hatcheries, nursery rearing and grow-out systems using seawater. It is an important component of the blue economy, contributing to food security, nutritional security, employment generation, export earnings, and sustainable utilization of marine resources. With increasing pressure on capture fisheries, mariculture has emerged as a promising solution to meet the growing demand for seafood while supporting the livelihoods of coastal communities.

Mariculture plays an important role in:

- Increasing seafood production
- Meeting future protein requirements
- Reducing pressure on wild fish stocks
- Enhancing income of coastal communities
- Generating employment opportunities
- Promoting entrepreneurship
- Supporting export-oriented fisheries
- Strengthening climate-resilient food production systems

Mariculture activities other than for human consumption include live bait farming for fishing, live ornamental animal and plant species and ornamental products (pearls and shells), fishes cultured as feed for certain carnivorous farmed species, culture of live feed organisms such as plankton, Artemia and marine worms for use as feed in hatcheries and grow-out systems, aquaculture hatchery and nursery outputs for on-growing in captivity or stocking to the wild and capture based aquaculture. In 2024, global mariculture produced nearly 27 million tonnes of aquatic animals, with production dominated by molluscs (over 74%) followed by finfish, crustaceans and other aquatic animals. In addition to aquatic animals, 37 million tonnes of seaweed were also produced.

Mariculture in India

The beginning of mariculture research in India started during 1970s led by the initiatives of ICAR-Central Marine Fisheries Research Institute (CMFRI) at Mandapam with the culture of seaweeds followed by seaweed and bivalve cultivation during 1980s. Since then, ICAR- CMFRI is in the forefront towards development and disseminating mariculture technologies in India through standardising seed production technology and farming of marine finfishes/shellfishes, Integrated Multitrophic Aquaculture (IMTA), Recirculating Aquaculture System (RAS). Despite India's estimated mariculture production potential of 4–8 million tonnes annually, the current production remains only about 0.1 million tonnes, highlighting the vast untapped potential for expanding mariculture and driving blue economic growth. With a coastline of over 7,500 km and an extensive Exclusive Economic Zone (EEZ) of approximately 2.37 million km^2, India possesses immense potential for the expansion of mariculture.

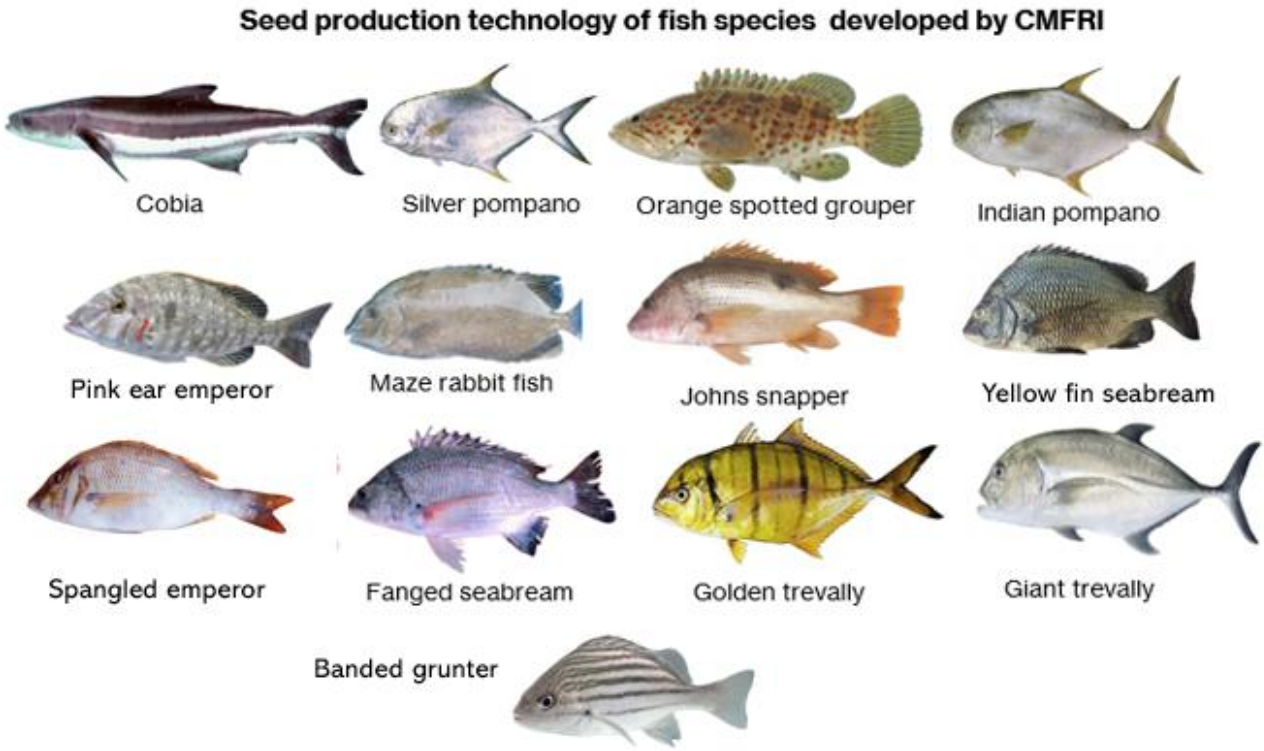
The country's diverse coastal ecosystems and favourable environmental conditions provide significant opportunities to boost sustainable marine aquaculture, enhance seafood production, create coastal livelihoods, and strengthen the blue economy. Central Marine Fisheries Research Institute has played a pioneering role in advancing mariculture in India through the development and standardization of hatchery-based seed production technologies for several high-value marine finfish, shellfish, seaweeds, and ornamental species. In addition, CMFRI has developed and demonstrated sustainable farming technologies, including cage culture, open-sea farming, seaweed cultivation, integrated multi-trophic aquaculture (IMTA), and molluscan farming, while facilitating their transfer to stakeholders through training, demonstrations, and capacity-building programmes to promote coastal livelihoods and the blue economy.

Understanding the importance of cage culture, the Central Marine Fisheries Research Institute initiated cage culture as a research and development activity to identify appropriate design and suitability of cages under Indian context as early as in the year 2005-06. The first open sea cage was launched in Bay of Bengal off Visakhapatnam coast during May 2007. After several modifications, a 15 m cage was launched in December 2007. This cage was stocked with sea bass and harvested after 6 months with 75% survival. This was the first successful harvest from open sea cage in lndia and this

success has given motivation and encouragement to the researcher and fish farmers. For ease of operation, later 6 m diameter cages were designed, installed and successfully demonstrated in several states of India with different commercially important finfishes and shell fishes. The indigenous 6-meter diameter cages of GI and HDPE for farming of different marine species have been demonstrated in Maharashtra, Tamil Nadu, Kerala, Karnataka, and Odisha.

The research towards the development of technology for seed production of marine species yielded commendable results within a few years and Mandapam Regional Centre of ICAR CMFRI succeeded in captive breeding of high value marine fishes, Cobia, *Rachycentron canadum* for the first time in the country. Broodstock development of cobia was initiated at the Mandapam Regional Centre of Central Marine Fisheries Research Institute in sea cages during 2008 and the first successful induced breeding and seed production was achieved in March 2010. Building upon this initial cobia success, CMFRI's dedicated mariculture research dramatically transformed India's marine aquaculture sector. Over the following 13 years, the institute's scientists expanded their pioneering work from the Mandapam Research Centre to its research centres in Visakhapatnam, Vizhinjam, and Karwar. By systematically addressing the complexities of broodstock development, induced spawning, and larviculture in captive

environments, CMFRI successfully standardized and developed hatchery production technologies of another 12 high-value marine finfish species. This rapid 13-year progression established a robust framework for steady supply of hatchery-produced seeds supporting commercial expansion of mariculture.



Species	Common name	Year	Technology developed at
Rachycentron canadum	Cobia	2010	CMFRI RC, Mandapam
Trachinotus blochii	Silver pompano	2011	CMFRI RC, Mandapam
Epinephelus coioides	Orange spotted grouper	2013	CMFRI RC, Vishakhapatnam
Trachinotus mookalee	Indian pompano	2016	CMFRI RC, Vishakhapatnam
Lethrinus lentjan	Pink ear emperor	2017	CMFRI RC, Vizhinjam
Siganus vermiculatus	Maze rabbit fish	2020	CMFRI RC, Karwar
Lutjanus Johnii	Johns snapper	2020	CMFRI RC, Vishakhapatnam
Acanthopagrus berda	Yellowfin seabream	2021	CMFRI RC, Karwar
Sparidentex jamalensis	Fanged seabream	2021	CMFRI RC, Karwar
Pomadasys furcatus	Banded grunter	2021	CMFRI RC, Vizhinjam
Lethrinus nebulosus	Spangled emperor	2022	CMFRI RC, Vizhinjam
Gnathanodon speciosus	Golden trevally	2024	CMFRI RC, Vishakhapatnam
Caranx ignobilis	Giant trevally	2024	CMFRI RC, Vizhinjam

Mariculture systems available for expansion in India

Sea cage farming

The cage culture which initiated in Norway during 70s got developed into a high-tech industry in many countries all over the world for high value fishes. The major advantage in countries where cage culture has been commercialized is that they have large, calm and protected bays to accommodate the cages safely against any unfavourable weather conditions. Recent technological advance is in cage design and with new species. In the past, the industry had typically used steel-framed rectangular support structures for the net cages, with walkways around them as work platforms. After that HDPE cages came into existence. Of recent submersible cages which can overcome rough oceanic conditions are being designed and used. Farming was mostly in the inshore waters and since the commercial aquaculture of marine finfish will continue to expand in future, it will take place more in offshore locations than have traditionally been used. By integrating the cage culture system into the marine aquatic ecosystem, the carrying capacity per unit area is optimized because the free flow of current brings in instantaneous exchange of water and removes metabolic waste and excess feed. Thus economically speaking, cage culture is a low impact farming practice with high economic returns and with least carbon emission activity. In view of the high production attainable in cage culture system and the presence of large sheltered coastal waters in many countries, marine cage farming can play a significant role in increasing fish production.

Recirculating Aquaculture Systems (RAS)

A notable technology-based development in the farming sector has been a significant expansion in fish production using closed-recirculation systems. Recirculation aquaculture systems (RAS) are systems in which water is (partially) reused after undergoing treatment. Each treatment step reduces the system water exchange to the needs of the next limiting waste component. RAS have been developed to respond to the increasing environmental restrictions in countries with limited access to land and water. RAS offer advantages in terms of reduced water consumption, improved opportunities for waste management and nutrient recycling and for a better hygiene and disease management, biological pollution control (no escapees), and reduction of visual impact of the farm. These systems are sometimes referred to as 'indoor' or 'urban' aquaculture reflecting its independency of surface water to produce aquatic organisms. In addition, the application of RAS technology enables the production of a diverse range of (also exotic) seafood products in close proximity to markets, thereby reducing carbon dioxide (CO2) emissions associated with food transport.

Bivalve farming

Bivalve culture in India is primarily focused on green mussels (*Perna viridis*) and Indian backwater oysters (*Crassostrea madrasensis*). It is a sustainable, low-investment mariculture practice. Predominately centered along the estuaries and backwaters of Kerala, Karnataka, Maharashtra and Goa, this farming method

provides vital supplementary income and affordable protein for coastal fishing communities. Methods of farming like long-line culture, raft culture and rack culture can be employed.

Integrated Multi-Trophic Aquaculture

Integrated multi-trophic aquaculture (IMTA) refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system. IMTA has been defined based on studies in marine habitats involving joint aquaculture of fed species, usually fish, together with extractive species such as bivalves and/or macroalgae. IMTA can also allow an increase in production capacity for harvesting of a particular site when regular options have established limitations.

Seaweed farming

Marine macroalgae (seaweed) cultivation offers substantial economic and ecological advantages, driven primarily by minimal capital requirements and low external resource dependency. For the past decade, Self-Help Groups (SHGs) in Palk Bay, Tamil Nadu, have operated economically viable farms using 12 ft x 12 ft raft systems with a 45-day cycle across 270 operational days per year. While this eco-friendly practice offers clear pathways to boost coastal livelihoods and generate carbon credits, industrial demand still eclipses the combined output of wild-harvested and farmed supplies.

The National Mariculture Policy 2019 has been framed to ensure a structured growth of mariculture for meeting the growing demand of fish in the country as well as to enhance nutritional security, wealth creation and employment while adhering to the principles of ecological wellbeing and environmental sustainability. Along with dedicated areas for mariculture activities, there is also need for establishment of fish brood banks and private hatcheries. Transitioning from wild-caught seeds to hatchery-produced, disease-resistant, and genetically improved seeds ensures predictable stocking, higher survival rates, and consistent growth cycles for farmers. The availability of standardized feeds for different species at affordable costs are also necessary. By establishing a synchronized supply chain that guarantees ready access to high-health seeds and standardized feeds, India's mariculture development can transition from a vision into a thriving reality.

Marine Fish Hatchery: Systems, Equipment and Facilities

Anuraj A
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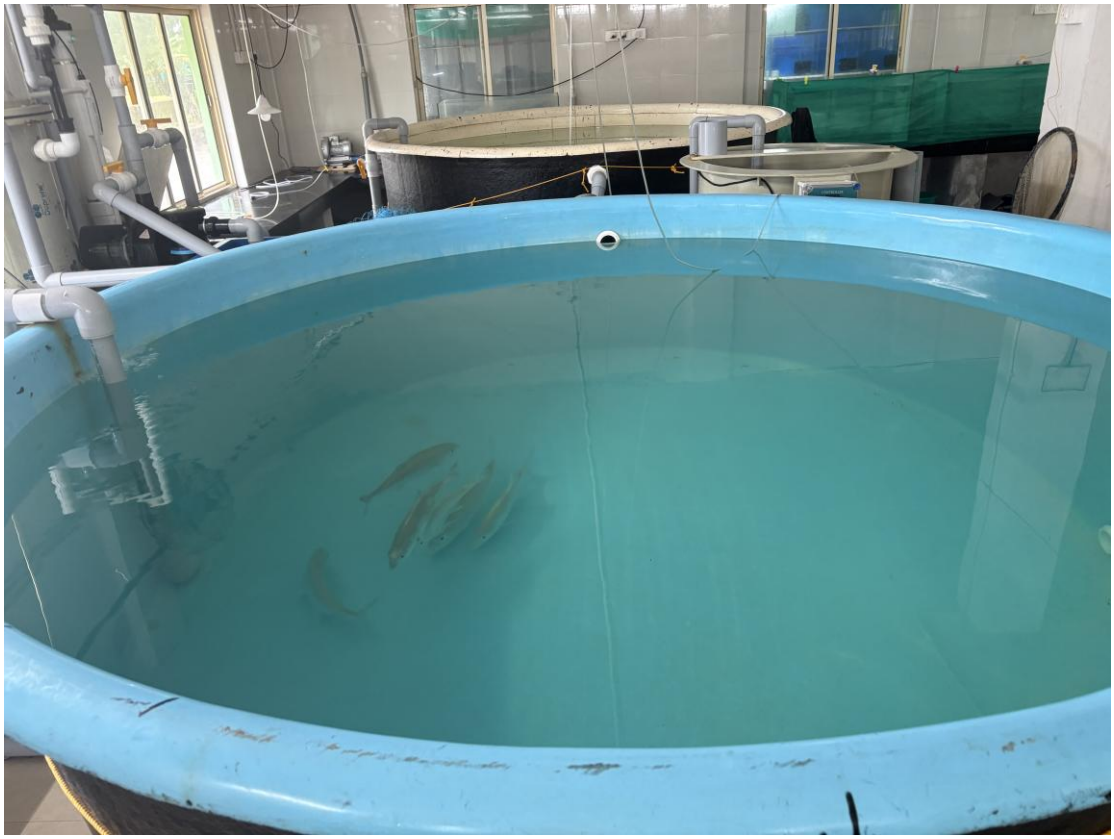
Marine fish hatcheries are specialized facilities designed to produce high-quality fish seed through controlled breeding, egg incubation, larval rearing and nursery rearing. They play a vital role in the expansion of sustainable mariculture by providing a reliable supply of healthy seeds for commercial farming. The availability of quality hatchery-produced seed also reduces dependence on wild seed resources, improves farm productivity, enhances profitability, and contributes significantly to coastal livelihood development and the blue economy. Modern marine hatcheries integrate scientific broodstock management, larval rearing, live feed production, water quality control, disease prevention, and advanced engineering systems to maximize seed production while maintaining high survival rates. The expansion of marine finfish mariculture is fundamentally constrained by the availability of high-quality, disease-free seeds. Unlike freshwater aquaculture, where seed production is well established and widely commercialized, marine fish hatchery production is more challenging. It requires advanced technology, careful control of environmental conditions, and strict biosecurity measures to produce healthy and high-quality seed.



A marine fish hatchery consists of various units like seawater intake, water treatment and storage, broodstock holding, indoor algal stock culture, intermediary and outdoor algal culture, rotifer culture, artemia hatching and enrichment, larviculture, nursery rearing, laboratory, feed and chemical storage, aeration facility, wastewater treatment and disposal, workshop and staff accommodation facility. The layout of a marine fish hatchery should facilitate smooth movement of water, personnel, materials, and fish while minimizing the risk of disease transmission.

Site selection

Site selection is one of the important criteria before designing a marine hatchery. The facility should preferably be located close to a clean seawater source. The intake point must be located away from river mouths, industrial discharge zones, agricultural runoff, and urban centres to prevent contamination from chemical pollutants, pesticides, heavy metals, and sudden salinity fluctuation. The site selected must be having reliable electricity, freshwater availability, transportation facilities, and protection from flooding. The topography of the selected site should ideally possess a gentle slope from the land toward the sea to facilitate gravity-assisted drainage, which reduces long-term operational pumping costs.

Ideal water quality parameters for selecting hatchery site

Salinity: Stable baseline of 30–35 ppt with minimal seasonal variations (<2ppt)

Temperature: Typically, 26–30°C for tropical and subtropical species like cobia, pompano, trevally etc.

pH: Maintained within the alkaline oceanic range of 7.9–8.3

Dissolved Oxygen (DO): Near saturation levels (>5ppm) at the source

Turbidity & Total Suspended Solids (TSS): Minimal baseline turbidity to reduce the mechanical load on primary filtration infrastructure. Areas prone to chronic harmful algal blooms (HABs) or heavy siltation must be avoided

Hatchery design

A modern marine fish hatchery is designed around a strict spatial zonation strategy. Rather than functioning as a single open space, the facility is segregated into discrete biosecurity zones managed under a strict linear or unidirectional workflow. This architectural framework creates physical barriers against pathogen entry and minimizes cross-contamination between different life stages. Water, air, personnel, and equipment must flow strictly from areas of high biosecurity (clean zones, such as live feed cultures and egg incubation) to areas of lower biosecurity (dirty zones, such as broodstock maturation and effluent treatment). Every section of the hatchery should have separate entry to avoid cross contamination from one section to other.

Structural Zonation and Access Control

The hatchery infrastructure is divided into distinct, isolated units

1. **Quarantine facility:** Physically isolated from all other sectors, this zone receives wild or external broodstock candidates. It operates on an independent, zero-discharge recirculating aquaculture system (RAS) or tank-based systems. Incoming wild fishes or farmed reared fishes are treated in the quarantine facility to ensure incoming pathogens are isolated and eradicated before entry into broodstock unit. The quarantine facility should be placed either near to the entrance of the hatchery or far off from the production area to avoid cross contamination. Generally the quarantine period varies from 1 to several weeks weeks and are carried out in small tanks of 1-2 m^3 to facilitate easy handling.

2. **Broodstock Maturation and Spawning facility:** A controlled environment housing large-volume tank. Broodstock holding facilities are fundamental hatchery components designed to maintain optimal numbers of parent (brood) fish, guaranteeing the reliable production and delivery of high-quality fertilized eggs to larval rearing units. It features restricted access, photoperiod-regulated lighting, and independent climate control to manipulate seasonal spawning cues.

   The positioning of these facilities, either indoors or outdoors depends entirely on the physiological requirements of the broodfish. Indoor setups are typically reserved for species that require strict regulation of temperature and photoperiods. Enclosed indoor facilities protect broodstock from environmental fluctuations. Holding tanks must feature reliable water supply, aeration, and lighting to promote gonadal development. During the design phase, ensure adequate space near the tanks to house Recirculation Aquaculture System (RAS) equipment, such as mechanical and biological filters, pumps, sterilizers, and temperature-control units. In contrast, outdoor systems are primarily utilized for the long-term maintenance of immature fish or as quarantine zones for treating wild-caught and post-spawned (spent) brooders before they are relocated to indoor environments.

   Broodstock tanks serve multiple purposes, including the culture, maturation, and spawning of the fish. Depending on the species and size of the fish, tank capacities range from 10 to 100 m^3

Rabbit fish in 1 ton spawning tank

with depths between 2 and 2.5 meters. While tanks can be circular, square, or rectangular with rounded corners, a round design is generally preferred. For optimal results, the interior should be a medium-range blue, green, or grey. For smaller species like berda, rabbit fish, a separate spawning tank of 1-2 m^3 is used as spawning tank. Fertilized eggs are collected using surface egg collectors or overflow systems before being transferred to incubation tanks. In RAS, a 500 µm mesh size bag is tied in egg collecting chamber to collect the eggs.

3. **Egg Incubation and Larval Rearing Facility (LRF)**

The fertilised eggs collected from broodstock/spawning tanks are incubated in incubation tanks till hatching. Most of the times, the hatched-out larvae in incubation tanks are reared in the incubation tanks itself till metamorphosis. The Larval Rearing Facility (LRF) is the biological core of the hatchery, where newly hatched larvae develop into functional post-larvae. This phase is characterized by rapid morphological transformations and high sensitivity to environmental variables.

This unit shall be separate from all other units and have proper bio security to avoid cross contamination from outside and within the facility. Larval tanks are usually circular fiberglass tanks with smooth internal surfaces. Tank capacities range from 1 ton to 20 tons depending on the species and production scale. The hatched-out fish larvae will be initially fed on live feed and on later stage gradually weaned from live feed to formulated pellet diets.

4. **Live Feed Production Facility** (Microalgae & Copepod/Rotifer/*Artemia* Cultures):

As the larvae of most marine finfish are extremely small and possess underdeveloped digestive tracts at first feeding, they cannot utilize inert commercial crumbles. The live feed production sector functions as a specialized primary factory within the hatchery, culturing live planktonic organisms to serve as nutrient delivery capsules. Each live feed unit must be housed in separate designated bio secured area to avoid cross contamination and should be provided with proper aeration supply, treated seawater and fresh water supply

lines, lighting, proper floor slopping and drainage system. The size and area of the unit should be decided based on the requirement of each live feeds.

Microalgae provide food for rotifers, bivalve larvae, and directly for certain marine larvae. Microalgae unit includes stock culture section, starter culture section, indoor culture section and outdoor mass culture area. The stock and starter culture section can be housed in same room provided with air conditioning facility. In this section, microalgae are maintained as stock in glass test tubes (20 ml) or conical flasks (100 ml to 500 ml) and cultured as starter cultures in conical flasks/haffkine's flasks (100 ml to 5 L) and in 20 litre carboys. In the indoor intermediate section, microalgae are cultured in large quantities in FRP of 100-1000 L. In outdoor culture section, microalgae are cultured in large quantities in FRP/ concrete tanks with a capacity of 5 -10 tons.

Rotifers (*Brachionus spp.*) are small, slow-moving zooplankton utilized as the first live prey for marine larvae. They are cultured at high densities (500 to 2,000 nos./mL) in dedicated 1-10 t capacity tanks based on requirements. The conical design of tank is suitable for effective bottom aeration to keep the rotifers and their feed in suspension, and simplifies harvesting and regular debris removal. As the rotifers naturally lack essential highly unsaturated fatty acids (HUFAs) like DHA and EPA required by marine finfish, they should be enriched for 4-6 hrs with microalgae or commercial enrichment products.

Copepod culture unit is essential in marine fish hatcheries for rearing of larvae with small mouth. Copepods are also more nutritionally Stock culture can be done in tanks of 50-500 L capacity. Tanks of PVC, HDPE or fibre are ideal. Cement tanks are not preferred for stock culture. For stock culture, white colour or light colours are desirable because it gives an idea about the population and health of copepods. Dark colour tanks of 1000-5000 L are ideal for mass culture.

The production of *Artemia* larval stages are usually carried out in adjacent area to the rotifer culture unit. Separate seawater and freshwater lines, aeration lines should be provided. The tanks should be made of FRP material with conical bottom for easy harvest of nauplii. The number of tanks for *Artemia* cyst hatching is based on the requirement for larval rearing.

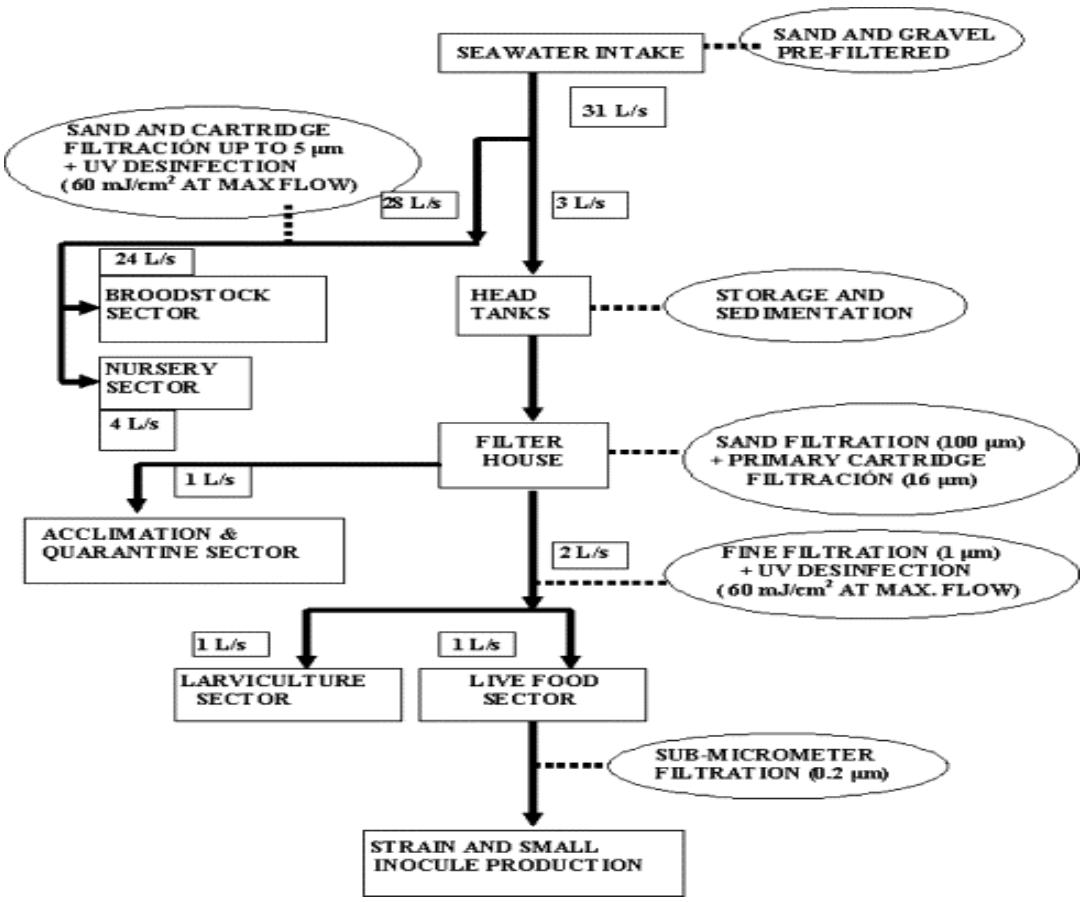
5. **Nursery Facility:** A transitional zone where advanced fry from LRF are adapted to commercial inert diets and variable ambient conditions before field deployment. Nursery rearing is the crucial phase in farming practices, where properly managed and well nurtured individuals will perform better with high growth, better survival, and reduced culture duration in grow-out period. Nursery rearing practices in hatchery is carried out in flow through or recirculation-based concept in FRP or concrete tanks. Circular or square shaped 1-10 tonnes

capacity of FRP tanks or concrete cement tanks with flow through facility having 1 meter water holding height and central drainage system can be employed.

Supporting components

1. **Water Supply System**

The water supply system is one of the most critical components of a marine hatchery. Continuous access to high-quality seawater is essential for broodstock maintenance, spawning, larval rearing, and live feed production. Seawater is generally pumped using borewell installed in the sea below the low-tide level to ensure uninterrupted water availability throughout the year. During rough season, surface water can be pumped with coarse screens that are installed at the intake point to prevent entry of debris, seaweed, jellyfish, and large organisms. The size and capacity of the pumps are calculated according to the water requirement. Freshwater is also required for cleaning, salinity adjustment, and preparation of culture media. Many hatcheries use borewell water, treated municipal water or rainwater harvesting systems as supplementary freshwater sources.



Simplified diagram flow-chart of seawater distribution and treatment system (Alvarez-Lajonchère et al, 2007)

2. **Water Treatment System**

   Raw seawater contains suspended particles, microorganisms, plankton, parasites, and potential pathogens. Therefore, it must undergo several treatment steps before use.

   The treatment system generally includes:

   Sedimentation tanks

   Sand filtration

   Activated carbon filtration

   Cartridge filters

   Micron bag filters

   UV sterilization

   Ozone treatment

   Chlorination and dechlorination

   Mechanical filtration removes suspended solids, while UV and ozone destroy bacteria, viruses, fungi, and protozoans

3. **Air blowers**

   The capacity of air blower is determined based on the scale of operation and aeration requirement in each section. Small scale hatcheries require 0.5-1.5 hp ring blower whereas large scale commercial hatchery requires 2 HP to 7.5 HP blowers. The capacity of air blower is determined based on the scale of operation and aeration requirement in each section. Small scale hatcheries require 0.5-1.5 hp ring blower whereas large scale commercial hatchery requires 2 HP to 7.5 HP blowers. It is always advisable to have a standby blower in the vent of failure of main blower.

