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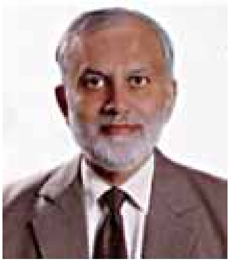

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FOREWORD

Indian marine fisheries have reached a record production of 4 million tonnes during 2012 indicating the resilience. Government of India and all state governments have very good policies and governance mechanism for managing the Indian marine fisheries in spite of several social and economic constraints. With the projected increase of Indian population to about 1.63 billion by 2050 in which younger generation comprises more proportion, the need for better nutritional requirement and protein content is the national priority. In this endeavour ICAR is taking forward the second green revolution to meet the projected demand of food grains, milk, meat, fisheries *etc.* In this aspect fisheries play a vital role. With all our efforts for better management of marine fisheries, the scope for enhancement of fish production is meagre. It is expected to reach 6 million tonnes by 2050 *i.e.*, about 1% cumulative increase. Presently, the Indian marine fisheries research is focusing on enhancing production rather than confining to conservation and sustainability research. In this endeavour CMFRI has taken up suitable research programmes like chlorophyll based marine fisheries assessment, GIS based marine fisheries management etc during the XIIth plan.

In the quest for enhancing the marine fish production, the area that India has not so far tapped is the mariculture, which has a vast potential. The increased demand for high valued marine fish in the past 10 years has made CMFRI to start serious and systematic research in Mariculture that lead to the large scale demonstration of cage culture along both the coasts covering most of the maritime states of India during 2007-12. This has addressed several problems like design, mooring, locations, species, seed, feed, policy and social acceptance. Now the open sea cage culture is a recognised scheme of NFDB/MOA eligible for 40% subsidy. In a short period of 5 years CMFRI is able to achieve the excellence in cage culture R&D. Globally there are very few books with all relevant information on sea cage culture although several countries are practising commercial sea cage culture.

I am very happy to note that CMFRI is bringing out a comprehensive book on cage culture covering all aspects with their own experience and expertise. On behalf of ICAR, I compliment CMFRI for their contributions in cage culture and wish the Institute great success in future in all aspects of research that leads to the enhancement of production of marine fish in India.

April 2013

Dr. S. AYYAPPAN

PREFACE

The cage culture in India was introduced by CMFRI during 2007 with the support of Department of Animal Husbandry, Dairying and Fisheries (DAHD&F), Ministry of Agriculture, Government of India. Though cage culture was in vogue in India since ancient times, it was in a primitive stage, lacking orientation. With the background of many advanced countries offering only the structures of the cages but not suitable technology to different locations in India, we initiated the open sea cage culture from Visakhapatnam in 2007. Starting from scratch, we were able to reach greater heights in terms of design, mooring, combating fouling, exchange of nets in sea and related aspects, mainly from the lessons that we learnt from the failure of the first cage. The technology thus developed was tested professionally at many locations along the Indian coast with all possible species, which helped to improve the design and economic viability of the cages. In this process, six generations of cages were developed, starting from high cost 15 m dia HDPE cages to 3 m dia low cost epoxy coated GI cages, suitable for establishing open sea cage farms in bays. In this historical achievement Team CMFRI contributed their mite, without which, we could not have reached this R&D level in open sea cage culture.

The demand for marine fish as a favourite food in Indian homes picked up during the last 10-15 years mainly due to promoting of the marine fish as health food containing the valuable omega-3 fatty acids. As a result, the demand for fish during the last decade has increased so much that the high valued fish like seer fish, pomfrets, seabass, red snappers, groupers, breams and mullets have soared, which ultimately affected their availability in the domestic markets. The entire landing of these "high valued fish" is a mere two lakh tonnes out of the 40 lakh tonnes of marine fish landings. This indicates the need to increase the production of these high valued marine fish, which at present mainly possible through open sea mariculture. Besides, to meet the increased requirement of fish of the population by 2050, the projection is to reach 4 million tonnes of fish production through mariculture. Thus CMFRI's effort in this direction is a good beginning and we hope to achieve the target in association with developmental agencies like NFDB, who are already extending good support.

