

Cage Aquaculture in Asia

*Proceedings of the First International
Symposium on Cage Aquaculture in Asia*

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*Proceedings of the First International Symposium on Cage Aquaculture
in Asia held November 2-6, 1999, in Tungkang Marine Laboratory,
Taiwan Fisheries Research Institute, Tungkang, Pingtung, Taiwan*

Edited by

I Chiu Liao
C. Kwei Lin



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P.O. Box 2725

Quezon City Central Post Office

1167 Quezon City, Philippines

E-mail: afs@cgiar.org; afs@compass.com.ph

Homepage: <http://www.cgiar.org/iclarm/afs/>

World Aquaculture Society-Southeast Chapter

Asian Institute of Technology

P.O. Box 4

Klong Luang, Pathumthani, Thailand 12120

E-mail: Lin@rccsun.ait.ac.th

Homepage: <http://www.was.org/organization/chapters.htm>

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FOREWORD

It is well recognized that aquaculture has been playing an increasingly important role to the world's fisheries production during the last couple of decades. The most significant contribution from aquaculture occurs in Asia, which produces 90% of the total world aquaculture production. However, the human consumption of fishery products has also risen rapidly, parallel to steady increase of the world population. In view of the stagnant production from capture fisheries, the increase in aquaculture output is anticipated to fill the gap that capture fisheries can no longer provide.

As records show, the bulk of aquaculture production relies primarily on land-based culture systems, but the expansion is likely to be impeded by highly competitive uses of land and water on one hand and high capital investment on the other. If aquaculture is expected to meet the supply of rising demand for aquatic foods, we need to venture to other frontiers. In contrast with land-based systems, the on-water aquaculture represents another dimension of the new frontiers. It is on this aquatic territory that the cage aquaculture may play a major role. With careful planning and management, cage aquaculture may make use of underutilized bodies of water. Although cage aquaculture existed for centuries, only in recent years has it been widely practiced and recognized for its potential to produce mass quantity of a large variety of aquatic animals in diverse environments such as ponds, rivers, lakes, reservoirs, estuaries and the open sea.

The First International Symposium on Cage Aquaculture in Asia provided an opportunity for the first time to the aquaculture community in Asia and outside of the region to meet and discuss the current developments in cage aquaculture. The main objectives of the symposium were to:

- examine the status of cage aquaculture in Asian countries
- exchange information among fish culturists, scientists, traders and planners in private and public institutions
- identify problems and opportunities
- assess research needs
- discuss sustainable culture technologies and their management

The symposium was held shortly after the most devastating earthquake recorded in the history of Taiwan. The logistic arrangements for the symposium were made possible with the spirit of the Taiwanese people who have shown their tenacity, resilience, solidarity, and cooperation in the face of adversity.

The proceedings comprise abstracts and full papers of diverse topics that were presented by speakers from 15 countries from Asia, Australia, Europe, and North America. A collection of photographs showing the evolution of cage development is also included. Over 200 participants attended the symposium. This enthusiastic participation indeed reflects the tremendous and expanding interest in cage aquaculture. We hope that this publication provides a landmark document for the status of cage aquaculture with particular reference to the Asian region.

The symposium was jointly organized by the Asian Fisheries Society and the Southeast Asian Chapter of the World Aquaculture Society (WAS-SEA) with sponsorships from various institutions. We thank the sponsors, particularly the National Science Council of Taiwan and the Research Council of Norway, for their full support. The generosity of the donors, advertisers and exhibitors is highly appreciated. We also acknowledge the partial financial support from the WAS-SEA for the publication of the symposium proceedings. We appreciate the meticulous work done by Ms. Jiin-Ju Guo and Ms. Mei-Chen Wu in preparing the manuscripts for printing. Last but not least, we are most grateful to the symposium host, the Taiwan Fisheries Research Institute, for its excellent hospitality.

I Chiu Liao

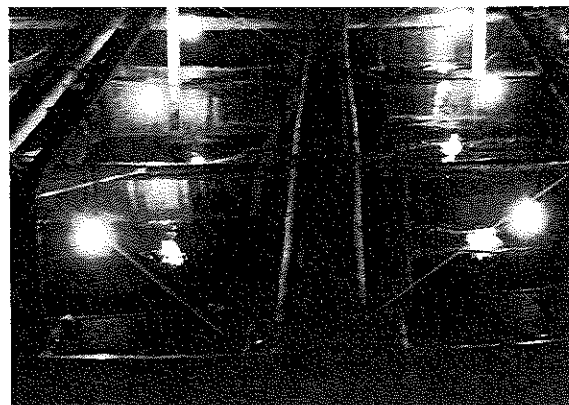
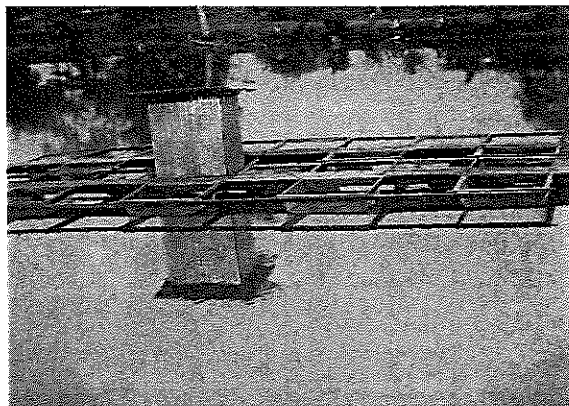
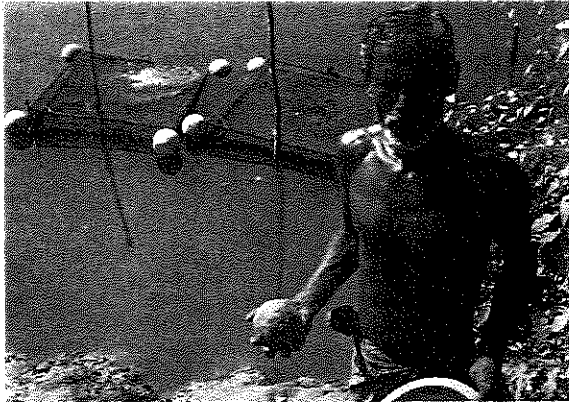
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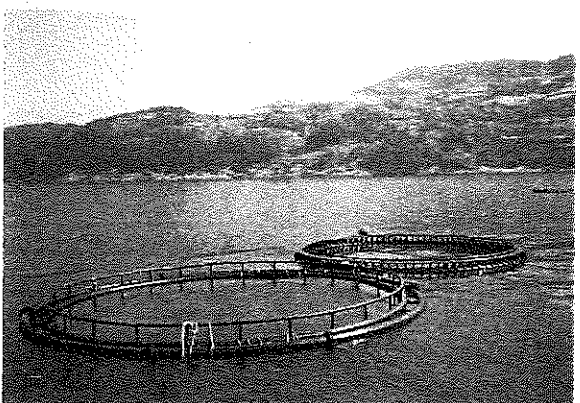
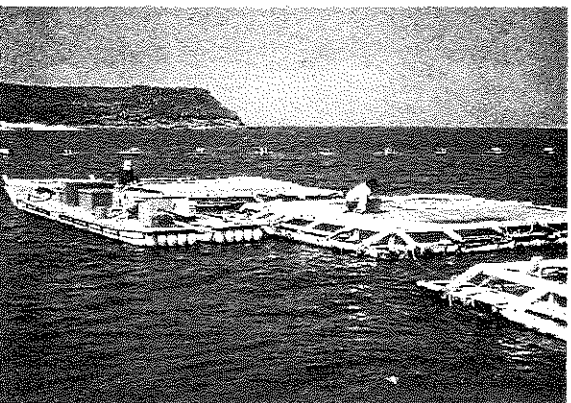
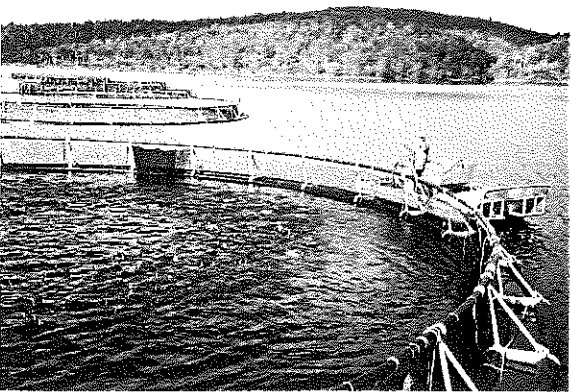
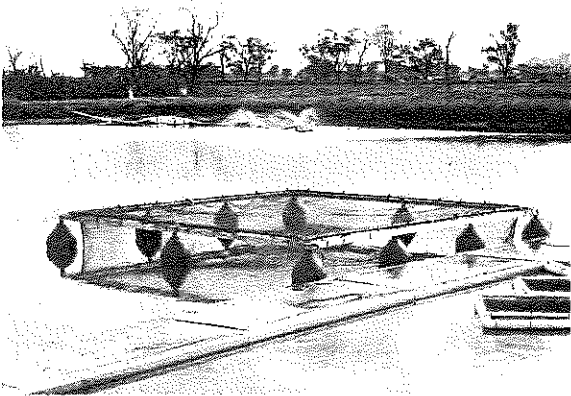
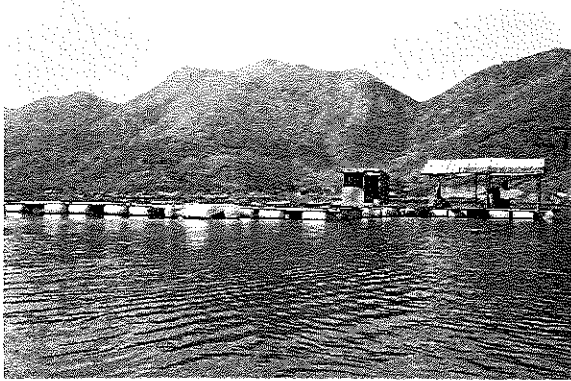
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Evolution of Cage Development

