Cage Culture Systems & Management

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Introduction

India possesses extensive marine fisheries resources, including an 8,118 km long coastline, a territorial sea spanning 193,834 km^2 (extending 12 nautical miles or 22.2 km from the shoreline), and a marine fisher population of approximately 4.0 million residing in 3,432 marine fishing villages across 66 coastal districts in 9 maritime states and 2 Union Territories, in addition to the Island Territories of Andaman & Nicobar and Lakshadweep. The infrastructure available consists of 6 major fishing harbours, 40 minor fishing harbours, and 1,537 marine fish landing centres. The relatively shallow inshore waters along the extensive coastline of the mainland and island territories provide potential for sea cage farming, particularly in sheltered areas such as bays, lagoons, and semi-exposed and exposed coasts with minimal wave action. The existing marine infrastructure and fisher population serve as complementary resources. Cage culture, a proven method for cultivating marine finfish, has been practiced for many years in countries like Australia, Norway, Chile, and several Asian nations since the 1950s. The growing demand for cultivating various marine finfish, driven by their high consumption value, has led to a global increase in marine aquaculture demand. In India, sea cage farming was initiated by CMFRI with support from the Ministry of Agriculture & Farmers Welfare and the National Fisheries Development Board (NFDB). It is gaining traction as a commercial seafood production system in the country. Numerous R&D programs in cage culture, along with demonstrations and participatory cage farming, have led to the development of an economically viable farming method, popularizing the technology.

Site selection

Effective cage culture depends on careful site selection, ensuring the chosen location is designed and operated to maintain optimal water quality and minimize stress conditions. Before finalizing a site for cage culture, it is essential to consider water and sediment quality, as well as gather relevant biological and natural distribution information for the targeted species. The various factors involved in site selection are as follows:

Physical factors

Physical criteria are crucial considerations in cage culture systems, including parameters such as current movements, turbidity, and water temperature. Turbidity, increased by heavy monsoons and freshwater runoff, makes water unsuitable for cage culture during such periods. The optimal water temperature depends on the species being cultivated; most tropical species prefer a range of 27–31°C, while temperate species thrive in temperatures between 20–28°C. In the Asian region, annual temperature variations range from 20–35°C in tropical countries to 2–29°C in temperate countries. Selecting an appropriate site for cage culture requires a thorough evaluation of these physical factors to ensure the success and well-being of the cultivated species.

Chemical factors

The assessment of water quality in cage systems is heavily dependent on the chemical parameters of marine waters used in cage culture. Key chemical factors in this context include salinity, dissolved oxygen, pH, ammonia, nitrates, and nitrites. Different species of fish have varying oxygen consumption rates; for example, pelagic fish like snapper and seabass require more oxygen than demersal species like grouper. Tropical species typically thrive in optimal salinity similar to normal-strength seawater and show intolerance to low salinities, such as 10–15 ppt. Therefore, a suitable cage culture site should maintain salinities between 15–30 ppt to allow flexibility in changing cultured species based on market demands. The preferable pH range for most marine species is between 7.0 and 8.5. Ammonia-nitrogen levels in the water should be kept below 0.5 ppm, with measurements recommended during neap tide when the water current is slow. Nitrite levels in a suitable cage culture area should not exceed 4 mg/liter, while nitrate levels should remain below 200 mg/liter. Although toxic blooms from a few tropical marine species of Cyanobacteria (e.g., Lyngba and Oscillatoria, Moore, 1982) are uncommon, various marine algae groups, including diatoms, cyanobacteria, and dinoflagellates, may form blooms.