There are very few books on cage culture from different countries. However, there is no single book that describes the technology comprehensively including biology, particularly relevant to India, the leading aquaculture country. We hope this book will address these issues and also fulfil the requirement of the researchers, students, entrepreneurs and policy makers.

I gratefully acknowledge the enthusiastic participation by several scientists, technical staff and all others including administrative and audit staff of CMFRI to make this programme a great R&D success.

Kochi - 18
April 2013

Dr. G. SYDA RAO
Director CMFRI

Marine cage farm at Mandapam, Tamilnadu (Gulf of Mannar)

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Installation of cage at Munambam, Kerala

Chapter 01

Introduction

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Marine cage farm at Karwar, Karnataka

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01

Introduction

Aquaculture aims at producing aquatic organisms of nutritional, ornamental, therapeutic and industrial value. Despite high economic risks, the global aquaculture industry continues to attract improved production capacity, new entrepreneurs, and new investors. This is a clear sign of the profitability of the industry, as high returns are the market's signal to attract more investors and increase production. The strong underlying growth in the global demand for seafood primarily benefits aquaculture, as capture fisheries production cannot grow much above current levels. The rapid developments in the technologies on which aquaculture depend, leading to an almost continuous increase in productivity and quality over time also attracts the entrepreneurs towards this sector. However, as new technologies are adopted, the cyclical and risky nature of the industry will also continue.

Fishing industry is facing a major crisis with fish stocks declining all over the world. The list of depleting fish stocks is getting longer and longer every year. According to the FAO, about 70% of the world's major species and eleven of the 15 major fishing areas are in the process of disappearing. This decline in the world fish supply is the result of over fishing, indiscriminate fishing methods and degradation of coastal and inland ecosystems due to various reasons (FAO, 2010). Fishing and aquaculture supplied the world-wide market with 148 million tonnes of fish in 2010 which rose to 154 million tonnes in 2011. With sustained growth in fish production and improved distribution channels, world fish food supply has grown dramatically in the last five decades, with an average growth rate of 3.2% per year in the period 1961-2009, outpacing

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Overview

Cage aquaculture involves growing fishes in existing water resources while being enclosed in a net cage which allows free flow of water. It is an aquaculture production system made of a floating frame, net materials and mooring system (with rope, buoy, anchor *etc.*) with a round or square shape floating net to hold and culture large number of fishes and can be installed in reservoir, river, lake or sea. Economically speaking, cage culture is a low impact farming practice with high returns and least carbon emission activity. Farming fish in an existing water body removes one of the biggest constraints of fish farming on land- the need for a constant flow of clean, oxygenated water. Cage farms are positioned to utilise natural currents, which provide the fish with oxygen and other appropriate natural conditions while also removing waste.

Advantages of cage aquaculture

- Many types of water bodies can be used (open sea, brackishwater, estuaries, reservoirs, lakes, rivers *etc.* which otherwise cannot be effectively harvested) for cage culture
- Since no ownership is required it is ideal for poor and landless people
- Fast growth of the stock compared to that in ponds
- 10-12 times higher yields than pond culture for comparable inputs and area
- Monitoring (feeding, sampling, observations *etc.*) are made simple
- Reduced culture period (2-3 crops/ year)
- Prevents loss of stock due to flooding
- No question of seepage and evaporation losses
- No need for water replacement
- Issues of pond excavation and dependence on soil characteristics are not there
- Avoids proximity of agricultural areas hence reduces hazards of pesticide contamination
- Can be conveniently located near urban markets and harbours avoiding the need for fish preservation and transportation

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Site Selection

Site selection is a key factor in any aquaculture operation, affecting both success and sustainability. Site selection is vitally important since it can greatly influence economic viability by determining capital outlay, by affecting running costs, rates of productions and mortality factors. Right choice of site contributes significantly in the success of cage farm also. Cursory site inspection may save money and minimize delay in aquaculture venture but very often it also pays poor dividends. It may cost a lot more in corrective measures. The first thing to do in site selection is to observe the regulations established by the regulatory authorities in terms of any installation on the coastal zone, in order to immediately discard those areas prohibited for aquaculture development (Michael, 1997). Such prohibition may arise due to conflicts with other uses (*eg.* navigation, fisheries, security, tourism, *etc.*) or due to the declaration of some locations as very sensitive areas due to their high ecological value. Before selecting a site for cage culture, environmental and topographical aspects have to be considered. For cage aquaculture the site can be either in open sea (Fig.3.1), estuarine (Fig.3.2) or backwater (Fig.3.3) depending on other favourable physico-chemical criteria considered for site selection.