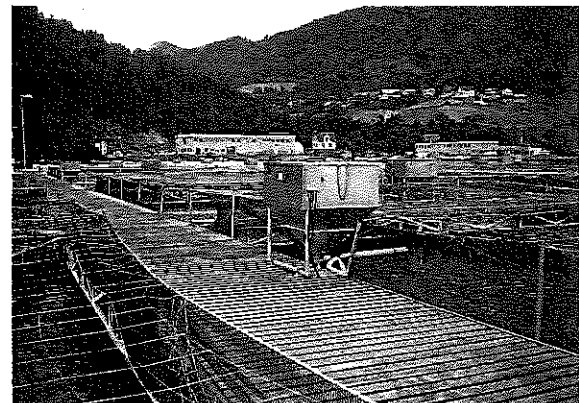
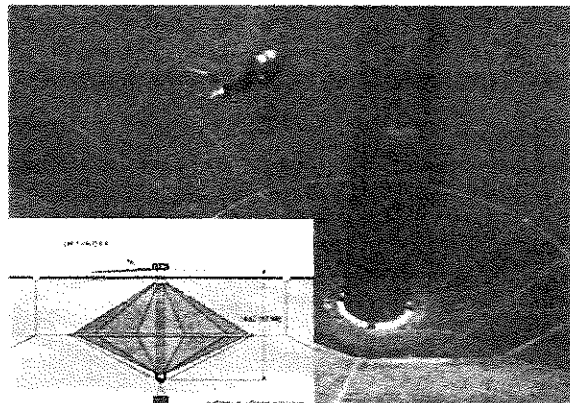
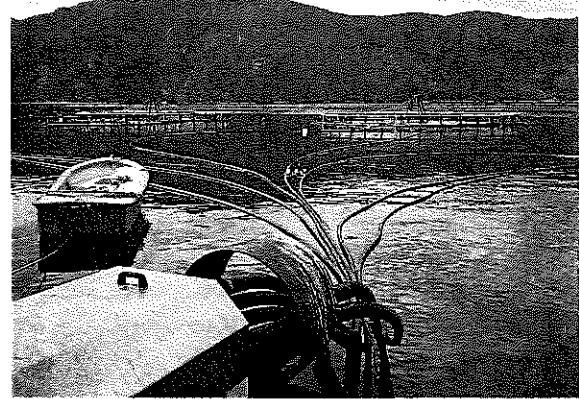
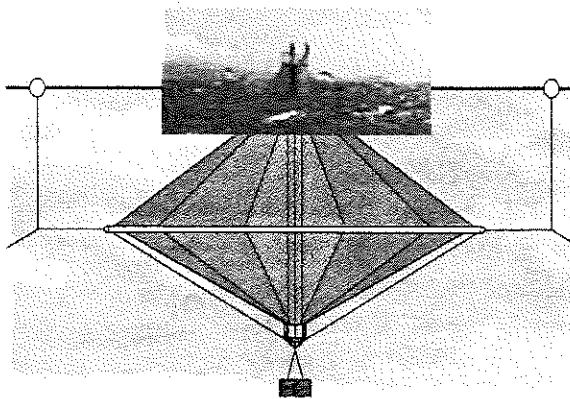
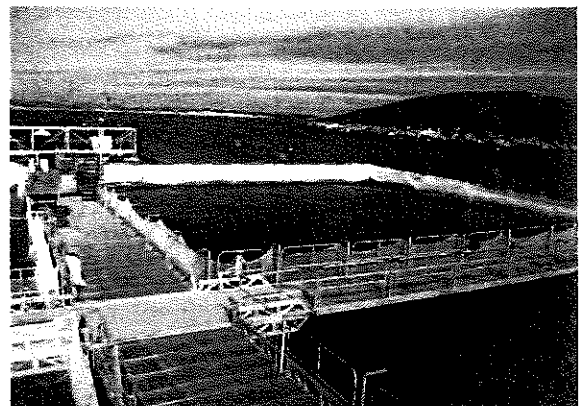
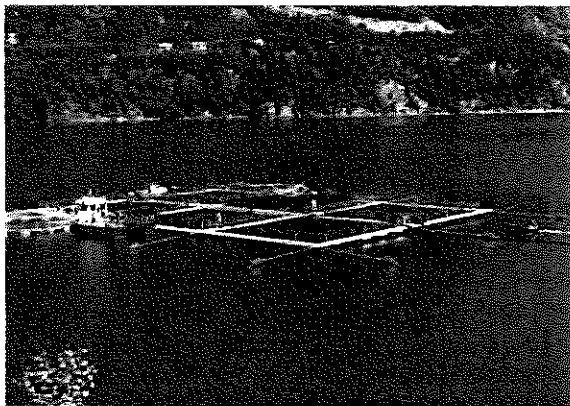
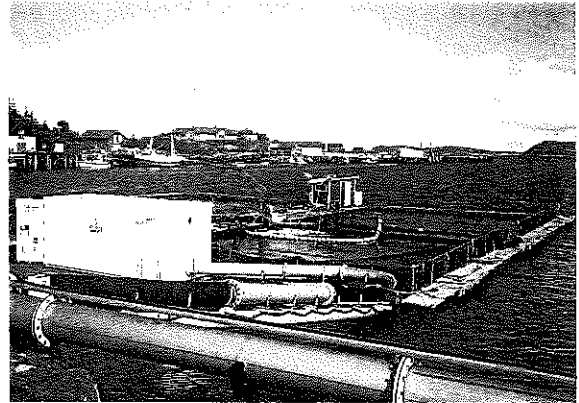
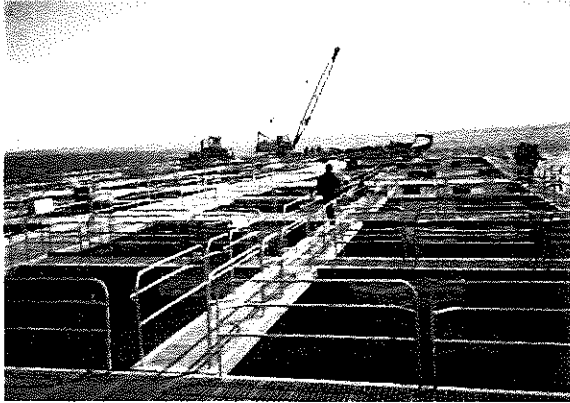
A. Simple, moderate-cost cages



B. Semi-modern to modern cages



C. Advanced cages



Evolution of Cage Development

1	5
2	6
3	7
4	8

A. *Simple, moderate-cost cages*

1. Pangas cages in Bangladesh (*Courtesy of K.I. McAndrew*)
2. Wooden platform cage (*Courtesy of Stirling Aquaculture*)
3. Bamboo nursery cages for sea bass (*Courtesy of A.C. Fermin*)
4. The first inland fish rearing cage in a dammed lake near Chunchon, Republic of Korea (*Courtesy of I.-B. Kim*)
5. Wooden cage (*Courtesy of Stirling Aquaculture*)
6. Tilapia cages in Sultan Kudarat, Cotabato, Philippines (*Courtesy of C.L. Marte*)
7. Grouper cages in southern part of Thailand (*Courtesy of P. Menasveta*)
8. Grouper cages in Negros Occidental, Philippines (*Courtesy of C.L. Marte*)