4. **Pumping station**

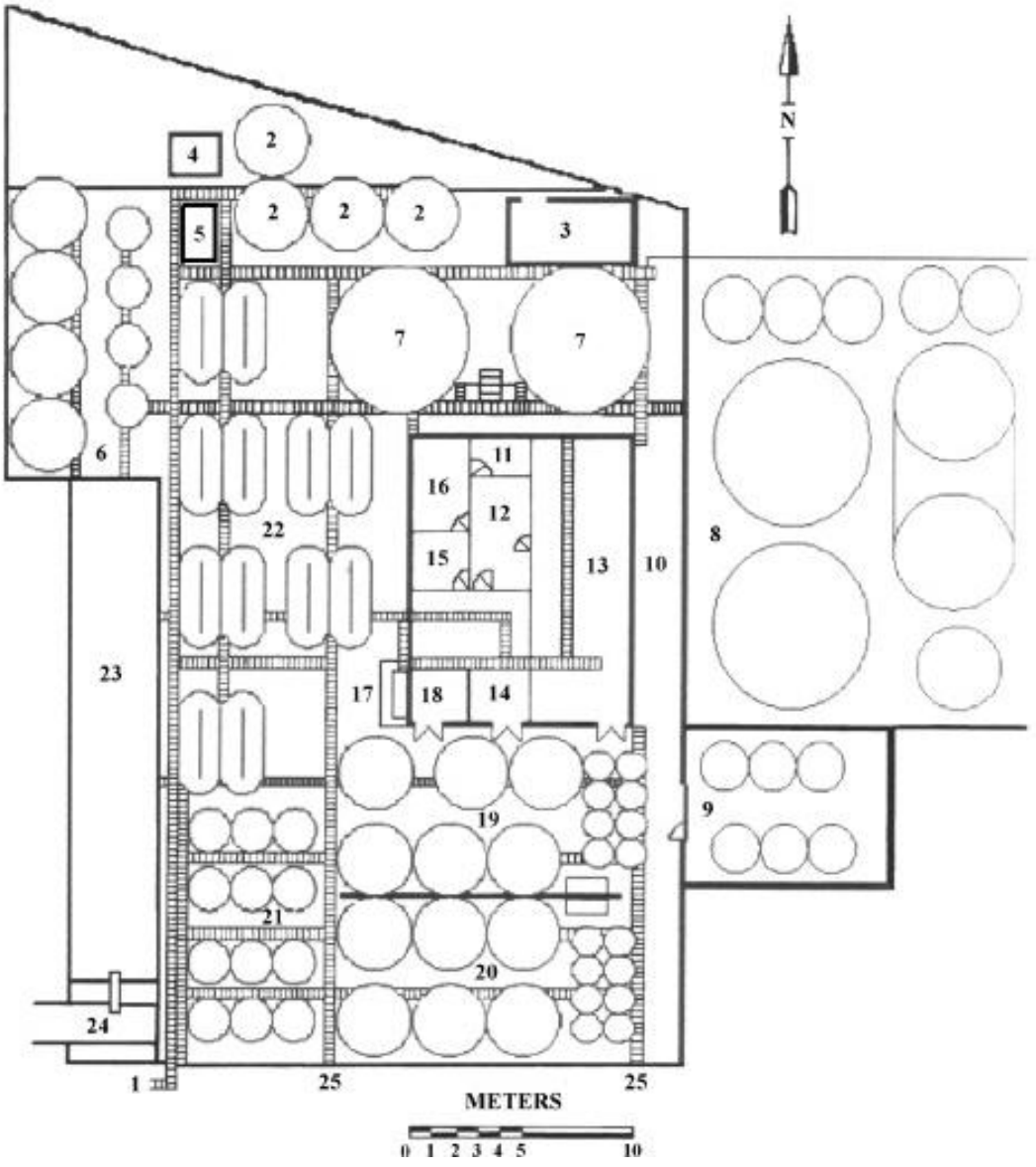
   The pumping station of the hatchery should have preferably a seawater pump that can withstand the two pumps each with the capacity to fulfil daily water requirements. The size and capacity of the pumps should be

5. **Electricity supply**

   The hatcheries electrical supply system typically rely on the public electrical service system. Tank areas and rooms sockets should be of waterproof and weatherproof standard. Electrical cables and connections are not kept clear of water tanks, and equipments should be positioned above water lines. The facility should have a backup diesel generator of sufficient capacity. The generator should be able to operate simultaneously most of the essential equipment like blowers, seawater pumps, sand filters, disinfection systems etc...

Common laboratory equipment for a marine hatchery

Compound microscope	Digital weighing balance
Stereomicroscope	pH meter
Haemocytometer	Dissolved oxygen meter
Sedgwick–Rafter counting chamber	Spectrophotometer
Salinity meter	Autoclave
Conductivity meter	Refrigerator and Deep freezer



General plant schematic upper view with all main outdoor and indoor areas of a tropical marine finfish hatchery (Alvarez-Lajonchère et al, 2007)

(1) main supply pipes ; (2) seawater storage 25-tonne tanks; (3) sand and big cartridge filter house; (4) blower house; (5) water treatment area for broostock and nursery areas; (6) acclimation and quarantine sector; (7) 50 m3 broodstock tanks; (8) broodstock tank area; (9) larval rearing room; (10) live food indoor building; (11) microalgae stock room; (12) microalgae

small inocule room; (13) live food 80 and 700 L culture room; (14) zooplankton inocules and rotifer intensive culture room; (15) glass ware washing and sterilization room; (16) general dry laboratory; (17) Artemia cysts decapsulating area; (18) Artemia incubation and enrichment room; (19) microalgae outdoor large scale culture area; (20) zooplankton outdoor large scale culture area; (21) artificial diet experimental tank area; (22) intensive nursery area; (23) stabilizing pond; (24) drainage trench

Microalgae Culture Techniques

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Microalgae (i.e. single-celled algae or phytoplankton) represent the largest, yet one of the most poorly understood groups of microorganisms on Earth. As happens with plants relative to terrestrial animals, microalgae serve as the natural nutritional base and primary source of bulk nutrients in the aquatic food chain. Microalgal use by indigenous populations has occurred for centuries. Cultivated microalgae have long been integral to the hatchery production of many farmed finfish, shellfish, and other commercially important aquaculture species. By contrast, macroalgae are less widely used in aquaculture, although they do provide an important source of nutrition for certain farmed invertebrates, such as sea urchins and abalone. However, the cultivation of microalgae is only a few decades old. Commercial large-scale culture started in the early 1960's in Japan with the culture of Chlorella by Nihon Chlorella (Taipei, Taiwan).

Microalgae serve as live food for commercially important molluscs, fish and crustaceans. Consumers are grown directly in the presence of their food, produced *in situ*. Depending on consumer requirements (Which often depend on life stages), the microalgae are consumed either directly (e.g. by herbivorous fish, bivalve molluscs, larval shrimp and prawns, zooplankton), or indirectly via the 'algae-zooplankton' food chain (e.g. most fish). Microalgae not only play an important role in aquaculture as a food source but, together with bacteria, also help maintain the oxygen and carbon dioxide balance in cultures.

Major Classes and Species of Cultured Algae Used in Aquaculture

- The major classes of cultured algae used as live feed include:
  - **Diatoms**
  - **Flagellated algae**
  - **Chlorococcalean green algae**
  - **Filamentous blue-green algae (cyanobacteria)**
- These algae range in size from **a few micrometres (µm) to over 100 µm**.

Common Marine Algae Used in Commercial Mariculture

Diatoms:

- *Skeletonema costatum*
- *Thalassiosira pseudonana*
- *Phaeodactylum tricornutum*
- *Chaetoceros gracilis*
- *Chaetoceros calcitrans*

Flagellates:

- *Isochrysis galbana*
- *Isochrysis tahiti*
- *Monochrysis lutheri* (also known as *Pavlova lutheri*)
- *Tetraselmis suecica*
- *Dunaliella* spp.

Green algae (Chlorococcalean): *Chlorella* spp.

Common Freshwater Algae Used in Aquaculture

- *Chlorella*
- *Scenedesmus*
- *Chlamydomonas*
- *Spirulina* (a blue-green alga commonly found in alkaline waters)

The role of microalgae in aquaculture hatcheries

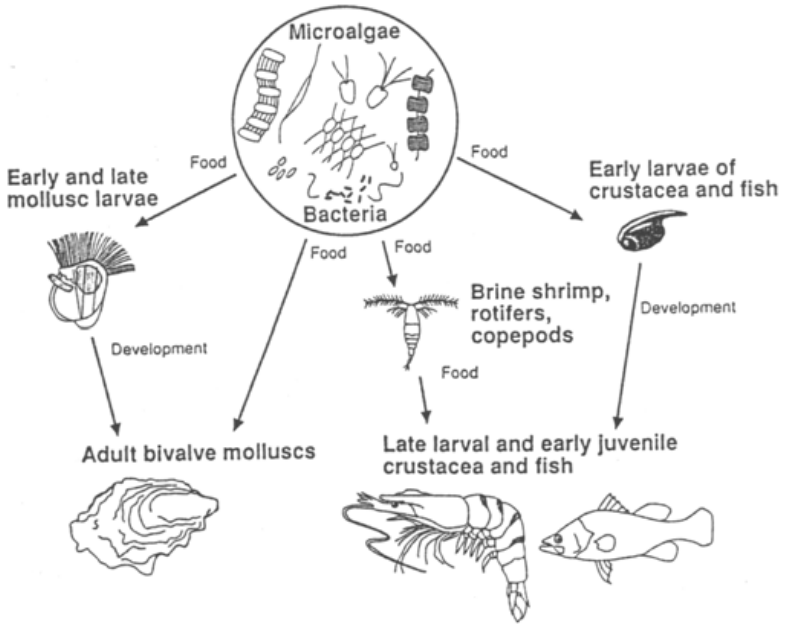


Fig.1 The central role of microalgae in mariculture (Brown *et al*., 1989)

The role of microalgae in aquaculture hatcheries may be summarized as follows:

•• All developmental stages of bivalve molluscs are directly reliant on microalgae as a feed source. Bivalve hatcheries therefore cultivate a range of microalgal strains for broodstock conditioning, larval rearing and feeding of newly settled spat.

•• Farmed gastropod molluscs (e.g., abalone) and sea urchins require a diet of benthic diatoms when they first settle out from the plankton, before transferring to their juvenile diet of macroalgae.

•• The planktonic larval stages of commercially important crustaceans (e.g., penaeid shrimps) are initially fed on microalgae, followed by zooplanktonic live prey.

•• The small larvae of most marine finfish species and some freshwater fish species also initially receive live prey, usually in the presence of a background of microalgae. Depending on whether these microalgae are allowed to bloom within the fish larval rearing tanks, or are added from external cultures, this is referred to as the "green water" or "pseudo-green water" rearing technique.

•• The zooplanktonic live prey referred to above are microscopic filter-feeders that are themselves commonly fed on microalgae, although inert formulated feeds have been developed as a more convenient diet form for use by hatcheries.

NUTRITIVE VALUE OF MICRO - ALGAE

- More than **40 species of algae** are presently used as live food for aquatic invertebrates and vertebrates.
- An ideal algal food should:

  - Be **non-toxic**.
  - Be **small enough to be ingested**.
  - Have a **digestible cell wall**.
  - Contain adequate **essential nutrients**.

- Different aquatic animals digest algae differently:

  - **Bivalve molluscs** (such as oysters and clams) cannot digest thick cell walls.
  - **Rotifers** (e.g., *Brachionus*) can digest thick-walled algae using their **mastax**.
  - Therefore, **Chlorella** is suitable for **Brachionus** but not for oysters or clams.

- The **amino acid content and balance** in algae are important for the growth and development of aquatic organisms.
- **Lipids**, especially **polyunsaturated fatty acids (PUFAs)**, are essential for the healthy development of fish larvae.
- The nutritional composition of algae changes with **culture conditions**:

  - During the **exponential growth phase**, algae contain **more protein**.
  - During the **stationary phase**, they contain **more carbohydrates**.

Algae	Protein	Lipids	Carbohydrates	Fibre	Ash	Nucleic acid	Moisture

Spirulina	62-68	2"3	15-20	5-8	10-12	6	5-6
Chlorella	40-50	10-15	12-16	6-8	8-10	6	5-8
Scenedesmus	50-55	12-19	10-15	10-12	6-8	4-6	5-7

Different Algal culture techniques

Algae can be produced using a wide variety of methods, ranging from closely controlled laboratory methods to less predictable methods in outdoor tanks. The terminology used to describe the type of algal culture includes:

Indoor/Outdoor. Indoor culture allows control over illumination, temperature, nutrient level, contamination with predators, and competing algae, whereas outdoor algal systems make it very difficult to grow specific algal cultures for extended periods.

Open/Closed. Open cultures such as uncovered ponds and tanks (indoors or outdoors) are more readily contaminated than closed culture vessels such as tubes, flasks, carboys, bags, etc.

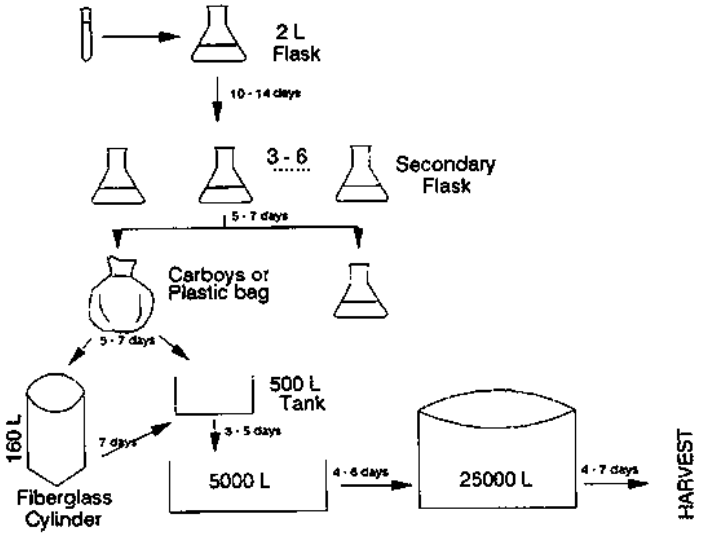
Axenic (=sterile)/Xenic. Axenic cultures are free of any foreign organisms such as bacteria and require a strict sterilisation of all glassware, culture media, and vessels to avoid contamination. The latter makes it impractical for commercial operations.

Batch, Continuous, and Semi-Continuous.

These are the three basic types of phytoplankton culture which will be described in the following sections.

Batch culture: The batch culture consists of a single inoculation of cells into a container of fertilized seawater followed by a growing period of several days and finally harvesting when the algal population reaches its maximum or near-maximum density. In practice, algae are transferred to larger culture volumes prior to reaching the stationary phase, and the larger culture volumes are then brought to a maximum density and harvested. The following consecutive stages might be utilized: test tubes, 2 L flasks, 5 and 20 L carboys, 160 L cylinders, 500 L indoor tanks, 5,000 L to 25,000 L outdoor tanks.

Batch culture systems are widely applied because of their simplicity and flexibility, allowing them to change species and remedy defects in the system rapidly. Although often considered the most reliable method, batch culture is not necessarily the most efficient method. Batch cultures are harvested just before the initiation of the stationary phase and must thus always be maintained for a substantial period of time past the maximum specific growth rate. Also, the quality of the harvested cells may be less predictable than that in continuous systems and for example, vary with the timing of the harvest (time of the day, exact growth phase).



Another disadvantage is the need to prevent contamination during the initial inoculation and early growth period. Because the density of the desired phytoplankton is low and the concentration of nutrients is high, any contaminant with a faster growth rate is capable of outgrowing the culture. Batch cultures also require a lot of labour to harvest, clean, sterilise, refill, and inoculate the containers.

Continuous Culture: **A** continuous culture **is a culture system in which** fertilised seawater is continuously supplied **to the growth chamber while an equal amount of algal culture is** simultaneously removed**, allowing the algae to remain close to their** maximum growth rate**.**

Types of Continuous Culture

1. Turbidostat Culture

- Algal concentration (cell density) is maintained at a **pre-set level**.
- Fresh culture medium is added **automatically** whenever the culture becomes too dense.
- **Cell density remains constant**, while the dilution rate varies.

2. Chemostat Culture

- Fresh culture medium is supplied at a **constant, predetermined rate**.
- The medium contains a **limiting nutrient** (e.g., nitrate).
- **Growth rate remains constant**, while cell density is determined by the nutrient supply.

Advantages of Continuous Culture

- Maintains algae near the **maximum growth rate**.
- Produces algae of **uniform and predictable quality**.
- Suitable for **automation and technological control**.
- Improves **system reliability**.
- **Reduces labour requirements**.

Disadvantages of Continuous Culture

- **High installation and operating cost**.
- **Complex** to manage.
- Requires **constant light and temperature**.
- Generally limited to **indoor, small-scale production**.

Semi-Continuous Culture: In the **semi-continuous culture** method, only a **portion of the algal culture is harvested periodically**. The harvested volume is immediately replaced with **fresh enriched medium** to restore the original culture volume, allowing growth to continue.

Procedure

1. Grow the algal culture.
2. Harvest part of the culture.
3. Refill the tank with fresh nutrient-enriched medium.
4. Allow the culture to regrow.
5. Repeat the harvesting and replenishment cycle.

Advantages

- Produces **more algae than the batch culture** using the same tank size.
- Extends the productive life of the culture.

- More economical than repeatedly starting new batch cultures.

Disadvantages

- Over time, **competitors, predators, contaminants, and metabolic wastes** accumulate.
- Eventually, the culture becomes unsuitable and must be replaced with a fresh culture.

Comparison of Continuous and Semi-Continuous Culture

Feature	Continuous Culture	Semi-Continuous Culture
Medium addition	*Continuous*	*Periodic*
Harvesting	Continuous	Partial and periodic
Growth	Near maximum, constant	Repeated growth cycles
Control	Highly controlled and automated	Moderately controlled
Cost	High	Lower than continuous
Productivity	High-quality, consistent algae	Higher yield than batch culture
Main limitation	Expensive and complex	Contamination and metabolite buildup

Isolation of Pure Algal Strains

Isolation of the required species of microalgae can be done by one of the following methods.

***1. Pipette method*:** Large organisms can be pipetted out using a micro-pipette under the microscope and transferred to culture tubes having suitable culture media.

2. Centrifuge or washing method: By repeated centrifuging of the samples at different revolutions and by inoculating the deposits, it is possible to get different organisms.

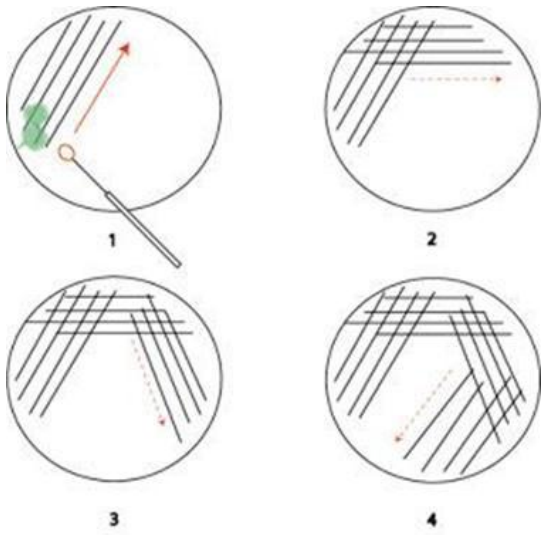
3. By exploiting the phototactic movements: By this method, most of the phytoflagellates can be isolated. Make a dark chamber with a small hole on one side and keep the sample in a beaker nearer to the hole. Place a candle near the hole outside. Since the flagellates have a tendency to move towards the light, it is visible after some time that these organisms crowd near the candlelight. By pipetting, these organisms can be separated, and by tube culture methods, it can be raised to a pure culture.

***4. Agar plating method*:** For preparing the agar medium, 1.5 gm of agar is added to 1 litre of suitable culture medium, e.g. Schreiber's medium, Miquel's medium, TMRL medium, and Conway medium, or even natural seawater.

This agar solution is sterilized in an autoclave for 15 minutes at 60 kg pressure and 100°C temperature. Now this medium is poured into sterilised 15 cm diameter Petri dishes and kept for 24 hours. For isolation, the required species can be picked up by platinum needle or loop under a microscope and streaked on the surface of the agar plate.

After inoculation, these Petri dishes are placed in an incubator for 7-8 days, providing light (1000 lux) and constant temperature (25°C). Within this time, the required species, if it has grown into a colony, is removed by a platinum loop under the microscope and transferred to culture tubes. Further, from culture tubes to small conical flasks and larger flasks, the algae can be grown on a mass scale.

Agar Plating Technique



Agar plates with algal streaks

The following agar plating technique can be used to isolate algal strains from raw seawater and for the maintenance of existing algal strains.

- Prepare a 0.9% agar medium by weighing out 9 g of agar powder and placing it into a 2 l conical flask to which 1 l of seawater is added
- Heat the flask on a Bunsen flame and let it boil twice, i.e. heat until it boils, let it Cool and let it boil a second time
- Add nutrients (see Tables 2.3 & 2.4) before autoclaving
- Cover the flask with aluminium foil
- Autoclave at 125 °C for 30 minutes at 1 atm
- Sterilise Petri dishes by incubation for 30 minutes at 150°C
- Agar plates are prepared aseptically by pouring the warm autoclaved agar into the sterile Petri dishes near a Bunsen flame or in a laminar flow, cover up the Petri dishes and leave them to cool for about 2 h
- Streak the algal sample onto the agar surface with a sterile platinum loop (previously heated to red-hot and cooled)
- Place the Petri dishes upside-down on an illuminated glass rack
- Depending on the density of the inoculum, cell colonies can be observed to grow on the surface after 5 - 21 days
- Select the best colonies and transfer them with a sterile platinum loop into a test tube filled with 5-10 ml of culture medium and shaken regularly during incubation on an illuminated glass rack; when a colour change is observed in the tube, check the isolated algal strain under the microscope

Serial dilution culture technique: This method is used mainly for the isolation of phytoflagellates (Sournia, 1971). In this method, mainly 5 dilution steps (the inocula corresponding to 1, 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} or 4 steps – 0.001, 0.01, 0.1, and 1 ml) are involved for the isolation of the required species. For the serial dilution technique, nearly 25 culture tubes (15 ml) are required. After filtering the seawater through a 10-20 micron sieve, the filtrate has to be inoculated into five series of culture tubes in various concentrations. This has to be kept under sufficient light (1000 lux) with uniform temperature (25°C) conditions. After 15 days, some discolouration can be seen in the culture tubes, due to the growth of microalgae. Further purification of this culture can be done by sub-culturing it in 500 ml or one-litre conical culture flasks. Once the culture is fully purified, it can be transferred into 3- or 4-litre Haufkin culture flasks and maintained as stock culture. After the isolation of the required organisms in culture tubes, they may be sub-cultured again in a few 50 ml test tubes. These test tubes are the base from which

the algal food starts producing and from where the continuous supply of non-contaminated algal feed is obtained for the operation of the large-scale culture systems. Once the system is started, the test tube culture can be transferred to small culture flasks and to bigger flasks by adding 3-5 ml of the stock culture. Therefore, every two weeks a new set of 10 test tubes for each species should be inoculated from the previous set. The filtration of water and medium enrichment should be done no earlier than 3 days before inoculation.

Procedure

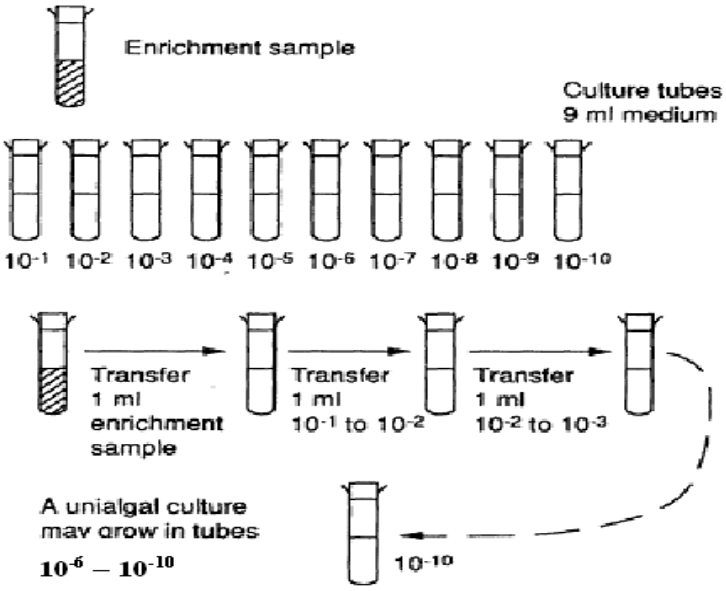
Using an aseptic technique, dispense 9 ml of medium into each of ten test tubes with a sterile automatic dispenser or sterile 10 ml pipettes. Label tubes 10-1 to 10-10, indicating dilution factor.

- Aseptically add 1 ml of enrichment sample to the first tube (10^{-1}) and mix gently.
- Take 1 ml of this dilution and add to the next tube (10^{-2}), mix gently.
- Repeat this procedure for the remaining tubes ($1O^{-3}$ to 10^{-10}).
- Incubate test tubes under controlled temperature and light conditions:

(a) Temperature and photoperiod — as close to the natural environment as possible

(b) Light intensity — slightly lower than the natural environment

- Examine cultures microscopically after 2—4 weeks by withdrawing a small sample aseptically from each dilution tube. A unialgal culture may grow in one of the higher dilution tubes, e.g. 10^{-6} to 10^{-10}. If tubes contain two or three different species, then micromanipulation can be used to obtain unialgal cultures



MAINTENANCE OF STOCK AND STARTER CULTURES

Stock cultures, otherwise known as master cultures, of the preferred species are the basic foundation of culture. They are normally supplied as monospecific (uni-algal) cultures from reputable culture collections maintained by national institutions or research laboratories. Since they are valuable, they are normally kept in specialized maintenance media, for example, Erdschreiber, or in F/2 media, or on nutrient-enriched agar plates or slopes, under closely controlled conditions of temperature and illumination. A special area or room of the algal culture room is usually allocated for this purpose.

Stock cultures are used **only** to provide lines of starter cultures (also known as inocula) when required. Every effort should be made to minimize the risk of contaminating the stock and starter cultures with competing microorganisms. The sterile procedures described below should be followed to ensure that contamination does not occur. Stock cultures are kept in small, transparent, autoclavable containers. For example, 500 ml borosilicate glass, flat-bottomed boiling or conical flasks fitted with a cotton wool plug at the neck, suitable for containing 250 ml of sterile, autoclaved medium, are ideal.

Starter culture management

Procedures for the maintenance of starter cultures (inocula) are almost identical to those described above. These cultures are specifically grown to provide inocula to start larger volume cultures needed to produce food. A line of starter cultures is originally set up from the stock culture of the required species. Starter cultures, like the stocks, can be grown in 500 ml boiling flasks in 250 ml of culture medium. With larger volume starters it is advantageous to increase the level of illumination and to aerate it with an air/carbon dioxide mixture.

Growth phases of cultures

Harvesting takes place in a semi-continuous culture during the exponential phase of growth. Batch harvests are made generally at the peak of exponential growth as the cultures enter the stationary phase. An illustration of the meaning of these terms is given in Figure 19. In this case the species cultured is the large, green flagellate, *Tetraselmis*. At inoculation from the starter culture, the starting cell density in the culture is 25 to 50 cells per ml (cells per microlitre).

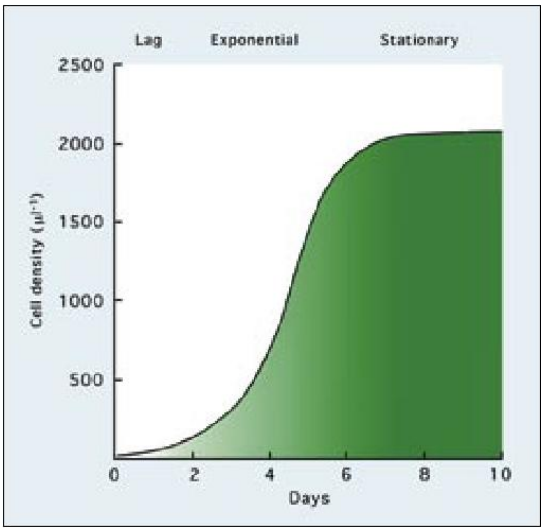


Figure: Phases in the growth of algal cultures illustrated by a typical growth curve for a green flagellate.

After inoculation, these cells grow and divide increasingly rapidly as they acclimatize to the culture conditions. This acclimatization period, which lasts for 2 to 3 days, is called the **lag phase**. Once adapted to the conditions, the rate of cell division accelerates and an increase in the number of cells in the culture is logarithmic. This period lasts for 4 to 6 days and is called the **exponential growth phase**. Cell division rate then slows as light penetration through the culture and/or nutrients become limiting. The culture then enters the **stationary phase**, which can last for many days in the case of flagellates or only for a short time for diatoms. Cultures of flagellates remain in this phase by the recycling of nutrients from dead and decaying cells, but in the case of diatoms, which may produce self-inhibiting metabolites, that attract bacterial growth, the culture collapses.

Extensive outdoor culture

Commercial hatcheries need to produce large volumes of good quality, high-food-value algae daily to support economic-scale seed production. Outdoor tank culture makes use of natural light. Culture in rectangular or circular tanks with overhead illumination is used in shrimp hatcheries in India. This involves the fertilization of a large volume of seawater with the basic nutrients necessary for production, namely nitrogen, phosphorus, and silica in one form or another. It is possible to induce mono-specific blooms by prior fine (<2 µ particle retention) filtration of the impounded seawater and the introduction of an inoculum of the required species, as long as it is hardy and vigorous. However, it is difficult to maintain such blooms for long periods because they rapidly become contaminated with other microorganisms.

Culture Techniques of Rotifer and Artemia

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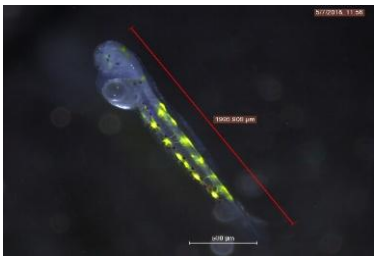
Live feed refers to small, microscopic living organisms which are used to feed fish larvae especially during the early larval stages. Live food organisms include all plants (phytoplankton) and animal (zooplankton) lives grazed upon by economically important fishes. Phytoplankton are generally eaten by zooplankton and forms the basis of the food chain. Live foods can swim in water column and are constantly available to fish and shellfish larvae and are likely to stimulate larval feeding response. Most of the fish and shellfish larvae in nature feed on small phytoplanktonic and zooplanktonic organisms. The success in the hatchery production of fish fingerlings for stocking in the grow-out production system is largely dependent on the availability of suitable live food for feeding fish larvae, fry and fingerlings. Live food organisms contain all the nutrients such as essential proteins, lipids, carbohydrates, vitamins, minerals, amino acids and fatty acids and hence are commonly known as “living capsules of nutrition”.



Upon hatching fish eggs, larvae obtain their nutrition from yolk sac for the first few days. Generally, there are two types of fish larvae: precocial and altricial. Precocial larvae are those that when yolk sac is exhausted, appear as mini adult exhibiting fully developed fins and mature digestive system. Such fish can ingest and digest formulated diet as first food. But altricial larvae (most of marine fish

larvae) having less yolk - reserves remain in a relatively undeveloped state with small mouth gape when yolk sac is exhausted. They also possess an undeveloped digestive system lacking a stomach. These types of larvae cannot digest formulated diet and has to be provided with live feeds appropriate to their mouth gape. Live feeds are able to swim in water column and thus constantly available to the larvae. In addition the movement of live feed in the water is likely to stimulate larval feeding responses since evolutionary history has probably adapted them to attack moving prey in nature.

SELECTION OF LIVE FEED

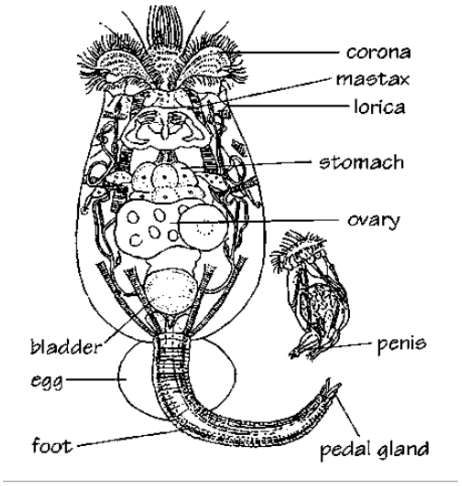
When selecting food to be fed to the larvae, the following points should be considered:

1. The food must be perceived by the larvae.
2. The size of food must be such that it can be accommodated by the mouth of the larvae.
3. The feed should have high nutritional quality especially Highly Unsaturated Fatty Acids (HUFA) essential to the growth and survival of the larvae.
4. The feed can be digested by the larvae.
5. Food organisms must be hardy.
6. They must be able to reproduce rapidly and can mass produced under controlled condition

ROTIFERS

Rotifers are very small organisms mostly ranging from 0.1 to 0.5 mm belongs to the Phylum Rotifera. Rotifers were found to be suitable as first feed for marine fish larvae in Japan in the late sixties and early seventies. Rotifers became ubiquitous in all mass rearing trials after their successful use in the mass rearing of the red seabream *(Pagrus major)* in Japan. The introduction of rotifers marked the first regular successes in the mass larval rearing of several marine species of economic value such as grey mullet *(Mugil cephalus),* sole *(Solea solea)*, gilthead seabream *(Sparus aurata)*, sea bass *(Dicentrarchus labrax)*, turbot *(Scophthalmus maximus)* and flounder *(Paralichthys olivaceus)*, milkfish *(Chanos chanos)* etc.. during seventies and eighties. They are now the first food of the initial larval stage of many fish species grown in commercial marine hatcheries.