Fig. 3.1. Open sea

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Chapter 04

Engineering Considerations

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Four meter dia GI cages at Veraval, Gujarat

04

Engineering Considerations

The Indian sea is perhaps the most difficult environment for designing any engineering structures. The monsoons of the country generate great forces on any floating or sea bed mounted structure and storm and cyclonic events also occur randomly. The constant 24 hour per day bending compression and tension of sea mounted structures are optimum conditions for its fatigue. Similarly constant motion in a corrosive fluid is ideal for mechanical wear and corrosion. Repairs and salvages are more difficult and in some cases access may be denied to some structures during a storm. Because of all these reasons the design of an aquaculture cage system is very complex in India and of course is the most difficult task. Hence, it is essential to select ideal construction materials and proper designing, suitable mooring and good management *etc.* in bringing out commercial cage aquaculture in the country which is quite simple and economically feasible.

Cage frame

The design of open sea aquaculture systems is a novel and unique engineering challenge that pushes the limits of structural integrity and economic viability. The system components can be technically simple but as a whole they are complex structures to dynamically represent. From an economical perspective, the commercial fish cage volume needs to be reasonably larger. The mooring systems that keep the cages on station must also be optimized considering both economic and structural integrity criteria. To achieve these long-term goals, engineering methods specific to open sea aquaculture need to be developed and perfected. Ocean currents induce both normal and tangential steady-state drag forces onto system components.

One of the most important things to design a fish cage system is to accurately predict the wave force acting on it. The difficulty of this prediction mainly comes from the complexity of the system and the floatation of the collar. The collar usually being square or round and providing the main buoyancy for the cage system, floats on the water surface makes it hard to decide the hydrodynamic coefficients (Beveridge, 2004).

A gravity fish cage system contains four components *viz.* the float collar system, the cage net system, the sinker system and the mooring system. The float collar system providing buoyancy and the sinker system providing weight, maintain the stable shape of the whole cage system (Olivares, 2003).

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Harvesting of lobsters at Veraval, Gujarat

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Species for Cage Culture

Many species of fish are suitable for cage culture. Picking the fish species that will do well in cages in the particular location is important. There must be a multidisciplinary approach in the selection of a species for cage culture and therefore the species introduced have to be selected under economic and biological limitations. Preliminary market and economic analyses to assess prices, demand, commercial value (present price and its variations) and the existing and potential markets, *etc.* should precede the selection of species for cage culture. The biological limitations that concern the rearing of the species are: availability of seed, faster growth, easy culture adaptation, endemic species, *etc.*

Species selection

For a species to be practical for cage culture, we must know its culture requirements and should be able to provide the water quality it needs and have access to commercial feeds that meet its nutritional requirements. The species proposed for cage culture should be fast growing so that the entire culture period shall be completed in less than 8 months under Indian conditions (monsoon *etc.*). They should fetch a price of above Rs.200 kg^{-1} at farm gate at current prices of 2013. Stocking high of slow growing species should be avoided for economic viability as they require more seed and feed. Before attempting to raise fishes in cages, the producer should carefully analyze potential markets, the production site, water quality, production costs and legal requirements.

Criteria for species selection

- For farming in floating cages, the species selected must have a good demand and high market value; should be hardy, tolerant to crowded conditions and perform well under such conditions; should be able to accept external source of feed (natural *e.g.* trash fish or artificial *e.g.* dry formulations), especially the carnivorous species which have little or no opportunity to find their food supply under confined conditions.
- *Seed availability:* The species selection for cage farming is based on whether seed (fry/fingerlings) are readily available either wild-caught (natural) or hatchery-bred (artificial). Wild-caught seed supply is usually seasonal and unpredictable but are more robust and hardy as they would already have undergone pre-selection by nature. In the case of hatchery-bred seeds, supply is more predictable, and, depending on