B. *Semi-modern to modern cages*

1. Grouper cages in Vietnam (*Courtesy of L.A. Tuan*)
2. Integrated inland saline cage culture trials in salt evaporation ponds within the Murray-Darling basin, Victoria, Australia (*Courtesy of G.J. Gooley*)
3. Atlantic salmon cages in Tasmania, Australia (*Courtesy of G.J. Gooley*)
4. Commercial cages in Penghu, Taiwan (*Courtesy of T.W. Sheng*)
5. Commercial cages in Penghu, Taiwan (*Courtesy of IC. Liao*)
6. Commercial cages in Shiao Liuchiu, Tungkang, Taiwan (*Courtesy of J.F. Shieh*)
- 7&8. Commercial cages in Norway (*Photos were taken by the late H.P. Cheng*)

C. *Advanced cages*

1. Cages by Nor-Maer A/S, Norway (*Courtesy of J. Gausvik*)
2. Cages by Nor-Maer A/S, Norway (*Courtesy of J. Gausvik*)
3. Sea Station^R cage in Cyprus (*Courtesy of J. Forster*)
4. Sea Station^R cage (*Courtesy of J. Forster*)
5. Commercial cages in Norway (*Courtesy of IC. Liao*)
6. Cages by Nor-Maer A/S, Norway (*Courtesy of J. Gausvik*)
7. Commercial cages in Norway with feeding pipes (*Photo was taken by the late H.P. Cheng*)
8. Commercial cages in Norway with automatic feeders (*Photo was taken by the late H.P. Cheng*)

KEYNOTE ADDRESSES

The Norwegian Regulation System and the History of the Norwegian Salmon Farming Industry

K.A. HJELT

Norwegian Fishfarmers Association

Pir-senteret

Postboks 1214

7462 Trondheim, Norway

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Abstract

The history of the Norwegian fish farming industry, which is a story of a young industry, can be traced back to the late fifties. During the sixties, pioneers who learned the hard way practically by trial and error appeared on the scene. In the beginning, rainbow trout in freshwater predominated, but in the late sixties and early seventies seawater based Atlantic salmon was successfully introduced. Since then, apart from huge problems at intervals, the fish farming business in Norway has experienced a steady growth, exceeding all future prognosis throughout the years that have passed.

Monitoring the pioneers, people from politics, fishery and agriculture who has their own ideas on how things should be organized, saw the potential in future aquaculture. To counteract this, the pioneers decided to set up in 1970 their own association, the Norwegian Fish Farmers' Association. The first decade of the industry was characterized by a struggle between different interests on establishing a base for salmon and trout farming.

From the legal perspective, activity commenced back in 1968, when the first law/act on fish disease took effect. Early on, veterinarians closely studied the fish farming industry and saw the need to follow up on fish on the basis of agricultural history. The ministry of agriculture was responsible for the law then and even now. This has had a tremendous positive impact on the development of the industry. A problem always occurs when fishes die. Farmers, together with the authorities, have always strived to avoid this. However, heavy outbreaks of diseases have occurred. The "import" of furunculosis in 1986 from Scotland is the worst example. This will be further discussed in this paper.

In 1972, the Government appointed a committee to look into the possibility of turning fish farming into a means of livelihood and came up with a proposal in 1977. However, as early as 1973, they have already forwarded a law regulating fish farming. The law fell under the Ministry of Fisheries and has been changed several times over the years. Whenever necessary, the law supported different regulations in order to solve different challenges that have occurred in fish farming. The different regulations and their impact on the direction and development of the industry will be discussed.

From 1973, it became necessary to register the fish farming activity and to fulfill certain criteria in order to obtain a license. In 1977, the issuance of new registrations was halted and since then the Government has released a relatively few number of licenses. This was based on the applicants' responsibility to encourage the growth of the aquaculture industry in Norway in a balanced and sustainable way. Demographic and political matters also played a role in identifying the locations where fish farming was biologically possible.

Three different laws on the whole, regulate fish farming in Norway, the aquaculture act being the superior (Ministry of Fisheries) though the fulfillment of regulations in the fish disease act (Ministry of Agriculture) and the pollution act (Ministry of the Environment) are also required. The pros and cons of these regulations will likewise be discussed.

Until 1991, only one company or legal person could own one license and there had to be a local connection. When this was altered in 1991 it had a huge impact on the size of the fish farming companies and the process of integration up to the present time. The number of companies engaged in salmon and trout farming has decreased from approximately 1,100 in 1990 to approximately 270 in 1998.

Since 1970, the Norwegian Fish Farmers' Association has been the main agency concerned in protecting the interests of the fish farmers. Through the association, they acquired important positions on the committee created in 1973. In 1978, they saw the need for a special organization for the sale and promotion of salmon and trout. Working with the government, the Fish Farmers' Sales Organization (FOS) was founded in 1978. Through

regulations, the organization obtained the right to sell all farmed salmon and trout first hand. In other words, fish farmers became obligated to report to and sell through FOS. FOS also obtained the right to set minimum prices for buying salmon and trout. The fish farmers ran the company. In the late eighties, Norwegian fish farmers faced market problems and overproduction. The fish farmers launched a freezing program with the intention of balancing the market and raising prices. Due to political and financial reasons, FOS went bankrupt in 1991. This, in turn, made life difficult for many fish farmers who did not get paid for their product. As a consequence, bankruptcy became common in the early nineties. This can, to a certain extent, explain the advancement of bigger companies. The importance of FOS and the impact of the bankruptcy to the industry will be discussed.

The development of Norwegian fish farming has, despite facing huge problem in their short history, evolved into a modern sustainable and highly competitive industry. From a production of approximately 600 tons of salmon and trout in 1971, the industry will be producing more than 400,000 tons of salmon and trout in 1999. Most of that will be exported to some 100 different countries all over the world. This paper concentrates on how that development has been possible despite problems concerning market, diseases, accusations of dumping as well as problems in the organization.

Introduction

The Norwegian fish farming history is a story about trial and failure during the last thirty years. From almost nothing in the sixties, it has produced about 400,000 metric tons of salmon in 1999. Although almost entirely based on the production of Atlantic salmon (*Salmo salar*), it was partly based on the production of rainbow trout (*Oncorhynchus mykiss*). During the last 30 years, it has developed from a small-scale local industry to its current worldwide industry. What is the reason for this? Is there anything in the history of the salmon industry in Norway that can give us some hints? Is this "fairy tale" from reality in some ways a product of planning and foresight, both from the industry itself and from the politicians and the governmental system, or did it just happen? To answer these questions, we have to look at the history of the salmon farming industry, the regulation system and the contributions of the fish farmers themselves. Through this paper, hopefully, we might find some answers.

Norway is one of the countries in the Northern Hemisphere that is blessed with a number of wild populations of Atlantic salmon in the rivers. The salmon has always had an economical impact, and been exploited in many ways, both in freshwater and in the sea (as food source and for sport fishing). As a consequence, there was an early interest for the biology of the salmon, and also for enhancement. This knowledge was one of the key factors when salmon farming started. Norway has always been a fishing nation, hence

the coastal inhabitants had gained knowledge and competence in keeping fish in nets, handling, adding value and export. This traditional competence proved useful in salmon farming. In addition, the fishing industry was able to get local foodstuff from growing salmon and trout. Last but not the least, we have an infrastructure along the entire coast. We have small communities and people in a place who know the fish and the sea well. Nature gave us very good conditions for farming salmon and trout. In my opinion, all of the knowledge and resources mentioned are crucial for the success of the industry.

In the fifties and sixties, people tried to grow rainbow trout "the European way", i.e., in freshwater ponds and in portioned size (200-500 grams). This never succeeded in Norway, and many people had to abandon the business. Fish diseases, technology and water quality were problems facing the fish farmers. The Ministry of Agriculture was responsible for providing veterinary services, and as early as 1967, they employed a veterinarian especially in charge of fish diseases. In 1968, the "Fish Disease Act" was enforced whose purpose was to prevent, control or eradicate diseases in freshwater fish. This was very important for the future development of aquaculture, because the central authorities through the Ministry of Agriculture then took on the overall responsibility for the prevention and control of fish diseases.

In the late sixties up to the early seventies, some pioneers first tried to farm salmon in seawater by pumping seawater into onshore dams and tanks. Later the idea about sea cages

was born. When this succeeded, it signaled the start of better things to come.

The development of the industry can be divided into three periods, namely:

- establishment
- expansion
- crises and reorganization

I will look further into the important events during the three decades, and the impact of those events on further development. In the end, I will look at the challenges we are facing at the beginning of the next millennium.

1970-1979: Establishment of the Aquaculture Industry in Norway

In March 1970, the fish farmers came together and founded "The Norwegian Fishfarmers Association" (NFF). The aim of the association was to "gather all the fish farmers in one association, and through the association work for the fish farmers" economic, professional, social and cultural interests. That meant the fish farmers spoke with one voice, and therefore had the opportunity to play an important role in drafting the future framework for the industry.

The interest for fish farming was growing, and there was a discussion about which ministry should have responsibility for the new industry. Should the Ministry of Agriculture, the Ministry of Environment or the Ministry of Fisheries be responsible for the farming of salmon and trout?