Topographical factors

Topographical criteria are crucial for the successful establishment of cage culture. For stationary cages, it is important to select a site where wind velocity stays below 5 knots, while floating cages require wind speeds not exceeding 10 knots. Wave heights should be limited to 0.5 m for stationary cages and 1.0 m for floating ones. Strategic placement away from navigation routes is recommended to minimize the impact of vessel-induced waves. Ensuring sufficient depth beneath the cage is vital for optimal water exchange, preventing oxygen depletion, and mitigating the accumulation of debris and noxious gases from waste decomposition. Ideal bottom conditions should include a firm substrate combining fine gravel, sand, and clay to enhance productivity in cage culture. Additional site selection criteria should consider accessibility to the cages and the ability to relocate them in response to potential threats like algal blooms or low dissolved oxygen events. Fouling tends to occur more rapidly in areas with low current velocities, high temperatures, high turbidity (enriched water), and high salinity. Therefore, an ideal culture site should be near the shore, preferably with a jetty for boat connection to farms, and close to a good road for land transportation.

Cage fabrication

The Central Marine Fisheries Research Institute (CMFRI) has been a pioneer in introducing open sea cage culture in Indian waters. The institute is actively promoting this innovative method at selected locations across all maritime states in collaboration with the fishing community. The refinement of cage design and mooring technology is an ongoing process, driven by the dedicated efforts of CMFRI scientists. Through their persistent work, CMFRI aims to enhance the effectiveness and sustainability of open sea cage culture, contributing to the advancement of marine fisheries in the region.

Design

The low-cost cage developed by CMFRI is constructed using high-quality 1.5" GI pipe (B class). With a diameter of 6 m and a height of 120 cm from base to railings, the cage is designed for durability and strength. All joints are double-welded to ensure extra strength. After fabrication, the structure undergoes a protective treatment, receiving a coat of epoxy primer and two coats of epoxy grey paint to prevent rusting. The meticulous attention to detail in both design and finishing results in a sturdy cage weighing approximately 700-800 kg.

Floatation

A puff or foam-filled High-Density Polyethylene (HDPE) cage is naturally buoyant, allowing it to float on the water surface. In contrast, a metal cage requires additional flotation, which is achieved by using 10 plastic barrels with a capacity of 200 liters each, filled with air. These inflated barrels not only ensure the cage's flotation but also create a stable platform around it. This stable platform provides a secure area where fishermen can stand and safely perform various tasks such as net clearing and replacement. The combination of buoyancy and stability enhances the functionality and safety of the cage system during operational activities in the water.

Advantage of the low cost cage

The design differences between HDPE cages and low-cost cages significantly impact their functionality and cost-effectiveness. The HDPE cage floats on the water surface, positioning the outer net at water level, which creates a potential entry point for predatory fishes between the outer and inner nets. In contrast, the low-cost cage has its outer net positioned 60 cm above the water level, preventing predatory fishes from entering the middle space.

Structurally, the HDPE cage can sink if more than three people climb on the side frame, while the low-cost cage can safely support the weight of 10-15 people on its platform. The cost distinction is also substantial. The HDPE cage, including netting and mooring, costs over Rs. 6,00,000 and requires multiple crops (4 to 5) to recover the input cost. In contrast, the low-cost cage, with all components included, costs only Rs. 1,50,000, allowing for quicker recovery of investment, potentially in a single crop.

Despite these differences, both cages have similar performance area-wise, with a diameter and net depth of 6 meters each. The advantages of the low-cost cage lie in its affordability, buoyancy, and potential for faster cost recovery.

Disadvantages

In contrast to HDPE cages, metal cages experience greater wind action because they float on barrels. Therefore, without robust mooring, floating in open sea conditions during the monsoon can be challenging. Apart from this, the performance of metal cages surpasses that of HDPE cages.