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Chapter 06

Cage culture and Sustainable Capture Based Aquaculture

Wild collected seabass at Balasore, Odisha

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Cage culture and Sustainable Capture Based Aquaculture

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The role of aquaculture is ever increasing as a complementary alternative to the outputs from the capture fishery sector or as a supplementary economic activity. Aquaculture is always considered as a potential means of relieving pressure on fish stocks, as well as a means of filling the increasing supply-demand gap for marine fishes (Williams, 1996). The Code of Conduct for Responsible Fisheries (CCRF) stresses: "States should consider aquaculture, including culture based fisheries, as a means to promote the diversification of income and diet. In doing so, States should ensure that resources are used responsibly and adverse impacts on the environment and local communities are minimized" (FAO, 1995). On a global scale, the decline of fish stocks has been a motivating factor for expanding the role of aquaculture in the fishing industry. It is well known that the ready availability of seed in adequate quantities is one of the major constraints in the development and expansion of mariculture. In this context, the concept of capture based aquaculture (CBA) can be considered as a viable option for augmenting the production of high value species. A sustainable means of CBA has to be developed for achieving the goals of aquaculture. CBA represents an overlap between fisheries and aquaculture and is defined as the practice of collecting seed material from early life stages to adults- from the wild, and its subsequent on-growing in captivity to marketable size, using aquaculture techniques (FAO, 2004).

Many species that are commercially important cannot currently be spawned in captivity. For others, the complete life cycle has only been done at the research and development level, which means that insufficient seed is available for aquaculture operations. For species where controlled breeding techniques have not been perfected, farmers have to depend on CBA by collecting either larvae, small to medium-sized juveniles, or even large individuals from the wild. CBA has developed due to the market demand for some high value species whose life cycles cannot currently be closed on a commercial scale.

Capture-based aquaculture is a worldwide aquaculture practice and has specific and peculiar characteristics for culture, depending on areas and species. An overview shows a worldwide distribution of this practice (Tucker, 1999; Garcìa, 2000; Nakada, 2000; Sadovy, 2000; EIFAC/ICES, 2001; Tibbetts, 2001; Hair *et al.,* 2002). It has been estimated that CBA accounts for about 20% of the total quantity of food fish production through aquaculture, which is about 7.5 million tonnes per year, mostly molluscs.

Chapter 07

Grow-out Culture

Marine cage farm with 2 square cages at Mundra, Gujarat

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Grow-out Culture

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Knowledge of the biology and culture requirements of each species is crucial in optimizing production from cages. The species chosen for culture is usually based on a number of biological and economical criteria. Each species chosen is also dependent on the prevailing conditions of the culture site. The environmental requirements of each species such as salinity, temperature, dissolved oxygen and pH, determine the selection of the species for the culture system. Two phases of growth are involved for most of the cultured species, if fry are used as the seed material. These two phases are the nursery phase and farm grow-out phase. For some species like seabass, cobia, pompano and mullets the nursery phase of fry is very crucial since the seed available from hatchery/ wild are of very small size ranging from 15 mm to 20 mm only.

Nursery rearing of fry

The main purpose of post hatchery nursery rearing is to culture the fry either procured from commercial hatchery (1.5-2.5 cm) or those collected from the wild to fingerling size (6-7 cm). The nursery rearing can be carried out either in earthen ponds of varying sizes ranging from 1000 to 2000 m^2 with a water depth of 80-100 cm or in *hapas* of different dimensions. Sufficient water exchange is recommended with inlet and outlet gates provided with fine screen (1 mm mesh size) to prevent predators and competitors from entering and the fry from escaping the pond (Kandan, 2009).

Nursery rearing of Asian seabass *Lates calcarifer*

When the fish are 45-50 days old or 1.0-2.0 cm length they are transferred to nursery rearing facilities outside the hatchery (Ruangpanit, 1988). During this phase the fish are fed with semi- moist compounded diet thrice a day. The juveniles can also be reared in *hapas* in the open waters. They can be moved from the rearing tanks for culture in *hapas* or in concrete tanks depending on the convenience and availability of the water bodies. The *hapas* usually used are 2 x 1 x 1.5 m and they are usually set in open water one day before stocking to remove the contaminants if any. Stock of 2,000-3,000 fry are raised to the fingerling size in these cages.