NFF proposed that an official committee should look into the matter, and submit its advice to the Government. This was accepted and the committee started the work in 1973. One of the first things the committee did was to propose the need for a law regulating fish farming. (The committee released its conclusions and recommendations in 1977).

The Fish Farmers' License Act of 1973 was a tool for controlling and guiding the development of fish farming, and the act was meant to be provisional. The fish farmers themselves (through NFF) enforced the act. The following points were the most important provisions of the act:

- all fish farming units in operation should be registered

- permission was needed for fish farming, permission should not be given if the plant:
 - could cause risks for the outbreak of fish diseases
 - could cause risks of pollution
 - was technically unfit, or the site was unfit
- restrictions on the size of the fish farm (license), i.e., max. 8,000 m³ of production volume

From then on, everybody who wanted permission (license) for farming salmon and trout had to apply for a license from the authorities, and a certain volume in m³ limited the license. Permissions were issued liberally until 1977. The production capacity was seen as sufficient and no new licenses were issued before 1981. At that time, 438 licenses were issued and the slaughter volume was about 4,300 metric tons (Table 1).

Knowledge was scarce, and one of the tasks of NFF was to play a major role in network building between members, as well as in gathering and in distributing information to members. The need for information led to the foundation of the Norwegian Fish Farmers' Magazine in 1976, which made a significant contribution to the spread of information, research results, etc. Up to 1976-77, the production of rainbow trout exceeded the production of salmon, and the inland market was the most important. NFF was involved in marketing and very soon began to look for new markets abroad. In 1974, the first market campaign for trout in Norway was launched. In 1978, relatively big quantities were frozen due to overproduction. A new market campaign was launched and proved to be successful. Soon, we were in balance again.

Early on, the producers were aware of the damage that bad quality (and fluctuating quality) could do to the market. Criteria for the quality of slaughtered salmon and trout were therefore launched by the organization, and was soon adapted by the authorities. This was very important, as we then had quality standards (by regulations) and it was the authorities' responsibility to see to it that "every fish sold possessed a minimum quality". The customers then knew the quality of what they bought, and were certain that they well also get that quality the next time.

Sales and marketing were important items

for the fish farmers, and through the middle of the seventies, much effort was exerted in finding the best way to do this. The fish farmers (through NFF) wanted to establish a sales organization owned and run by the fish farmers. With permission from the authorities, the Fish Farmers' Sales Organization (FOS) was founded in 1978. FOS had a monopoly on the first-hand trade of farmed salmon and trout in Norway. A license provided by FOS was required in order to purchase salmon from farms. FOS also decided on the minimum prices for farmed fish and undertook marketing activities in the export markets. FOS could, by their monopoly, take a fee both from the owners (the fish farmers) and the buyers (exporters), and through this finance the activities in marketing, research and development, and quality control.

As a result of an initiative from NFF, the first conference and exhibition on fish farming was held in 1979. The intention was not only to establish an arena for equipment and services to the fishfarming community, but also to serve as a meeting place for people involved in the business, as well as an area for exchanging new developments within the industry, including new knowledge in research. The conference and exhibition was later turned into an international arena "Aqua Nor" and has been held every other year since then.

As mentioned before, different interests had different views about where the administrative responsibility for fish farming should be placed

within the Government. As a consequence of the conclusions and recommendations submitted by the committee created in 1973, the Parliament in 1980 decided that the ministry who should be responsible for fish farming was the Ministry of Fisheries, and that fish farming should be developed into an independent industry free of subsidies. The competing view was that fish farming should be part of the Ministry of Agriculture's responsibility, and should evolve as part of existing farms along the coast.

This decided, the establishing period came to an end (Table 2). We then had:

- one voice (NFF)
- regulation by laws
- monopoly on first-hand sale (FOS)
- marketing body in FOS
- quality standards in the form of regulations
- the fish farmers' own trade journal
- an arena for conferences and exhibitions
- fish veterinary system
- a trade department for fish farming

As a whole, these "instruments" were crucial for the further development of the industry.

1980-1989: Expansion of the aquaculture industry in Norway

In 1981, the temporary Fish Farmers' License Act of 1973 was replaced by a new provisional Fish Farmers' License Act. License was not issued if the facility:

Table 1. Number of on growing licenses, tons harvested and smolt production from 1971-79.

Year	Licenses	Salmon (ton)	Trout (ton)	Smolt Production (millions)
1971	55	100	540	—
1972	61	145	780	2.0
1973	169	320	900	2.9
1974	284	700	1,500	3.3
1975	310	950	1,800	3.8
1976	334	1,900	2,050	4.2
1977	399	2,500	1,800	4.6
1978	438	3,500	2,100	6.1
1979	441	4,140	2,690	5.8

From 1973, the number of licenses registered has always been higher than the number that actually is producing. Licenses also include small inland registrations, so the actual number in sea is lower. In addition to the smolt production in Norway, some were imported.

Table 2. Events throughout the years 1970-79.

1970	Foundation of Norwegian Fish Farmers Association (NFF).
1971	NFF proposal; a governmental committee to look into fish farming; member info sheets.
1972	NFF negotiated fish feed prices for members, governmental committee appointed.
1973	Fish Farmers' License Act of 1973, registration of licenses, request for new licenses, regulation for quality grading, size grading proposed.
1974	National sale campaign for trout, NFF discussion on sales organizing and market problems.
1975	Discussions about sales organizing, NFF membership to the European Aquaculture Association (FEAP).
1976	Norwegian Fish Farmers' Magazine established, Ministry of Fisheries positive to a sale organization.
1977	A white paper from the governmental committee stating that aquaculture could be a self-sufficient industry and the Ministry of Fisheries should be in charge.
1978	The Fish Farmers' Sales Organization (FOS) established; monopoly on first hand sales of farmed salmon and trout, marketing campaign (frozen trout in stock).
1979	National conference and exhibition for aquaculture.

- could cause risk in the spread of disease among fish (according to the Fish Disease Act – Ministry of Agriculture)
- could cause risk of pollution (according to the Act on Pollution – Ministry Environment)
- had a distinctly unfortunate location or technically unfit

From the 1981 law and during the eighties, the aims of regulating the industry as given by the government were:

- to regulate the production of farmed salmon/trout in Norway in accordance with market demand
- to have a regional distribution of fish farms
- to establish the owner-operator structure in the industry
- to make it possible for a legal person to have majority owner-interest in one farm only

In 1980, we had a production of approximately 7,500 metric tons of salmon and trout (Table 3). Due to the termination of license issuance in 1977, the number of fish farms had been quite stable. The authorities decided to release 50 new licenses in accordance with the new law. In contrast to the principal view of the association these licenses were given for a volume of 3,000 m³. Approximately 780 applicants applied for these 50 licenses. This indicated the huge interest for fish farming. In 1983, another 100 new licenses were issued, and at the same time all existing licenses could (by application) get a volume up

to 5,000 m³. The interest to get a license was growing and there were approximately 1,200 applicants!

The 1981 law was replaced by the permanent Fish Farmers' License Act in 1985 (Table 4). There was no liberation mentioned in the law, which meant that the Ministry of Fisheries had the responsibility to decide on the total number of new licenses to be issued and their regional distribution. The authorities have issued licenses in patches, and this practice is still political. The volume regulation in m³ was chosen by the authorities because in this way, they could protect the environment (production limit). The maximum volume allowed would take care of the objective for building an industry with small-scale facilities, and through that, include regional politics. It should also, together with issuing licenses in patches, be a part of limiting the production in accordance with market demands.

Knowledge about technology, biology and economy was still scarce and the association had been arguing that professional competence should be one of the demands you had to fulfill in order to secure a license. This was part of the new law, which states that "when issuing licenses, particular emphasis should be placed on the condition that the breeders possess the necessary professional competence". One hundred fifty new licenses were issued in 1985, each with a volume of 8,000 m³ (existing licenses could get

the same). As in 1981 and 1983, there was still a huge interest in getting a license. There were approximately 2,000 applicants.

Based on the new licenses issued, the production volume increased approximately by 10% in 1981, 75% in 1983, and 30% in 1985. Add these figures, and we will see that there was a tremendous increase in the production capacity in the first half of the eighties. The fish farmers were partly against this increase because they were afraid of overproduction and price effects. Neither did the supporting system have sufficient capacity, specially the veterinary system and the bureaucracy needed to handle the new situation.