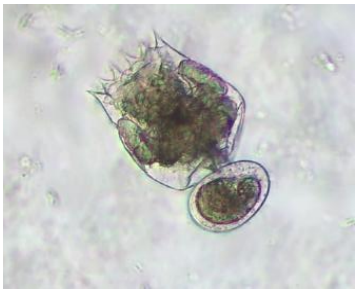
Morphology of rotifer



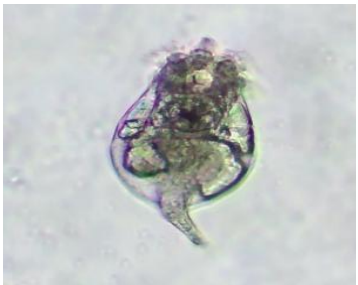
The success of rotifers as a culture organism are manifold, including their planktonic nature, tolerance to a wide range of environmental conditions, high reproduction rate. Moreover, their small size and slow swimming velocity make them a suitable prey for fish larvae that have just resorbed their yolk sac but cannot yet ingest the larger *Artemia* nauplii. However, the greatest potential for rotifer culture resides, however, is the possibility of rearing these animals at very high densities. Even at high densities, the animals reproduce rapidly and can thus contribute to the buildup of large quantities of live food in a very short period of time. Last, but not least, the filter-feeding nature of the rotifers facilitates the inclusion into their body tissues of specific nutrients essential for the larval predators.

Rotifers are capable of reproduction though both sexual and asexual methods. The life span of rotifers has been estimated to be between 3.4 to 4.4 days at 25°C. Generally, the larvae become adult after 0.5 to 1.5 days and females thereafter start to lay eggs approximately every four hours. It is believed that females can produce ten generations of offspring before they eventually die.

Euryhaline rotifer species, *Brachionus* are used extensively used for marine fish larval rearing in many hatcheries throughout the world. *B. plicatilis* (L type) and *B. rotundiformis* (S-type) are the two common species used for larviculture of marine fishes. The differences among the two types can be clearly distinguished by their morphological characteristics: the lorica length of the L-type ranging from 130 to 340 mm (av. 239 mm), and of the S-



B. rotundiformis



B. plicatilis

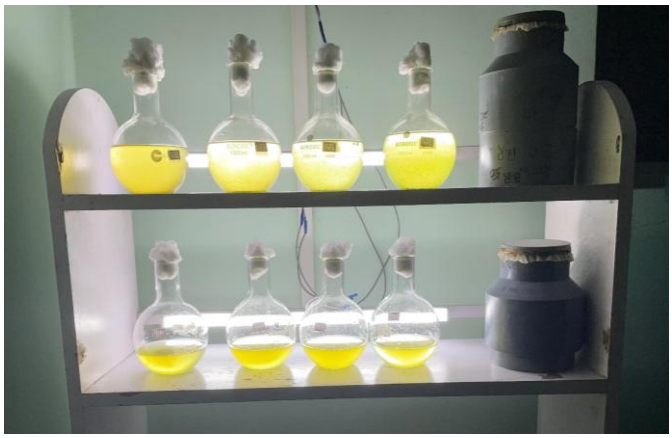
type ranging from 100 to 210 mm (av. 160 mm). Moreover, the lorica of the S-type shows pointed spines, while of the L-type has obtuse angled spines. Another strain. SS-type rotifers (Super small rotifers) are preferred for the first feeding of fish larvae with small mouth openings (rabbitfish, groupers, and other fish with mouth openings at start feeding of less than 100 mm). Those rotifers, however, are genetically not isolated from S-strains, but are smaller than common S-strains.

Stock culture

Relying only on mass cultures of rotifers for reinoculation of new tanks is too risky an approach because the threat of mass mortality. In order to minimize this risk, small stock cultures are generally kept in closed vials in an isolated room to prevent contamination with bacteria and/or ciliates. These stock cultures which need to generate large populations of rotifers as fast as possible are generally maintained on algae.

- Sterilized seawater of 25 ppt salinity is used
- Inoculation of the tubes (50 ml) is carried out with an initial density of 2 rotifers.ml^{-1}.
- The tubes are placed at a distance of 20 cm from fluorescent tubes (light intensity of 3000 lux)
- 4 ml of microalgae is added daily
- After one week the rotifer density should have increased to 200 individuals/ml. The rotifers are rinsed, a small part is used for maintenance of the stock, and the remaining rotifers can be used for upscaling.

Upscaling of stock cultures to starter cultures



The upscaling of rotifers is carried out in static systems consisting of conical flask of 500 ml placed 2 cm from fluorescent light tubes (5000 lux). The rotifers are stocked at a density of 50 individuals/ml-

and fed 400 ml freshly-harvested algae (10^6 cells.ml^{-1}). Next two days rotifers are fed approximately 50 ml of algae. Within 3 days the rotifer concentration can increase to 200 rotifers/ml.

Mass culture

Batch culture system is probably the most common method of rotifer production in marine fish hatcheries. The culture strategy consists of either the maintenance of a constant culture volume with an increasing rotifer density or the maintenance of a constant rotifer density by increasing the culture volume. Batch culture system normally follows a 4–5-day culture period. Initially a tank (0.5-1 ton) is inoculated with rotifers (≥ 200 nos./ml). The rotifers are then fed each day with microalgae (10^6 cells/ml) and the volume of the culture is also increased to keep up with rotifer growth. Many species of microalgae such as *Nannochloropsis*, *Chlorella*, *Pavlova*¸ *Isochrysis* etc, are used for feeding rotifers. Rotifer densities reaches up to 500 nos. /ml after 4-5 days. Rotifers are harvested after the culture period using 300 µ and 50 µ mesh sieves, so that dust free rotifer will be collected on the 50 µ mesh sieves. Both filters are placed inside a container full of water to avoid damage to the rotifers due to pressure of outgoing water. A gentle air bubbling along the inner side of the filter helps to keep the filter free from clogging. A part of the harvested rotifers are used as the innoculum for the next culture.

Ideal water quality parameters	
Salinity	10 – 35 ppt
Temperature	20- 28ºC
Dissolved Oxygen	>3 ppm
pH	7.5-8.5
Ammonia	<0.5 ppm

Rotifers are also cultured using a combination of microalgae and baker's yeast and promotes better growth of rotifer cultures. The tanks are half filled with algae (10^6 cells/ml) and inoculated with rotifers at a density of 100 nos./ml. The first day active baker's yeast is administered two times a day at a quantity of 0.25 g/10^6 rotifers. The next day the tanks are completely filled with algae at the same algal density and 0.375 g baker's yeast per million rotifers is added twice a day. The next day the rotifers are harvested, and

new tanks are inoculated (i.e. two-day batch culture system). These harvested rotifers need to be enriched with microalgae or enrichment diets. Rotifers are often cultured at temperatures and salinities different from the larval rearing tanks. So they must be acclimated for at least 6 hours to larval rearing conditions before introducing into larval rearing tanks.

Enrichment

Rotifers have a limited nutritional value for fulfilling the nutritional requirement of marine finfish larvae. The high content of the essential fatty acid eicosapentaenoic acid (EPA 20:5n-3) and docosahexaenoic acid (DHA 22:6n-3) in some microalgae (*e.g.* 20:5n-3 in *Nannochloropsis occulata* and 22:6n-3 in *Isochrysis galbana*) have made them excellent live food diets for boosting the fatty acid content of the rotifers. Rotifers are enriched by stocking the harvested rotifers @ 500 nos./ml in microalgae cultures (10^6 cells/ml) for 4-6 hrs before feeding to larvae. It can also be enriched with specially formulated artificial diets like Selco products/Algamac/commercial oil emulsions as per manufactures or using homemade emulsions.

ARTEMIA

Among the live diets used in the larviculture of fish and shellfish, nauplii of the brine shrimp *Artemia* constitute the most widely used food item. It is also called as brine shrimp or sea monkey. The total length is about 8-10mm for adult males and 10-12mm for females, the width including legs is about 4mm for both sexes. The widely used species of *Artemia* is *A. salina*. The females can produce eggs either as a result of mating or via parthenogenesis. The thin shelled eggs hatches immediately, and thick shelled eggs can remain in dormant state and forms cysts. These cysts are metabolically inactive, do not further develop as long as they are kept dry and can be stored up to 2 years. Upon immersion in seawater, the biconcave-shaped cysts hydrate, become spherical, and within the shell the embryo resumes its interrupted metabolism. In less than 24 hrs, the outer membrane of the cyst bursts and the embryo appears surrounded by the hatching membrane. While the embryo hangs underneath the empty shell, the development of the nauplii is completed and within a short period of time the hatching membrane is ruptured and the free-swimming nauplii comes out. This freshly hatched nauplius I stage (Instar I) (length of 400-500µ) is popularly used for feeding the larvae.

Each gram of *Artemia* cyst contains 200000 to 300000 eggs and atleast 50% will hatch within 20-24hrs on proper hydration. To estimate the amount of *Artemia* required one must consider both the volume of the tank and the expected number of *Artemia* the larvae will consume. Based on the stage or the age of the larvae, estimate a daily *Artemia* requirement per ml. *Artemia* nauplii are usually maintained in the larval culture tank at densities of 0.5 to 2 per ml for most species of finfishes The requirement of *Artemia* nauplii should be calculated based on the volume of larval rearing tank and the species under culture. Also, *Artemia* nauplii left over in the tank should be determined daily by taking water samples from the larval rearing tank to back calculate the requirement of nauplii/l and requirement of cysts in g for producing the required amount of nauplii.

Weight of *Artemia* cyst required =

Total volume of all rearing tanks (in ml) X No. of *Artemia* required per ml

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Percentage hatch rate X No. of cysts per gram

Artemia nauplii when required in large quantities, it is essential to disinfect the cysts before hydration to reduce the bacterial load to increase the quality and quantity of hatching.

Procedure for hatching *Artemia* cysts in hatchery

Artemia cysts are hatched into nauplii following the standard procedure involving the following steps

1. Hydration of cyst

Artemia cysts (<100 g/l) are put into container containing low salinity water or freshwater at 25ºC for 1 hour with aeration. After an hour, hydrated cysts are filtered through 100- 125 µm sieve. Hydration steps ensures the spherical shape of the cyst, which allows for easy removal of cysts.

2. Decapsulation

Decapsulation procedure ensures disinfection of cysts, complete removal of shell from the hydrated cysts, minimize illumination requirements for hatching, reduces hatching time and increases nutritional value of nauplii.

a. Using Sodium hypochlorite: Hydrated cysts are kept in a beaker filled with 5% sodium hypochlorite solution @ 15 ml for every 1 g cyst. In order to prevent the temperature rising above 300 ºC, the beaker containing the hydrated cyst and sodium hypochlorite are kept in a trough containing cool water or ice. In about 10 minutes, chorion of hydrated cysts gets dissolved and is then filtered through a 100 µm sieve.

b. Using Calcium hypochlorite: The scoop net containing hydrated cysts are kept in a bucket filled with water containing calcium hypochlorite having 200-250 ppm of chlorine. In about 10 minutes, chorion of hydrated cysts gets dissolved and is then filtered through a 100 µm sieve.

Note: The decapsulated cysts should be thoroughly washed in tap water or seawater for about 10 minutes until no chlorine smell can be detected. To ensure complete removal of chlorine, the cysts are dipped in 0.1% sodium thiosulphate solution or 0.1N hydrochloric acid.

3. Hatching/ Incubation of decapsulated cyst

Decapsulated *Artemia* cysts are hatched in a cylindroconical FRP tanks/jars having transparent bottom with continuously aerated from the bottom with air-lines. Decapsulated cysts are stocked @ 5 g/l of seawater in smaller volume tanks (< 20 L) to 2 g/l of seawater in tanks with large volumes. The optimum water quality parameters required for hatching of cysts is 27-30ºC temperature, 8-8.5 pH, 25-35 ppt salinity, 1000-2000 lux light and saturated dissolved oxygen concentration

4. Harvesting of nauplii.

The decapsulated cysts hatch out after a period of 16-24 hrs. Harvesting is done by taking advantage of phototactic movement of *Artemia* nauplii. The top of the cylinder is closed with a lid and illumination is provided at the bottom transparent part. After 5-10 minutes, the nauplii gets accumulated at the bottom. The outlet of the tank at or near bottom is opened and water is sieved through 100-125 µm net to harvest the hatched out nauplii. Then harvesting net should be submerged in water all the time so as to prevent physical damage of the nauplii. They are then rinsed thoroughly with water to remove possible contaminants and hatching metabolites.

***Artemia* enrichment**

Since *Artemia* have poor content of essential fatty acids, eicosapentaenoic acid (EPA: 20:5n-3) and even more importantly docosahexaenoic acid (DHA: 22:6n-3), modification of

the nutritional value of *Artemia* for aquaculture purposes has been done for years. Taking advantage of the primitive feeding characteristics of *Artemia* nauplii, it is possible to manipulate the nutritional value of HUFA-deficient *Artemia*. Since second instar stage (about 8 h following hatching) are non-selective particle feeders, simple methods have been developed to incorporate different kinds of products into the *Artemia* prior to feeding to predator larvae. This method of bioencapsulation, also called *Artemia* enrichment or boosting, is widely applied in marine fish and crustacean hatcheries for enhancing the nutritional value of *Artemia* with essential fatty acids.

Artemia are non-selective filter feeders and therefore will ingest a wide range of foods. The main criteria for food selection are particle size, digestibility, and nutrient levels. The best feeds for *Artemia* are live microalgae and the combinations of live phytoplanktons fed to *Artemia* cultures have demonstrated superior enrichment characteristics (i.e., increased HUFAs). In addition to live algae, *Artemia* cultures can be enriched by feeding a wide variety of processed foods, including yeasts, fish meal, soybean powder, egg yolk, and micronized rice bran. *Artemia* are enriched with commercially available enrichment medium (DC DHA Selco, algamag, ORI-N3 Skretting). The enriched, *Artemia* are rinsed, concentrated, counted, and then fed to larvae.

Counting rotifer and *Artemia*

Collect a representative sample of the rotifer or brine shrimp stock using a small beaker or glass container.

Mix the sample thoroughly using a pipette.

Transfer 1 mL of the mixed sample into a 10 mL graduated cylinder and add 9 mL of seawater (SW) to prepare a 10-fold dilution.

Mix the diluted sample thoroughly and transfer it to a small beaker. Withdraw five 1 mL aliquots and place each into a counting chamber. Add a few drops of Lugol's solution to stain and immobilize the rotifers or brine shrimp.

Using a stereomicroscope, count the number of rotifers or brine shrimp in each 1 mL aliquot and calculate the average density (individuals/mL) of the diluted sample.

Multiply the average density by 10 to account for the 10-fold dilution and determine the actual density (individuals/mL) of the original stock culture.

Volume of rotifer/*Artemia* to be transferred for feeding larvae in tanks

$$V = \frac{\text{Desired feeding rate (ind/ml) x vol of rearing tank (ml)}}{\text{Density of harvested rotifer/}\textit{Artemia}\text{ (ind/ml)}}$$

Maintenance and Culture of copepods

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Copepods are the most common planktonic crustaceans that occur in almost all kinds of water bodies on the earth's surface. There are more than 210 families, 2400 genera and 24,000 species identified in this group. Planktonic copepods are considered to be the most abundant metazoans on earth. From the Lower Cretaceous period onwards, these groups were diversified and adapted to almost all kinds of aquatic habitats and successfully colonized everywhere. In the marine environment, copepods are present in all types of water bodies from pelagic to deep sea and from sea shore to deep hydrothermal vents. Some of them are adapted to live inside the body cavity of many animals. These form the important secondary producers/primary consumers and ultimately contribute significantly to the food chain in large ecosystems. Almost all types of marine organisms, directly or indirectly depend on these small organisms for their food. Copepods form important food for many marine fishes and invertebrates. Certain fishes and fish larvae were evolutionarily adapted for feeding on copepods. Copepods are nutritionally superior than almost all live feeds. Many fishes, especially those with weak fish larvae, totally depend on copepod nauplii for their survival at least for the initial few days. Due to their smaller naupliar stages and nutritional superiority, copepod cultures became an integral component in marine finfish hatcheries.

Copepods are much superior in nutrition than most of the popular and common live feeds in the hatchery. Feeding marine fish larvae with copepods increases their survival, growth rates, reduces deformities and enhances pigmentation and stress tolerance more than almost all other popular live feeds.

Among the planktonic copepods, three major groups are very important in terms of live feeds- calanoids, cyclopoids, and harpacticoids. All these three groups are being utilized as live feeds in the hatcheries. There is always a limitation in the high-density cultivation of copepods. Rotifers can be cultured to a high density of 2000/ml. But in the case of most of the copepod cultures, the density rarely exceeds 2-3/ml for adults and 10/ml for nauplii. Calanoids are comparatively more difficult to culture than cyclopoids and

harpacticoids in small quantities. But large-scale cultures are more easy for calanoids. Calanoids have smaller pelagic larvae and can be more easily produced on a large scale in hatcheries. Copepods that scatter their eggs are ideal for large-scale cultivation in hatcheries.

Species and culture

More than 60 species of copepods have been raised in laboratories but very few are popular for large scale production. Copepods can be cultured extensively, intensively, and semi-intensively. The extensive cultures are mainly in tanks, outdoor ponds, lagoons or enclosed fjords. By using sieves of appropriate mesh sizes, these cultured copepods can be made available to fish larvae. In extensive systems, culture is done normally by producing microalgal blooms using ordinary agricultural fertilizers. Agriculture fertilizers, both organic and inorganic, were used with or without the combination of fishmeal, rice bran, wheat bran and fish feeds as inputs for nutrients. But here the main disadvantage is the unpredictable nature of production. Semi-intensive culture is generally carried out in indoor tanks with a regular supply of microalgae in combination with other inert feeds. Here regular harvest is possible and yields a mixed culture of different species of copepods. Here also the culture may not be stable for longer periods. CMFRI recommends intensive culture for large-scale production. Intensive culture is developed generally by maintaining a selected isolated pure culture of copepod species with desired qualities. Basically, there are small stock culture units, large mass culture units, and modified culture tanks fitted with structures for harvesting naupliar stages on regular basis. Specialized nauplii collection units can be attached to mass culture units also. All water quality parameters were regularly monitored and adjusted.

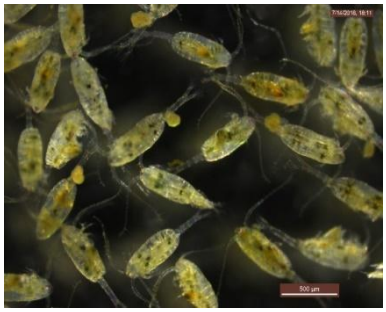
Though intensive culture may not be economical, most of the hatcheries prefer this because of the assured production of copepods and nauplii of desired size and species. This will help larvae to thrive well during critical periods of larval rearing. Once the critical period is crossed, the larvae can be fed with enriched rotifer and *Artemia*.

Copepod species developed for use as live feed

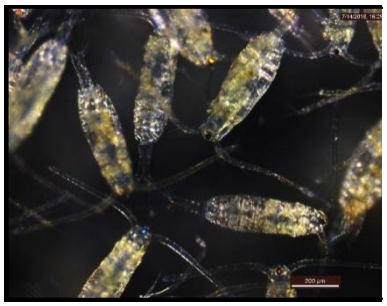
Pure stock and mass cultures of 12 species of copepods that have been identified as suitable for larval rearing are maintained at Vizhinjam Research Centre of CMFRI.

Calanoid copepods (*Temora turbinata, Pseudodiaptomus serricaudatus, Acartia spinicauda, A. bilobata, A. southwelli, A. tropica, Parvocalanus crassirostris, Bestiolina. coreana, B. similis*), Cyclopoid copepods (*Oithona brevicornis* and *Dioithona oculata*) and Harpacticoid copepod (*Euterpina acutifrons*) are being produced in CMFRI. *Apocyclops cmfri* is a promising new species identified from Karwar waters and cultured here.

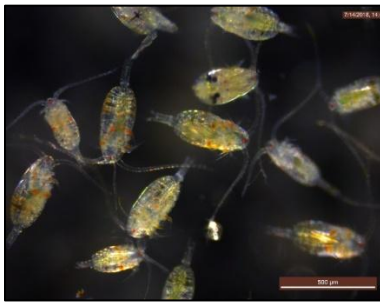
Temora turbinata



Pseudodiaptomus serricaudatus

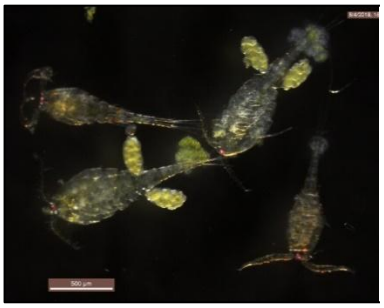


Acartia southwelli

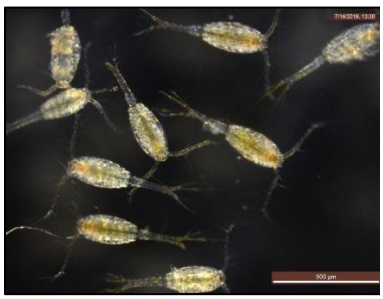


Parvocalanus crassirostris

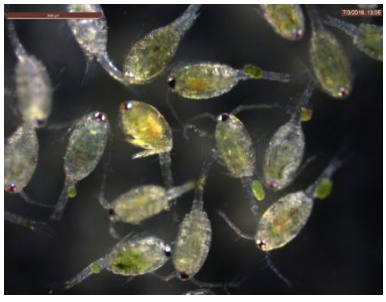
Bestiolina similis



Apocyclops cmfri



Oithona brevicornis



Dioithona oculata

Euterpina acutifrons

Copepods developed by CMFRI

Stock culture

The stock culture of microalgae is a prerequisite for copepod culture. Microalgae need to be contamination free. The algal requirement is comparatively less when compared to other live feeds but the purity of the culture is very important. Contaminated algal culture can collapse the stock of copepods. For each species of copepods algae or a combination of algae in the recommended doses are essential.

Stock culture of copepods can be done in tanks of 50-500 litre capacity or even in bigger tanks. Tanks of plastic, HDPE or fibre are ideal. Cement tanks are not ideal. White colour or light colours are desirable because they support visibility. It is easy to assess the population and health of copepods on white background. Cleaning is also easy on white background. In stock culture, the health status of the copepod is more important than its population status.

Since production is totally dependent on population, regular harvest is possible even from the stock culture without affecting the total population. Stock culture of copepods can be done in tanks of 50-500 litre capacity or even in bigger tanks. Tanks of plastic, HDPE or fibre are ideal. A few hundred copepods are sufficient to inoculate in stock culture tanks. Tanks attain maximum density within 10-20 days depending on the species cultured. Normally the stock culture can continue for 2-3 months with proper maintenance. There are basically no differences in the maintenance of stock and mass culture.

Maintenance of stock culture

On alternate days, the sediments need to be siphoned off from the culture tanks to reduce the ciliate growth and also to maintain good growth of copepods in the culture. The siphoned sediment and water should be kept in 20litre buckets with mild aeration for a few hours for the settling of debris. Live copepods, eggs, and larval forms accumulated in the clear surface of the buckets can be carefully filtered out by passing through a filter of the sieves of the desired mesh size. Copepods collected can be washed and reintroduced in the culture tanks. The sediment can be diluted again and this process can be repeated several times so that all healthy and live copepods are collected and introduced back into the culture. This process is essential for egg broadcasting species because all the eggs will be settled in the bottom with faecal pellets and wastes. In this

way, ciliates and dead organisms can be regularly removed from the tanks. In the case of egg-producing copepods, the filtrate need to be diluted with clear filtered sea water and kept for one or two days with mild aeration. The freshly hatched nauplii can be sieved out regularly using a 30µm sieve and can be introduced back into the culture system. The water level in the culture tank should be brought back to the original level by adding clean, dechlorinated or ozonized and filtered seawater. The tank needs to be washed and reused completely after one month of culture.

Another method of keeping stock culture is without siphoning the bottom for 7 days. Keep on adding feed and maintain water quality parameters without disturbing the culture. After 7 days, remove the bottom debris and transfer the entire culture into another fresh tank. The old tank can be washed, sterilized, and reused.

Mass culture

For the mass culture of 1000-5000 litres, 50-100 litres of inoculum is required. Inoculum needs to be cultured in 1000-litre tanks for inoculating 5 tonne or 10 tonne tanks. Up to 75% of the stock can be used for culture. The inoculum will be ready again within 8-10 days and the tanks will be ready for harvest within 10-25 days period. Thus, a series of tanks starting from 100 litre, 500 litre, 1000litre and 5 tonnes/ 10 tonnes are necessary for establishing a large-scale production system. Care should be taken to increase the volume of water slowly with an increase in population after inoculation, especially in large systems. All tanks should never be filled beyond 75-80% of their capacity. Flat base round drainable tanks are ideal and the water depth less than 1m. Complete indoor tanks also can be used with normal lighting conditions. All tanks should be placed in a bit elevated position so as to assist easy siphoning of bottom samples. Mild aeration is essential in all tanks.

Mass culture can be done as batch culture and continuous culture. For batch culture, the entire tank content can be harvested. For continuous culture, daily harvest is possible from the larger tanks. Most of the species can be cultured in both ways but continuous culture is more successful in egg-broadcasting copepods of the genera *Parvocalanus, Bestiolina, Temora* and *Acartia*.

Maintenance of mass culture

Mass culture tanks of any capacity can be used for large-scale production. Mild aeration needs to be provided accordingly the entire area of the tanks needs to be aerated but there should not be any turbulence or strong flow of water. The inoculum needs to be introduced into 4-5 times higher volume and slowly increase the water level to optimum tank size depopulation of copepods as daily doses. In large volumes of water, unused algae may settle down as debris and can create the development of unwanted organisms. If conditions are favourable within one week, we can reach the maximum capacity of production. In most of the species, we can reach maximum volume within 7-15 days. Depending on the level of sediments, bottom debris needs to be siphoned off from the culture tanks to reduce the ciliate growth and to maintain good growth of copepods in the culture. The siphoned sediment and water should be kept in buckets with mild aeration for a few hours for the settling of debris. If a large volume of water needs to be filtered, use one or more sieves to collect the sediments. In such cases, an open wide flat tray can be used to reduce the pressure of outflowing water. Live copepods, eggs and larval forms accumulated in the clear surface of the buckets can be carefully filtered out by passing through a filter of the desired mesh size. Copepods collected can be washed and reintroduced in the culture tanks. The sediment can be diluted again and this process can be repeated several times so that all healthy and live copepods are collected and introduced back into the culture. This process is essential for egg broadcasting species because all the eggs will be settled in the bottom with fecal pellets and wastes. In this way, ciliates and dead organisms can be regularly removed from the tanks. In the case of egg-producing copepods, the filtrate should be diluted with clear filtered sea water and kept for one or two days with mild aeration. The freshly hatched nauplii can be sieved out regularly using 30µm sieve and can be introduced back into the culture. The water level in the culture tank should be brought back to the original level by adding clean, dechlorinated or ozonized and filtered seawater.

Sieves of different mesh sizes made from plastic pipe connectors and bolting silk

Siphoned sediments from the culture tanks kept for isolation of naupliar stages

Induced Breeding of Silver Pompano

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Breeding and seed production of marine fishes depend extensively on quality broodstocks, induced maturation, spawning, larval rearing, live feed culture, and the availability of good quality water. Following the successful seed production of Cobia, Silver pompano, Indian pompano, Vermiculated spine foot, Pink ear emperor, and Orange-spotted grouper and the farming demonstration of those species in marine cages and brackishwater cages/ponds, popularized the technology among the farmers about its suitability for aquaculture. Pompanos are marine fishes in the genus *Trachinotus* belongs to the family Carangidae. The genus *Trachinotus*, occurs in all tropical oceans and comprises 19 species (Fricke et al., 2019). *Trachinotus blochii* is a deep-bodied carangid usually found around shallow coastal waters over rocky and coral reefs. Occasionally they are in small schools. The availability of silver pompano in the commercial fishery is relatively scarce, and its high market demand raises the potential for culture along the Indian coast. Pompano aquaculture has been successfully established in many countries. Silver pompano aquaculture was done in Indo-Pacific countries, especially in China, Vietnam, Malaysia, India, and the Philippines. In India, the Central Marine Fisheries Research Institute (CMFRI)

initiated aquaculture research on pompano at its Mandapam Regional Centre in 2007, and the first successful broodstock development, induced breeding, and seed production was achieved in July 2011 (Gopakumar et al., 2012).

Broodstock collection, Transportation and Quarantine

Wild collection and transportation of adult/sub-adult marine finfish have a pivotal role in developing the broodstock in captive conditions. All the silver pompano (*Trachinotus blochii*) broodfishes are collected by wild collection from the sea only. Wild collection done from Alappuzha, Vizhinjam, Kanyakumari, Tuticorin and Ramanathapuram areas along the southwest and southeast coast of India. Availability of the broodfishes from a particular area can be assessed by a short-term market survey or by interviewing fishermen who target the particular fish. Wild collection of fish is mainly done using Gill nets and Hook and line fishing.

Fig.2. Silver pompano fishes removing from the gill net operated off Alappuzha coast, Kerala, India

Handling

Handling of brood fishes during the collection process should be minimal to prevent physical injury and physiological stress. Damage to the slime (mucus) layer, scales, and skin of the fish can result in infection which leads to secondary infection and may lead to

mortality after the transportation. Knitted fine-mesh dip nets are recommended for handling fish to minimize injury and scale loss (Rottman *et al*., 1991).

Transportation

Ideally, transporting tanks/packets should be filled with water from where the broodfish are collected. Silver pompano can be transported both in tank method and plastic bag method. Size of the plastic bag is crucial for transportation and the plastic bags should be filled with 3 parts oxygen to 1 part of water. If the fish weight is more than 200 gm, it is better to opt tank method for transportation. So as to maintain the water temperature levels in a controlled manner, it is better to keep the plastic bag with fish inside the insulated or air-conditioned chamber in the vehicle. The collection process of broodfish always leads to a high level of physiological stress in them. So as to resolve this, a high level of dissolved oxygen is necessary for them to recover from the oxygen debt situation.

Fig.3. Plastic bag with brood fish loading to the vehicle

In the tank method of transportation, one holding tank of Fibre glass or triple layered plastic tanks (Aquatech, India) of suitable capacity like 250 or 500 or 1000 L (according to the quantity needed to transport and capacity of the vehicle), Oxygen cylinder and a small air pump (battery operated) can be used to transport the fish. Tanks should be aerated. The

tank should be equipped with pure oxygen regulated to maintain dissolved oxygen concentrations at a minimum of 7 ppm (Kohler, 1997). A portable generator of 220-240 Voltage can be used as a stand by equipment to avoid critical conditions like air cut off etc. Warm water also reduces available oxygen and increases the metabolic rate of the fish, adding further physiological stress. The stocking density of fish is a critical factor which determines the survival of the brood fishes. A stocking density of 100 g/50 L is found advisable for the transportation of silver pompano. It is advisable to transport the fish during the early morning hours or night hours to avoid the temperature hike from sunlight. Ice blocks wrapped in plastic cover may be added to the holding tank during transportation to prevent an increase in water temperature.

Quarantine

After unloading the fish from the transporting vehicle, immediately transfer to the quarantine section. Quarantine tanks (fibre reinforced plastic) are of 3000 L capacity with 24 hr aeration facility. Stocking density inside the quarantine tanks is of crucial factor for the survival of wild fish transported to the hatchery. A stocking density of 100 gm/200 L with 200% water exchange was found optimum for the silver pompano quarantine facility.

Various treatment procedures can be used to limit the entry of external parasites in the hatchery system from the wild-caught fishes transported. The infected fishes were primarily treated with formalin at the rate of 10 ppm as bath treatment for 5 consecutive days which was found to be effective during the course of infection with 200 % water exchange (100 % two times) every day. Dip treatment with chloroquine phosphate (Lariago 250 mg tablets; Ipca Laboratories Pvt. Ltd.) at a dosage of 500 mg/100 L of water (Ramesh kumar *et al*., 2015) was found effective for silver pompano fishes. Feeding during the treatment should be avoided in the daytime so as to maintain the water quality parameters in a stable condition. Short time exposure of brooders (maximum 5 minutes) in freshwater and treatment with 100 ppm formalin for 2- 5 min, were also found helpful in removing the external parasites. Once the quarantine period is over, they can be transferred to the

maturation tanks. It is advisable to do freshwater dip treatment quarterly for the silver pompano brooders.