Nursery rearing of seabass fry in ponds or in *hapa* to the size of stocking is essential before release into the cages. Nursery ponds may range in size from 500-2000 m^2. A water

Chapter 08

Feed and Feeding

Feeding in cages at Mandapam, Tamilnadu (Gulf of Mannar)

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Feed and Feeding

For culturing fish in captivity, the most important factor is nutrition and feeding. If the feed is not consumed by the fish or if the fish are unable to utilize the feed because of some nutritional deficiency, growth will be affected. Faulty nutrition obviously impairs fish productivity and results in deterioration of health until recognisable diseases ensue. The requirement of nutrients varies throughout the life cycle of an individual. At early stages, the requirement of nutrients is comparatively high which declines with age. Also the requirements depend upon the feeding habits that change according to the morphology of the digestive system. Feeds and feeding are the critical factors that determine the economic

Fig. 8.1. Trash fish being chopped by *sidi* tribe, Veraval

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Chapter 09

Diseases and Control

Harvested Seabass

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09

Diseases and Control

Aquaculture development is towards intensification and enhancement of aquatic production. Like any other farming sectors, intensification will lead to disease problems in aquaculture also. Disease outbreaks impede both economic and social perspectives of aquaculture. Cage culture aims at increased production from minimum volume and it can therefore lead to conditions conducive for disease outbreaks of different levels of impact to the cultured stock as well as environment. Addressing health questions with both pro-active and reactive programmes has become a primary requirement for sustaining aquaculture production and product trade. It is reported that the principal diseases in cage aquaculture of marine finfish and shellfish in Asia are caused by environmental and management affects, nutritional causes, and viral, bacterial, parasitic, and fungal pathogens. Good management practices are the best means for controlling disease occurrence in cage farms.

Fish cultured in cages are particularly susceptible to disease conditions due to sudden change in water quality parameters, or due to handling stress during sampling *etc.* Regular monitoring of water quality and behaviour of the stock is essential to prevent disease outbreaks. In addition to diseases caused by infectious agents, environmental stresses and nutritional deficiencies can also lead to infections that are secondary (Sobhana, 2009).

Fishes stocked in coastal cages may be exposed to a wide range of pathogens. There exists a link between trophic state and bacterial/fungal infections in fish. Chua (1979) observed that the ectoparasitic isopod *Nerocilia* sp. that attacked caged rabbit fish (*Siganus rivulatus*) was more prevalent in organically enriched waters. Both wild fish populations and intermediate hosts in the life cycle of a fish parasite represent a risk for cage farming. Sea lice *Lepeophtheirus* salmonis and *Caligus elongatus*, reported as major threats to cage farms (Bruno and Stone, 1990) is transferred from the environment to the cultured species through a scavenging host. Prior to cage installation suitable sites with no parasites and pathogens are to be selected. In such cases also pathogens are transferred to the system from wild fish or some intermediary carriers.

Diseases caused by viruses

Viral nervous necrosis (VNN)

VNN disease has been found in all warm water marine environments where marine fish have been cultured in cage environments, particularly in juvenile stages. VNN also