At least until the mid-eighties, production and demand had been more or less balanced. But it was the supply of smolt that really set the limit for production, not the volume in existing on-growing farms. Smolt production in freshwater is difficult, both technologically and biologically (up to the late eighties the survival rate from eggs to smolt was, on the average, between 20-40%). Further, there was no balance in the granting of new on-growing licenses and smolt licenses, which in turn led to a shortage of smolt compared to actual production capacity in the sea. There was also a regional imbalance because most smolt production sites were built in the western part of Norway. This was partly because of differences in water supply and temperature, but salmon farming in sea was also concentrated at the coast from mid Norway and southward. NFF was concerned about this and pointed out the problem several times. Because of the imbalance, smolt was imported from Finland and Sweden, and this was not good (especially due to disease risks). In spite of this imbalance, issuance of new smolt production licenses was stopped (as for on-growing licenses) from 1977-1981, and a few were issued from 1981-83. The production allowance for a license was at that time 500,000 smolt annually. This was raised to one million in 1984. The authorities started to issue new licenses in 1983, based on applications already received. In 1984, applicants from Northern Norway were given priority. This led to a higher production capacity, but compared with the capacity in sea farming, there was still an

imbalance.

The Fish Farmers' License Act of 1985 liberated the possibility to get smolt production licenses. A license should be given as long as it did not cause risk for the spread of diseases among fish, did not cause risk of pollution, and did not have a distinctly improper location in relation to the surrounding environment. This was against the warnings coming from the fish farmers who were afraid of building up a huge smolt production capacity that in turn, would increase the production of salmon far above market demands. Because of a high demand for smolt, the earnings in smolt production was high (high prices), and liberation of banking operations in Norway coincided with the political liberation of smolt production. This led to an uncritical realization of smolt production capacity within a short time (1986-89), which in turn led to the "collapse" of the salmon and trout industry.

The development of an aquaculture industry is dependent on research and the availability of new information. Research and development has not always been at pace with the growth of the industry. Because the industry expanded so fast, the need for new information became crucial. The fish farmers were convinced that more R&D was needed, and during the eighties, four different research programs were launched through FOS/NFF. Still, the authorities grants were too small considering the needs of the industry.

- "Healthy fish" in 1983 with the aim of looking into different aspects of fish diseases.
- "New species in marine aquaculture" in 1985 to do research on possible species that could have a potential in culture.
- "Quality fish" which was a cooperation between the industry and the authorities, the aim was to increase professional knowledge about quality, quality measures, information to the industry and put forward relevant R&D projects (1988).
- "Environmental impact from aquaculture" in 1989.

They all evolved into national research programs, and were partly financed by the industry, mainly through FOS. The results from those pro-

grams (and other relevant R&D) has been a good scientific base for the development of the industry until today. Along with this, a mutual understanding and trust between the industry and research institutions evolved. This in turn narrowed the gap between the producer and the scientist, which has had a strong impact on the development of the industry.

Breeding programs are important in domestication, as well as in aquaculture. Historically, competence in this matter had evolved in the agriculture sector, but in the early seventies, a central research station (i.e. Akvaforsk owned by the Ministry of Agriculture) started a breeding program on salmon and on rainbow trout. In 1984, the fish farmers (through FOS and NFF) decided to establish their own breeding station, the Norwegian Fishfarmers' Breeding Station which started operations in 1987. The Station, whose cost reached about US\$ 5.5 million, concentrated on the fast growth, late maturation, color and fat content of salmon. Resistance against diseases, shape, and skin color were later included. There is no doubt that what has been gained through breeding throughout the years has played a major part in the development of the industry into a highly effective producer of high quality food that it is today.

Because of the high demand for smolt, smolt was imported from Scotland in 1985, as approved by the authorities. This move turned out to be fatal, because these smolts also introduced the bacterial disease furunculosis (*Aeromonas salmonicida*) into Norwegian aquaculture. Since this was a new disease to the Norwegian fish farmers, a heavy eradication and control system was launched through the cooperation efforts of the fish farmers and the authorities. Treatment included the use of antibiotics, in substantial amounts. Disease was not really controlled until effective vaccines had been developed. In the mid eighties, another new disease occurred. Eventually it was found out that the disease named ISA (Infectious Salmon Anaemia) was caused by a virus. ISA caused heavy mortality and the strategy to control it was to keep the outbreaks at an absolute minimum. The number of outbreaks reached a peak in 1990 (80 out-

breaks), but was down to below ten in 1994. This was made possible through a close cooperation between the industry and the veterinarians. The plan for control, eradication and prevention included demand for health control and health certificates in smolt production and transport, regulations of transportation, regulations of treatment of waste and blood water from slaughter houses, and the establishment of disease fighting zones. Such close coordination proved crucial, and annual outbreaks have been low since that time.

The bacterium cold water vibriosis (*Vibrio salmonicida*) caused heavy mortalities in the second half of the eighties, but through better understanding of fish farming husbandry, better feed, and effective vaccines, said disease was also put under control.

If we trace back the production development after the liberation of smolt production, the history is as follows: Smolt production capacity went from approximately 61 million in 1986 to more than 150 million in 1987. In 1988, the fish farmers requested for a new volume level on their licenses, arguing that the 8,000 m³ was too little, causing high densities and risks of disease outbreaks. They lobbied for a limit on each license of 12,000 m³, which the authorities approved. In theory, this meant a rise in production capacity by 50%, and the extra volume was in fact to a great extent used for production! Almost all the smolt produced went to the sea, and the production of salmon almost doubled from 47,420 tons in 1987 to 80,370 in 1988.

Another doubling of production was reached in 1990 when approximately 165,000 tons were produced. In 1988, a surplus in smolt production occurred for the first time. At the same time, the industry experienced growth in the international level (Scotland, Ireland, Canada, etc). The smolt producers struggled because of low prices, and the production of salmon soon caused market problems and declining prices. By the end of 1989, the Scottish and Irish fish farmers claimed that the Norwegians were dumping salmon (below production prices) into the EU market, which in turn led to an EU investigation in 1990. In 1988, the authorities gave out extra 30 licenses to the two northernmost counties in

Norway in accordance with regional politics. This did not have a significant influence on the production capacity for a very long time.

By the end of the decade we had:

- expanded the production capacity several times
- expanded the smolt production capacity (self-contained from 1987)
- heavy involvement in the research and development (R&D) of the industry
- started our own breeding program
- been exposed to heavy mortality due to diseases
- acquired effective vaccines against bacterial diseases
- constantly been involved in raising the level of professional competence in the industry
- experienced increasing market problems
- learned so much from these events

1990-1999: Crises, Reorganization and Further Development of the Aquaculture Industry

In January 1990, FOS launched a "freezing program" to solve the market problems by creating a balance between export and demand. This freezing programme of Norwegian salmon was different from earlier stabilization programmes, which only concentrated on between season stabilization. Since it was more of a long-term project, hence it was larger in size and involved more risks. The farmers had no choice but to be part of the programme since the sales organization had a legal monopoly. A fee on the sales of fresh salmon partly financed the freezing program. One obstacle in stabilizing the market for farmed

Table 3. Number of on growing licenses, tons harvested and smolt production from 1980-89.

Year	Licenses	Salmon (ton)	Trout (ton)	Smolt Production (millions)
1980	426	4,135	3,360	8.0
1981	439	8,420	4,485	10.1
1982	450	10,265	4,690	10.9
1983	479	17,000	5,100	15.1
1984	586	22,300	3,640	20.3
1985	607	28,655	5,140	24.5
1986	704	45,650	4,310	33.0
1987	747	47,420	8,790	44.0
1988	782	80,370	9,325	85.0
1989	791	124,000	3,730	73.0

Licenses also include small inland registrations, so the actual number in sea is lower.

Table 4. Events throughout the years 1980-89.

1980	Governmental decision; the administration of fish farming under the Ministry of Fisheries.
1981	New provisional Fish Farmers License Act, New "Pollution Act" Ministry of Environment, 50 new licenses, NFF arguing for better veterinarian services.
1982	Veterinarian service and breeding on the agenda.
1983	NFF wanted 2-3 localities on each license, 100 new licenses given, R&D: "Healthy Fish".
1984	Decision to build a breeding station.
1985	Permanent Fish Farmers' License Act, 150 new licenses, liberation of smolt production, Aqua Nor, import of disease from Scotland.
1986	R&D: New species in marine aquaculture, price drop, heavy mortality due to diseases.
1987	Focus on fish health/health certificates in smolt production, The Fish Farmers' Breeding Station opened, diseases.
1988	R&D: Quality fish, focus on training and education; professional knowledge.
1989	R&D: Environmental impact from aquaculture, fall in prices, diseases.

salmon for FOS was that the sales organization did not have any means to regulate the level of production. The program was expensive and FOS was granted a loan of about 1.3 billion NOK from a bank. Some of the problems encountered were:

- the actual production was higher than predicted
- prices in markets were lower than predicted
- dumping charges from USA
- all time high catch of Pacific salmon
- lack of loyalty from some of the fish farmers

Dumping charges from EU were withdrawn, probably due to the freezing scheme, but the accusation of dumping from USA ended with an extra duty of approximately 26% on fresh salmon (1991). A promising market was gone overnight. In May 1990, the export of fresh salmon to the USA was 1.261 tons; this dropped to 24 tons in 1991. By the end of 1991, Scottish and Irish fish farmers again filed complaints of dumping, which in turn led to minimum import prices on salmon from Norway to EU. In 1990, the freezing program included about 49,000 tons, and at the end of the year approximately 22,000 tons were in stock. The program continued and was stopped in July 1991. Approximately 35,000 tons of salmon were frozen, and at the end of the year about 50,000 tons were in stock. Because of the cost, the fee imposed on the fish farmers and the trouble in the markets, FOS had to hold back the money for the salmon delivered by the farmers.