Broodstock management of Silver pompano in RAS

Proper care should be given to broodstock in captivity (here RAS) to get successful spawning. The viability of the larvae is very much dependent on broodstock nutrition. The nutritional components in the diet, the feed intake rate or the feeding period can all affect spawning, egg and larval quality (Gopakumar *et al*., 2012). Improper care may lead to disease outbreaks and mortality in maturation tanks. In the case of maturation of wild caught silver pompano in RAS, the male and female broodstock of above 1.5 Kg is an ideal size for successful captive breeding and hatchery production of good quality larvae. Stocked fishes were fed once daily at the rate of 5 % of their body weight with fresh cleaned sardines, and anchovies. Fresh squid was given every day along with vitamin C and vitamin E tablets once a week.

Maturation Tanks

After the fish are transferred to the maturation tanks with the recirculation facility, they are usually segregated by sex and kept in a sex ratio of 2:1 (male: female). Segregation of fishes has done by cannulation and tagging process. It is preferable to place round tanks as maturation tanks to ensure proper water circulation. Silver pompano is comparatively fast swimming fishes and any small disturbance may tend the fish to jump out of the tank and thereby tank should be covered with a net. The stocking density of broodstock maintained in RAS was 1 kg/1000 L. Pompano broodstock performed better in circular tanks with 10 Ton capacity. Excess broodstock can be maintained in coastal/open sea cages.

Water quality requirements

Seawater to be used in the facility should enter a storage tank where it should be treated with hypochlorite solution. Water quality requirements in the maturation tank system are a temperature of 27–29 ºC, salinity of 27–32 ppt, ammonia of ≤ 0.02 and a pH of

7.8–8.5, permitting adequate feeding of the broodstock while maintaining optimal and stable water quality.

Fig. 4. Broodstock fish tanks

Feeding

Wild-caught pompano brooders can be trained to accept and maintain on trash fish, squid meat and formulated feed for over four years. Newly collected pompano should not be fed until all therapeutic treatments are completed. This delay assures the fish will be hungry when feed is first offered, and prevents habituating fish to ignore feed by presenting it to them when stress or disease agents impede their appetites (Kohler, 1997). Initially, fishes are fed with squid and trash fish by hand feeding. After a period of one month, mix squid meat (better to keep the formulated feed inside the end portion of squid) with formulated feed and train them to accept it.

Fig. 5. Feeding the Silver Pompano broodstock

It is very important to observe the broodfish during feeding, so that we can understand the feeding pattern and health profile of the broodstock. If there is any reluctance to feed, the fish should be shifted to the quarantine section as soon as possible and start the treatment.

Tagging

A Passive Integrated Transponder (PIT) tag, also known as a radio frequency device permanently marks fish internally. The tag is designed to last throughout the life of the fish, providing a reliable, long-term identification method. Passive Integrated Transponder (PIT) tags act as a lifetime barcode for an individual animal, analogous to a Social Security number, and, provided they can be scanned, are as reliable as a fingerprint (Gibbons & Andrews, 2004). In maturation tanks, PIT tagging can be used to answer questions regarding growth rates and maturation stages.

Fig.7 (a) PIT tags and tagging gun, (b) PIT tag reader, (c) PIT tagging of Pompano brooder fish,

(d) Reading the PIT tag in pompano brooder fish

Normally, intramuscular insertion is preferential (below the muscular region of dorsal fin) for pompano brooders. In normal cases, pit gag causes no mortality and little incidents of infection. The maturation stages of the fish can be assessed by cannulation of the particular fish and can be recorded in the register of the particular fish. Each tag represents a specific number which can be recorded in a register along with the growth measurements (and maturity stages) of the fish. After a definite period, fish can be recaptured, and PIT tag reading can be used to identify the particular fish. Various studies confirmed that pit tagging won't cause any serious impact on the survival or growth of the fish in hatchery conditions.

Ovarian biopsy to assess gonadal maturity (Cannulation)

Monitoring of oocyte development in fish was carried out at frequent intervals to determine its maturity. Oocytes collected via cannulation were observed under microscopes to analyze the diameter of the eggs. The procedure of Ovarian biopsy is given below

1. Female brooders have to be transferred to a small tank containing anaesthesia, the anaesthetic agent used is 2-phenoxy ethanol (standardized to 10ml for 100 L seawater).
2. Flexible, sterile catheters, an infant feeding tube with a total length of 520 mm and size 2.00 mm, (FG -06) are introduced through the genital pore into the oviduct for a few cm up to the ovary. A mild pressure will be applied to suck out the oocytes till a small sample of oocytes up into the catheter and placed the sample on a glass slide.
3. After sampling, release the animal into the tank, where recovery from sedation will take place. The fish will be recovered from the sedation within 2-3 minutes. Take care to hold the fish in the tank till it recovers from sedation to avoid bleeding in the fish due to a slap at the tank due to anaesthesia
4. The biopsy sample is then examined under the microscope; the diameter of the oocytes is measured, and the different stages of gonad development are also noted.

The different maturity stages are;

a) **Early developing stage**- Immature ovaries are relatively small with a size of 80-120 µ in diameter. Ovarian tissue was dominated by previtellogenic oocytes and strands of stromal tissue. Ovary with different stages of previtellogenic oocytes visible in the early developing stage ie; pre perinuclear oocyte, early perinuclear oocyte, and late perinuclear oocyte.

b) **Maturing stage-**Vitellogenesis begins with the appearance of oil droplets, yolk vesicles, and cortical alveoli vesicles surrounding the nucleus stage. Oocytes increase in size with a diameter of 350- 450 µ.

Fig.8: Cannulation

c) Mature egg stage:- The wall becomes thin due to the expansion of the ovary as it ripens and oocytes mature. Induce breeding is carried out at this stage with an egg diameter of >500 µ.

d) Spent/Artesia stage- Characterized by the presence of previtellogenic atretic oocytes without yolk granules and vitellogenic atretic oocytes with yolk granules.

Microscopes connected to a system with ZEN software, a modular image-processing and analysis software for image acquisition, processing, analysis and documentation for ova diameter studies.

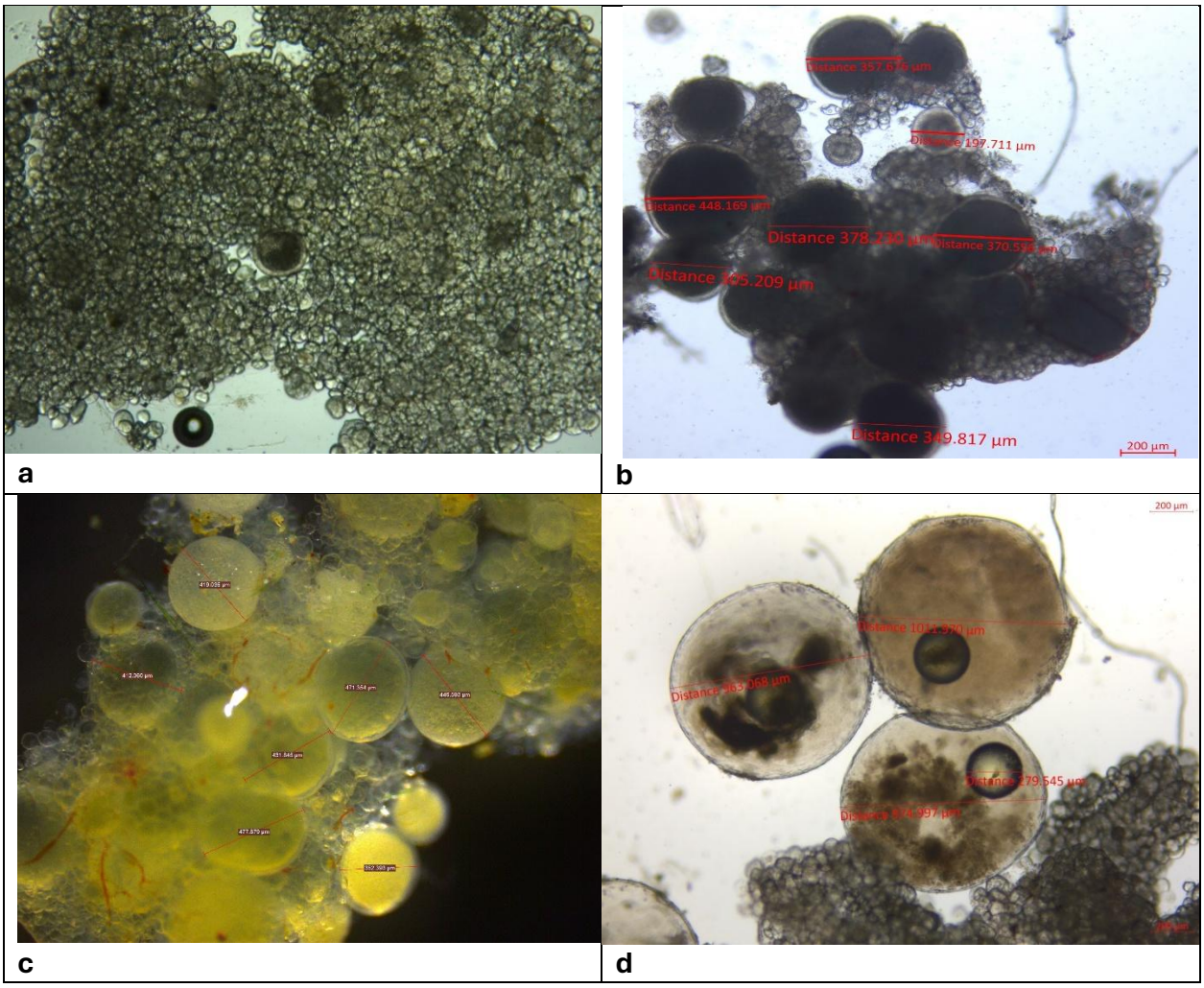

Fig.9. Developmental stages of oocytes a; immature/ honeycomb stage, b; Maturing stage, c; Mature, d; Spent/Artesia

Hormonal Induction

In captivity, natural spawning is rare due to the absence of environmental cues such as seasonal variations, currents, or photoperiods. To overcome this, hormonal induction is employed to stimulate the final phase of oocyte development and ovulation.

Criteria for Induction:

- Oocyte diameter must exceed 450 µm.
- Fish selected should be healthy and mature, preferably weighing between 1.5–5 kg.
- Common sex ratios include 1:2 or 1:3 (female: male).

Hormonal Agents and Dosages:

- *Human Chorionic Gonadotropin (hCG):* 350 IU/kg body weight, administered as a single dose intramuscularly.
- *LHRHa Analogue:* Initially trialed at 100 µL/kg for females and 50 µL/kg for males, later standardized to 150 µL/kg for females and 75 µL/kg for males.

Fig.10: Hormonal inducement of Silver pompano

Egg collection

Once spawning has occurred, egg collection must be handled carefully to preserve egg viability. Aeration in the spawning tanks is turned off to allow non-viable eggs to settle. Floating, fertilized eggs are gently collected using a scoop net with 500 µm mesh. These are then transferred to temporary containers for evaluation. Eggs are examined under a microscope to assess quality, quantity, and developmental stage. Only those at the appropriate stage of development and with a healthy appearance are selected. Egg collectors may also be used if set up properly, enabling the separation of floating (fertilized) eggs from those that sink (unfertilized or poor-quality). Frequent monitoring helps prevent collector clogging, which could damage the eggs.

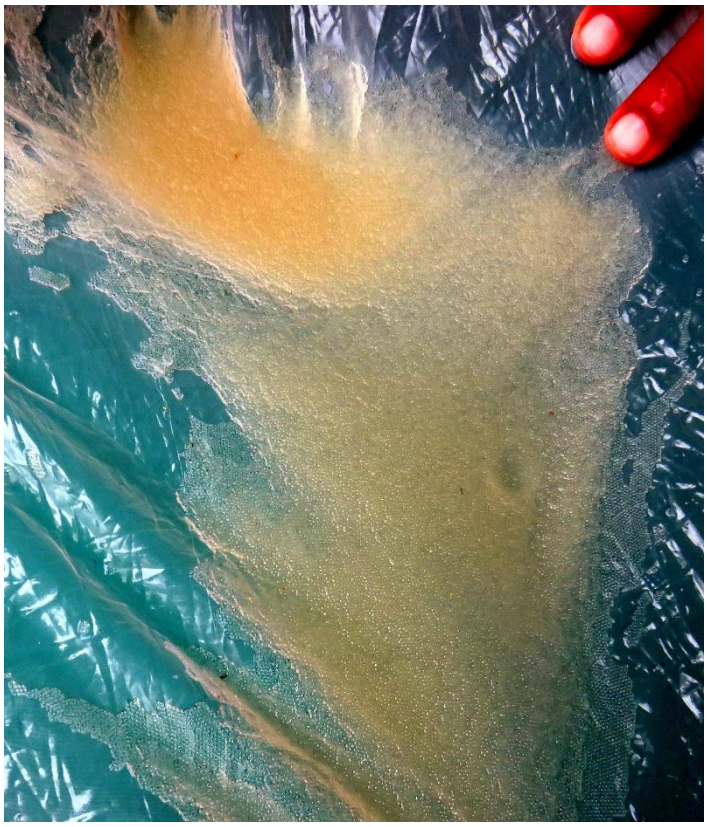

Fig. 11: Collected Pompano eggs

Larval Rearing

Newly hatched larvae must be assessed for health before being stocked into larviculture tanks. Under microscopic observation, larvae are evaluated for body shape, pigmentation, internal organ visibility, and presence of deformities or parasites. A typical stocking density is 5–10 larvae per litre. At hatching, the larval mouth is closed, and the digestive tract is undeveloped; initial survival depends entirely on the yolk sac. Larvae are stocked in 5000 L tanks containing 4000 L of filtered seawater and green water at a microalgal density of 1 × 10^6 cells/mL. Mild aeration is maintained. By the third day post-hatch (dph), the larvae's mouth opens (approximately 230 µm in size), and external feeding begins. The feeding schedule is as follows:

- 3–14 dph: Enriched rotifers (5–8 rotifers/mL)
- 8–12 dph: Co-feeding with enriched Artemia nauplii

- 13–18 dph: Artemia nauplii (3–5/mL)
- From 19 dph onwards: Transition to inert larval diets

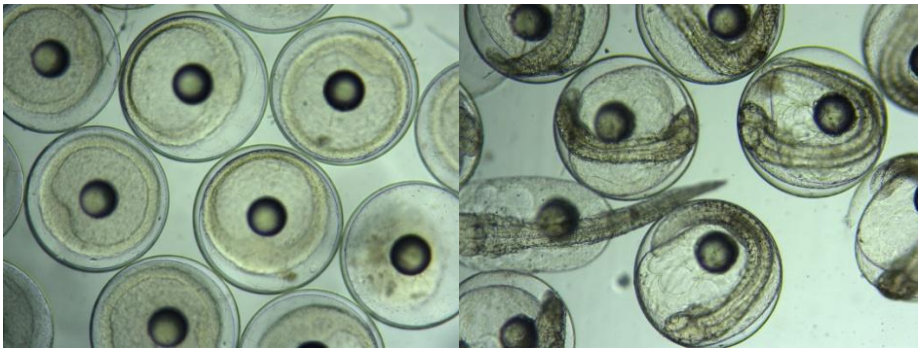

Fig 12. (a) Fertilized eggs (b)Hatching started

(c) 1 dph (d) 2 dph

Larval metamorphosis begins at 18 dph and is completed by 25 dph, by which point juveniles are formed. To prevent cannibalism, size grading is performed between 20 and 25 dph. The critical mortality window is between 3–5 dph, primarily due to developmental issues; beyond this, cannibalism becomes the main threat. Water exchange is carefully managed:

- Up to 7 dph: Minimal exchange
- 8–14 dph: Gradual increase from 10% to 100%
- Post 25–30 dph: Nursery phase begins with a daily 100% water exchange.

During this nursery phase, juveniles are transitioned to larger pellet feeds, starting with 800 µm size, followed by floating larval diets of increasing size. Key water quality parameters, salinity, temperature, pH, oxygen, and ammonia, are continuously monitored. Juveniles

measuring 1–1.5 inches are suitable for transfer to grow-out systems in marine or brackish water cages for further rearing.

Summary

Silver pompano (*Trachinotus blochii*) has proven to be a highly promising species for sustainable mariculture in India, due to its rapid growth, broad salinity tolerance, high market demand, and excellent adaptability to captive conditions. Through significant advances in hatchery technology, broodstock management, and larval rearing protocols developed by ICAR-CMFRI, this species has transitioned from exploratory research to practical commercial farming. The successful establishment of breeding, larval rearing, and nursery rearing techniques has created a robust foundation for pompano seed production. With the standardised protocols now widely adopted across India's coastal regions, silver pompano cultivation offers a viable livelihood option for small-scale fishers, entrepreneurs, and coastal farming communities. The species' resilience and favourable economics make it a key contributor to India’s blue economy and a benchmark model for the development of marine finfish aquaculture in the country.

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Larval and Nursery Rearing

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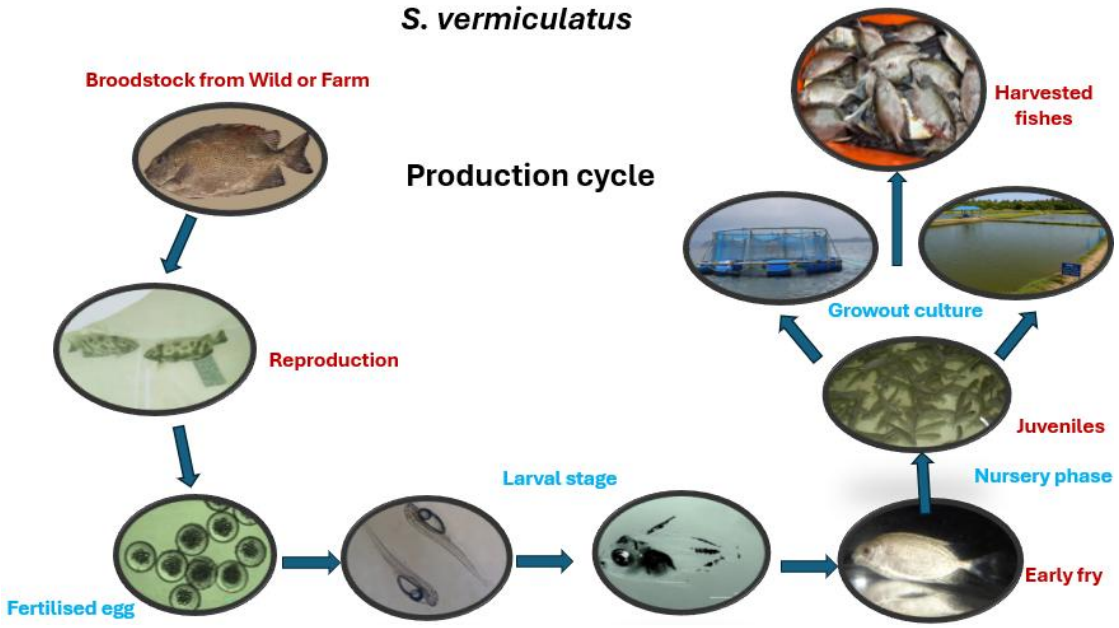
In finfish mariculture, seed production and larval rearing are the bottlenecks which are considered as the main limiting factor hindering its development in commercial scale. Larval and nursery rearing form the most delicate bridging phase in marine finfish hatcheries. This stage transforms newly hatched, fragile larvae into robust fingerlings capable of thriving in open grow-out environments like sea cages, earthen ponds, or Recirculating Aquaculture Systems (RAS).



1. Larval Rearing (Hatch to Metamorphosis)

The rearing tanks are usually made of plastic, fibreglass or concrete. The shape of the tanks can be rectangular or circular. Volume ranges from 1 to 10m^3. The tanks are usually placed in indoor or semi outdoor conditions and protected from heavy sunshine and heavy rain, preferably under roofing. Light is necessary for larval rearing, either diffused light or artificially provided using tube lights. There should be a separate section for larval rearing in hatchery, which should be also biosecured with

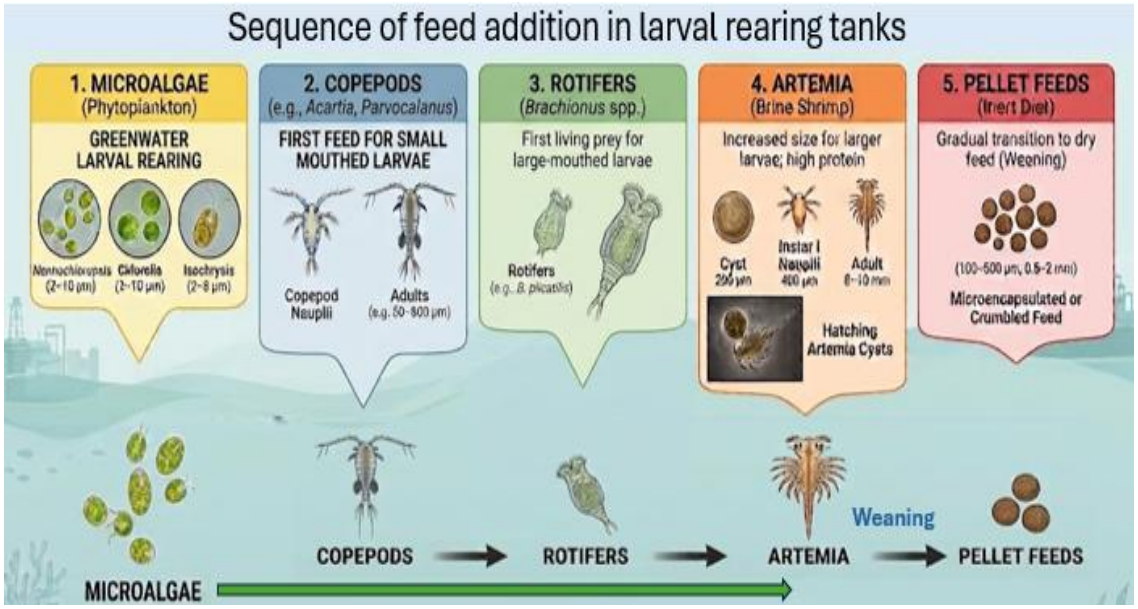
restrictions in entry of personnels and equipment's to avoid cross contamination and pathogen entry. The persons working in larval rearing section should wash their hands and feet on every entry and exit, and disinfection of all equipment's should be performed before and after usage.

The fertilised eggs collected from spawning tanks are stocked in larval rearing tanks without causing any damage for incubation and hatching. The number of eggs varies between species and tank size. In case of cobia, the number of eggs stocked is between 5-10 no./l while the number of eggs stocked is between 10-20 no./l in case of pompano. Larvae of marine fishes which are herbivores as juveniles or adults, are primarily carnivorous during the larval stage, feeding upon smaller planktonic organisms. Fish larvae must feed frequently to ensure fast growth, a prerequisite for high survival. Fish larvae upon hatching for the first 2-3 days get nourishment from their endogenous yolk sac which contains vital energy reserves like proteins, free amino acids, glycogen, and fat droplets. Soon after the exhaustion of yolk, sufficient quantity and appropriately sized live feeds should be available in the larval rearing tanks to avoid starvation and mass mortality.

The marine fish larvae are generally classified into altricial and precocial type. The altricial type of larvae is having very less yolk reserves at hatching and hence, the larvae are in an undeveloped stage when the yolk sac is completely resorbed. The development of digestive system is also very primitive in these types of larvae. Many of the marine fin fishes which are suitable for aquaculture are having the altricial type of larvae which poses challenges in their larviculture. When the yolk reserves are fully exhausted, the larval size and mouth gape are very small and the perceptive powers for searching and taking external feed is also very less. The period when the yolk reserves are fully exhausted and larvae need to resort to exogenous feeding is a critical period in the larviculture of most marine fin fishes. Unless proper live feeds of required size are provided in sufficient densities in larviculture tanks, large scale mortality will occur. Proper management of live feed is the most vital pre-requisite for the success in terms of survival and growth of the larvae.

For most marine species, hatcheries use the green water larval rearing technique, in which fertilised eggs are stocked in tanks containing microalgae. Massive mortality is a common occurrence in many hatcheries during the early the larval stages due to inappropriate feed uptake. Successful initiation of feeding depends upon availability of suitable kinds and sizes of prey, which usually is zooplankton 50–100 μm in width. Sizes of copepods are perhaps the most common prey of small fish larvae in wild. Nevertheless, most of the marine fish hatcheries use rotifer in the genus *Brachionus* as starter feed for larvae, which are quite easy to maintain and produce in large quantities in very limited time. Ever since the rotifer began to be used from 1960's in marine fish hatcheries, it paved the way for successful hatchery seed production technology of multitude of marine species. However, larvae of marine fish species (grouper, snapper,

rabbit fish), whose mouth opening is less during exhaustion of yolk should be fed with copepod nauplii before they can be survived with rotifers and Artemia



Some common factors affecting mass rearing of marine finfish larvae

Type of Food

- **Species needs**: Different fish species require specific live feeds based on mouth size and developmental stage
- **Nutritional value**: Rotifers and Artemia are common, but they often need enrichment with fatty acids. Copepods are high in nutritional value and of small size, but maintenance and production in large quantities require utmost care and more time
- **Size progression**: Larvae shift from small sized zooplankters to larger prey as they grow and eventually weaning them to artificial feeds of different sizes and protein content

Food Density

- **Feeding rates**: Maintaining the right number of prey items per ml of culture water prevents starvation or waste
- **Species behavior**: Active hunters need higher prey concentrations than sluggish or weak swimming larvae
- **Overfeeding risks**: Excess food affects the water quality and causes bacterial blooms in tanks

Water Quality

- **Oxygen levels**: Dissolved oxygen must stay high to support high metabolic rates in growing fish larvae
- **Waste removal**: Ammonia and nitrite levels must remain near zero through optimised feeding and water exchange schedules

- **Salinity and pH**: Stable chemical parameters prevent osmotic shock and reduce larval stress

Environmental Factors

- **Light intensity**: Low to moderate light helps larvae locate food without causing high stress.
- **Photoperiod**: Natural light cycles regulate feeding behavior and daily biological rhythms.
- **Temperature control**: Stable warmth speeds up digestion and growth according to species limits.

Larviculture protocol of cobia

Newly hatched larvae of cobia normally measure 3.4 mm size. Larval mouth opens at 3-5 days post hatch (dph). Newly hatched cobia larvae generally start feeding at 3 dph and they can be fed with the enriched rotifer (*B. rotundiformis*) at the rate of 10-12 nos / ml, two times a day till 10 dph. From 8 dph, the larvae can be fed with enriched Artemia nauplii at the rate of 2-3 nos / ml, 2 times a day. During the rotifer and Artemia feeding stage, green water technique can be used in the larviculture system with the microalgae *Nannocloropsis occulata* at the cell density of $1x10^7$ cells / ml. The weaning to artificial larval diets has to be started from 15- 18 dph. While weaning, formulated feed should be given 30 minutes prior to feeding with live feed.

Artificial feed (100-800 µ) should be given to larvae based on mouth size of the fish. Continuous water exchange is required during weaning stage. Between 25-40 dph, the larvae are highly cannibalistic and hence size-grading has to be undertaken at every three days interval. During this stage, the fry could be weaned totally to artificial diets (800-1200 µ). The water exchange can be practically nil till 7dph, and it can be gradually increased from 10- 100 % from 8 to 12 dph, however tank bottom siphoning should be carried out from day 1. The environmental conditions required during the larviculture period are DO: > 5mg /L , NH_3 : < 0.1mg /L, pH: 7.8 – 8.4, Salinity: 25-35 ppt, water temperature: 27-33° C.

Larviculture protocol of silver pompano

The newly hatched larvae are stocked at a density of 15000 larvae in FRP tanks of 2 ton capacity filled with 1.5 ton filtered seawater. The tanks are provided with mild aeration and green water at a cell density of 1 $x10^7$ /ml. The mouth of the larvae opens on 3dph, and the mouth size was around 230 µ. The larvae are fed from 3dph to 14 dph with enriched rotifers at a density of 6-8 nos. per ml in the larviculture tanks. Co-feeding of rotifers with enriched Artemia nauplii has to be done during 12-14 dph, and thereafter upto 19 dph with enriched Artemia nauplii alone by maintaining a density of 3-5 nos. per ml in the larviculture tanks. Weaning to larval inert feeds has to be started from 15 dph

and co-feeding with Artemia needs to be continued until 19 dph. From 20 dph feeding can be entirely on larval inert feeds. Copepods may be fed along rotifer to increase the survival of larvae. The metamorphosis of the larvae starts from 18 dph and all the larvae metamorphose into juveniles by 25 dph. Though cannibalism is not witnessed, grading has to be done during 20-25 dph to separate the shooters. The water exchange can be practically nil till 7dph and it can be gradually increased from 10-100 % from 8 to 14 dph.