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Chapter 10

Biofouling of Cage

Fouling attachment in cage at Visakhapatnam, Andhrapradesh

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Biofouling of Cage

Biofouling, refers to the accumulation of organisms on submerged surfaces, and its associated negative effects on farming equipment, water quality and fish health (Braithwaite and McEvoy, 2005; de Nys and Guenther, 2009). Surfaces immersed in the marine environment become colonised by marine organisms, a process which is called biofouling (Railkin, 2004). Within a short span of immersion, a surface becomes 'conditioned' through the adsorption of macromolecules such as proteins, present in the water. Bacteria colonise within hours as may unicellular algae, protozoa and fungi. These early colonisers form a biofilm, which is an assemblage of attached organisms that is often referred to as microfouling or slime. Finally a layer of macrofouling colonises the surface, consisting of larger algae such as brown and green seaweed, and invertebrates such as barnacles, mussels, ascidians and hydroids. Biofouling in marine aquaculture is a specific problem where both the cultured species and/or infrastructure are exposed to a diverse array of fouling organisms, with significant production impacts. In cage aquaculture, biofouling causes physical damage to the infrastructure, mechanical interference, biological competition and environmental modification. Fouling of infrastructure restricts water exchange, increases disease risk and causes deformation of cages and structures. Stresses on cultured animals will increase, growth will decrease, and removal of metabolites will be limited to the point that biofouling may be detrimental to fish health. In addition, fouling organisms may contain fish pathogens (Kent, 1982) that, coupled with increased stress due to poor water quality, could result in disease outbreaks. Increased biofouling could also lead to structural failures and sinking of aquaculture cages (Huguenin, 1997), leading to fish escape and subsequent adverse environmental, economic, and social implications. Fouling of the net mesh is undesirable in cage aquaculture. During peak settlement, fouling organisms may rapidly clog net meshes and subsequently limit the flow of high quality oxygenated water.

The diversity and intensity of biofouling in aquaculture is site specific, depending on season, geographic location and local environmental conditions. There are many problems associated with fouling in aquaculture (Lane and Willemsen, 2004). Problem areas include fouling on infrastructure (immersed structures such as cages, netting and pontoons) and stock species (farmed species, particularly shellfish such as mussels and oysters). Biofouling greatly reduces the efficiency of materials and equipment: it physically damages equipment (abrasion/brittleness/increased load) and flow can be significantly reduced directly reducing food supply. Biofouling communities can directly compete for resources with cultured

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Chapter 11

Management Measures

Lobster harvest at Veraval, Gujarat

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Management Measures

To get the maximum benefit out of the cultured system, given the restrictions imposed by the site, species or type of feed used, the stock must be kept in conditions which minimize losses and promote good growth and finally optimum production. It is to be considered first that the cages must be of a reasonable size that makes management by an individual or small group easy (Beveridge, 2004).

The major factors to be taken care in cage management are:

- Stocking the candidate species at optimum density appropriate to the site and rearing conditions
- Feeding the fish in the most cost effective manner aimed at maximum production
- Ensuring the best possible water quality within the cages
- Maintaining cages, moorings, anchors, nets and related accessories
- Regular monitoring of the cultured species by sampling, for details on health conditions, removal of dead fishes, and treatment of infected fish
- Grading of fish: When size variation increases in a cage, it often creates competition between the larger and the smaller fish. This can result in stress, especially for the smaller fish. In addition, when feeding, the bigger fish are stronger and get more feed. As a consequence, the smaller fish get weaker and more susceptible to disease. As they get sick, they will also become a source of infection for bigger fish as size variation is also a source of cannibalism (leading to horizontal disease transmission). For cannibalistic species, grading is essential during the initial stage of growth.
- Water quality should be monitored on a regular basis and be maintained at optimal conditions.
- Over-feeding to be avoided as it can induce stress and unconsumed feed will pollute the water.
- Good records of water quality conditions, growth and mortalities should be kept so that management procedures can be properly evaluated and modified as and when necessary.

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Sociological Perspectives

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Marine cage culture is a new entrant in Indian mariculture sector. The first sea cage was established at Visakhapatnam during 2007. The cage culture technology focuses on conversion of open sea into a controlled production system. This involves a number of socio-political issues apart from the technological ones. Prominent among them is the production enhancement of desirable fish species in bulk.

Fish culture in the open sea using cages is an age old concept in many countries in Southeast Asia. Open sea cage culture is considered as an answer to increasing demand for sea food in the context of the declining yield trend in capture fisheries and the problems faced by coastal farming technology due to diseases and its conversion for other purposes.

India's recent entry into sea cage culture marks a significant milestone in the mariculture pursuits of the country. The history of mariculture research in India dates back to early seventies when pioneering attempts were made by CMFRI to farm mussels in the coastal waters using lines. Though the technology was successfully demonstrated, it did not capture the imagination of the fisher folk for their own reasons. The major stumbling block was due to resource abundance amenable to exploitation through capture fisheries. With the capture fisheries production leveling off in the recent years, the potential for sea cage culture is huge. The success demonstrated at different localities in the country has paved way for thinking of cage culture as a major investment for enhanced fish production in the country.