The sea cage frame is designed with flotation properties and consists of two collar rings and a middle ring functioning as a catwalk in between them (Fig. 1). When using HDPE, the pipe ends are fused together through a plastic fusion welding process. The two flotation collar rings can be filled with either polyurethane foam (PUF) or thermocol. Various support pipes, brackets, and T-joints secure the two collar rings, the middle catwalk ring, and the handrail ring in their positions. The handrail pipe, which is devoid of PUF, incorporates galvanized steel brackets for corrosion resistance, matching the pipe diameter. The handrail's maximum height should be around 100 cm, shorter than the shortest person. Essential for operational and maintenance activities such as feeding, cleaning, monitoring, and grading, the service systems (catwalk, handrail, etc.) are integral components. The catwalk's minimum width is approximately 60 cm. Brackets and base supports, along with vertical and diagonal supports, not only connect the collar rings, catwalk ring, and handrail but also enhance the overall stability and sturdiness of the frame structure.

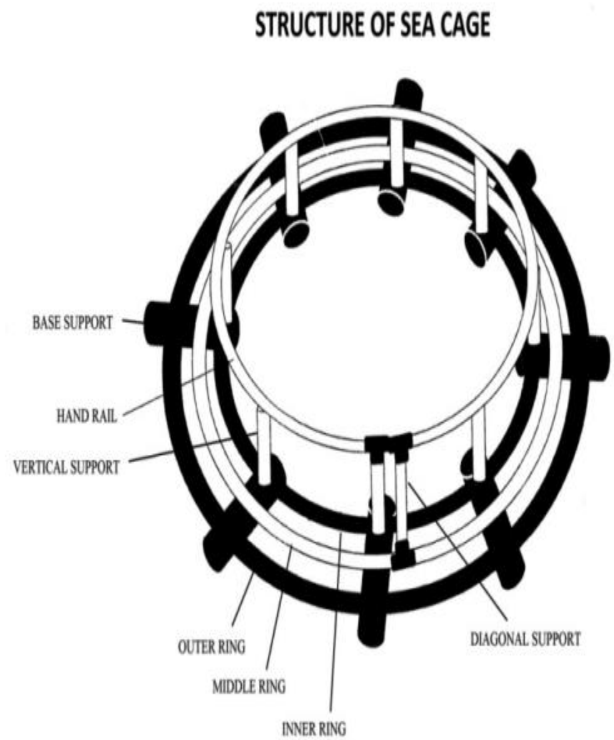

Fig. 1. Plan View of HDPE Sea Cage Frame – Collar Rings and Handrail

To maintain the shape and structure of the net bags (Fig. 2), the ballast pipe serves as another necessary support system. Typically, a 1.5-inch (38 mm) diameter HDPE ballast pipe, featuring holes at regular intervals for water flow, is utilized. Metal lines are inserted inside the pipe to increase weight, ensuring that the ballast remains submerged in water.