In their desire to do something about the production, FOS and NFF devised 'starvation periods' for the salmon. Though a voluntary program, it also gained results. The idea was to stop the feeding of the salmon for certain periods, and thereby delay their growth. To get the desired effect, the authorities had to make the program compulsory by regulation, something that was also done in 1995. In the spring of 1991, the fish farmers, (through FOS) as a part of "production control", paid for the destruction of approximately 20 million smolt. By 1991-1992, the annual production went down for the first time, but has again steadily increased since then (Table 5).

Negotiations were going on between NFF/FOS/banks and the government. In the autumn of 1991, the fish farmers were "hocked

off" and as a consequence of probably high level political decisions, FOS went bankrupt in November 1991 (Table 6). The economy for the fish farmers had been under pressure for a long time, and many of the fish farming companies went bankrupt. A monopoly like FOS could probably not serve as such in a more international trading sphere, but many did not approve of the way it was implemented because of the negative impact it had on most fish farmers. From the day FOS went bankrupt, a change in the law regulating the export took place, which meant that there was free trade of salmon. A change was also made in the Fish Farmers' License Act, i.e., the principle of one person to have legal majority ownership in one farm only. The owner-operator structure was no longer a goal. This meant that we could now have both vertical and horizontal integration. This was the start of the restructuring of the industry that is still going on.

Since many of the fish farmers were economically vulnerable due to bankruptcy and the freezing program, they sold or were taken over by other companies during the nineties. In 1988, we had about 1,000 decision-makers in the industry; at present, we only have about 270. With the bankruptcy, marketing through FOS also disappeared. After discussions about reorganizing future marketing, the Norwegian Seafood Export Council was founded in 1991. The council's activities were regulated by law, and financed through a fee on export of fish. The council's main task is to market (generic) Norwegian fish worldwide.

In fish farming, fishing, and processing, a large amount of waste is created. This actually is not a waste but rather a resource. The different branches of the fishing industry (aquaculture, processing, fishing) and the three ministries responsible for fishing, environment and fish health together with the Norwegian Research Council started a foundation in 1992. The aim of the foundation was to support R&D in such a way that wastes/by-products from the industry could be converted into resources. Today, the aquaculture industry is recycling more than 95% of what was earlier considered as waste. Before we had to pay to get rid of it, but today, the fish

farmers get rid of it for free or are actually being paid for it.

In 1995 "stop feeding" programs were no longer sufficient in the long run to ensure that production did not exceed the demand from markets. The fish farmers asked for a regulation through feeding quotas, and through cooperation with the authorities, this was put into practice in 1996. Through this regulation, each license (12,000 m³) gets a certain amount of feed, which they can use throughout the year. The size of the quotas were regulated each year, based on statistical figures from smolt available, biomass in sea, markets, etc. Because of this regulation, the production is much more predictable now than in the previous years.

Throughout the nineties, NFF has put much effort into developing skills in statistics, and today, we have a very good tool that we use in giving our members and the authorities the best figures available. This is done in close cooperation with the fishing authorities and the Norwegian Seafood Export Council. Our policy is to make it possible for the fish farmers to make decisions based on reliable statistics and figures.

In 1995, we were again accused of dumping by EU producers, which through negotiations among the Norwegian authorities, the fish farmers in Norway and EU ended in a deal. The deal included floor prices on importation to EU, an indicative ceiling for the total amount of salmon coming into EU from Norway, consultation meetings twice a year and a trilateral cooperation among Scotland, Ireland and Norway. The deal was put into effect starting July 1997 and will be in force for five years. Together with the feeding quotas, this has stabilized both production and prices. Through more knowledge, better vaccines, better feed, and better management along with the restructuring of the industry, we have gained control of diseases, production and wastes as well as the impact of the industry on the environment. This has also made us a highly effective industry based in rural areas. The cost of production has steadily decreased and today the production cost for one kilo of salmon is about 17 NOK. In 1987, it was approximately 32 NOK. The same trend has occurred in smolt production,

from a production cost of about NOK 15/smolt in 1987 to approximately NOK 7 today.

When FOS went bankrupt, the industry as such did not have any way of financially supporting R&D. As early as 1992, NFF was already requesting for a R&D tax on export. The fish farmers should be responsible for the utilization of the money. This will probably be carried out in the year 2000, with an annual amount of about 25 million NOK.

On the environmental side, we are facing two main challenges, the salmon escaping from the farms to the wild and to have a better control with sea lice. Apart from the damages and the losses caused by the parasite to the industry, it may ruin our reputation and cause negative interactions with populations of wild salmon. The fish farmers have steadily worked for better equipment, especially when sites are located in rougher localities. Next year, we will introduce the issuance of a certificate for new equipment, which means that the equipment should meet certain technical standards. This includes the moorings. A monitoring system for evaluating the environmental standard of the localities and their carrying capacity will also be introduced. Aquaculture will also take an active part in coastal zone management in Norway.

Throughout the decade, we have experienced:

- production and market crises
- freezing program
- collapse and bankruptcy
- restructuring and integration
- new organization of marketing
- control of diseases
- several accusations of dumping
- regulation by feeding quotas
- "understanding" with EU
- economic crises in Russia/Asia

By learning from these and through a fruitful cooperation with the authorities, the fundamentals for further growth have been established.

Summary

The history of salmon farming in Norway is relatively short, but in such a short span of time,

Table 5. Number of on growing licenses, tons harvested and smolt production from 1990-99.

Year	Licenses	Salmon (ton)	Trout (ton)	Smolt Production (millions)
1990	813	165,000	4,000	64.0
1991	827	156,000	6,000	73.0
1992	845	141,000	8,000	63.0
1993	839	170,000	9,000	65.0
1994	840	207,000	15,000	86.0
1995	807	249,000	14,000	97.0
1996	817	292,000	23,000	98.0
1997	820	316,000	34,000	110.0
1998	820	343,000	47,000	118.0
1999		395,000	47,000	120.0

Licenses also include small inland registrations, so the actual number in sea is lower. Values in 1999 are estimates. In 1991, approximately 20 million smolts were destroyed.

Table 6. Events throughout the years 1990-2000.

1990	Freezing program (FOS), first hand value of farmed fish exceeded first hand value of wild catches, bankruptcy among fish farmers, accusations of dumping, disease problems
1991	Dumping custom in USA, liberation on owner structure, FOS bankrupt, free trade of farmed salmon and trout
1992	Restructuring, better prices and optimism at the end of the year, Norwegian Seafood Export Council founded, NFF asked for a R&D tax
1993	Hardly no disease problems, dumping accusations from Scotland/Ireland
1994	Economical by good year, minimum import prices in EU, Norway voted no to EU membership
1995	Regulated "Stop feeding" program
1996	Feeding quotas, dumping accusations and negotiations with EU
1997	Deal with EU; floor prices, consultations, indicative ceiling on volume to EU. Information (internet), statistics
1998	Coastal management plans, some IPN problems, focus on updating laws and regulations
1999	Focus on information to the public, better contact with governmental committees/politicians, focus on WTO
2000	Probably regulations on; technical certificate, environmental monitoring, Research & development tax on export

we have evolved from being small producers with a domestic market, to a worldwide industry exporting a variety of products to more than 140 countries. How did we achieve this? Maybe some answers can be found in the history discussed earlier. Norway is blessed with natural conditions fit for aquaculture. We had pioneers who saw the opportunity and worked hard for what they believed in. Throughout the history of the industry, the fish farmers have always spoken with one voice, and therefore viewed as a serious partner with insight and knowledge. Apart from the bankruptcy of FOS in the middle eighties

(during the period of liberalism), all the main thoughts and ideas of the fish farmers have been given full attention by the authorities. We have always worked with the authorities and closely cooperated specially with the Ministry of Fisheries, the Ministry of Agriculture and the Ministry of Environment, who are in charge of the industry. Further, the fish farmers have been heavily involved in research and development, education and all endeavors related to the aquaculture industry. Though there was a fairly good understanding that what we wanted was a regulated industry, we also wanted to play a major part in

drafting the regulations (which we have achieved). From the very beginning, we wanted to build an independent industry free of any subsidies, this we also have achieved. Through determined efforts in R&D and through cooperation, we have had a tremendous development in feed and feed technology, equipment and technology, vaccines and fish farming management. This in turn has made us more cost effective and has been crucial for our success as producer and exporter of farmed salmon and trout.