Perception of stakeholders

The perception of the stakeholder constituency and to reflect on the challenges and prospects of open sea mariculture is important. Since cage culture is a new technology it could be either adopted or rejected by the stakeholders. Innovation diffusion studies have recognized that adoption/non-adoption of a practice newly introduced is influenced by whether it matches with the adopters' needs, situation, and perceptions of the innovation (Rogers, 2003). The perception of people on the probability of its adoption is mainly determined by innovation characteristics (Rogers, 2003). A notable feature of the innovation transfer model being attempted across the cage culture sites in India is the way in which the various agencies and institutions are integrated. The dominant mode is that of Public-Private Partnership.

Chapter 13

Economic Evaluation

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Cage in open backwater at Cochin, Kerala

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Economic Evaluation

Cage culture is one of the intensive methods of aquafarming, however, it involves less costs than raceway or enclosure methods (Collins and Delmendo, 1979). The capital involvement consists of collars, floats, mooring facilities, nets *etc.* It is usually less than 10 % of the total operational costs. The nets and the physical facilities are usually given a life span of four years in view of the marine conditions especially in tropical environment. With proper maintenance the frame also can be retained for more than five years.

The main expenses in marine cage farming are cost of feeds (30–50%) and seeds (30–35%), which usually make up 60–85% of the total operational cost (Arroyo, 1973; Collins and Delmendo, 1979; Chua and Teng, 1980). The high expenditure on feeds is due to the exclusive dependence on external source for food supply and hence the quantity taken is in accordance with the feed conversion efficiency. Trash fish is still popularly utilized as feeds for carnivorous fish although formulated feeds are increasingly popular. Despite the fact that formulated feeds yield very good conversion ratios, their high cost has raised the production cost of fish considerably.

Amongst other expenses, labour cost, cost of fuel, repairs and maintenance, bird netting, netting for predators and general depreciation play a significant role in the economics of cage culture.

The optimal cage size depends on the economics of operation, types of species cultured and the environmental conditions. It was shown by Huguenin and Ansuini (1978) that large nets are more economical to operate than the smaller cages. From the economic point of view, instead of keeping one or two cages at a particular site, it is better to install a battery of 5-10 cages.

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Economic analysis

The success of the adoption of any innovation or new technology lies in its economic performance. The rate of return per rupee invested is the economic indicator that guides the investor to choose a particular enterprise or practice. Besides, the analysis of the economic performance serves as an indicator for the investor to allocate his resources in the enterprises. This becomes very much essential, since the resources are scarce and the investor is interested to invest his scarce capital resource in that enterprise that gives the maximum return for his investment.

Chapter 14

Ofshore Cage Systems

Lobster harvest at Kanyakumari, Tamilnadu

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Offshore Cage Systems

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Offshore mariculture has the potential of being a major food source to cater for the increase in future food demand. Since there is an overall interest and justification for offshore aquaculture, research and development activities in that line needs encouragement also. However, selection of a suitable site for an aquaculture venture determines investment, running cost and strongly influences the ultimate success of the resulting aquaculture enterprise (Lawson, 1995). The major challenges of siting and operating cage systems in exposed offshore sites are storm survival and servicing or operating capabilities. All over the world, no offshore area has any substantive track record of experience on which to base decisions (Willinsky and Huguenin, 1996) on installations like cages and sea stations.

Offshore cage designs

As with inshore cages, the variety of cage designs has arisen out of attempts to deal with a number of design objectives for offshore cages as follows (Scott *et al.*, 1993):

(i) To provide a stable cage shape to avoid stressing the stock and to provide a stable working environment.

(ii) To provide adequate water exchange to satisfy metabolic requirements of stock and remove wastes from the cage area.

(iii) To absorb or deflect environmental forces, to maintain the structural fitness of the system.

(iii) To provide an efficient working environment, for routine husbandry, and where equipment and materials (harvested fish, feed, tanks and bins, *etc.*) can be handled if necessary.

(iv) To maintain position, to provide a secure location, free from navigation hazards, *etc.*

(vi) To keep capital and operating costs as low as possible.