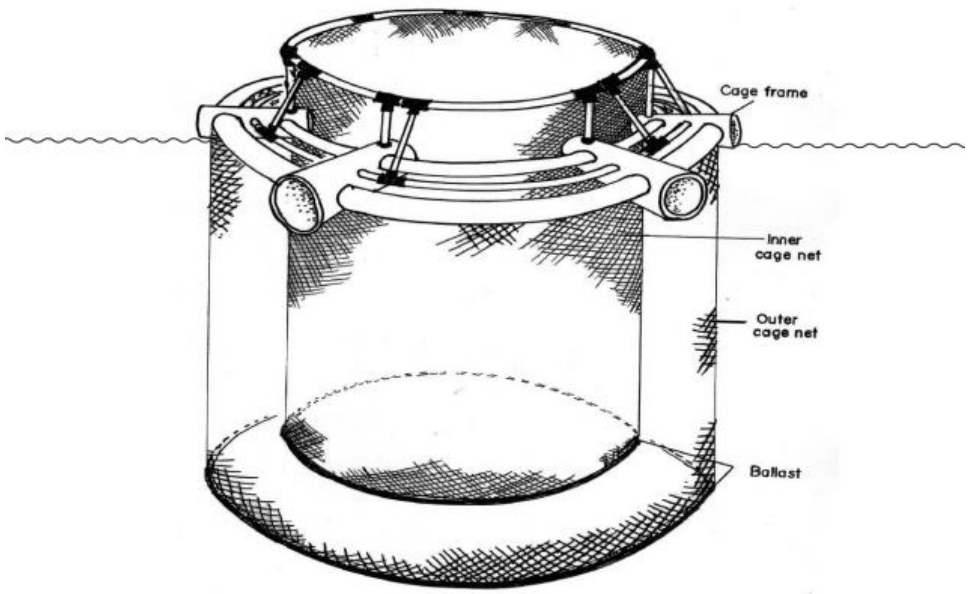

Fig. 2. Layout of HDPE Sea Cage – Frame and Net Cages (inner & outer)

Mooring system

Mooring system/assembly holds the cage in desired position and at desired depth using mooring lines, chains and anchors. Individual cages can be moored using single-point mooring system (Fig 3).

Single-point Mooring System components required for 10 cages:

(a) Anchors (embedment type) / Gabion Boxes – 100 kg each, 10 nos.

(b) D-Shackles – for 12.5 tonne SWL (Safe Working Load), 3 x 10 = 30 nos.

(c) Mooring Chains – 38-42 mm thick, length four times the depth at site, 10 nos.

(d) Buoys – 200 litre buoyancy, 4 x 10 = 40 nos.

(e) Anchor Marker Line – poly-steel rope of 36 mm diameter and 37 m length.

(f) Mooring Rope – poly-steel rope of 48 mm diameter, 3-4 strands, and 100 m length. Also splicing, steel thimble and oval ring of 22 mm at one end, 10 nos.

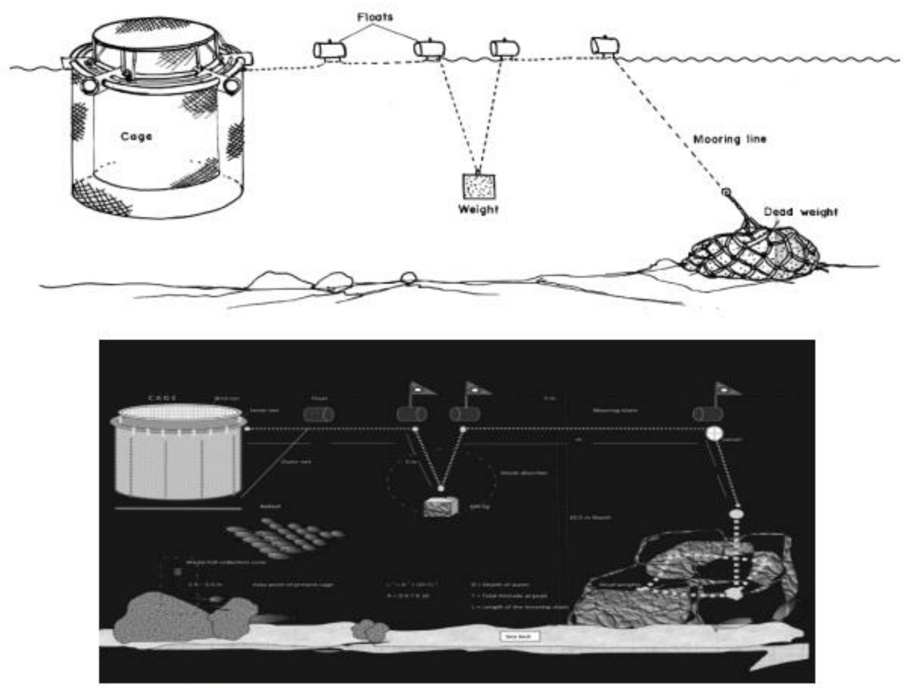

Fig. 3. Single-point mooring system for Sea Cage: Schematic diagramme (above) and Artist's view (below)