Larviculture protocol of Indian pompano

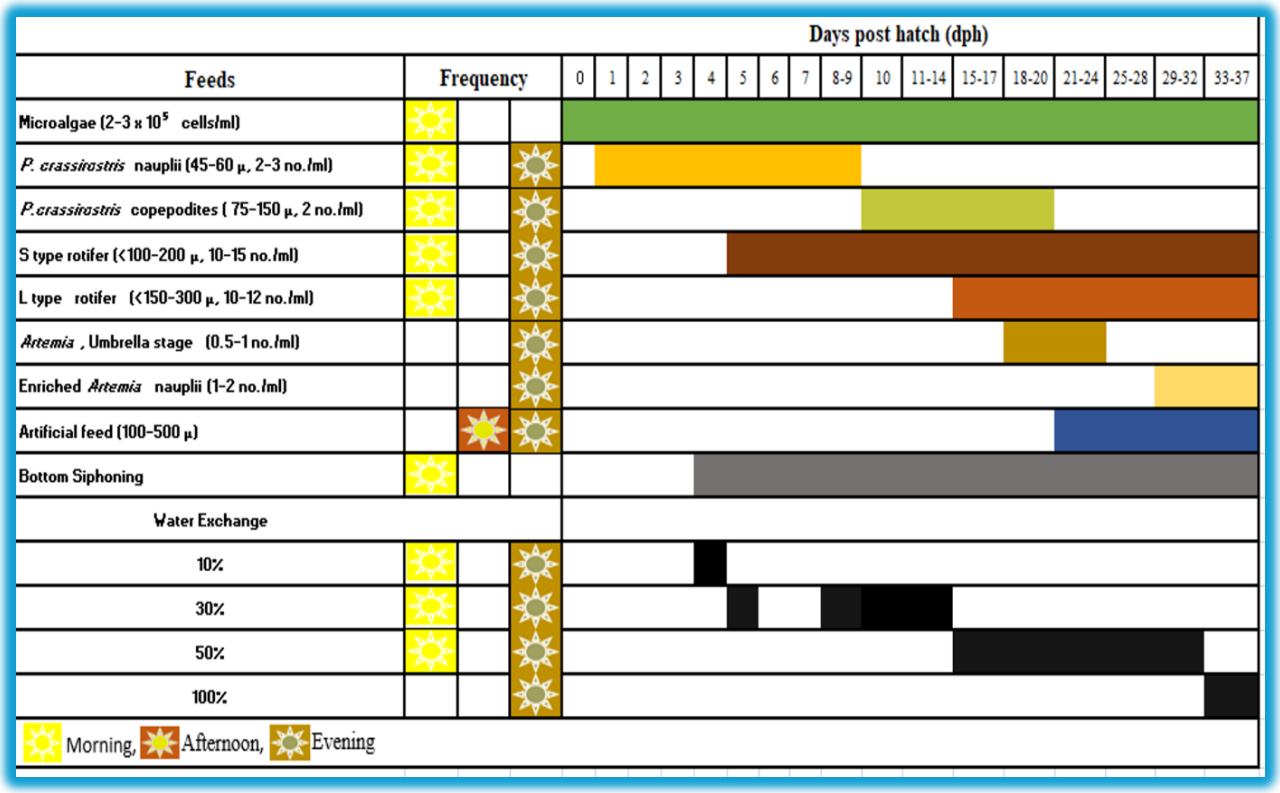
The newly hatched larvae measured 2.1-2.2 mm in total length. The mouth opening was formed after 42-46 h post hatch. The newly hatched larvae collected from the water surface of hatching tank are stocked in larval rearing tank@ 10 nos./L. Water depth of the larval rearing tank was maintained at a minimum of 80 cm. Green water is used for larval rearing. Copepod nauplii and rotifers (<100µ) were given as feed from 2-5 dph @ 2 nos./ml and 10-15 nos./ml respectively. Larger rotifer (15-25 nos./ml) and Artemia nauplii (2 no./ml) were used in larval rearing tank from 6-12 dph and 7-16 dph respectively. Weaning of larvae with inert diet was started from 15th day. Metamorphosis of the larvae started from 17th day and was completed by 22nd day. The size of the metamorphosed fry ranged from 16 to 17 mm. Juveniles of Indian pompano were harvested after 25-30 days of larval rearing and were shifted for nursery rearing. The average survival during the larval rearing was around 21 %. Longer duration of light (1000 lux) was provided for two to eight days of larval rearing afterwards, natural lighting was followed

Larviculture protocol of orange spotted grouper

The newly hatched larvae of orange spotted grouper measure 1.2- 1.4 mm total length. The recommended initial stocking density for orange spotted grouper is 10 larvae/L. The mouth opens between 2–3 days after hatching (around 60 hrs) depending upon temperature and the yolk is completely absorbed by 3rd-4th dph. Their initial mouth gape is very less, so they have to be provided with appropriate size of feed i.e. copepod nauplii and screened rotifers. *Nannochloropsis* sp is introduced into the larval-rearing tanks on 2nd dph at algal cell density of 1×10^5 cells/ml. Rotifer and copepod nauplii filtered with 100 µm mesh are introduced into the larval rearing tanks on 2nd dph, after the larval mouth opening has been formed. The rotifer and copepod nauplii density in the larval

rearing tanks is maintained at 5-7 and 2-3 individuals/ml respectively during 2nd -5th dph. After 5th dph, small rotifers (filtered with 150 µm mesh) are introduced at densities of 10-15 individuals/ml, which is gradually increased to 20 individuals/ml from 11th to 18th dph. Freshly hatched out Artemia nauplii are fed at density of 0.5 individual/ml from 17th dph, and their size increasing with advancing in rearing period. Adult copepods are fed during 16th-20th dph in larval rearing. Weaning of grouper larvae with artificial diets starts from 20th dph. Artificial diet with a particle size of 200-300 µm is used initially. The formulated feed is sprinkled onto the surface of the water in small amounts frequently throughout the day. Formulated feed is added in small amounts so that the feed is consumed within 5 or 10 minutes, as excess feed should not be allowed to accumulate on the bottom of the tank where it gets decomposed and degrade water quality. Orange spotted grouper larvae metamorphose to juveniles at about 30th-35th dph.

Schedule of feeding and water management followed in maze rabbit fish larval rearing



2. Nursery Rearing (Metamorphosis to Stocking Size)

Larval rearing phase ends after the larvae achieve full metamorphosis. Fry harvested from larval tanks are often not large nor strong enough for stocking directly in grow-out farms. They must be reared in indoor or outdoor nursery systems to make them stock ready and sturdy for grow out culture. Nursery rearing practices in indoor based culture is performed either by flow through or recirculation-based concept in FRP (Fibre Reinforced Plastic) /concrete/collapsible tanks, outdoor based system is performed in

hapa erected or installed in earthen ponds, coastal cages and marine cages. The growth in all these systems are influenced by different environmental factors. The outdoor culture system exhibits better growth in comparison with indoor culture systems due to availability of natural feed in addition to the feed provided and water movements also favour growth.

Nursery rearing of Indian pompano

FRP and concrete cement tank-based rearing

A flow through culture system is used. Circular or square shaped 1-10 tonnes capacity of FRP tanks or concrete cement tanks with 1 m water holding height and central drainage system are considered ideal. The advanced fry (2-2.5 cm) is directly released to nursery rearing tank at 1000 nos/m^3 and maximum carrying capacity should be less than 5.0 kg/m^3. The stocked fry is fed with 500 µ in size at 4-6 times per day at 5-6% of body weight or till satiation. As feeding frequencies are more at initial stage, thus it is recommended for 100% water exchange in two different spells in the morning and evening at 50% in each time. Oxygen supply should be maintained always above 4.0 ppm. The stocked fry reaches 2.5 to 3.0 g in size (survival: 75-95%) in a month of rearing, which can be shifted to outdoor nursery systems.

RAS based rearing

RAS is indoor tank-based water recirculation systems in which fish larvae are grown at high density under controlled environmental conditions. The water is reused after mechanical and biological processes and with addition of less than 5% addition of water externally. Metamorphosed larvae (0.5-0.7 g) of 25-30 days old can be stocked in the tank (5m^3) at 2000 nos./m^3 or 1000 nos./m^3 based on the culture duration, ie either 2 or 3 months respectively. The grading of the larvae is compulsory for the first month of the culture at forthnightly intervals. Fishes should be fed with high quality feed with intially 52% protein and later stage reducing to 40% protein content. The pellet size of 0.3-0.8

mm should be given at 3 hour interval during first month, 1-1.2 mm at 4 hour interval during second month and 1.5-1.8 mm at 5 hour interval during third month. The fishes can be harvested with an average size of 12 g after 2 months at an average survival rate of more than 90%. When the fishes are harvested after 3 months, they reach an average size of 27 g with a survival rate of more than 96%.

Hapa based in ponds

Rectangular hapas are installed in the pond and are supported with bamboo or casuarina poles. The sizes can vary from 2 x 2 x 1.5 m to 4 x 3 x 1.5 m with mesh sizes of 0.5 mm. The ideal stocking density is 250/m^3. The fish accepts artificial feeds, and the diet with high nutrient content (Crude Protein 45% and Crude Fat 10%) and frequency of 4-6 times/day at 5-8% of body weight is recommended during the initial phase. The stocked advanced fry (2-3 g) can reach 30-40 g in 60-75 days with 60-75% survival.

Hapa based in coastal cages

The initial stocking size should be 3.0-5.0 g in size due to rough climatic conditions. In general a hapa of either 2x2x2.5 or 3x3x2.5 size are recommended for nursery in cages. The mesh size of the hapa should be 5 mm in size and should be stitched with feed mesh of 1 feet height at water and air interface to avoid feed wastage through hapa mesh. Optimum stocking density is 300-350 nos./m3 and this stocking density can be maintained till 25.0 g in size. Immediately after stocking, the fingerlings can be fed with floating pelleted feed of 0.8 to 1.0 mm in size, at 5-6% of body weight. Feeding frequency

should be 4-6 times and minimum of 4 times /day is highly recommended at initial stage. A survival of 75-80% can be achieved with proper management.

Hapa based in marine cages

Rectangular hapa's of 2x2x2.5 or 3x3x2.5 or other optimum size is preferred for nursery rearing and a similar stocking size adopted in coastal cages can be followed. The recommended stocking density is 400-500 nos./m3 till 20.0 g and then slowly the stocking density is reduced as fish grow. Stocked fishes are fed at 5-8% of body weight with minimum of 4 times/day with floating feed. Feed mesh prepared using mosquito mesh should be attached at water and air interface to avoid wastage of floating feed due to wave actions. Hapa should be exchanged once a month. The survival of nursery reared fingerling in this system is in the range of 70-80%.

Nursery rearing of silver pompano

Hapa based in ponds

Rectangular hapas are installed in the pond and are supported with bamboo or casuarina poles. The 1-1.5-inch fry are stocked at a density of 150-200 nos./m^3 in hapa nets (2 x 2x 1.5 m to 5x 5 x 1.5 m). Fishes are fed with formulated diets at 10 % of body weight per day, gradually decreasing to 8 %. The feed ration for a day should be distributed in four equal intervals. Installing lights near hapa can aggregates small food organisms like crustaceans and rotifers, which can supplement their feed source. Pompano can be harvested when they reach the weight of 30 g or released into pond.

Hapa based in coastal/marine cages

Rectangular hapas of 2 m x 2 m x 3 m are installed in cage frames. The 1.5-inch fry are stocked at a density of 100 nos./m^3. Artificial illumination can be installed in the floating cages to attract zooplanktons which will serve as supplemental food. The amount of feed per day shall be given in 4 equal rations. Harvest pompano when they reach the weight of 60 g (approx. 80-90 days).

Tank based rearing/RAS based rearing

The advanced fry (2-2.5 cm) from larval rearing tanks are stocked in rectangular tanks of 2-10 tonnes at a stocking density of 1000 nos/m^3 or 1.5-2 cm fry can be stocked in 5 tonnes of circular RAS tanks at a stocking density of 1000-2000 nos./m^3. The larvae in tank-based flow through system should be harvested after 1 month or nursery reared further in outdoor hapa system. RAS based nursery rearing can be done upto 2-3 months with fortnightly grading.

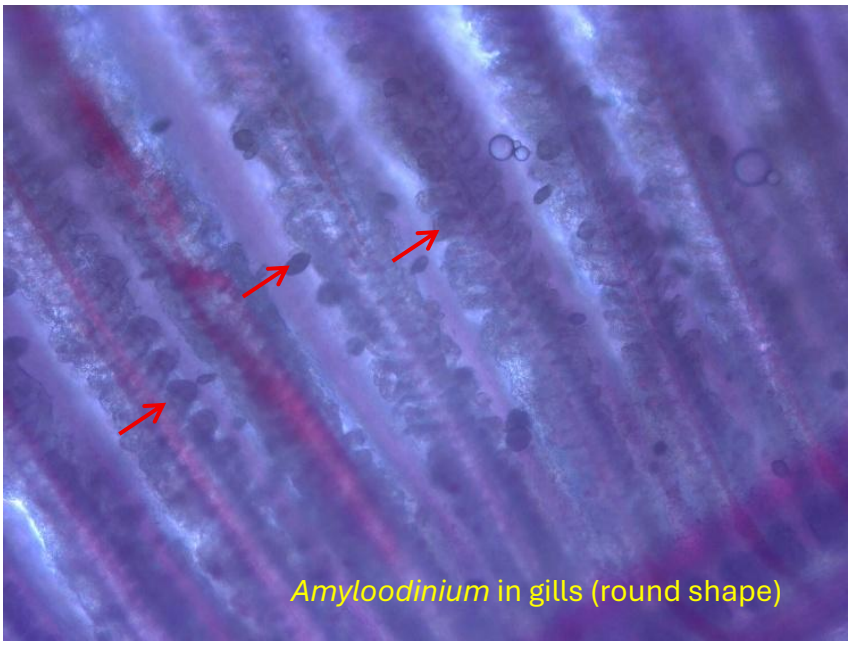
Nursery rearing of cobia

Nursery rearing of cobia juveniles is carried out for a period of one month to achieve a size of 20 grams, which is ideal for stocking in cages. The nursery rearing of juveniles

could either be carried out in tanks (minimum 10 t capacity) or in sea cages (6 m diameter) fitted with smaller mesh sized nets. Recommended stocking density in indoor nursery tanks is 1 number per 10 litres with 200% water exchange and for nursery cages it is 1.8-3.0 kg/ m^3. Suitable sized artificial feeds (800 – 1800 micron) should be provided during nursery rearing. Floating or slow sinking pellet feed with 50% crude protein and 10% crude fat composition would be suitable for successful nursery rearing.

Mortality during larval and nursery phase

Amyloodinium ocellatum is an obligate parasite which can cause mass mortality during larval and nursery rearing of marine fishes. *Amyloodinium* infection can be detected as rapid opercular movement and surface gasping of fishes at the surface or erratic swimming in the bottom of the tank before losing equilibrium. During heavy infestation of this parasite, they also attach to the skin of fish, giving a powdery or velvet look generally referred as velvet disease. Freshwater dip treatment (2-4 minutes) based on tolerance of the fish species or copper sulphate (0.75 mg/l, 12-14 days) baths have been suggested as an primary aid in controlling *Amyloodinium* infection. Use of



formalin treatment (15 ppm) for consecutive 3 days followed by chloroquine phosphate (5 ppm) for consecutive 3 days is also found to be effective. *Amyloodinium* entry into can be prevented by filtering incoming seawater rigorously using fine micron filters or UV sterilization. Disinfecting tanks, pipes and equipment's periodically during rearing could also prevent outbreak.

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Marine Cage Farming

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Sea cage culture is the farming of fish in floating net enclosures that permit natural water exchange while providing a controlled rearing environment. Successful production depends on appropriate cage design, durable construction materials, efficient mooring systems, and sound management practices. Recognizing its potential, CMFRI initiated open-sea cage culture research in 2006–07 and developed indigenous HDPE cages suited to Indian conditions. Subsequent refinements led to economically viable 6 m diameter cages. With an estimated production potential of 3.2 million tons from just 1% of India's inshore waters, sea cage farming offers a promising and sustainable livelihood option for coastal communities.

Sea cage farming offers several advantages over conventional pond-based aquaculture. Cage fabrication is relatively simple, rapid, and cost-effective, while the initial investment required is only about 30–40% of that needed for traditional pond farming. By utilizing natural water bodies such as the open sea, lagoons, and sheltered bays, cage farming eliminates the need for valuable land resources and makes productive use of otherwise underutilized coastal areas. Cage size and location can be modified or expanded with ease, providing greater operational flexibility. Fish harvesting is faster and more efficient, enabling a consistent supply of fresh fish to meet market demand. Additionally, sea cage farming creates alternative livelihood opportunities, generates supplementary income for coastal communities, and supports sustainable aquaculture development with appropriate regulatory approvals.

Grow-out technologies are fundamental to the success of marine cage farming, enabling the efficient rearing of juveniles to market size under controlled conditions. Advances in cage design, stocking density, feeding strategies, health management, and environmental monitoring enhance growth performance, survival, and feed utilization while minimizing disease outbreaks and environmental impacts. These technologies improve production efficiency, product quality, and economic returns, making marine cage farming a reliable and sustainable aquaculture practice. Furthermore, optimized

grow-out systems support the diversification of high-value marine finfish species, reduce fishing pressure on wild stocks, strengthen coastal livelihoods, and contribute significantly to food security and the sustainable development of the blue economy.

Site selection for marine cage farming

Site selection is one of the most critical factors determining the success and sustainability of marine cage farming. An ideal site should provide suitable environmental, biological, and logistical conditions that promote fish growth while minimizing operational risks and environmental impacts. Water quality parameters such as temperature, salinity, dissolved oxygen, pH, and low levels of pollutants should remain within the tolerance limits of the cultured species throughout the production cycle. Adequate water depth and moderate currents are essential to ensure continuous water exchange, maintain oxygen levels, and prevent the accumulation of waste beneath the cages. Sites should be protected from strong waves, storms, and cyclones, while still allowing sufficient water circulation.

The seabed should be stable and free from sensitive habitats such as coral reefs and seagrass beds to reduce ecological impacts. Accessibility to hatcheries, feed suppliers, markets, harbours, and emergency services is important for efficient farm management and reduced operational costs. The site should also have secure navigation routes, minimal conflicts with fishing, tourism, and shipping activities, and comply with local environmental regulations and coastal zone management policies. Regular monitoring of environmental conditions and carrying capacity is necessary to prevent overstocking and

maintain ecosystem health. Careful site selection ultimately enhances fish survival, growth performance, production efficiency, environmental sustainability, and the long-term economic viability of marine cage farming.

Design of marine cages for grow out farming

The design and construction of sea cages are critical determinants of the technical efficiency, durability, and economic viability of marine cage farming. Cage design should be based on the biological and behavioural characteristics of the cultured species. Pelagic fishes, which actively swim near the surface in schools, require larger swimming space and perform better in circular or hexagonal cages that facilitate continuous movement. In contrast, demersal species are relatively sedentary, occupy territories near the bottom, and readily adapt to square or rectangular cages, which also offer advantages in cage assembly and farm management. An effective cage design should be simple, cost-effective, easy to fabricate using locally available materials, structurally strong, and capable of ensuring adequate water exchange while securely retaining fish throughout the culture period.

The cage frame forms the primary structural component and is commonly fabricated using galvanized iron (GI), high-density polyethylene (HDPE), mild steel, or PVC. In India, HDPE PE100 and GI pipes are widely preferred because of their durability, strength, and affordability. Circular HDPE cages provide excellent resistance to wave action and are suitable for commercial-scale farming, whereas epoxy-coated GI cages offer an economical alternative for small-scale farmers. A typical low-cost GI cage consists of a 6 m diameter circular frame supported by airtight fibre barrels that provide buoyancy and a stable working platform for routine operations.

Net cages are generally fabricated from HDPE twine because of its resistance to seawater corrosion, chemicals, and biofouling, ensuring long service life with proper maintenance. Mesh size is selected according to the cultured species and production stage to allow efficient water exchange while preventing fish escape. Ballast pipes fitted along the bottom of the net maintain cage shape and stability.

A reliable mooring system is essential to anchor cages securely and minimize the effects of waves, currents, and wind. The design of the mooring system is site-specific and

depends on environmental conditions, cage type, and operational requirements. Strong anchors, durable mooring lines with high breaking strength, and properly designed connections are necessary to maintain cage stability, reduce structural stress, and safeguard fish stocks during adverse weather conditions.

Fish seed selection and stocking

Stocking healthy fish seed of appropriate size and density is essential for achieving high survival, uniform growth, and optimum production in marine cage farming. Hatchery-produced larvae are generally reared for 30–60 days before being stocked in grow-out cages. Nursery rearing, either in land-based ponds, hapas, or floating nursery cages, is recommended to produce robust and acclimatized fingerlings suitable for sea cage culture. Only healthy, disease-free, and uniform-sized fingerlings should be selected to minimize size variation, reduce competition and cannibalism, and improve overall production performance. Proper stocking practices contribute significantly to efficient feed utilization, better growth, and higher economic returns.

Species selection is a key factor influencing the success and profitability of marine cage farming. The ideal candidate species should be well adapted to marine conditions, exhibit rapid growth, efficient feed conversion, short culture duration, high survival, and resistance to common diseases. In addition, a species should have consistent seed and feed availability and command a high market price to ensure economic viability. In India, several high-value marine species are successfully cultured in sea cages, including cobia, silver pompano, Indian pompano, orange-spotted grouper, Asian seabass, red snapper, and spiny lobster. Selection of suitable species based on local environmental conditions and market demand enhances production efficiency and farm profitability.

Food and feeding

Feed management is one of the most important aspects of marine cage farming, as feed accounts for nearly 60% of the total production cost. Marine finfish require a high-protein diet (35–40%) to achieve optimal growth and efficient feed conversion. Feed pellet size should be adjusted according to fish size, while feeding rates generally decrease from about 10% of body weight in juveniles to around 3% as fish grow. A feed conversion ratio (FCR) of approximately 1:1.2 is considered desirable for efficient production. Feeding should follow recommended rations, as overfeeding results in feed wastage, increased production costs, and deterioration of water quality. Feeding frequency depends on the age and size of the fish, with larvae and fry requiring more frequent feeding than larger

fish. Feed intake is also influenced by water temperature, dissolved oxygen, season, and other environmental conditions. Proper feed management, using either moist or pelleted feeds, enhances growth, improves feed utilization, and minimizes environmental impacts.

Feeding management plays a crucial role in achieving optimum growth, feed efficiency, and profitability in marine cage farming. Feeding rates generally decrease with increasing fish size, from about 10% of body weight in juveniles to 2.5–3% in larger fish. Feeding schedules should be adjusted according to fish size, water quality, temperature, dissolved oxygen, and feeding behaviour. Proper feeding frequency and fixed feeding times improve feed utilization and reduce wastage.

Cobia is a fast-growing species with excellent meat quality and requires a high-protein diet. During nursery rearing, juveniles are fed at 5–10% of body weight using protein-rich diets (about 45% protein and 5% lipid). During cage culture, chopped oil sardine is commonly fed at 6% of biomass per day initially, with the ration reduced by 2% every three months. Feeding is usually carried out twice daily (06:00 and 18:00 h), and an FCR of 1.4–1.8 is commonly achieved.

Asian seabass requires careful feeding during nursery rearing because of cannibalistic behaviour. Fry are initially fed chopped trash fish several times daily and gradually weaned to formulated feeds containing about 45% protein. During grow-out, fish are fed chopped fish or sinking pellets twice daily at 10% biomass initially, later reduced to 5% once daily, achieving an FCR of approximately 1.8:1.

Silver pompano, a fast-swimming species, readily accepts floating, sinking, or chopped feeds. Nursery fish are fed 3–4 times daily with high-protein diets (up to 50% protein), while larger fish require lower protein levels (about 30%). Proper feeding management results in an FCR of around 1.8:1.

Harvesting and marketing

Harvesting is one of the major advantages of marine cage farming, as it is simple, efficient, and less labour-intensive than conventional aquaculture systems. Fish can be harvested either partially or completely depending on market demand, allowing farmers to maximize returns by supplying fresh fish continuously. Harvesting is generally initiated when most fish attain marketable size. During harvest, the total number of fish and their combined weight should be recorded to evaluate production performance. Cage-farmed fish are usually marketed through local fish markets or sold directly at the farm gate, where they command premium prices due to their freshness and superior quality.

Good management practices

Successful marine cage farming requires regular monitoring and effective management to ensure high productivity and environmental sustainability. Cage nets should be inspected frequently to prevent fish escapes, repaired promptly when damaged, and cleaned or replaced periodically to minimize biofouling. Appropriate stocking densities,

high-quality feeds, and optimized feeding practices help reduce stress and improve growth and feed efficiency. Fish growth, health status, and water quality parameters such as temperature, dissolved oxygen, and pH should be monitored regularly. Mooring systems must be inspected to maintain cage stability. Sustainable practices, including cage rotation or fallowing, careful site selection in areas with adequate water flow, environmental monitoring, and the adoption of Integrated Multi-Trophic Aquaculture (IMTA), further enhance production while minimizing ecological impacts.

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Marine Ornamental Aquaculture: Potential for Livelihood and Employment Generation

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Marine and freshwater aquarium keeping is amongst the most popular of hobbies with millions of enthusiasts worldwide. As a result the trade of marine ornamentals has been expanding in recent years and has grown into a multimillion dollar enterprise mainly due to the emergence of modern aquarium gadgets and technologies for setting and maintenance of miniature reef aquaria. Since the marine ornamental trade is operated throughout the tropics, the global marine ornamental trade is estimated at US$ 200-330 million. India is endowed with a vast resource potential of marine ornamentals distributed in the coral seas and rocky coasts with patchy coral formations. In the context of the expanding global scenario and the increasing demand in the domestic trade, it appears very much lucrative for India to venture into this industry. But it is a multi stakeholder industry ranging from specimen collectors, culturists, wholesalers, transhippers, retailers, hobbyists, researchers, government resource managers and conservators, and hence involves a series of issues to be addressed and policies to be formulated for developing and expanding a sustainable trade. In recent years it has been reported that nearly 1500 species of marine ornamental fishes are traded globally and most of these are associated with coral reefs. Nearly 98% of the marine ornamental fishes marketed are wild collected from coral reefs of tropical countries such as Philippines, Indonesia, Solomon Islands, Sri Lanka, Australia, Fiji, Maldives and Palau. This has been threatening the long term sustainability of the trade due to indiscriminate exploitation of coral reef areas. The three key words in the development of marine ornamental fish trade are – collection, culture and conservation. The development of technologies for hatchery production of selected marine ornamental fishes is the only option for evolving a long term sustainable trade without damaging the coral reef ecosystem. Even at an international level, the technologies for hatchery production of ornamental fishes are limited to a few species. The main steps in captive production of ornamental fishes are broodstock development, breeding, live feed culture, larviculture

protocols, growout methods, aquarium technology, diseases, packing and transportation, etc. The Central Marine Fisheries Research Institute (CMFRI) has been focusing on this vital aspect for the past few years. CMFRI is successful in developing hatchery technology for 21 species of marine ornamental fishes. The marine ornamental fish trade is low volume and high value industry in rural and urban areas, and hence it is very lucrative to initiate a trade purely based hatchery produced species. The setting up of a small-scale hatchery with details of economics are also included in this manuscript.

Captive breeding of marine ornamentals in India: Initiatives by CMFRI

These investigations made CMFRI have resulted in the development of hatchery technology for 21 species of marine ornamental fishes such as clown fishes *Amphiprion percula* (True percula/ clown anemone fish); *A. ocellaris* (Common Clown/False clown aenemonefish); *A. sandaracinos* (Yellow Skunk Clown)*; A. frenatus* (Tomato clown), *A. clarkii* (Clark's anemone fish), *A. sebae* (Sebae clown) *A. perideraríon*(Pink anemone fish) *A. ephippium (Red saddle back anemone fish), A.nigripes (*Lakhadweep clownfish)*,Premnas biaculeatus* (Maroon clown/ Spine cheek anemone fish. The species under damsels for which technology developed under captivity included *Dascyllus trimaculatus* (Three spot damsel); *D. aruanus*(Striped damsel)*;Pomacentrus caeruleus* (Blue damsel)*; P. pavo* (Sapphire or Peacock Damsel)*;Neopomacentrus nemurus* (Yellow tail damsel)*; N. filamentosus* (Filamentous tail damsel)*;Chrysiptera cyanae* (Sapphire devil); *C. unimaculata* (One spot damsel), and *Chormisviridis* (Green chromis), and also dotty back *Pseudochromis dilectus* (Redhead Dottyback), purple fire goby *Nemateleotris decora* for the first time in the world (Madhu and Rema Madhu,2002,2006; Madhu *et al.,* 2006a,b,c; Gopakumar*et al.,* 2007; Rema Madhu, *et al.,* 2007; Madhu *et al.,* 2008, Madhu and Rema Madhu, 2014, Madhu et al.,2016). It is well accepted that the trade developed from tank reared fish and other ornamentals is the final solution for a long term sustainable trade. The economic viability of ornamental fish production is more lucrative when compared to other mariculture species, due to their high unit value. The complete package of practices developed for their production can be taken up as an alternative livelihood option for small and large scale fish farmers. The transfer of technology to the public and private sector entrepreneurs who have approached for the technology is being planned by imparting hands on training through different modes

under the Consultancy Processing Cell (CPC) of the CMFRI and organized trainings. In addition, the hatchery produced seeds are also being sold to the farmers and aquarium hobbyists and traders through Single Window System and seed counters are in operation n marine hatcheries of CMFRI at Cochin and Mandapam. This has resulted in the emergence of several ornamental fish trade shops all over the country. Recently the National Fisheries Development Board (NFDB) has also developed schemes to fund for ornamental fish culture in the unutilized hatcheries of the prawn farmers in India.

Captive Breeding

For the breeding of ornamental fishes under captive condition, the following few important steps are to be followed apart from maintenance of high water quality, provision of suitable environmental parameters, creating suitable condition for spawning and system for raising the larvae and juveniles.

The major aspects involved in ornamental fish culture are:

- Collection and transportation of broodstock
- In case active broodstocks are not available, pair formation and broodstock developments to be under taken in captive conditions
- Breeding system/ broodstock rearing setup and management
- Provision of Substrate for egg deposition
- Feed formulation and broodstock feeding and feeding schedule
- Incubation of eggs , parental care and management of parameters.
- Morphology and embryology of eggs
- Egg hatching and larvae handling techniques
- Larval rearing
- Nursery rearing
- Growout culture
- Quarantine
- Harvest of juveniles for trade
- Packing and transportation

Allied Section for Larval Rearing

- Microalgae stock and mass culture (freshwater and marine)
- Zooplankton stock and mass culture (rotifers, copepod and cladoceran) for marine.
- Zooplankton stock and mass culture (rotifer, moina, daphnia and copepod) for freshwater species
- Zooplankton harvesting and handling

- Artemia cyst hatching and harvesting
- Live zooplankton bio enrichments

Collection and transportation of fishes

For the captive mass production of ornamental fishes, the basic requirement is to have a sufficient number of broodstocks or breeding pairs which can either be collected from the coral reef habitat or can be purchased from the pet shop depending upon the availability. In the wild, the clown fishes generally occupy in social groups cantered in a host sea anemone with a sexually active pair of adults and one to three juvenile or sub adult fish. Invariably the female was somewhat larger than the male, and showed monogamous pair formation, and these pairs are need to be collected for broodstock development and breeding programme. During transportation, the fishes and sea anemones should be kept in separate plastic transportation bags.

Quarantine

Fish newly obtained from the wild or from pet shops may carry pathogens that can infect healthy, valuable broodstock. Therefore, they are isolated in a separate tank or system for about three to four weeks, during which they are closely monitored and treated with medications if any disease symptoms appear. Similarly, before being sold, fish should also be properly screened and placed under quarantine.

Pair formation

In the circumstance of non-availability of adult breeding pairs, individuals from different size groups are collected and encouraged to form pairs under captive conditions. This is achieved by stocking a minimum of five individuals of each sex, representing various size classes, together with a single host sea anemone in a 1000 L FRP tank equipped with a biological filtration system to reduce aggression. The rearing tanks in the hatchery are maintained under an incident light intensity of 2500–3000 lux, as sea anemones require adequate light for optimal survival under laboratory conditions. Feeding is provided at 10% of body weight per day, divided into three portions, using wet feeds such as shrimp, green mussel, and clam meat, along with live feeds including *Brachionus plicatilis*, *Artemia* nauplii, and adult *Artemia*. Successful pair formation depends on maintaining stable environmental conditions, including a temperature range of 26–29°C, salinity of

33–34 ppt, dissolved oxygen levels of 4.6–6.2 ml/L, and pH maintained between 8.1 and 8.8 in all rearing tanks.

Sex change and pairing

Clownfishes are protandrous sequential hermaphrodites, meaning they first mature as males. A clear dominance hierarchy is formed in which the female is the most dominant, followed by the male, while all juveniles remain subordinate to the breeding pair. In general, all individuals begin life as males and later transition into females when they attain larger size or when a mate is lost. The male and female maintain a monogamous pair bond that typically persists until one of them dies. If the female dies first, the largest male undergoes a rapid sex change to become female, while the second-largest or dominant juvenile assumes the role of male and pairs with the newly transformed female. This natural adaptation can be used to develop breeding pairs in captivity by establishing appropriate social structures.

After 3 to 4 months of rearing during pair formation, one pair in each tank usually outgrows and establishes itself as the spawning pair. Since newly formed pairs tend to be highly aggressive and often spend more time defending territory and evading subordinates rather than engaging in reproduction, it is essential to transfer each breeding pair into separate broodstock tanks.

Broodstock development and maintenance

Formed pairs are subsequently transferred to separate glass aquaria for broodstock development, with the number of pairs maintained according to production capacity and seed demand in commercial hatcheries. Broodstock are fed wet feeds such as green mussel, shrimp, clam meat, and fish egg mass, along with formulated diets enriched with vitamins, minerals, and algal powder at 10% of body weight, given in split doses at 3-hour intervals during the daytime. In addition, enriched live feeds are provided daily, including rotifers, *Artemia* nauplii, and adult *Artemia*. The incorporation of enriched live feeds has been shown to significantly enhance egg quality and hatchability compared to non-enriched diets.

Water quality maintenance

The maintenance of optimal water quality is likely the most critical factor for successful breeding of marine fishes under controlled conditions. As a precautionary measure,

seawater should be passed through a series of sand filtration units before being supplied to the rearing tanks. In all breeding tanks, temperature should be maintained between 26 and 30°C, while dissolved oxygen levels (4.8–6.3 mL/L), pH (8.0–8.9), and salinity (32–36 ppt) must be carefully regulated. Continuous water recirculation is required to ensure proper water movement and to maintain good water quality, supported by a specially designed filtration system throughout the rearing period. Additionally, 25% of the water should be replaced weekly to prevent stress responses such as elevated plasma cortisol levels, which may lead to Cushing-like conditions, suppression of gonadal steroidogenesis, and eventual development of gonadal atresia.