The future challenges will be:

- expansion of markets
- environmental matters
- coastal zone management
- value added products
- international trade and customs
- food safety
- documentation
- alternative/new feed stuff
- other species in aquaculture

The Major Problem of Cage Aquaculture in Asia Relating to Sea Lice

J.-S. HO

Department of Biological Sciences
California State University
Long Beach, California 90840-3702
USA

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Abstract

It is a well-known fact that several species of sea lice (Copepoda, Caligidae) have become the major pathogens of salmonid fishes farmed in sea cages in Europe, North America and South America. The disease caused by the infestation of sea lice may account for losses in excess of 20% of the total production in said areas.

Over 400 species of sea lice are currently known, with most of them occurring in the tropical and temperate waters throughout the world oceans. Thus, the operation of cage aquaculture of warm water fishes in Asia is destined to be confronted with assaults by more species of sea lice.

Examination of sea lice of Asia regarding their pathogenicity, patterns of distribution, host specificity, and effects on the fishes in coastal culture revealed that *Caligus epidemicus*, *C. orientalis* and *C. punctatus* are the potential "major pathogens" of cage aquaculture in Asia. A monitoring of these three species is highly recommended if cage aquaculture is to be developed into a major industry in Asia. It should be noted that other species of caligids are not to be neglected. Although sea lice presents potential threats to the aquaculture industry in Asia, regrettably, there is only a handful of specialists in Asia to help cope with this putative problem. Thus, to prepare a group of specialists to work on the sea lice of Asia is considered as one of the most indispensable preparatory works to the modernization of cage aquaculture in Asia.

Introduction

To raise fish in a cage net or net-pen placed in the sea is in essence introducing an unnatural (artificial) habitat to a natural setting. Thus, it is expected that all kinds of problems are to occur in the cage aquaculture. Although many of these problems have been encountered and solved in nearly 40 years of cage culture of salmonid fishes in Northern Europe, some problems have been attended to without much success. One of them is the problem of sea lice (Boxshall and Defaye 1993).

The modern technology of cage aquaculture originated in Norway in the 60's with farming of Atlantic salmon (*Salmo salar*) and rainbow trout (*Onchorhynchus mykiss*). The sea lice (*Caligus elongatus* and *Lepeophtheirus salmonis*) that plague the salmon farms now were then known to

occur on the wild fish and did not cause problem to the farmed fish. It was in the 70's that the infestation of sea lice in Norway became a serious problem (Hastein and Bergsjø 1976). Later, the same problem appeared in Scotland (Rae 1979), Ireland (Tully 1989), France (Messenger and Esnault 1992), and Canada (Hogans and Trudeau 1989). Faced with the problem of sea lice in the Northern Hemisphere, the Atlantic salmon was introduced to southern Chile for cage culture in the early 80's by the importation of salmon eggs free of sea lice. However, in the 90's, the problem of sea lice occurred and the causative agent, *Caligus flexispina*, is a species normally found in three species of fishes native to southern Chile (Carvajal *et al.* 1998).

For more than 20 years now, several ways of controlling and treating the sea lice have been studied and applied, in the hope of effectively

suppressing the infestation problem but to no avail. Furthermore, according to MacKinnon (1997), no less than 20% of the total yearly market value of this industry is still lost due to the problem of sea lice.

Thus, before developing cage aquaculture to a large scale in Asia, we should first study if the sea lice will pose a problem.

Pathogenicity of Sea Lice

Sea lice are natural parasites living on the body surface of fish, including the oral and branchial cavities. They feed on the mucus, epidermal cells and blood of their hosts. They are characterized by having a mouth tube with a pair of pectinate mandibles inserted in it. The mouth tube is made up of the labium and labrum and equipped close to the tip of the former is a pair of strigil (masticatory apparatus consisting of a divided dentiferous bar). At feeding, the copepod's mouth tube is applied to the surface of the fish and tissues (including mucus) of the fish are scraped off by movements of the strigil. The debris is then picked up by the mandibles which act as conveyors to move the fish tissue into the buccal cavity (Kabata 1974).

Except for the chalimus stages that are attached to a fixed place on the fish host, the preadult and adult stages of sea lice are still highly mobile, and can therefore move to practically any place on the fish body. Mechanical damage to the skin can then spread out to many parts of fish body even though only a single sea louse is present. Also, regardless of being fed or not, sea lice always cling to their host by digging into the host skin using their claw like antennae and maxillipeds. Thus, even if the host is losing only the mucus and the damage is confined to the epithelium, the mere presence of sea lice is enough to cause "stress" to fish. Under such continuous elicitation of "stress" by the sea lice, the fish lose appetite, retard from its normal growth, and eventually, die if untreated.

Artificial infestations of young Mozambique tilapia (*Oreochromis mossambicus*), black sea bream (*Acanthopagrus schlegeli*) and Malabar rockcod (*Epinephelus malabaricus*)

with sea lice have demonstrated that the host fish can die without any appreciable disease (Lin 1996). The size of the host also makes the difference in fish death. The larvae of rockcod (2-3 cm long) died within three minutes after attack by a single *Caligus epidemicus*, yet those 20 cm long young rockcod did not die until four or five days later after the attack of nearly 100 sea lice (Lin 1996).

Thus, there is no doubt that sea lice can cause a major problem to the development of cage aquaculture in Asia. They can kill the fish in the cage net and if not, will weaken the fish so as to cause them to succumb to secondary infections, or reduce the market value of the fish.

Sea Lice of Asia

It is a well-known biological phenomenon that the diversity of life is greater in the warm water than in the cold water. Since the seawater in Asia is generally warmer than that in northern Europe, there must be many more species of sea lice in the waters of Asia than in northern Europe where the cage aquaculture of salmonids has been in operation for several decades. This is part of the reason why I felt that sea lice will pose a major problem in Asia when cage aquaculture is developed to a large-scale such as the salmon farming in northern Europe.

Currently, the family of sea lice (Caligidae) is composed of 445 species attributed to 33 genera; of which, more than three-quarters are members of the genera *Caligus* and *Lepeophtheirus*. The former genus contains 239 species and the latter, 107 species. These two genera contain the species that cause problems of fish farming in the sea. Therefore, the following discussion shall be restricted to these two genera.

In contrast to the 12 species of *Caligus* and 13 species of *Lepeophtheirus* occurring in the waters of northern Europe, there are 103 species of the former genus (Table 1) and 41 species of the latter genus (Table 2) recorded from the Asian waters. However, the actual number of species of sea lice of these two genera in Asia is considered to be higher. As can be clearly seen from Tables 1 and 2, most of the recorded data

Table 1. Species of *Caligus* reported from Asia.