Netting Materials

Nylon (PA) and Polyethylene are the most important and widely used synthetic fibers, especially in the fabrication of fishing gear. The mesh size for net cages must be chosen based on the species of fish being farmed and to ensure optimal water exchange. Proper water flow is crucial as it enhances water quality, reduces stress, improves feed conversion, and allows for holding more fish. Net cages should match the dimensions of the cage frame and the depth of water at the site, and they must be securely fastened to the cage frame. For sea cage farming, three types of nets are essential:

(i) Outer Predator Net

Due to the turbulent sea conditions and the presence of carnivorous animals, it is important to use a suitable outer net cage to prevent predators from entering the sea cage culture. A braided UV-treated HDPE netting with a thickness of 3 mm and a mesh size of 80 mm is recommended for its strength, durability, and cost-effectiveness. The suggested dimensions for the predator net cage are a diameter of 7 m and a depth of 5 m, with the entire structure submerged.

(ii) Inner Fish Rearing Net

For constructing the inner net cage for fish rearing or grow-out, twisted HDPE netting with a thickness of 0.75-1.5 mm and a mesh size of 16 to 40 mm, depending on the size of the cultivable species, is appropriate. The recommended dimensions for the fish rearing net cage are a 6 m diameter and 5 m depth, with 4.0 m submerged and the remaining 1.0 m extending up to the handrail, resulting in a total volume of 113 cubic meters.

(iii) Bird Net

A protective bird net is necessary to prevent predatory birds from preying on the fish. The ideal material for the bird net is HDPE twisted and UV-treated twine with a thickness of 1.25 mm and a mesh size between 60 and 80 mm. High-Density Polyethylene knotted netting is preferred for constructing net cages, and the mesh size is determined by the size of the individual farmed fish. Three sets of net cages, each with different mesh sizes (18 mm, 25 mm, and 40 mm), are required for the farming operation. To maintain the cylindrical shape of the net cages, it is important to use appropriate ballasts. Concrete blocks tied at suitable intervals or an HDPE pipe with a diameter of 1.5 inches (38 mm) filled with MS chain or a 10 mm thick wire rope can be used for this purpose.

Nets suitable for open sea cage culture

Selecting the appropriate mesh size for fish nets in cage fabrication is crucial for factors such as the species being farmed, water exchange requirements, and predator prevention. Aeration is essential for improving water quality, reducing stress, enhancing feed conversion, and supporting a higher fish population in the cages, especially under open sea conditions.

For predator prevention in open sea cage culture, it is important to use a suitable net. A braided UV-treated HDPE net with a thickness of 3 mm and a mesh size of 80 mm is recommended due to its strength, durability, and cost-effectiveness. This netting effectively withstands turbulent sea conditions and provides protection against cannibalistic animals.

The cage diameter can be adjusted based on specific needs, ranging from 6 m to 8 m, with a depth of 5-7 m for ease of handling. Stability in the water is ensured by mounting the cages to floating circular frames using ropes and rings.

The inner cage, which directly contains the cultivable species, can be constructed from twisted HDPE with a thickness between 0.75 mm and 1.5 mm, depending on the size of the species. The mesh size for the inner cage typically varies from 16 mm to 28 mm, with recommendations for sea bass being between 1.25 mm/26 mm and 1.5 mm/30 mm. Periodic cleaning of the inner cage is necessary to maintain its durability.

To prevent predatory birds, protective nets made from HDPE twisted and UV-treated material with a thickness of 1.25 mm and a mesh size ranging from 60 mm to 80 mm are recommended. These nets protect the fish population from aerial predators and contribute to the overall success of open sea cage culture.

Selection of fish species

Cobia (*Rachycentron canadum*), Silver Pompano (*Trachinotus blochii*), Seabass (*Lates calcarifer*), Snappers (*Lutjanus* sp.), Groupers (*Epinephelus* sp.), and Spiny Lobster (*Panulirus* sp.) are all highly suitable for sea cage farming. When selecting a species for cultivation in cages, several key factors should be considered:

To manage the high production costs associated with net cage farming, it is advisable to choose species with high market value. It is essential to select species that are hardy, can tolerate confined and crowded conditions, and are resilient during handling for net cage maintenance. Net cage stocking densities significantly exceed those of pond culture, with marine carnivore fish culture in ponds accommodating about 5 fish per square meter compared to 40 fish per square meter in net cages. The frequent competition for food in the crowded environment of net cages increases physical contact and stress among fish. Species such as groupers and seabass are well-suited to these crowded conditions.