Substrate for egg deposition

Clownfish produce capsule-shaped eggs that are firmly affixed to a suitable substrate inside the tank. The eggs are usually deposited in dense clusters and adhere strongly to rough surfaces due to a sticky coating secreted during spawning. This attachment helps maintain stability, prevents egg dispersal, and ensures adequate aeration throughout development. Since the eggs are substrate-bound, a rough surface is required, typically placed close to the host sea anemone or within the rearing tank. In captive breeding systems, materials such as tiles, earthen pots, oyster shells, or PVC pipes are commonly used to promote egg laying. These substrates also allow the eggs to be transferred safely and without damage to hatching tanks when necessary.

Breeding and spawning

Clownfish broodstock maintained under captive conditions may begin breeding within 4–6 months when provided with adequate nutrition and favorable environmental parameters. Prior to spawning, the male selects an appropriate nesting site near the sea anemone and cleans it by removing algae and other debris. On the day of spawning, both parents spend considerable time preparing the site, which serves as a clear indication that spawning is imminent.

In laboratory conditions, spawning generally takes place during daylight hours, typically between 05:00 and 15:30, and lasts for about 1–1.5 hours. Females lay around 300–1,000 capsule-shaped eggs at intervals of 12–15 days, depending on species, body size, and prior spawning history. These eggs measure approximately 1.5–3.0 mm in length and 0.8–1.84 mm in width and are firmly attached to the substrate via a stalk (Fig.). Under

controlled conditions, a breeding pair usually spawns twice within a lunar month, yielding an estimated annual fecundity of 7,200–24,000 eggs per pair.

Parental care and egg morphology during incubation period.

Parental care is essential for successful larval hatching; therefore, the breeding pair should be kept in the spawning tank until around 4 pm on the anticipated hatching day. The incubation period is approximately 168 hours for *Amphiprion* species and 144 hours for *Premnas* at a water temperature of 27–29°C. During incubation, both parents continuously tend to the egg clutch, primarily by fanning the eggs with rapid movements of their pectoral fins to improve water circulation and by mouthing the eggs to remove dead or weak embryos as well as accumulated debris. The eggs are initially white to bright orange during the first two days after spawning. As development proceeds, they gradually darken, appearing black between the third and fifth day of incubation. By the fifth day, a faint silvery sheen begins to appear, which becomes more pronounced, and by the seventh day the eggs turn fully silvery due to the development of the larvae's large eyes. At this stage, the embryos' reflective eyes are clearly visible through the egg capsule even from a short distance, indicating that hatching is imminent and will typically occur in the evening after sunset.

Although both parents participate in brood care, the male performs the majority of parental duties and spends significantly more time at the nest site than the female. His nest attendance increases steadily as hatching approaches, reaching nearly 70% of the total time. Under a temperature range of 27–29°C, hatching generally occurs on the seventh day of incubation (168 hours), shortly after sunset.

Hatching and larval transfer

The incubation period of clownfish eggs typically varies from 6 to 15 days, largely influenced by water temperature. At temperatures ranging between 26 and 30°C, hatching usually occurs within 6–7 days. About one day prior to hatching, the embryos develop a distinct silvery appearance, and their reflective eyes become clearly visible through the egg capsule, providing a reliable sign that hatching is approaching.

On the expected day of hatching, the egg-bearing substrate is generally moved from the parental tank to a 100-L hatching tank approximately two hours before sunset. The hatching tank is kept in complete darkness to encourage and synchronize the hatching

process. Larvae emerge by breaking the egg capsule tail-first, with hatching beginning shortly after sunset. Peak hatching activity is usually observed between 19:00 and 20:30 hours under dark conditions.

Newly hatched larvae are about 3–4 mm in length and are transparent, with large eyes, a visible mouth, and a small yolk sac (Fig.). After briefly resting at the bottom of the tank, they become free-swimming. Larval rearing is commonly carried out using a green-water system enriched with *Nannochloropsis oculata* and *Chlorella salina*, along with very small rotifers (*Brachionus rotundiformis*) as the initial live microzooplankton feed.

The larval period generally lasts up to 20 days, after which most fry undergo metamorphosis and begin to resemble juvenile fish. During this transition, they shift from a partially pelagic phase to an epibenthic lifestyle and readily accept feeds such as minced shrimp, fish flesh, mussel meat, clam meat, and formulated diets.

Methods for larval rearing

The larval rearing of clown fishes can also be carried out in three ways (i) Same tank or parental tank method, (ii)Transferring of eggs to hatching tank and subsequent larval rearing, (iii) Transferring of larvae to the larval rearing tank.

Larval feeding

The success of the first feeding strike in clownfish larvae is initially low but improves quickly during early development. Survival at this stage depends on providing high densities of appropriately sized, nutrient-enriched live feed. Because larvae have a very small mouth gape (about 80–123 µm), they can only ingest extremely small prey; therefore, failure to locate and capture sufficient food before energy reserves are depleted can lead to starvation and mortality. Since yolk reserves are limited, exogenous feeding begins within a few hours after hatching depending on the species. To enhance feeding efficiency, rearing tanks are maintained under continuous light (24 h) up to 20 days post-hatch (DPH). Good hygiene is also essential, with daily siphoning of dead larvae, feces, and debris, along with at least 25% daily water exchange. Larval feeding is divided into three phases. From 1–5 DPH, larvae are fed super-small rotifers (*Brachionus rotundiformis*, 60–100 µm) and copepodites under a green-water system at densities of 30–50 mL^{-1} after enrichment with vitamins and fatty acids. From 6–10 DPH, diets shift to

pre-adult copepods, nauplii of *Diaphanosoma celebensis*, and S-type rotifers (*Brachionus plicatilis*) enriched with microalgae at 5–10 mL^{-1} to meet increasing nutritional demands. From 11–20 DPH, larvae are fed larger prey including adult copepods, adult *D. celebensis*, and L-type rotifers (*Brachionus plicatilis*), matching their increased mouth size and improving growth and metamorphosis success.

Rearing conditions

Maintaining excellent water quality is a key requirement for successful larval rearing of clownfish and other marine fishes under controlled conditions. During larval culture, the period between the 3rd and 8th day post-hatch (DPH) was identified as particularly critical, likely due to the transition to exogenous feeding. However, once larvae successfully completed 8 DPH, no further mortality was observed.Given the fragile nature of the larvae, gentle aeration was supplied using PVC columns fitted with 20-µm mesh screens placed at all four corners of the rearing tanks to maintain adequate dissolved oxygen levels. These columns were arranged to promote continuous water circulation, ensuring uniform oxygen distribution and optimal rearing conditions.Throughout the larval rearing period, water quality parameters were carefully maintained at optimal levels: pH 8.0–8.2, temperature 26–30°C, dissolved oxygen 5.5–7.8 mg/L, salinity 33–35 ppt, with ammonia (NH_4^+/NH_3) and nitrite (NO_2) maintained at 0 mg/L, and nitrate (NO_3) kept below 0.2 mg/L. Tanks were cleaned daily using cotton and magnetic scrapers to remove debris and biofilm, and one-fourth of the water was replaced each day with equal volumes of filtered seawater.

Light intensity

Head-butting syndrome was another major challenge during larval rearing, primarily caused by the underdeveloped retina, which led larvae to repeatedly strike the tank walls. To minimize this problem, two key measures were implemented. First, all four sides of the rearing tanks were covered with black cloth or painted black to eliminate light reflection. Second, low-intensity lighting was maintained by suspending two 60-watt bulbs or night lamps 15–20 cm above the water surface, operated continuously from day 0 to day 20. This lighting helped larvae locate and capture feed more effectively and

encouraged them to remain near the water surface at night instead of sinking to the bottom, thereby reducing overnight mortality.

Juvenile rearing

As the larvae reach 19–20 DPH, clownfish larvae transform into juveniles, transitioning from a pelagic to an epibenthic lifestyle and resembling miniature adults. Growth rate at this stage is influenced by rearing tank size, stocking density, feed quality and quantity, and water temperature. Because clownfish exhibit a social hierarchy, dominant individuals tend to grow faster and suppress the growth of subordinates. This can be minimized by either rearing juveniles together in larger tanks with adequate host anemones or by segregating them into smaller groups across multiple juvenile rearing tanks of 250–1000 L capacity equipped with biological filtration.

At the early juvenile stage, stocking density is maintained at about 90–100 individuals (8–10 mm size) with a single host sea anemone in a 100-L glass or Perspex tank for the first 1–2 months. During this period, variations in banding patterns and growth rates become evident. Once fish reach 24–35 mm total length, stocking density is further reduced to 30–50 individuals per 100-L tank with one sea anemone and 80 L of biofiltered seawater until they reach market size. In larger 500-L FRP tanks, approximately 130–150 juveniles can be maintained with 1–3 sea anemones.

Juvenile feeding

During juvenile rearing, a 100% survival rate was achieved by feeding wet diets such as mussel meat, prawn muscle, fish eggs, and minced trash fish at 15–20% of body weight. In addition, *Artemia* nauplii (10–15 individuals/mL) and rotifers (*Brachionus plicatilis*, 50–55 individuals/mL) were provided after enrichment with brown algae (10^4 cells/mL) and green algae (10^6 cells/mL), along with cod liver oil and fat-soluble vitamins A, D, E, and K. These were administered twice daily, helping to maintain fish coloration and supporting the inclusion of adult *Artemia* (2–4 individuals/mL) as part of the diet.

Packing and Transportation

Fish are typically starved for 2–3 days prior to export or transport to reduce waste production during transit. A small quantity of fresh water is added to the packing water, and in some cases, sedatives are used to calm the fish during long-distance journeys.

Packing is carried out immediately before transportation. Fish are placed in double-layered polythene bags filled with oxygen and a small amount of water, either individually or in groups, to ensure they remain fully submerged. For short-distance transport, these bags are placed in cardboard boxes, whereas for long-distance shipment they are packed in Styrofoam boxes with ice to maintain a low temperature. Paper layers may be inserted between bags to prevent visual contact and reduce stress, particularly in aggressive species. Packaging techniques have improved significantly over time due to customer feedback, and many exporters now report near 100% survival rates to most destinations, provided reliable connecting flights are available.

Setting up of a small-scale hatchery

Small-scale hatcheries for marine ornamental fish are those where the capital costs and technologies are accessible for relatively low cost which focuses on broodstock development, larviculture, nursery rearing and grow-out to marketable size. The small scale hatcheries can be easily adapted to culture a range of different species. A typical small-scale hatchery for marine ornamental fish consists of the following units and facilities .

1. Broodstock tanks
2. Larviculture tanks
3. Live feed unit

Nursery rearing and grow-out tanks

4. One sand filter
5. Outdoor live feed (Phyto and zooplankton) production tanks
6. Seawater and freshwater supply system.

Hatchery equipment and accessories

(i) Water Pump: Two types of pumps are required for the small-scale hatchery operation. A pump of 5HP is required to pump seawater to the hatchery's sand filter tank. A separate submersible pump is required to distribute water within the hatchery system.

(ii) Generator: A generator of 1 KVA is essential as backup electricity supply for the hatchery.

(iii) Aeration system: Small 100 watt air pump with at least one backup is needed.

(iv) Other hatchery equipments

a. An ordinary microscope.
b. Thermometer
c. Salinometer
d. pH meter
e. Water analysis kit
f. Hand nets
g. Plastic wares like buckets, bins, hoses etc.

(v) Manpower: The small scale hatchery can be managed by two full time staff – One technician and two workers. Basic training on technical aspects is needed for day to-day hatchery operation. Daily routine works include cleaning broodstock and larval tanks, feeding broodstock and larval tanks, harvesting microalgae, rotifers, *Artemia* etc.

Advantages of small-scale hatcheries
1. Low capital inputs
2. Simple construction
3. Ease of operation and management
4. Flexibility
5. Quick economic returns.

Economic Assessment
The candidate speceis selected for economic analysis is the true clown *Amphiprion percula*.

Capital Investment

This component involves all the expenditure on the infrastructure and establishment of the hatchery. The items included in this component generally have a life span larger than one year and they are used to generate the future income from the hatchery. The items include

Capital Investment items	**Quantum**	**Cost in Rupees**
Temporary Shed	144m2 (12 X 12m)	1,10,000
Tanks		6,40,000
i. Broodstock	**12**	
ii. Larval rearing	12	
iii. Nursery and grow out	18	

iv. Microalgae (outdoor)	4	
v. Rotifer (outdoor)	3	
vi. Sand filter /Over head tank	1	
Artemia hatching tanks (Transparent Perspex)	3	10,000
Power installation		10,000
4 HP diesel pump	1	19,000
1/2 HP submersible pump	1	6,000
Generator 2 KVA	1	30,000
Air pumps	2	40,000
PVC piping, plastic wares (water supply/aeration/drainage)		45,000
Netting, miscellaneous etc.		40,000
TOTAL COST		**9,50,000**

Operating expenses

This component is for the expenses that are spent during each production cycle and are essential for the routine operation of the hatchery. The items included are:

	Items	1st year	2nd year	3rd year
1	Broodstock fishes/Anemone	25,000	5,000	5,000
2	Feeds	12,000	12,000	12,000
3	Artemia	4,000	12,000	12,000
4	Chemicals for microalgal culture	6,000	6,000	6,000
5	Electricity	36,000	36,000	36,000
6	Diesel	24,000	24,000	24,000
7	Maintenance	12,000	18,000	18,000

8	Workers salaries(1xRs. 8000; 2xRs.5000)	2,16,000	2,16,000	2,16,000
9	Miscellaneous expenditures	12,000	12,000	12,000
	TOTAL	**3,47,000**	**3,41,000**	**3,41,000**

Non-operational expenses

These are related to the capital cost and investment write off. There are two items under this component for small-scale hatcheries.

i) Depreciation

ii) Interest on capital investment

Technical assumptions for production

It is assumed to be an indoor system located in a coastal area with access to both salt and freshwater and easy transportation access to market. There are 12 broodstock pairs. At any time there are 10 active spawning pairs. Each pair will spawn 2 times per month. An average of 400 larvae are produced during each spawn. The survival rate of the larvae to the grow out phase is 50%. The period from larvae to juvenile is 30 days. There is a 60% survival rate for juveniles to market size, which are saleable. The period from nursery to market size is 120 days. In a month, 240 saleable sized fishes can be produced from one pair of clown fish. Each fish can be sold at a rate of Rs.100. The sale of the fishes will start from second year onwards. The first year of operation will be construction and set up of the building, procurement of equipment and collection and maintenance of brooders. The first spawning is expected in eighth month of first year. The first harvest and sale will occur at the first month of second year.

	Amount in Rs.		
Revenue	**Year 1**	**Year 2**	**Year 3**
Sale of clownfish fingerlings @ s.100/fingerlings(240 juveniles x 10 pair x12 month =28,800 numbers		28,80,000	28,80,000

28800 x Rs 100 = Rs. 2880000)			
Non operating expenses			
a. Depreciation (20%)	1,90,000	1,90,000	1,90,000
Interest rate on capital investment @12%	78,000	78,000	78,000
Operating cost :TOTAL EXPENSES	2,63,000	2,57,000	2,57,000
	5,31,000	**5,25,000**	**5,25,000**
Profit	**———**	**23,55,000**	**23,55,000**

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Mussel Farming

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Mariculture, the farming of marine organisms in coastal and offshore waters, is an important component of sustainable aquaculture. Among mariculture practices, bivalve farming is gaining importance because it provides nutritious, affordable and eco-friendly animal protein. Bivalves such as mussels, oysters and clams are filter feeders and do not require artificial feed, making their culture economical and environmentally sustainable. They also support food security, coastal livelihoods, employment generation and water quality improvement through natural filtration.

Mussels are among the most commercially important bivalves cultured worldwide. Mussel farming has a history of more than 700 years, with early organized culture practices reported from France during the thirteenth century. Since then, farming methods have improved and expanded across temperate and tropical coastal regions. Mussels are preferred for culture because of their fast growth, high reproductive capacity, efficient use of natural food, good meat yield and strong consumer demand.

Distribution and Biology of Mussels

Globally, the European blue mussel (*Mytilus edulis*) is widely cultured in temperate regions, while the green mussel (*Perna viridis*) is important in tropical countries. Major mussel-producing countries include Spain, France, the Netherlands, Denmark, China, the Republic of Korea and New Zealand. In India, mussel farming is still developing, though the country has vast coastal resources suitable for expansion. The annual cultured mussel production is about 20,000 tonnes. The two major species cultured in India are the green mussel (*Perna viridis*) and the brown mussel (*Perna indica*). These species are valued for fast growth, high meat yield, adaptability and good market demand.

Mussel farming in India is mainly practiced along the southwest coast, especially in Kerala and Karnataka, where environmental conditions are favourable. The Central Marine Fisheries Research Institute (CMFRI) has played a major role in developing and promoting low-cost, eco-friendly and farmer-friendly mussel farming technologies. CMFRI has standardized rack, raft, longline and rope culture methods and promoted them through training, demonstrations and extension programmes. These efforts have improved farmer participation, household income and women's involvement through self-help groups.

Mussels are found along the Indian coastline and are known by local names such as Kallumekai, Kadukka and Chippi. They naturally inhabit rocky shores, estuaries,

backwaters and coastal waters where suitable substrates are available. They form dense natural beds in intertidal and subtidal zones, which support capture fisheries and provide seed for farming. Among Indian mussels, the green mussel is the most widely distributed and commercially important. It attaches to rocks, wooden structures, mangrove roots and other hard surfaces using strong byssal threads.

Kerala is one of the most productive regions for green mussels in India. Important mussel beds occur at Neendakara, Chaliyam, Narakkal, Koduvally, Thikkodi, Port Kollam, Chombala, Chellanam, Elathur, Moodadi, Mahe, Anchangadi, Ethai and Azhikkal. These areas favour spat settlement, fast growth and high survival. Along the Karnataka coast, important mussel beds occur at Gangoli, Malpe, Karwar, Someswara, Bhatkal, Byndur, Uchila, Gokarna, Coondapur, Suratkal and Dhareshwar. Green mussels are also reported from Goa, Maharashtra, Tamil Nadu, Andhra Pradesh and the Andaman and Nicobar Islands, though in lower densities.

The green mussel is a suspension-feeding marine bivalve. It filters seawater through the mantle cavity and traps food particles using cilia and mucus on the gills. Its diet includes phytoplankton, microalgae, small zooplankton, bacteria, detritus and suspended organic matter. Since it depends entirely on natural food, no supplementary feeding is required.

Perna viridis grows rapidly under favourable conditions, with shell length increasing by about 8–14 mm per month. In about five months, it can reach 80–90 mm shell length and 35–40 g body weight. Growth depends on temperature, salinity, dissolved oxygen, pH, plankton availability, water movement, stocking density and fouling. The species is dioecious, with separate males and females. Females have orange to reddish gonads, while males have creamy yellow or pale white gonads. Fertilization is external, and females release millions of eggs. Larvae pass through trochophore, veliger and pediveliger stages before settling as spat on hard substrates. Along the southwest coast, spat settlement usually occurs from July to September, and the juveniles reach seed size by September for use in farming.

Farm Site Selection for Mussel Culture

Farm site selection is a key factor in the success of mussel culture because growth, survival, meat quality, production and profitability depend on the environmental conditions of the culture area. A suitable site should have clean, well-oxygenated water free from sewage, industrial effluents, agricultural runoff, oil pollution and other contaminants, as mussels are filter feeders and can accumulate pollutants. The site should have abundant natural food such as plankton and suspended organic matter, with good primary productivity, suitable salinity of 27–35 ppt and temperature of 26–32°C. Moderate water movement is essential to supply food and oxygen and remove wastes, while the bottom should be firm with low siltation to prevent gill clogging. The area should

be protected from strong waves, cyclones and heavy swells, and should have access to roads, landing centres, labour, seed areas, markets and storage facilities. Mussel farming can be done in open sea and estuarine areas. Open sea sites require stable salinity, good water quality, moderate currents, limited wave action and a minimum depth of about 5 m; longline and raft systems are commonly used, though fouling, poaching, storms and rough seas are major risks. Estuarine sites are shallow, sheltered and easier to manage, with depths below 4 m preferred; rack and horizontal rope culture are commonly practiced. However, estuarine farming is affected by monsoon-related salinity reduction, pollution and sedimentation. Therefore, open sea sites are better for large-scale production, while estuarine sites are cheaper and suitable for small-scale farmers, making proper site selection essential for sustainable and profitable mussel farming.

Mussel Farming Methods

Mussel farming is a sustainable form of mariculture because mussels are filter feeders that depend on naturally available plankton and suspended organic matter. Therefore, no artificial feed is required, making the practice economical and environmentally friendly. The selection of a farming method depends on local conditions such as water depth, tidal range, current speed, bottom type, wave exposure, seed availability, investment capacity, and labour availability. Mussel farming methods are broadly classified into bottom culture and off-bottom or suspended culture. Suspended culture methods generally give better growth, higher production, and improved meat quality because mussels receive better water circulation and food supply.

1. Bottom Culture

Bottom culture involves spreading mussel seed directly on prepared seabed plots. It is commonly practiced in temperate countries where extensive intertidal flats and firm bottoms are available. Seed collected from natural mussel beds is transferred to culture grounds at suitable stocking densities. This method requires low investment and simple management. However, it is more affected by predators, sedimentation, poor water movement, and environmental disturbances.

2. Pole or Bouchot Culture

Pole culture is one of the oldest mussel farming methods and originated in France. In this system, wooden or bamboo poles are fixed vertically in intertidal areas. Mussel spat either settles naturally on the poles or is attached after collection. The mussels grow by attaching firmly to the poles with byssus threads. Protective netting may be used to prevent loss from predators and waves. This method is suitable for areas with a wide tidal range and moderate water movement.

3. Stake Culture

Stake culture is widely practiced in tropical countries, especially in Southeast Asia. Bamboo or wooden stakes are driven into soft-bottom coastal areas where natural spatfall occurs. Juvenile mussels settle on the submerged portions of the stakes and grow to marketable size. This method is inexpensive, simple, and suitable for sheltered bays and estuaries. However, continuous use may cause sediment accumulation and reduce water depth in the farming area.

4. Rack Culture

Rack culture is the most common method used for green mussel farming in India, particularly in shallow estuaries and backwaters. The system consists of bamboo or wooden poles supporting horizontal or vertical ropes on which mussels are grown. It is easy to construct, uses locally available materials, requires low capital investment, and allows simple maintenance and harvesting. CMFRI has standardized and promoted rack culture technology among coastal communities, especially in Kerala. Due to its low cost and good returns, it is suitable for small-scale farmers and women's self-help groups.

5. Raft Culture

Raft culture is practiced in sheltered coastal waters, bays, and lagoons with sufficient depth and good plankton availability. Floating rafts made of timber, steel, or HDPE pipes support vertical ropes called droppers, on which mussels are cultured. Good water circulation around the ropes provides food and oxygen, leading to fast growth and high meat yield. This method is suitable for commercial farming in protected waters.

6. Longline Culture

Longline culture is an efficient method for offshore mussel farming. It consists of buoy-supported horizontal ropes anchored to the seabed, with several vertical culture ropes suspended from them. Mussel seed is attached to the ropes using cotton or synthetic mesh, after which the mussels attach naturally. Longline systems allow good water exchange, high stocking density, and large-scale production. However, regular cleaning is needed to remove fouling organisms such as barnacles, algae, ascidians, and unwanted juvenile mussels.

Overall, rack and stake culture are suitable for shallow estuarine areas and small-scale farmers, while raft and longline culture are better for deeper coastal waters and commercial production. Bottom culture is simple and low-cost but more vulnerable to predators and sedimentation. Therefore, the farming method should be selected according to site conditions, available resources, and market demand.

Mussel farming in India has grown significantly during the last two decades, especially along the southwest coast. The development and demonstration of low-cost farming technologies by CMFRI have encouraged adoption by coastal farmers in Kerala, Karnataka, Goa, Tamil Nadu, and Maharashtra. Mussel farming has become an important

livelihood activity, providing additional income to fishing communities, women's self-help groups, and coastal entrepreneurs. With increasing domestic demand and export potential, the sector has good scope for expansion through improved seed production, value addition, cold-chain facilities, and post-harvest processing.

Successful mussel farming depends mainly on the availability of healthy seed and proper seeding techniques. Mussel seed or spat is collected from clean natural beds, preferably from subtidal rocky areas free from sewage, industrial waste, agricultural runoff, and other pollutants. Good-quality seed is usually 15–25 mm in shell length, as it withstands handling and attaches well after stocking. After collection, the seed is sorted to remove damaged, undersized mussels and fouling organisms such as barnacles, algae, tube worms, and ascidians. It is then washed with clean seawater before use.

Culture ropes made of coir or nylon are used for seeding because their rough surface helps mussels attach firmly with byssus threads. About 500–750 g of seed is required per metre of rope. The cleaned seed is spread evenly on a biodegradable cotton mesh, the rope is placed over it, and the mesh is wrapped and tied securely. Within 2–3 days, the mesh decomposes and the mussels attach naturally to the rope. Knots at 25 cm intervals prevent seed from slipping.

Seeded ropes are suspended from racks, rafts, or longlines. The upper end should remain submerged during low tide, while the lower end should stay above the seabed to avoid mud, sedimentation, and predators. Regular inspection, thinning, removal of dead mussels, and cleaning of fouling organisms are essential. Ropes should be spaced about 25 cm apart to ensure good water flow, food availability, uniform growth, high survival, and better meat yield.

Seeding, Rearing, Harvesting and Health Management in Mussel Farming

Successful mussel farming depends on healthy seed, proper seeding techniques, good farm management, safe harvesting, and disease prevention. Mussel seed or spat is usually collected from clean natural beds, preferably from subtidal rocky areas with minimum pollution. Collection sites should be free from sewage, industrial effluents, agricultural runoff, oil pollution, and other contaminants to ensure healthy seed and safe seafood production.

Good-quality mussel seed is generally 15–25 mm in shell length. Seed of this size can tolerate handling and transport and attaches well after stocking. After collection, the seed is sorted to remove damaged, undersized, or weak individuals, along with fouling organisms such as barnacles, algae, tube worms, and ascidians. The selected seed is then washed thoroughly with clean seawater to remove mud, silt, and debris.

Culture ropes made of coir or nylon are commonly used because their rough surface helps mussels attach firmly using byssus threads. About 500–750 g of seed is required

for one metre of rope. For seeding, cleaned mussel seed is spread evenly on a biodegradable cotton mesh, and the culture rope is placed along the centre. The mesh is wrapped around the rope and seed and tied securely. Within 2–3 days, the cotton mesh decomposes in seawater, while the mussels attach firmly to the rope. Knots are tied at intervals of about 25 cm to prevent seed from slipping and to maintain uniform distribution.

Seeded ropes are suspended vertically from racks, rafts, or longlines. The upper end should remain submerged even during low tide, while the lower end should stay above the seabed to avoid mud, sedimentation, and predators. After stocking, regular inspection is necessary to check attachment, mortality, fouling, and overcrowding. Thinning of dense clusters improves water circulation, reduces competition, and promotes uniform growth. Ropes should be spaced about 25 cm apart to ensure proper water flow and food availability.

Mussels generally grow faster in suspended culture than on the seabed because they receive better oxygen, plankton, and water circulation. The upper and middle portions of the rope often show faster growth than the lower portions due to better food availability and less sedimentation.

Harvesting is usually done after 5–7 months, when mussels reach marketable size. In India, harvesting is commonly completed before the southwest monsoon, mainly from April to June. Ropes are lifted manually from racks, rafts, or longlines, and mussels are detached, washed, sorted, and graded. Dead, damaged, and undersized mussels are removed. Fresh mussels should be protected from heat and sunlight and transported under cool, moist conditions.

Since mussels are filter feeders, depuration is important for food safety. In this process, live mussels are kept in clean, filtered, disinfected seawater for about 24 hours to remove contaminants, bacteria, sediments, and gut contents. Proper depuration improves hygiene, shelf life, and consumer acceptance.

Mussels are marketed mainly as live shell-on products, but value-added products such as frozen half-shell mussels, IQF meat, cooked mussels, pickles, smoked products, canned mussels, and ready-to-eat items offer better income opportunities. Good hygiene, cold-chain management, proper packaging, and food safety standards are essential for domestic and export markets.

Although mussel farming is low-risk, disease and mortality may occur due to poor seed, pollution, overcrowding, high temperature, salinity changes, low oxygen, and poor water exchange. Regular monitoring of growth, survival, water quality, fouling, and disease signs is essential. Healthy seed, proper stocking density, good farm layout, adequate spacing, removal of dead mussels, and basic biosecurity practices help maintain healthy stocks and sustainable production.

Integrated Multi-Trophic Aquaculture (IMTA)

Integrated Multi-Trophic Aquaculture (IMTA) is an environmentally sustainable aquaculture system in which different aquatic organisms belonging to different trophic levels are cultured together. It is designed to improve resource use, reduce waste, and increase farm productivity. Unlike intensive monoculture systems, which may cause nutrient enrichment, organic waste accumulation, poor water quality, disease problems, and habitat degradation, IMTA uses natural biological processes to recycle nutrients within the farming system.

The basic principle of IMTA is that the waste produced by one cultured species becomes a useful resource for another. In conventional aquaculture, uneaten feed, faeces, and metabolic wastes from fed species such as marine finfish may enter the environment and cause pollution. In IMTA, these wastes are utilized by extractive species such as bivalves and seaweeds. This reduces environmental impact while producing additional crops of economic value.

A typical marine IMTA system includes three major components: fed species, organic extractive species, and inorganic extractive species. Fed species such as seabass, cobia, pompano, groupers, or other marine finfish are usually cultured in cages or pens and receive formulated feed. They act as the main source of nutrients in the system.

Organic extractive species include filter-feeding bivalves such as mussels, oysters, and clams. These organisms remove suspended organic particles, phytoplankton, and fine particulate wastes from the water. By filtering the water column, they reduce organic pollution and improve water clarity while producing a valuable shellfish crop.

Inorganic extractive species mainly include seaweeds. Seaweeds absorb dissolved nutrients such as ammonia, nitrate, phosphate, and carbon dioxide released from fish culture. Through photosynthesis, they also add oxygen to the water. In addition to improving water quality, seaweeds are useful raw materials for food, fertilizers, pharmaceuticals, cosmetics, and biofuel industries.

The success of IMTA depends on proper selection of species. Cultured organisms should be native or well adapted to local environmental conditions such as temperature, salinity, water depth, and current pattern. They should occupy complementary trophic levels so that nutrients are efficiently transferred from one group to another. Selected species should also have fast growth, good survival, disease resistance, compatible production cycles, and strong market demand.

IMTA provides several environmental benefits. It reduces nutrient loading, eutrophication, organic enrichment, and water quality deterioration. Bivalves remove suspended particles, while seaweeds absorb dissolved nutrients, thereby improving ecosystem health. The system also increases nutrient-use efficiency and reduces the

environmental footprint of aquaculture. Seaweed cultivation can also contribute to carbon sequestration, making IMTA relevant in the context of climate change.

Economically, IMTA allows farmers to harvest more than one product from the same farming area. Finfish, shellfish, and seaweeds can be produced together, reducing dependence on a single crop and lowering financial risk. Since bivalves and seaweeds require little or no external feed, operational costs are reduced. IMTA also creates employment opportunities in seed production, farming, harvesting, processing, value addition, and marketing.

In India, IMTA has good potential for sustainable expansion of marine aquaculture. With proper site selection, suitable species combinations, nutrient modelling, scientific management, and policy support, IMTA can improve farm income while protecting coastal ecosystems.

Thus, IMTA is a holistic and eco-friendly aquaculture approach that converts waste into useful biomass. By integrating fed fish with bivalves and seaweeds, it improves water quality, increases productivity, supports livelihood generation, and promotes sustainable development of mariculture.