Within the net cage environment, where small fish serve as the primary food source, it is important for selected species, especially carnivorous ones, to be adaptable to alternative food sources. Although dry feed is commonly used, it often results in significant feed loss. A practical approach is to use feeding trays suspended in the net cage to catch falling pellets, a technique borrowed from shrimp net cage culture. Additionally, spiny lobsters and rabbitfish *(Siganus canaliculatus*) can graze on algae growing on the net cage sides, which helps control bio-fouling and provides a portion of their diet.

The source of seed for cultivation, typically fry or fingerlings, can be either wild-caught or hatchery-bred. Wild-caught seeds are often more robust and hardy due to natural pre-selection but come with the challenge of being seasonal and unpredictable. Hatchery-bred seeds offer a more reliable and scheduled supply, depending on whether the parent stocks were wild-caught or farm-raised.

Although many species are cultured globally, species such as *Lates calcarifer*, *Epinephelus* spp., *Trachinotus* sp., *Rachycentron* sp., *Lutjanus* spp., and *Acanthopagrus* spp. have proven particularly suitable for cage farming in India and are currently being successfully farmed in various coastal states.

The success of grow-out culture in cages largely depends on the quality of fish seed. To prevent escapes, it is crucial to stock seeds of uniform size that are compatible with the mesh size of the fish net cage. This practice not only facilitates the selection of appropriate feed sizes but also minimizes feed wastage and reduces cannibalism. It is vital that the seeds chosen are healthy and free from diseases and deformities.

In India, the main challenge to expanding sea cage farming is the scarcity of fish seeds. Currently, only a few hatcheries produce seeds for Cobia, Pompano, Seabass, and Groupers. In addition to these species, seeds from wild-caught fishes like Mullets, Snappers, and Milkfish can also be used for cage farming. To meet the growing demand from farmers, there must be an immediate focus on either increasing commercial hatchery production or exploring seed importation options until self-sufficiency in seed production is achieved. Culture details of some cultivable species done by CMFRI

Species	Stocking Size (Length/ Weight)	Stocking Density (Nos./ m 3)	Production per Cage (kg)
Cobia	15 cm/ 35 g	8-10	2400 kg/ 7 months
Pompano	10 cm/ 35 g 3	0-40	1800 kg/ 8 months
Seabass	10 cm/ 30 g	30-40	2000 kg/ 8 months
Grouper	15 cm/ 40 g	15-20	2000 kg/ 7 months

Fish Nutrition

The fundamental principles of any feed material are based on five main constituents: (i) Protein, (ii) Carbohydrate, (iii) Fat, (iv) Minerals, and (v) Vitamins. Proteins are essential for the growth of animals, and a deficiency in protein can lead to growth retardation. Marine fishes, in particular, require a higher protein content in their feed, ranging from 35% to 40%, for optimal growth. It is also important to adjust the feed pellet size as the fish grow. Initially, the standard feeding rate for juvenile fish is 10% of their body weight, which should be gradually reduced to 3% as they mature. A feed with a Feed Conversion Ratio (FCR) of 1:2 is recommended for efficient growth. To avoid wastage and environmental pollution, it is essential to adhere to the recommended feeding ration, as overfeeding can be harmful. In aquaculture, it is common to feed carnivorous fish with low-value trash fish, but this practice is both economically inefficient and environmentally unsustainable, as it contributes to pollution. Under normal farming conditions, the Feed Conversion Ratios (TFCR) for marine carnivorous fish typically range from 2:1 to 4:1.