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Seaweeds and their Farming Methods

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As the global demand for food, bio-based products, and sustainable livelihoods continues to increase, there is a growing need to utilize natural resources in ways that balance economic development with environmental sustainability. In response to this challenge, attention is increasingly shifting towards renewable marine resources that can support future food systems, coastal economies, and ecosystem resilience. Among these resources, seaweeds have emerged as one of the most promising biological assets, offering opportunities that extend far beyond their traditional use (Khan, Sudhakar and Mamat, 2024). In recent years, seaweeds have attracted considerable scientific, industrial, and policy attention owing to their versatility and their potential to contribute to multiple sectors simultaneously (Buschmann *et al.*, 2017). Their expanding applications, increasing global demand, and compatibility with sustainable production systems have positioned seaweed farming as an emerging marine enterprise with significant economic and environmental relevance. For coastal nations such as India, endowed with an extensive coastline and favourable environmental conditions, seaweed cultivation offers an opportunity to diversify marine-based livelihoods while promoting the sustainable utilization of coastal resources. The development of a successful seaweed sector, however, depends on more than cultivation alone. A comprehensive understanding of the resource, appropriate farming practices, post-harvest management, product diversification, and the broader socio-economic and environmental significance of seaweed farming is essential for realizing its full potential. Bridging scientific knowledge with practical applications is therefore crucial for promoting the sustainable growth of the sector and ensuring its long-term benefits for coastal communities.

Keeping these aspects in view, this chapter presents a comprehensive overview of seaweeds and their importance, followed by an account of their global market potential, cultivation practices, post-harvest handling, value addition, livelihood relevance, women's empowerment, and their role in addressing climate change and advancing the Blue Economy. The chapter is intended to provide scientifically sound and practically relevant information for researchers, extension professionals, students, entrepreneurs, and coastal farming communities involved in the development of the seaweed sector.

What are seaweeds?

Seaweeds are large, photosynthetic marine algae, commonly referred to as marine macroalgae, that grow naturally in coastal and marine environments across the world (Adarshan *et al.*, 2023). Unlike microscopic algae (phytoplankton), which are too small to be seen with the naked eye, seaweeds are multicellular organisms that vary greatly in

size, shape, colour, and habitat. They range from a few centimetres to several metres in length and form an important component of marine ecosystems. Found attached to rocks, coral reefs, shells, or other firm substrates in shallow coastal waters, seaweeds flourish in regions where sunlight penetrates the water column, enabling them to perform photosynthesis efficiently (Pereira, 2021). Like terrestrial plants, seaweeds contain chlorophyll and other photosynthetic pigments that enable them to convert sunlight, carbon dioxide, and dissolved nutrients into organic matter while releasing oxygen into the surrounding water. However, despite their plant-like appearance and ecological role, seaweeds are not true plants. They lack specialized tissues such as true roots, stems, leaves, flowers, seeds, and vascular systems that transport water and nutrients in land plants. Instead, the entire body of a seaweed is known as a thallus, which is structurally simple yet highly adapted to survive in dynamic marine environments. The thallus generally consists of three main parts. The holdfast anchors the seaweed firmly to hard surfaces such as rocks or artificial farming structures but does not absorb nutrients like the roots of terrestrial plants. The stipe is a stem-like structure that provides support and flexibility, allowing the seaweed to bend with waves and currents without breaking. The broad, leaf-like blade serves as the primary photosynthetic surface where sunlight is captured for food production. In some species, small gas-filled structures known as air bladders or pneumatocysts are present, which help keep the blades buoyant and closer to the water surface where light availability is greater (Khan, Sudhakar and Mamat, 2024). Seaweeds absorb water, dissolved minerals, and nutrients directly across the entire surface of their thallus rather than through a root system. This unique adaptation enables them to efficiently utilize nutrients available in seawater, making them highly productive even without soil, freshwater irrigation, or chemical fertilizers (Roleda and Hurd, 2019). Their growth is influenced by several environmental factors, including light intensity, water temperature, salinity, nutrient availability, water movement, and tidal fluctuations. Consequently, healthy seaweed beds are commonly found in clear, nutrient-rich coastal waters where these conditions are favourable.

Based on the dominant photosynthetic pigments they contain, seaweeds are broadly classified into three major groups: Green Seaweeds (Chlorophyceae), brown seaweeds (Phaeophyceae), and red seaweeds (Rhodophyceae). The colour of each group is determined by the pigments that mask or complement chlorophyll, enabling different species to absorb light efficiently at varying water depths. Green seaweeds (Chlorophyta) are characterized by their bright green colour due to the dominance of chlorophyll *a* and *b*. They are commonly found in shallow coastal waters where sunlight is abundant. Fast-growing genera such as Ulva are increasingly studied as sources of food, animal feed, and bio stimulant or biofertilizer products because of their high growth rates and favourable nutrient profile (Hofmann *et al.*, 2025), while Caulerpa species are likewise valued as edible seaweeds and sources of bioactive compounds for food and nutraceutical applications (Pangestuti *et al.*, 2021). Brown Seaweeds (Phaeophyceae) possess the pigment fucoxanthin, which gives them their characteristic brown or olive-

green colour. They generally occur in temperate and colder marine waters, although several tropical species are also distributed along the Indian coastline. Brown seaweeds, including *Sargassum*, *Turbinaria*, and *Padina*, are economically important because they are rich sources of alginate, a valuable hydrocolloid extensively used in the food, pharmaceutical, textile, and cosmetic industries (Anjana and Arunkumar, 2024) Red Seaweeds (Rhodophyta) contain pigments such as phycoerythrin and phycocyanin, which allow them to absorb blue-green wavelengths of light and grow at greater depths than many other seaweeds (Mendes *et al.*, 2024). This group includes commercially significant genera such as *Kappaphycus*, *Gracilaria*, *Gelidiella*, and *Hypnea*. Red seaweeds are the principal source of agar and carrageenan, two commercially important hydrocolloids that have widespread applications in food processing, microbiological media, pharmaceuticals, cosmetics, and biotechnology.

India possesses a rich diversity of marine macroalgae distributed along its extensive coastline, particularly along the shores of Gujarat, Tamil Nadu, Andhra Pradesh, Lakshadweep, and the Andaman and Nicobar Islands. Species such as *Kappaphycus alvarezii*, *Gracilaria* spp., *Ulva*, *Sargassum*, *Turbinaria*, and *Hypnea* are of particular scientific and commercial interest owing to their abundance, biochemical composition, and cultivation potential (Rao and Mantri, 2006). The diversity observed among seaweed species is reflected not only in their colour and morphology but also in their growth characteristics, habitat preferences, and biochemical constituents. These differences determine their suitability for specific purposes, ranging from food and hydrocolloid production to agricultural and industrial applications. As scientific research and commercial cultivation continue to expand worldwide, seaweeds are increasingly being recognized as one of the most valuable renewable resources of the marine environment (Buschmann *et al.*, 2017). Understanding their diverse functions and applications is therefore essential to appreciating their growing importance in sustainable coastal development.

Importance and uses of seaweeds

Seaweeds are among the most valuable biological resources of the marine environment because of their remarkable diversity in chemical composition and functional properties. Rich in carbohydrates, proteins, vitamins, minerals, dietary fibre, essential amino acids, polyunsaturated fatty acids, and a wide range of bioactive compounds, seaweeds have become indispensable in several sectors, including food, agriculture, pharmaceuticals, cosmetics, biotechnology, environmental management, and renewable energy. Their ability to grow rapidly without the need for freshwater, fertile land, or chemical fertilizers further enhances their significance as a sustainable marine resource.

Food and Nutritional Importance

Seaweeds have been consumed as food for centuries, particularly in countries such as Japan, China, Korea, and Indonesia, where they form an integral part of the daily diet. In

recent years, their popularity has expanded globally owing to increasing awareness of healthy and functional foods. Nutritionally, seaweeds are an excellent source of dietary fibre, essential minerals such as iodine, calcium, iron, magnesium, and potassium, vitamins including A, C, E, and several B-complex vitamins, as well as proteins and bioactive compounds with antioxidant properties. Many species are naturally low in fat while containing valuable polyunsaturated fatty acids, making them suitable for balanced diets. Regular consumption of edible seaweeds has been associated with improved digestive health, better mineral intake, enhanced immune function, and a reduced risk of certain lifestyle-related disorders, although these benefits depend on the species consumed and the quantity included in the diet (Kumar, Tarafdar and Badgujar, 2021). Beyond direct human consumption, seaweeds are increasingly incorporated into processed foods such as soups, salads, noodles, snacks, bakery products, beverages, and health supplements. Their unique gelling, thickening, and stabilizing properties also improve the texture and shelf life of many food products.

Applications in Agriculture

Seaweeds have gained considerable importance in sustainable agriculture because they serve as natural biofertilizers and plant bio stimulants. Seaweed extracts contain naturally occurring plant growth regulators such as auxins, cytokinins, gibberellins, and betaines, along with essential micronutrients, amino acids, and polysaccharides that stimulate plant growth and improve overall crop performance. Application of liquid seaweed extracts or seaweed-based formulations has been shown to enhance seed germination, root development, nutrient uptake, chlorophyll synthesis, flowering, fruit set, and crop yield. In addition, these products improve plants tolerance to drought, salinity, and other environmental stresses while supporting beneficial soil microorganisms (Khan *et al.*, 2009). As agriculture increasingly shifts towards environmentally friendly production systems, seaweed-based bio stimulants are becoming an important component of integrated nutrient management and organic farming. Seaweeds are also used as feed supplements for livestock, poultry, and aquaculture species. Their nutritional composition and bioactive compounds can improve feed quality, animal health, growth performance, and disease resistance when included in balanced diets.

Industrial Applications and Hydrocolloids

One of the most economically important uses of seaweeds is the extraction of hydrocolloids-natural polysaccharides with excellent thickening, gelling, stabilizing, and emulsifying properties. These compounds have become indispensable raw materials for numerous industries. Agar, primarily obtained from red seaweeds such as *Gracilaria* and *Gelidium*, is widely used in the food industry as a gelling agent and in microbiology laboratories as a culture medium for growing microorganisms. It also finds applications in pharmaceuticals, confectionery, and biotechnology (Lee, Lim and Ho, 2022).

Carrageenan, extracted mainly from red seaweeds such as *Kappaphycus* and *Eucheuma*, is extensively used to improve the texture, stability, and viscosity of dairy products, processed foods, meat products, toothpaste, cosmetics, and pharmaceutical formulations (Campbell and Hotchkiss, 2017). Alginate, obtained from brown seaweeds such as *Sargassum*, *Turbinaria*, and *Laminaria*, is valued for its water-binding and film-forming properties. It is widely utilized in the textile industry, paper manufacturing, wound dressings, pharmaceuticals, food processing, dental impression materials, and several other industrial products. The global demand for these hydrocolloids continues to increase, making commercially important seaweeds valuable industrial raw materials.

Pharmaceutical and Biomedical Applications

Seaweeds are the rich sources of biologically active compounds, including polyphenols, flavonoids, sulphated polysaccharides, pigments, sterols, peptides, and antioxidants. These compounds have attracted considerable scientific interest because of their diverse biological activities. Numerous laboratory and clinical studies have demonstrated that seaweed-derived compounds possess antioxidant, antimicrobial, antiviral, anti-inflammatory, anticoagulant, immunomodulatory, antidiabetic, and anticancer potential. Consequently, seaweeds are increasingly being explored for the development of pharmaceuticals, nutraceuticals, functional foods, wound-healing materials, and biomedical products (Lomartire and Gonçalves, 2022). Although many applications are still under active research, seaweeds represent a promising source of novel bioactive molecules for future drug discovery and healthcare innovations.

Cosmetics and Personal Care Products

The cosmetic industry extensively utilizes seaweed extracts because of their moisturizing, antioxidant, anti-ageing, and skin-conditioning properties. Seaweed-derived compounds are incorporated into facial creams, lotions, shampoos, soaps, sunscreens, face masks, body scrubs, and spa products (Pereira, 2018). Polysaccharides and antioxidants present in seaweeds help retain skin moisture, improve elasticity, protect against oxidative stress, and promote healthier skin and hair. Growing consumer preference for natural and sustainable cosmetic ingredients has further increased the demand for seaweed-based formulations.

Environmental Importance

Apart from their commercial value, seaweeds perform several vital ecological functions that support the health of marine ecosystems. Through photosynthesis, they absorb carbon dioxide and release oxygen, thereby contributing to primary productivity and maintaining ecological balance in coastal waters. Seaweeds efficiently absorb dissolved nutrients such as nitrogen and phosphorus from seawater, helping reduce nutrient pollution and mitigate eutrophication (Cotas *et al.*, 2023). Their ability to remove excess nutrients has led to their use in wastewater treatment systems and integrated multi-

trophic aquaculture (IMTA), where they improve water quality while producing valuable biomass. Seaweed beds also provide food, shelter, nursery grounds, and breeding habitats for numerous fish, crustaceans, molluscs, and other marine organisms, thereby enhancing marine biodiversity and supporting coastal fisheries. Furthermore, because of their capacity to absorb atmospheric carbon dioxide during growth, seaweeds are increasingly recognized for their potential role in climate change mitigation through carbon sequestration and blue carbon initiatives.

Bioenergy and Emerging Biotechnological Applications

Growing concerns regarding fossil fuel depletion and climate change have stimulated research into renewable sources of energy. Owing to their rapid growth rate, high biomass productivity, and absence of competition with agricultural land and freshwater resources, seaweeds have emerged as a promising feedstock for the production of bioethanol, biogas, biohydrogen, and other renewable biofuels (Samal and Sukla, 2025). In addition, advances in marine biotechnology have opened new opportunities for utilizing seaweeds in the production of biodegradable packaging materials, bioplastics, pharmaceuticals, nanomaterials, enzymes, pigments, and high-value specialty chemicals. These emerging applications are expected to further expand the commercial importance of seaweeds in the coming decades. The extraordinary versatility of seaweeds, combined with their environmental sustainability and wide-ranging industrial applications, has transformed them from a traditionally harvested marine resource into a globally important bioresource. Their increasing demand across diverse sectors not only highlights their economic value but also underscores their potential to support sustainable agriculture, food security, environmental conservation, and coastal livelihood development. This growing global demand has, in turn, accelerated interest in commercial seaweed cultivation, making seaweed farming an increasingly attractive and economically viable enterprise.

Global market and emerging opportunities

The expanding range of applications of seaweeds has led to a rapid increase in their global demand over the past few decades. Asian countries, particularly China, Indonesia, the Republic of Korea, and the Philippines, account for the largest share of global seaweed production and supply much of the raw material required by the food, hydrocolloid, pharmaceutical, cosmetic, and agricultural industries (Belattmania, Reani and Sabour, 2022). The global seaweed industry has evolved from a traditional coastal activity into a multi-billion-dollar bioeconomy, driven by the increasing demand for healthy foods, natural bio stimulants, hydrocolloids, sustainable packaging materials, pharmaceuticals, cosmetics, and renewable bio-based products. Continuous research and technological advancements are further expanding the commercial applications of seaweeds, creating new opportunities for farmers, entrepreneurs, and coastal industries.

Although India possesses a long coastline and rich seaweed biodiversity, commercial cultivation is still at a developing stage compared to several leading seaweed-producing nations. However, favourable coastal conditions, growing domestic demand, supportive government initiatives, and increasing private-sector participation provide significant opportunities for expanding seaweed farming in the country. With appropriate scientific cultivation practices, value addition, and market linkages, India has considerable potential to emerge as an important contributor to the global seaweed industry. The growing domestic and international demand for seaweed products has made seaweed farming an increasingly attractive livelihood option (Krishnan and Kumar, 2010). Understanding the factors that make seaweed cultivation economically, socially, and environmentally beneficial is therefore essential for promoting its wider adoption among coastal communities.

Why should we promote seaweed farming?

The increasing global demand for seaweed products, coupled with the abundance of suitable coastal resources, has made seaweed farming an attractive opportunity for sustainable coastal development. Compared to many conventional farming activities, seaweed cultivation requires relatively low investment, simple infrastructure, and minimal external inputs. Since it is carried out in the sea, it does not compete for agricultural land or freshwater resources, making it particularly suitable for countries with extensive coastlines such as India. Another major advantage of seaweed farming is its short cultivation cycle. Most commercially cultivated species can be harvested within 30-45 days, allowing farmers to obtain multiple harvests in a year and generate regular income (Seth and Shanmugam, 2016). The activity can also be integrated with existing fishing and aquaculture practices, providing an additional source of livelihood during periods of low fishing activity or seasonal fishing restrictions. Seaweed farming is well suited to small-scale coastal communities because it is relatively easy to learn and can be adopted using locally available materials and appropriate technical guidance. It provides opportunities for individual farmers, fisher groups, self-help groups, and community-based organizations to participate in income-generating activities. Moreover, the increasing emphasis on sustainable marine resource utilization and government support for seaweed cultivation further strengthens its potential as a future-oriented coastal enterprise (Rebours *et al.,* 2014). With its low resource requirement, quick returns, and expanding market opportunities, seaweed farming represents a practical and sustainable option for improving coastal livelihoods while supporting the long-term development of the marine sector.

Seaweed farming practices

The successful adoption of seaweed farming depends not only on the growing market demand but also on the application of appropriate cultivation practices. Although seaweed farming is relatively simple compared with many other aquaculture activities,

its productivity and profitability are strongly influenced by the selection of suitable species, appropriate farming sites, and the cultivation method employed. Careful planning at each stage helps ensure healthy crop growth, higher biomass yield, and improved product quality.

Selection of Species

The first step in successful seaweed farming is the selection of a suitable species. This decision should be based on local environmental conditions, market demand, availability of healthy planting material, and the intended end use of the harvested biomass. A species that performs well in one coastal region may not necessarily thrive in another due to differences in temperature, salinity, water movement, and seasonal variations (Radulovich *et al*., 2015). In India, commercially cultivated species include *Kappaphycus alvarezii*, *Gracilaria* spp., and *Ulva* spp., owing to their rapid growth, good adaptability, and industrial importance. Selecting healthy, disease-free planting material from reliable sources is equally important, as it directly influences crop establishment and overall productivity.

Site Selection

Selection of a suitable farming site is one of the most critical factors determining the success of seaweed cultivation. An ideal site should provide environmental conditions that support healthy growth while minimizing physical damage to the crop. The farming area should have clean, unpolluted seawater with good water exchange to ensure a continuous supply of dissolved nutrients and oxygen. Salinity and temperature should remain within the tolerance range of the cultivated species, while sufficient sunlight is essential for efficient photosynthesis. Moderate water currents are desirable because they facilitate nutrient transport and prevent the accumulation of sediments on the seaweed surface. However, sites exposed to strong waves, cyclones, or excessive turbulence should be avoided, as they may damage farming structures and dislodge the crop. Water depth should allow the seaweed to remain submerged during low tide while still receiving adequate sunlight. The site should also be free from industrial discharge, sewage outfalls, excessive siltation, and heavy grazing by herbivorous fishes or sea urchins. In addition to environmental suitability, practical considerations such as ease of access, availability of labour, transportation facilities, and proximity to landing centres are important for efficient farm management and harvesting operations (Kim *et al*., 2017).

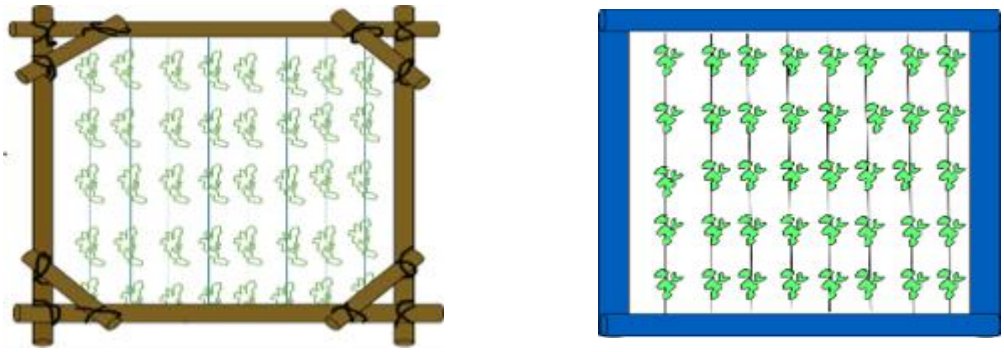
Seaweed Farming Methods

Seaweed cultivation can be carried out using different farming methods depending on the cultivated species, water depth, tidal range, wave action, current velocity, and available farming infrastructure (García-Poza *et al*., 2020). Although the design of each farming system varies, the basic principle remains the same: healthy seaweed propagules are attached to a suitable support, such as ropes or nets, and allowed to grow

under favourable environmental conditions until they attain harvestable size. Selecting an appropriate farming method is therefore essential for ensuring healthy crop growth, minimizing production losses, and improving overall farm productivity.

1. Floating Raft Method

The floating raft method is one of the most widely adopted techniques for commercial seaweed farming, especially in sheltered coastal waters such as bays, lagoons, and estuaries. It is particularly suitable for species such as *Kappaphycus alvarezii* and *Gracilaria* spp. In this method, a square or rectangular raft is constructed using bamboo, PVC, or HDPE pipes and kept afloat with buoyant materials. The raft is anchored securely to the seabed to prevent drifting. Culture ropes are stretched across the frame, and seaweed fragments are tied at regular intervals. As the raft floats with the natural movement of the sea, the crop remains suspended in the upper water column, where favourable light and water conditions support rapid growth. The floating raft method facilitates easy monitoring, cleaning, and harvesting of the crop. It is highly productive but requires sturdy anchoring and periodic inspection, particularly during rough weather.



(A) (B)

Fig. 1 (A) Bamboo Raft Method of Seaweed Cultivation, (B) HDPE Raft Method of Seaweed Cultivation

2. Long-line Method

The long-line method is widely used for commercial farming in relatively deeper coastal waters. It is especially suitable for large-scale cultivation because it allows efficient utilization of available farming space with comparatively less structural material. A strong horizontal rope, known as the main line, is anchored at both ends and supported by floating buoys. Seaweed seedlings are attached either directly to the main rope or to shorter culture lines suspended from it. This arrangement provides ample space for growth while allowing the farm to cover a much larger area than a raft system. The long-line method is relatively easy to expand, making it suitable for commercial enterprises. However, the stability of the system depends on proper anchoring, particularly in areas with strong currents or seasonal storms (Ganesan *et al.*, 2019; Mantri, 2025).

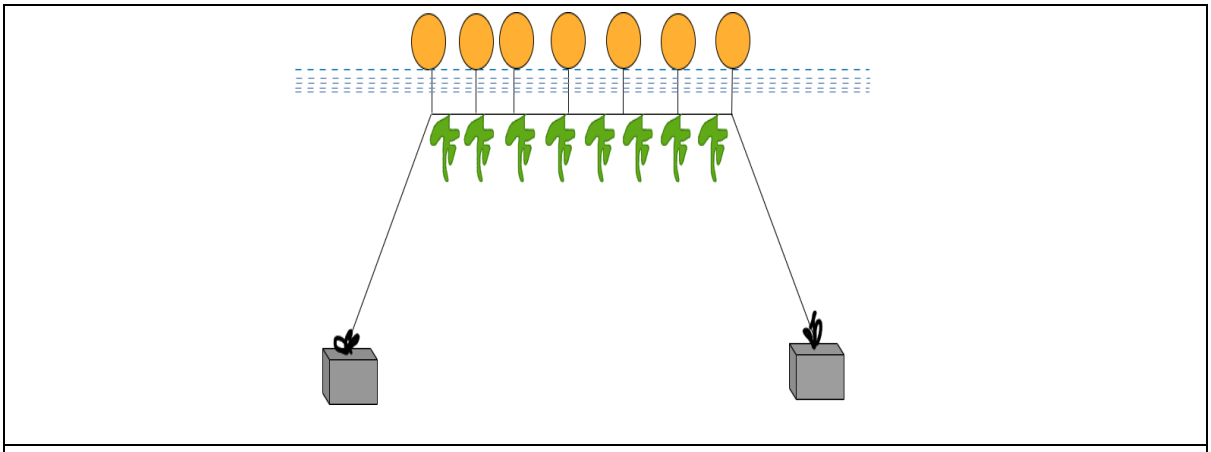


Fig. 2 Long-line Method of Seaweed Cultivation

3. Off-bottom Method

The off-bottom method is commonly practiced in shallow coastal areas where the seabed is sandy, muddy, or covered with seagrass. It is one of the most economical farming techniques and is widely adopted by small-scale coastal farmers. The method involves fixing wooden, bamboo, or PVC stakes into the seabed and stretching culture ropes between them approximately 20–50 cm above the bottom. Seaweed propagules are tied to these ropes at predetermined intervals. Raising the culture ropes above the seabed reduces sediment deposition on the crop while allowing adequate water movement around the growing seaweed. Because of its simple construction and low investment requirement, the off-bottom method is particularly suitable for community-based farming programmes (Hurtado-Ponce, Agbayani and Chavoso, 1996). However, it performs best in protected coastal areas where wave action is minimal.

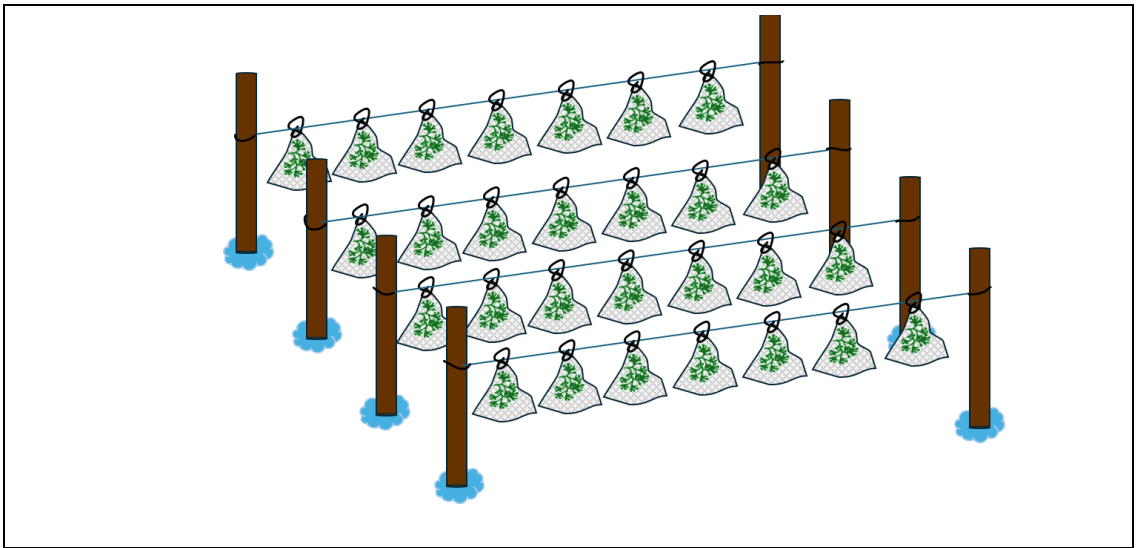


Fig. 3 Off bottom net bag method of Seaweed Cultivation using Bamboo Poles

4. Monoline Method

The monoline method is a simplified version of rope-based cultivation and is generally

adopted for small-scale farming, pilot demonstrations, and experimental cultivation. In this method, a single culture rope is stretched horizontally between two fixed supports or anchored floats. Seaweed fragments are tied directly onto the rope at regular intervals and left to grow until harvest. The system is inexpensive, easy to install, and requires minimal construction materials, making it suitable for beginners and resource-limited farmers. However, because only one culture line is used, the production capacity is lower than that of raft or long-line systems (Kavale, Yadav and Mantri, 2021).

Fig. 4 Monoline Method of Seaweed Cultivation

5. Tube-net Method

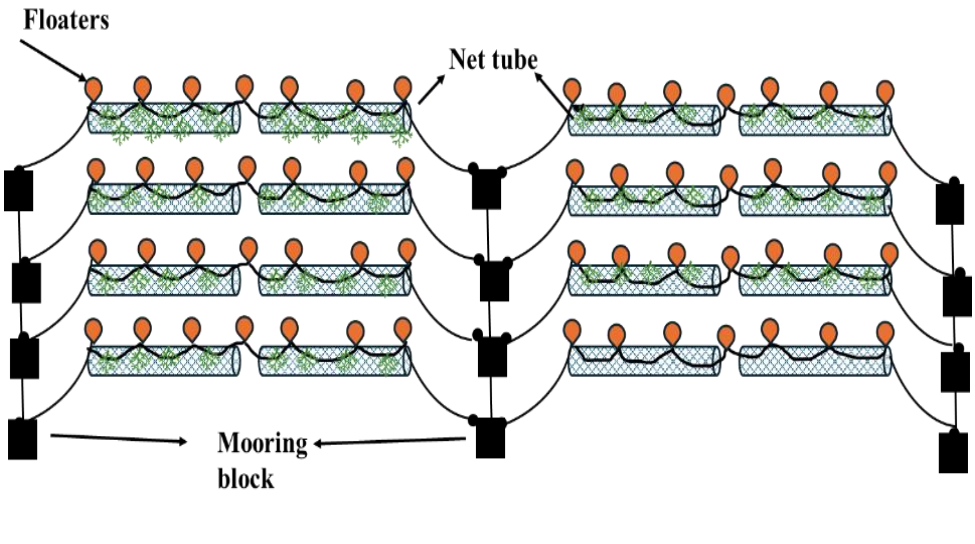


Fig. 5 Tube-net Method of Seaweed Cultivation

The tube-net method is particularly useful for fragile or loosely attached seaweed species that may not remain securely tied to ropes during cultivation. Instead of fastening individual propagules onto ropes, the planting material is placed inside long cylindrical mesh tubes. These nets are suspended from floating rafts or long-line systems, allowing seawater to flow freely through the mesh

while preventing the propagules from being dislodged by waves or currents (Megarajan *et al.*, 2024). The mesh also provides partial protection against grazing by herbivorous organisms. To maintain healthy growth, the nets should be inspected and cleaned periodically to remove fouling organisms that may reduce water exchange and light penetration.

6 Integrated Multi-Trophic Aquaculture (IMTA)

Integrated Multi-Trophic Aquaculture (IMTA) is an advanced and sustainable aquaculture approach in which seaweeds are cultivated together with other aquatic organisms occupying different trophic levels, such as finfish, shrimp, mussels, or oysters. In this system, dissolved nutrients released from the cultured fish or shrimp, particularly nitrogen and phosphorus, are utilized by seaweeds for growth, while filter-feeding organisms remove suspended organic matter from the water (Neori *et al.*, 2004). This natural recycling of nutrients improves resource-use efficiency, enhances water quality, and reduces the environmental impacts associated with aquaculture (Nederlof *et al.*, 2022). By integrating seaweed cultivation with other aquaculture practices, IMTA not only promotes environmentally sustainable production but also provides farmers with an additional source of income through diversified farming.

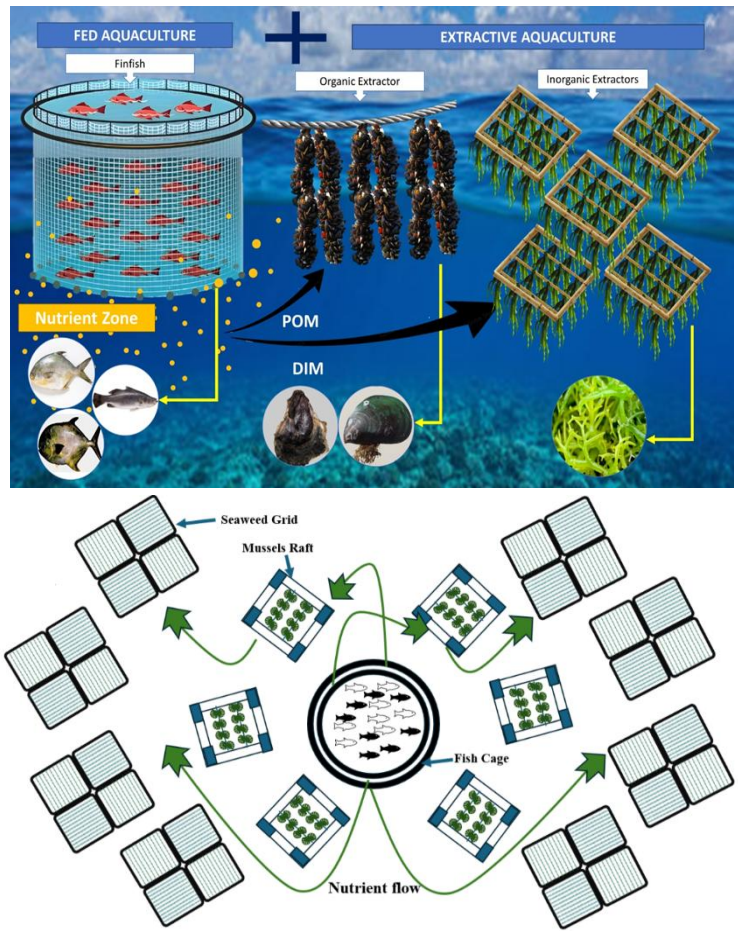


Fig. 6 Integrated Multi-Trophic Aquaculture (IMTA) in Seaweed Cultivation

Post-harvest handling and value addition

The success of seaweed farming does not end with harvesting. Proper post-harvest handling is equally important to preserve product quality and maximize its market value. Poor handling practices can lead to contamination, quality deterioration, and reduced returns, making careful processing an essential part of the seaweed value chain. Seaweeds should be harvested at the appropriate stage of maturity and handled carefully to minimize damage. Immediately after harvesting, the biomass is washed with clean seawater to remove sand, shells, epiphytes, and other adhering impurities. It is then sorted to separate healthy material from damaged or discoloured portions, ensuring a clean and uniform product for further processing. Drying is the most critical post-harvest operation, as freshly harvested seaweed contains high moisture content and is highly susceptible to spoilage. Sun drying on clean nets, bamboo mats, or raised platforms is the most commonly adopted method because it is simple, economical, and suitable for coastal communities. Proper drying reduces the moisture content to a safe level, thereby improving shelf life and facilitating storage and transportation. Once dried, the seaweed should be packed in clean, moisture-resistant bags and stored in a cool, dry, and well-ventilated place to maintain its quality until marketing or processing (Sánchez-García *et al*., 2021). While dried seaweed itself is a valuable commercial product, value addition can substantially enhance farmers income and create new market opportunities. Depending on the species and intended use, seaweed can be processed into products such as seaweed powder, flakes, liquid seaweed extracts, biofertilizers, plant bio stimulants, animal feed supplements, and food ingredients. At the industrial level, commercially important hydrocolloids such as agar, alginate, and carrageenan are extracted from selected seaweed species and are widely used in the food, pharmaceutical, cosmetic, and biotechnology industries (Anjana and Arunkumar, 2024; Rupert *et al.*, 2022). Thus, efficient post-harvest handling combined with value addition not only improves product quality and shelf life but also increases profitability, reduces post-harvest losses, and strengthens the overall sustainability of the seaweed farming enterprise.

Livelihood relevance and women's empowerment

Seaweed farming has emerged as a promising livelihood option that supports the economic development of coastal communities while promoting the sustainable use of marine resources. In many coastal regions, fishing remains the primary source of income, however, seasonal fishing bans, declining fish catches, and climate-related uncertainties often affect household earnings. Seaweed cultivation offers an alternative and supplementary livelihood that can be integrated with existing fishing and aquaculture activities, thereby improving income stability and enhancing the resilience of coastal communities. Beyond cultivation, seaweed farming generates employment across the entire value chain, including nursery development, preparation of planting material, farm installation, crop maintenance, harvesting, drying, processing, value

addition, packaging, and marketing (Duarte, Bruhn and Krause-Jensen, 2022). These diverse activities create opportunities for entrepreneurship, support the development of small-scale enterprises, and strengthen local economies. The formation of self-help groups (SHGs), cooperatives, and farmer producer organizations (FPOs) further facilitates collective production, improves access to markets, and enhances the adoption of improved farming technologies. A notable feature of the seaweed sector is its potential to empower women through meaningful participation in both production and post-harvest operations (Msuya and Hurtado, 2017). Activities such as seedling preparation, tying of propagules, sorting, drying, grading, processing, packaging, and value addition require skill, precision, and careful handling, enabling women to play a central role in the seaweed value chain. Participation in these activities provides opportunities for income generation, entrepreneurship, capacity building, and financial independence while strengthening their role in household decision-making and community development. Across several coastal regions, women-led self-help groups have successfully demonstrated that seaweed farming can serve as an effective tool for socio-economic empowerment and inclusive rural development. By creating sustainable livelihood opportunities, generating employment, and promoting women's economic participation, seaweed farming contributes significantly to the overall development of coastal communities. Its ability to combine livelihood enhancement with social inclusion makes it an important component of sustainable coastal development.

Seaweed farming, climate change and the blue economy

Climate change has emerged as one of the greatest challenges affecting marine ecosystems and coastal livelihoods. Rising sea surface temperatures, ocean acidification, changing rainfall patterns, and the increasing frequency of extreme weather events have significantly influenced marine biodiversity and fisheries production. In this context, seaweed farming is increasingly recognized as a nature-based solution that can contribute to climate resilience while supporting sustainable coastal development. As seaweeds grow, they absorb carbon dioxide through photosynthesis and convert it into biomass, thereby contributing to the marine carbon cycle (Bhuyan *et al.*,2021). They also take up dissolved nutrients, such as nitrogen and phosphorus, from seawater, helping to improve water quality and reduce nutrient enrichment in coastal ecosystems. Although seaweed farming alone cannot mitigate climate change, it can complement broader climate adaptation and mitigation strategies by promoting healthier and more productive coastal environments. Seaweed farming is also closely aligned with the principles of the Blue Economy, which emphasizes the sustainable use of ocean resources for economic growth, improved livelihoods, and environmental conservation. Unlike many land-based production systems, seaweed cultivation does not require fertile land, freshwater, or chemical fertilizers, making it a resource-efficient and environmentally sustainable marine enterprise. In addition to supporting food, agriculture, pharmaceuticals, and other industries, seaweed farming creates employment opportunities, encourages entrepreneurship, and strengthens the resilience of coastal communities. With increasing scientific research, technological advancements, and supportive government initiatives, seaweed farming is gaining recognition as an important component of

sustainable coastal resource management. By integrating environmental stewardship with livelihood generation and economic development, seaweed farming has the potential to play a significant role in building climate-resilient coastal communities and advancing a sustainable Blue Economy (Saravanan, Chatterjee and Bhowmick, 2023).

Government schemes and initiatives for promoting seaweed farming in India

Recognizing the immense potential of seaweed farming for livelihood generation, sustainable aquaculture, and the Blue Economy, the Government of India has introduced several policy initiatives and financial support programmes to promote the development of the seaweed sector. These initiatives focus on expanding commercial cultivation, strengthening infrastructure, improving access to quality planting material, enhancing post-harvest management, and creating market opportunities for seaweed farmers.

1 Pradhan Mantri Matsya Sampada Yojana (PMMSY)

In June 2020, the Government of India introduced the Pradhan Mantri Matsya Sampada Yojana (PMMSY) with a total budget of ₹20,050 crore to accelerate the expansion of the fisheries sector, with seaweed cultivation as a key area (Krishna, 2021). Between 2020 and 2025, ₹640 crore has been earmarked specifically for promoting seaweed cultivation, reflecting the government's commitment to developing this sustainable sub-sector. Of this allocation, ₹194.09 crore is dedicated to flagship initiatives such as the establishment of a Multipurpose Seaweed Park in Tamil Nadu and a Seaweed Brood Bank in Daman and Diu. To scale production, approvals have been granted for 46,095 rafts and 65,330 monocline tube nets for seaweed farming. Under PMMSY, India targets an increase in seaweed production to 1.12 million tonnes over the next five years (Dineshkumar, Bhagiya and Mantri, 2025). Indian seaweed cultivation currently depends on *Kappaphycus alvarezii* along with a narrow set of native species, and this narrow genetic base is contributing to weaker growth rates and greater vulnerability to disease outbreaks. To address this challenge, the Department of Fisheries notified guidelines on 31 October 2024 for the import of live seaweeds, enabling access to improved strains and supporting productivity, biosecurity, and trade expansion. The Union Budget 2026–27 provides a record ₹2,761.80 crore for the fisheries sector, with ₹2,530 crore for scheme-based support. PMMSY remains the core programme, receiving ₹2,500 crore to strengthen fisheries and aquaculture development.

2 Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PMMKSSY)

The Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PMMKSSY) complements PMMSY by promoting modernization and formalization of the fisheries sector. Although it is not exclusively designed for seaweed farming, the scheme supports activities related to quality assurance, traceability, market access, digitalization, infrastructure development, and value chain strengthening. These interventions benefit seaweed farmers by improving market connectivity, encouraging value-added processing, and enhancing the competitiveness of seaweed-based products in domestic and international markets.

3 Seaweed Mission

Due to seaweed's potential for industrial uses, climate resilience, livelihood generation, and nutritional security, the Indian government has designated seaweed production and value addition as a priority area under the blue economy. Under the PMMSY (Pradhan Mantri Matsya Sampada Yojana), the government has set aside a total budget of Rs. 640 crores for seaweed cultivation in India between 2020 and 2025. In order to expand and strengthen the seaweed production ecosystem and value chain, the Indian government has identified and prioritized seaweed resources as essential to the growth of the blue economy and has launched a number of initiatives, including seed banks, seaweed parks, clusters, and CoE, improved seaweed germplasm, climate resilient villages, and farming models. The mission aims to transform seaweed farming into a sustainable livelihood option while enhancing India's contribution to the growing global seaweed industry (Singh *et al*., 2026).

These initiatives collectively are creating an enabling ecosystem for the sustainable growth of seaweed farming in India by integrating scientific research, infrastructure development, capacity building, entrepreneurship, and market support. Such coordinated efforts are expected to enhance farmers' incomes, strengthen coastal livelihoods, and promote the sustainable development of the country's marine bioeconomy.

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Diseases and Integrated Disease Management in Aquaculture

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Aquaculture, the fastest-growing food-producing sector, contributes significantly to food security, nutrition, employment, and poverty reduction. However, intensive and semi-intensive farming practices, along with climate change, have increased stress in cultured animals, leading to increased frequency and severity of several infectious and non-infectious diseases. Unscientific management practices, the unethical introduction of exotic animals, and the transboundary movement of fish seeds and adults are other reasons for the introduction of novel pathogens. All these have resulted in serious economic losses, making disease management one of the largest constraints of the aquaculture industry (Elabd et al., 2024). The World Bank reports that aquaculture diseases cause an estimated economic loss of 6 billion USD annually worldwide (Cain, 2022). The economic losses due to diseases in Indian aquaculture are not accurately assessed. However, an earlier survey in Andhra Pradesh, India reported an annual loss of Rs. 40 million due to diseases in aquaculture (Augustine et al., 2020).

In aquaculture, disease occurrence is rarely caused by a single causative agent; instead, disease develops through complex interactions among the host, pathogen, and environmental conditions, which is generally known as the disease triad. Understanding these interactions forms the basis of effective disease prevention and integrated disease management. Accordingly, an Integrated Disease Management (IDM) strategy that includes multiple complementary strategies is required for effective and sustainable disease management in aquaculture. Rather than concentrating on pathogen elimination, IDM preserves the balance in the disease triad, improving the sustainability of aquaculture systems (Yasin et al. 2025).

Aetiology of aquaculture diseases

Any damage that hinders the performance of normal activities of fish, like environmental stress, toxins, pollutants, climate change, malnutrition, and infectious agents, can be termed a disease. The most noticeable sign of disease in any aquaculture system is the presence of weak or dead animals. However, careful and routine observation can identify

the disease before the fish start dying because clinical signs such as anorexia, gasping, surfacing, rubbing against objects, skin discolouration, and lethargy often precede the mass mortality.

Aquatic diseases are broadly classified into infectious and non-infectious categories. Infectious diseases are caused by pathogenic microbes, which include bacteria, viruses, protists, and metazoans. Lafferty et al. (2015) estimated that bacteria, viruses, protists, and metazoans constitute about 25, 34, 19, and 18%, respectively, of the total infectious agents in aquaculture. Conversely, non-infectious diseases in fish are caused by environmental factors, such as changes in water quality, ammonia/nitrite toxicity, low oxygen, fluctuations in water physicochemical characteristics, presence of pollutants and toxins, nutritional deficiencies, or genetic anomalies, and these diseases are not contagious.

Bacterial diseases: The major bacterial pathogens in aquaculture include *Vibrio* spp. (*V. harveyi*, *V. parahaemolyticus*, *V. alginolyticus*, *V. anguillarum*, and *V. vulnificus*), *Aeromonas* spp. (*A. veronii* and *A. hydrophila*), *Streptococcus* spp. (*S. agalactiae* and *S. iniae*), *Photobacterium damselae, Tenacibaculum spp. (T. maritimum, T. soleae, T. dicentrarchi, and T. discolor*), *Lactococcus garvieae*, *Nocardia seriolae, Mycobacterium spp. (M. marinum, M. fortuitum, M. chelonae, M. salmoniphilum, M. shottsii, and M. pseudoshottsii), Edwardsiellas spp. (E. ictaluri* and *E. tarda*), *Renibacterium salmoninarum* and *Flavobacterium columnare* (Austin and Austin 2016; Irshath et al. 2023). Most bacterial pathogens are opportunistic. Accordingly, bacterial disease outbreaks are usually caused by a multitude of stressors like reduced physicochemical and microbiological water quality, poor nutritional status, sudden climate change, increased handling, transport stress, and high stocking density (Burge et al. 2014).

Viral diseases: Viral infections are another concern in aquaculture and can cause high mortality rates in infected populations. Major viral diseases include viral hemorrhagic septicemia (VHS), infectious salmon anaemia (ISA), *Red Sea Bream Iridoviral* disease, viral nervous necrosis or viral encephalopathy and retinopathy (Genus: *Betanodavirus* and Family: *Nodaviridae*), infectious pancreatic necrosis, infectious hematopoietic necrosis, lymphocystis disease virus, Herpes virus infections of fry and fingerling channel catfish, *etc* (Lorenzen et al., 2019).

Fungal Diseases: Although less common, fungal diseases can cause significant economic losses under high stress or after injuries. The most frequently encountered fungal pathogens in fish include *Aphanomyces* sp. (causes epizootic ulcerative syndrome, EUS), *Saprolegnia, Achlya, Dermocystidium, Branchiomyces, Aspergillus, Ichthyophonus*, *Lagenidium, Haliphthoros, Halocrusticida, Halioticida, Atkinsiella, Pythium*, *Fusarium, Ochroconis, Exophiala, Scytalidium, Plectosporium, Cladosporium* spp. and *Acremonium* (Sadler et al., 2020).

Parasitic Diseases: Parasitic diseases usually do not cause direct loss due to fish mortality, but increase production costs through treatment or reduction in growth and product quality. Amyloodiniosis caused by *Amyloodinium ocellatum*, a parasitic dinoflagellate, is a major threat to marine aquaculture, causing significant mortality in various fish species. *Ichthyophonus hoferi* and *Ichthyophthirius multifiliis* are fish pathogenic protists causing a granulomatous systemic infection, called ichthyophoniasis, which can result in heavy mass mortalities in >80 freshwater and marine species, leading to huge economic losses. *Gyrodactylus salaris*, a parasitic flatworm, affects farmed and wild fish populations (Buchmann & Bresciani, 2006). Other important protozoan diseases of fishes include velvet disease, cryptobiasis, ichthyobodosis (coastiasis), coccidiosis, microsporidiosis, myxosporidiosis, chilodonellosis, and Trichodina infection. Generally, metazoan parasites are less pathogenic in fishes and include various monogeneans, trematodes, cestodes, and crustaceans (Sanil 2020).

Components of integrated disease management

1. **Biosecurity:** Aquaculture disease prevention by decreasing the risk of potential pathogen intrusion into aquaculture facilities and spreading of any infection elsewhere during disease outbreaks can be achieved through ‘Biosecurity management’ (Ahmed et al. 2024). Biosecurity is defined as a strategic and integrated approach to analyse and manage the risks affecting health and the environment (FAO 2018). While biosecurity targets mitigating disease risks, it provides extra advantages, like increased production, decreased economic losses, enhanced food safety and quality, environmental sustainability, and improved fish health and immunity (Azad et al. 2022), supporting the

sustainability of the aquaculture industry. Hence, implementation of a well-developed biosecurity management plan at the farm level is essential to mitigate the risk of pathogen intrusion or transmission (Ahmed et al. 2024).

The following protocols are part of biosecurity practices in the aquaculture sector.

- Development of quick and sensitive disease diagnostic kits is necessary for early disease diagnosis, thus helping in the implementation of early steps for disease control and management practices.
- Implementation of effective quarantine methods at all the hatcheries to eliminate pathogens. Restrict personnel movement through designated entry points equipped with footbaths, hand sanitisers, and protective clothing.
- Keeping separate equipment for different life-stage units and executing 'all-in, all-out' production systems also help to reduce the risk of pathogen dissemination.
- Screening of all broodstock before initiating the breeding programmes
- Screening of eggs, fry and fingerlings before rearing in the nursery phase
- Regular monitoring of fish health and environmental health in farms
- Maintenance of optimum stocking density and providing nutritionally balanced feeds to avoid stress
- Avoid use of trash fish as the feed.
- Avoid the usage of chemicals and antibiotics in open-water farming systems.
- Periodic sterilisation of biofilters and the entire system
- Strict quarantine measures such as egg disinfection, water treatments, clean feed and disposal of mortalities should be routinely followed. In a study evaluating various aquaculture disinfectants, iodophor and BKC were graded as the most effective disinfectants for aquaculture disinfection programmes (Sumithra et al. 2026a). Similarly, another study by ICAR-CMFRI showed that 20 ppm iodophor for 10 min, 400 ppm H_2O_2 for 10 min, and 40 ppm glutaraldehyde for 5 min were the optimal protocols for marine egg disinfection (Sumithra et al., 2026b).
- Exclusion of vectors and reservoir hosts capable of transmitting pathogens from the aquaculture systems. The fixing of bird netting, perimeter fencing, crab

barriers, screened water inlets, and predator exclusion devices reduces the contact between farmed animals and potential disease reservoirs.

- Proper disposal of dead animals through incineration, deep burial, or composting

2. **Water quality management:** Water is the key medium for pathogen transmission in aquaculture environments, so water quality management is a principal element of integrated disease management. Application of pathogen-free water sources and implementation of water treatment methods like, filtration, sedimentation, ultraviolet irradiation, ozonation, or chlorination before use in production units are part of good water quality management. Chlorination is graded as the best water treatment methodology to prevent disease outbreaks in hatcheries. Apart from this, maintaining optimal physicochemical parameters of water, including temperature, dissolved oxygen, pH, salinity, ammonia, nitrite, and alkalinity, is also required to reduce physiological stress and improve immunity in farmed animals. Regular monitoring of these characteristics aids in the early detection of hostile environmental stresses that predispose animals to disease outbreaks (Boyd and Tucker, 2012).

3. **Nutrition and immunostimulants:** Optimal nutrition is another key part of IDM in aquaculture, as it directly affects the growth, health, stress tolerance, and immune competence of farmed animals. A balanced feed with optimal levels of proteins, essential fatty acids and amino acids, lipids, vitamins, and minerals improve both innate and adaptive immune responses, decreasing the susceptibility to infectious agents. Apart from the essential nutrients, functional feed additives/immunostimulants have gained significant attention as sustainable alternatives to antibiotics. Nutritional immunostimulants with proven beneficial actions in aquaculture include functional amino acids like glutamate and glutamine, arginine, alanine, tryptophan, methionine, histidine, lysine and taurine, nucleotides, vitamins A, C, D, and E, minerals like calcium, phosphorus, copper, selenium, zinc, iron, chromium, cobalt, and magnesium, etc (Vijayaram et al. 2024). Further, components like β-glucans, carotenoids, mannan oligosaccharides, lectins, chitosan, levamisole, hormones like thyroxine, and plant-derived phytochemicals are also reported to act as efficient

immunostimulants for fish (Wang et al. 2016). Application of immunostimulants during stressful conditions, like transportation, grading, or seasonal environmental changes, can significantly improve disease resistance and survival.

4. **Vaccination:** Vaccination is an effective preventive strategy for controlling infectious diseases in aquaculture. Vaccines can stimulate the fish immune system to develop specific and long-lasting protection against pathogens without contributing to antimicrobial resistance or leaving harmful residues in aquatic products. Even though vaccination has been widely adopted in finfish aquaculture worldwide against vibriosis, furunculosis, streptococcosis, infectious pancreatic necrosis and infectious hematopoietic necrosis, no fish vaccines are commercially available in India.

5. **Probiotics and microbiome management:** The concept of applying probiotics (live beneficial microorganisms) and microbiome management as a disease management strategy in aquaculture is based on their beneficial activities in improving water quality and fish health, altering the microbial community in the aquatic environment and within the GI tract, and promoting non-specific immune response against pathogens (Li et al. 2019). The mode of action of probiotics includes competitive exclusion by colonising in the gut and thus preventing pathogenic bacterial colonisation by producing specific inhibitory compounds, making resources unavailable to pathogens, creating substances that inhibit the quorum sensing system, and increase the host immunity or digestibility of feed by producing digestive enzymes, improving the net availability of critical nutrients, and the host immunity, etc (Rohani et al. 2022).

6. **Surveillance and diagnostics:** Timely and precise disease surveillance, routine health and water quality monitoring, and accurate diagnostics are another principal component of IDM in aquaculture, enabling the implementation of appropriate control measures, minimizing economic losses, preventing the spread of pathogens and ensuring biosecurity in farming systems (WOAH, 2024). Further, any mortality rate surpassing 0.3% per day should be investigated to

identify the aetiology. A daily mortality rate >1.5% should be considered an epizootic, requiring urgent response.

7. **Responsible antimicrobial use:** Antibiotic treatments have been widely used against bacterial illnesses in aquaculture for several years (Gram et al. 2001). The increasing threat of infectious diseases in intensive and semi-intensive aquaculture practices require an inevitable therapeutic application of antibiotics. However, selective pressures from the usage of antibiotics fuel antimicrobial resistance (AMR). Over the past ten years, the availability of evidence around antimicrobial resistance in aquaculture environments has broadened (Caputo et al. 2023). The World Organisation for Animal Health (2023) and the FAO (2021) highlight that responsible use of antimicrobials in humans, terrestrial and aquatic animals is the principal criterion for AMR preventive measures, thus forming a key component in IDM in aquaculture. Antibiotics should be used only in closed aquaculture facilities, when a bacterial infection has been accurately diagnosed through clinical examination and laboratory testing. Further, use of antimicrobials as a routine prophylactic measure or as a substitute for poor husbandry practices is not recommended. Oxytetracycline, florfenicol, oxolinic acid, sulfadimethoxine/ormetoprim, and enrofloxacin are a few authorised antimicrobials for use in aquaculture (USFDA 2023). Responsible antimicrobial use also includes selecting approved antibiotics by authorised aquaculture professionals based on pathogen identification and antimicrobial susceptibility testing, administering the correct dose for the recommended duration, and strictly observing withdrawal periods before harvest to ensure food safety, etc. Further, following good farming practices, including biosecurity, vaccination, optimal nutrition, water quality management, and regular health surveillance, is required to reduce disease incidence and the need for antimicrobial treatments. Further, proper use of alternatives such as probiotics, prebiotics, and immunostimulants is also required to support disease prevention and reduce antibiotic dependence.

Conclusion

Aquaculture is an indispensable component of the global food production sector.

However, intensified farming practices have increased the occurrence of several diseases, posing major constraints to the sustainability of the sector. Disease outbreaks in aquaculture also threaten biodiversity, ecosystem health, international trade, and consumer safety. Therefore, effective disease management is a central strategy to achieve sustainable aquaculture development. Since aquaculture diseases happen as a result of an imbalance among the host, pathogen, and environment rather than the pathogens alone, an integrated disease management targeting all these three components are necessary. Unlike conventional methodologies that depend on drugs, IDM uses multiple strategies, including biosecurity, water quality management, routine surveillance and early diagnosis, balanced nutrition, immunostimulants, vaccination, probiotics, microbiome management, responsible antimicrobial use, and good husbandry practices to reduce disease risks while reducing environmental impacts. The adoption of the 'One Health' approach, which identifies the interrelation of aquatic environments, animal health, and human health, can further strengthen integrated disease management practices and transform aquaculture into a robust, health-promoting, nutritious food production system. Further, selective breeding for disease-resistant stocks and climate-resilient farming practices can also play a major role in addressing the aquatic disease challenges in future. Briefly, sustainable disease management in aquaculture requires a paradigm shift from reactive treatment to proactive prevention. By merging good aquaculture practices with proper nutrition, early diagnosis, biosecurity, vaccination, and responsible antimicrobial use, IDM offers a holistic pathway toward the long-term sustainability of the global aquaculture industry.

Socio-Economic Analysis in Mariculture Systems

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Mariculture, the farming of marine organisms in coastal and offshore waters, has emerged as one of the most promising sectors for augmenting fish production, enhancing livelihood opportunities, and supporting the Blue Economy in India. Over the past two decades, ICAR-Central Marine Fisheries Research Institute (CMFRI) has developed and disseminated several mariculture technologies, including sea cage farming, mussel farming, oyster farming, seaweed cultivation, Integrated Multi-Trophic Aquaculture (IMTA), and coastal pond farming. These technologies have demonstrated significant biological and technical success. However, their large-scale adoption depends not only on technical feasibility but also on their socio-economic viability.

Socio-economic analysis provides a systematic framework for understanding the economic performance, social acceptability, institutional support, environmental sustainability, and livelihood impacts of mariculture enterprises. It helps policymakers, researchers, development agencies, and entrepreneurs assess whether mariculture technologies are economically profitable, socially inclusive, environmentally sustainable, and capable of improving the quality of life of coastal communities.

Objectives of Socio-Economic Analysis

The major objectives are:

- To assess the profitability and financial viability of mariculture enterprises.
- To evaluate employment generation and livelihood enhancement.
- To examine technology adoption and factors influencing adoption.
- To analyse market opportunities and value chains.
- To evaluate environmental and social sustainability.
- To identify institutional, policy, and financial constraints.

Components of Socio-Economic Analysis

A comprehensive socio-economic evaluation generally includes the following components.

1. Socio-demographic Analysis

This examines the characteristics of mariculture farmers and households, including:

- Age and education
- Family size
- Occupation
- Fishing and farming experience
- Land and water ownership
- Income sources
- Gender participation
- Membership in Self-Help Groups (SHGs), cooperatives, and Farmer Producer Organisations (FPOs)

These variables influence technology adoption, investment decisions, and enterprise performance.

2. Economic Analysis

Economic analysis determines whether a mariculture enterprise is financially profitable and sustainable.

The major economic indicators include:

- Capital investment
- Fixed and variable costs
- Gross revenue
- Net income
- Benefit-Cost Ratio (BCR)
- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Payback period
- Break-even analysis

These indicators help compare different mariculture technologies and identify the most profitable production systems.

3. Employment and Livelihood Analysis

Mariculture contributes substantially to employment generation in coastal areas through:

- Hatchery operations
- Nursery management
- Cage and raft fabrication
- Seed transportation
- Feed supply
- Farm management
- Harvesting
- Processing
- Marketing

Both direct and indirect employment opportunities are considered during socio-economic evaluation.

4. Adoption Behaviour

Technology adoption depends upon:

- Profitability
- Risk perception
- Availability of quality seed and feed
- Technical knowledge
- Institutional support
- Credit availability
- Market access
- Government incentives

Understanding these factors helps improve extension strategies.

5. Social Impact Assessment

Socio-economic studies also evaluate:

- Poverty reduction
- Women's empowerment
- Youth employment
- Community participation
- Social equity
- Livelihood diversification
- Reduction in migration

These impacts determine the long-term sustainability of mariculture interventions.

Methodology for Socio-Economic Studies

Socio-economic studies generally follow the following methodology.

Primary Data Collection

Data are collected using:

- Structured questionnaires
- Household surveys
- Farm surveys
- Focus Group Discussions (FGDs)
- Key Informant Interviews
- Participatory Rural Appraisal (PRA)
- Case studies

Secondary Data

Secondary information is obtained from:

- ICAR-CMFRI reports
- Department of Fisheries
- NFDB
- State Fisheries Departments
- Scientific publications

Analytical Tools

Common analytical methods include:

- Cost-return analysis
- Enterprise budgeting
- Partial budgeting
- Discounted cash flow analysis
- Livelihood analysis
- Value chain analysis
- SWOT analysis
- Regression analysis
- Sustainability indicators
- Multi-Criteria Decision Analysis (MCDA)

ICAR-CMFRI Studies on Mariculture

ICAR-CMFRI has undertaken extensive socio-economic evaluations covering different mariculture systems across the Indian coastline. These studies demonstrate that successful mariculture depends on a combination of technology, economics, institutions, and market access.

Sea Cage Farming

Sea cage farming is one of CMFRI's flagship technologies involving species such as Asian Seabass, cobia, Indian pompano, silver pompano and orange-spotted grouper.

Socio-economic studies have shown that:

- Sea cage farming generates substantially higher income than traditional capture fisheries.
- Cage farming creates year-round employment.
- Farmer groups and SHGs perform better than individual farmers due to shared investment and labour.
- Feed cost remains the single largest operational expenditure.
- Reliable seed supply and technical support are critical for profitability.
- Market demand for premium marine fish remains strong, particularly in urban centres.

Economic analyses indicate that well-managed commercial cage farms can achieve attractive benefit-cost ratios, especially when optimal stocking density and efficient feed management are maintained.

Mussel Farming

CMFRI pioneered scientific mussel farming in India and demonstrated its commercial feasibility in Kerala.

Socio-economic studies revealed that:

- Mussel farming requires relatively low investment.
- It is highly suitable for women's Self-Help Groups.
- Production cycles are short.
- Income generation is rapid.
- Women gained financial independence and increased participation in household decision-making.

Major constraints identified include:

- Seasonal market fluctuations

- Lack of cold storage
- Limited value addition
- Transportation bottlenecks

Nevertheless, mussel farming remains one of the most successful livelihood interventions promoted by CMFRI.

Integrated Multi-Trophic Aquaculture (IMTA)

CMFRI has promoted IMTA involving finfish, seaweeds, and filter feeders.

Socio-economic studies indicate that IMTA:

- Enhances overall farm productivity.
- Diversifies income sources.
- Reduces environmental impacts.
- Improves nutrient recycling.
- Increases resilience against market fluctuations.

Although initial investment and technical complexity are relatively higher, IMTA offers significant long-term sustainability benefits.

Major Constraints Identified by CMFRI Studies

The important constraints affecting adoption of mariculture include:

- High initial investment for cage farming.
- Limited institutional credit.
- Irregular supply of quality seed and feed.
- Marketing inefficiencies.
- Price fluctuations.
- Disease risks.
- Extreme weather events.
- Limited insurance coverage.
- Regulatory issues related to site allocation.
- Inadequate post-harvest infrastructure.

Addressing these constraints is essential for scaling up mariculture in India.

Policy Implications

Based on socio-economic evidence generated by CMFRI, the following policy interventions are recommended:

- Strengthen hatchery networks for quality seed production.
- Expand institutional credit and insurance coverage.
- Promote cluster-based mariculture development.
- Encourage Farmer Producer Organisations and cooperatives.
- Improve cold chain and marketing infrastructure.
- Develop value-added marine products.
- Strengthen extension and capacity-building programmes.
- Promote women and youth entrepreneurship.
- Integrate mariculture into Blue Economy and coastal livelihood programmes.
- Develop digital advisory and decision-support systems.

Conclusion

Socio-economic analysis is indispensable for the sustainable development of mariculture. While biological productivity determines technical success, socio-economic viability determines whether farmers adopt and continue mariculture enterprises. ICAR-CMFRI's research demonstrates that scientifically developed mariculture technologies are capable of generating substantial income, employment, and livelihood opportunities when supported by appropriate institutions, market linkages, extension services, and policy interventions.

Future development should focus on sustainable intensification, inclusive growth, climate resilience, and integrated coastal resource management. Strengthening socio-economic research alongside technological innovation will be critical for achieving India's Blue Economy goals and ensuring that mariculture becomes a viable livelihood option for coastal communities.

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