Feeding

Feeding rates and frequencies are crucial for fish growth. Small larval fish and fry require frequent feeding with a high-protein diet, often in excess. However, as the fish grow, the feeding rates and frequencies need to be reduced. Given that feeding is a labor-intensive task, the feeding schedule must also be economically viable. Generally, increasing feeding frequencies leads to better growth and feed conversion.

The timing of fish feedings is affected by several factors, including the time of day, season, water temperature, dissolved oxygen levels, and other water quality variables. These factors must be considered when creating a feeding regimen to balance fish health, growth, and economic efficiency.

Feeds can deteriorate during storage, which decreases their nutritive value, palatability, and appearance. To maintain optimal quality, feeds should be kept in dry, ventilated warehouses away from direct sunlight and at a stable temperature. Feeds should ideally be used within two months of manufacture and inspected regularly. Extended storage can lead to problems like fungal growth, vitamin degradation, and fat rancidity. Additionally, minimizing handling is important to avoid damaging feed bags and turning pellets into powder, which fish tend to avoid. Effective pest control measures are also necessary to prevent contamination from rats and cockroaches. While proper feed storage is relatively simple, maintaining high quality remains essential.

Cage Management

In Sea Cage management, optimizing production at the lowest possible cost is essential. The farm operator's skill and efficiency are vital for effective management, which includes tasks such as adjusting feeding rates, managing stocking densities, minimizing losses from diseases and predators, monitoring environmental conditions, and ensuring overall technical efficiency. Regular inspections of the cage frame and mooring are necessary, with any required maintenance and repairs being performed promptly. Bio-fouling, which obstructs the net cage mesh and diminishes water exchange, can cause low oxygen levels and waste buildup, ultimately leading to fish mortality. Therefore, it is crucial to brush the net cage mesh on a regular basis.

Harvesting

To achieve the highest returns, harvesting should be aligned with market demand. Adopting a partial harvesting approach, where larger fish are collected first, helps to prevent market gluts and subsequent declines in sale prices. Accurate and detailed site-specific harvest records must be maintained. Large-scale sea cage farming requires a well-conceived postharvest and marketing strategy. Essential facilities for production centers include proper harvesting gear, equipment for icing, holding, and storing fish, live-fish transport capabilities, and links to post-harvest processing centers and market distribution networks.

Carrying capacity

When selecting a site for fish farming, one of the most critical factors to evaluate is the site's carrying capacity, which denotes the maximum production level it can sustain. In intensive cage fish farming, the waste generated can alter the characteristics of the water body, affecting both abiotic and biotic factors. On the other hand, less intensive methods might cause excessive algae growth, which can reduce overall productivity and impact the venture's profitability and viability. Thus, it is essential to conduct a precise assessment of sustainable production levels for the site before beginning fish culture. Carrying capacity is assessed through two main factors: loading, which refers to the weight of fish per unit of water flow, and density, which is the weight of fish per unit area of the water body. Understanding and managing these factors are crucial for ensuring responsible and sustainable practices in cage fish farming.

Environmental impact

One of the negative aspects of the cage culture system is the release of waste, including uneaten feed, feces, and other debris, into the aquatic environment. This waste can accumulate beneath the cages, potentially reducing dissolved oxygen levels, and is particularly likely to settle on the sea bed in sheltered inshore sites. To address this problem, it is recommended to avoid continuous farming at the same sheltered site for extended periods and to switch sites after several crops. Alternatively, semi-exposed or exposed sites with effective tidal flushing should be chosen to prevent waste accumulation at the cage bottom. Adequate spacing between cages and farms is also important for controlling diseases. The misuse of antibiotics, which may be released into the environment, can lead to the emergence of antibiotic-resistant bacteria. Furthermore, cage culture can pose risks such as disease introduction, parasite transmission, and changes in aquatic flora and fauna. Thus, considering the environmental carrying capacity based on site characteristics is crucial for successful sea cage farming.