Species	Locality	Species	Locality
<i>absens</i>	Taiwan	<i>lagocephali</i>	India
<i>acanthopagri</i>	Taiwan	<i>lalandei</i>	Japan, New Zealand
<i>aesopus</i>	New Zealand	<i>laticaudus</i>	China, India, Japan, Malaysia, Taiwan
<i>amblygenitalis</i>	India	<i>latigenitalis</i>	Japan, Korea
<i>annularis</i>	India, Indonesia	<i>latus</i>	Australia
<i>arii</i>	India, Sri Lanka	<i>longicaudus</i>	China, India, New Zealand, Sri Lanka
<i>asymmetricus</i>	Australia, India	<i>longipedis</i>	India, Japan
<i>bicycletus</i>	India	<i>longirostris</i>	Australia
<i>bifurcus</i>	China	<i>macarovi</i>	Japan, Korea
<i>biseriodentatus</i>	China, India, Indonesia, Sri Lanka, Thailand	<i>malabaricus</i>	India, Malaysia
<i>bonito</i>	China, India, Japan, New Zealand	<i>multispinosus</i>	China, India
<i>brevicaudus</i>	India	<i>nengai</i>	India, Taiwan
<i>brevis</i>	Japan, New Zealand	<i>orientalis</i>	China, Japan, Korea, Taiwan
<i>buechlerae</i>	New Zealand	<i>oviceps</i>	Japan, Korea, Taiwan
<i>calotomi</i>	Japan	<i>pagrosomi</i>	Australia, Japan
<i>callyodoni</i>	India	<i>parapetalopsis</i>	India
<i>chiloschyllii</i>	India	<i>parvilatus</i>	Korea
<i>chrysophrysi</i>	India	<i>patulus</i>	Philippines
<i>clavatus</i>	India, Sri Lanka	<i>pelagicus</i>	India
<i>confusus</i>	China, India, Sri Lanka	<i>pelamydis</i>	New Zealand
<i>constrictus</i>	India, Sri Lanka	<i>phipsoni</i>	India
<i>cordiventris</i>	Japan	<i>planktonis</i>	India
<i>cordyla</i>	India	<i>platurus</i>	India, Sri Lanka
<i>cornutus</i>	India, New Zealand	<i>platytarsis</i>	Australia, India
<i>coryphaenae</i>	China, India, Japan, New Zealand, Sri Lanka, Taiwan	<i>polycanthi</i>	India, Japan, Taiwan
<i>cossacki</i>	India	<i>pomadasi</i>	India
<i>costatus</i>	China	<i>priacanthi</i>	India
<i>cybii</i>	China, India, Japan, Philippines, Sri Lanka, Thailand	<i>productus</i>	India, New Zealand, Sri Lanka
<i>dakari</i>	India, Sri Lanka	<i>punctatus</i>	China, Japan, Korea, Taiwan
<i>dasyaticus</i>	Australia, India, Japan	<i>quadratus</i>	India, Japan, Korea
<i>diaphanus</i>	India, Sri Lanka	<i>rapax</i>	Australia
<i>dieuzeidei</i>	Japan	<i>raniceps</i>	India
<i>eleutheronemi</i>	China, Malaysia	<i>regalis</i>	Australia, India
<i>elongatus</i>	India, New Zealand	<i>reniformis</i>	India
<i>epidemicus</i>	Australia, New Zealand, Philippines, Taiwan, Thailand	<i>robustus</i>	India, Sri Lanka
<i>epinepheli</i>	Australia, India, Japan, Sri Lanka, Taiwan	<i>rotundigenitalis</i>	China, India, Malaysia, Taiwan
<i>fistulariae</i>	Japan	<i>russelli</i>	India
<i>fortis</i>	Australia, India	<i>savala</i>	India, Sri Lanka
<i>fugu</i>	Japan	<i>sciaenae</i>	India
<i>furcisetifer</i>	India	<i>sclerotinosus</i>	Australia, Japan
<i>glandifer</i>	Japan	<i>sensorius</i>	Australia
<i>hamruri</i>	India	<i>seriolae</i>	Japan, Korea
<i>holocentri</i>	India	<i>spinosus</i>	India, Japan
<i>hoplognathi</i>	Japan, Korea	<i>stokesi</i>	Australia
<i>indicus</i>	India	<i>tenax</i>	India, Sri Lanka
<i>infestans</i>	Australia, India, Indonesia, Sri Lanka, Thailand	<i>tanago</i>	Australia, Japan, Korea
<i>kahawai</i>	New Zealand	<i>triabdominalis</i>	Australia
<i>kanagurta</i>	India, Korea, Malaysia, Taiwan	<i>triangularis</i>	Japan
<i>kirtii</i>	India	<i>truncatogenitalis</i>	Australia
		<i>tylosuri</i>	India
		<i>undulatus</i>	China, India
		<i>unguidentatus</i>	China, India
		<i>willungae</i>	Australia

are from Japan and India; with a few from Australia, China, Korea, New Zealand, Taiwan and Sri Lanka; almost none from Indonesia, Malaysia, Philippines and Thailand; and none at all from Bangladesh, Cambodia, Iran, Myanmar, Pakistan, Singapore and Vietnam. Of course, many of the species recorded so far will be found again from where they have not been reported previously.

Table 2. Species of *Lepeophtheirus* reported from Asia.

Species	Locality
<i>aesopus</i>	India, Sri Lanka
<i>anguilli</i>	India
<i>argenteus</i>	New Zealand
<i>atypicus</i>	Taiwan
<i>brachyurus</i>	India, Sri Lanka
<i>bychowskyi</i>	Japan, Korea
<i>chantoni</i>	Japan
<i>crassus</i>	India
<i>distinctus</i>	New Zealand
<i>edwardsi</i>	China
<i>elegans</i>	Japan, Korea
<i>elongatus</i>	Australia
<i>erecsoni</i>	New Zealand
<i>goniistii</i>	India, Japan, Korea, Sri Lanka
<i>haplogenyos</i>	Japan
<i>hastatus</i>	Japan, New Zealand
<i>heegaardi</i>	New Zealand
<i>hexagrammi</i>	Japan, Korea
<i>histiopteridi</i>	New Zealand
<i>hospitalis</i>	China, Japan
<i>kabatai</i>	India
<i>lagocephali</i>	India
<i>lateolabrax</i>	China
<i>latigenitalis</i>	India
<i>longipalpus</i>	India, Sri Lanka
<i>longiventris</i>	China, Japan
<i>nordmanni</i>	Japan, New Zealand
<i>paralichthydis</i>	Japan, Korea
<i>parviventris</i>	Korea
<i>parvulus</i>	Japan
<i>plectropomi</i>	Australia
<i>polyprioni</i>	New Zealand
<i>rotundiventris</i>	India, Sri Lanka
<i>salmonis</i>	Japan
<i>scutigera</i>	Japan, Korea, New Zealand
<i>sekii</i>	Australia, Japan, New Zealand
<i>semicossyphi</i>	Japan, Korea
<i>sheni</i>	China, Japan
<i>shiinoi</i>	India
<i>spinifer</i>	India, Sri Lanka
<i>tuberculatus</i>	Korea

But, based on the recent works carried out in Korea and Taiwan, it seems that some sea lice new to science were found. For instance, both Korea and Taiwan are geographically located close to Japan and share many identical constituents of marine fauna with Japan. Yet, new species of sea lice were recorded recently from both places (Kim 1993, 1995; Lin *et al.* 1994, 1996; Ho *et al.*, in press), indicating that there probably are many new species of sea lice in Asian waters waiting to be discovered and studied.

In general, only about 16% of the fish have been examined for sea lice, and most of those yet-to-be-examined fish are from the tropical and subtropical waters. This is a good indication that there must be many more new species of sea lice living in the waters of Asia waiting to be discovered and studied.

It is regrettable to note that even though there are more species of sea lice in Asia, there are not more specialists of sea lice in Asia than in northern Europe. As far as I am aware, there are only six sea lice specialists in Asia, one in Australia (Dr. J. Brian Jones of Animal Health Laboratory), three in Japan (Dr. Kunihiko Izawa of Mie University, Dr. Kazuya Nagasawa of Far Sea Fisheries Research Institute, Dr. Shigehiko Urawa of National Salmon Resources Center) and one each in Korea (Dr. Il-Hoi Kim of Kangreung National University) and Taiwan (Dr. Ching-Long Lin of National Chiayi Institute of Technology). India is one of the only two countries in Asia where the sea lice fauna is better known, but, currently, there is no specialist working on sea lice in this country. Consequently, the shortage of sea lice specialists in Asia is considered to be the major roadblock for the development of cage aquaculture in this part of the world.

Sea Lice of Fishes Cultured in Asia

In Asia, no less than 20 species of fishes have been successfully cultured in brackish or salt water. Therefore, in assessing the potential problem(s) that sea lice may cause to the cage aquaculture, it would be more informative to check first which species have caused problems

in the past in Asia. A search of literatures revealed that the following ten species have caused fish kill or mortality in Asia:

Caligus acanthopagri Lin, Ho & Chen – caused mortality to black porgy (*Acanthopagrus schlegeli*) (Lin *et al.* 1994) and four other species [black sea bream, Malabar rockcod, Mozambique tilapia, and common spade fish (*Scatophagus argus*)] (Lin 1996) cultured in coastal brackish ponds in Taiwan.

Caligus epidemicus Hewitt – caused mortality to Mozambique tilapia (Lin and Ho 1993) and ten other species [black porgy, milkfish (*Chanos chanos*), Malabar rockcod, giant perch (*Lates calcarifer*), large scale mullet (*Liza macrolepis*), grey mullet (*Mugil cephalus*), common spade fish, blue tilapia (*Oreochromis aurea*), three-striped tigerfish (*Terapon jarbua*), and snubnose pompano (*Trachinotus blochii*) cultured in coastal brackish ponds in Taiwan (Lin 1996).

Caligus orientalis Gussev – caused mortality to Mozambique tilapia cultured in brackish water ponds in Xiamen, China (Hwa 1965); to eight species of fishes (black sea bream, black porgy, milkfish, Malabar rockcod, giant perch, largescale mullet, grey mullet, and Mozambique tilapia) cultured in coastal brackish ponds in Taiwan (Lin 1996); and to pen-cultured rainbow trout (*Oncorhynchus mykiss*) in Hokkaido, Japan (Urawa and Kato 1991).

Caligus patulus Wilson – caused mortality to milkfish cultured in coastal brackish ponds in Panay, Philippines (Lavinia 1977, Jones 1980).

Caligus punctatus Shiino – caused mortality to 12 species of fishes (black sea bream, black porgy, milkfish, Malabar rockcod, Japanese sea bass, giant perch, largescale mullet, grey mullet, blue tilapia, Mozambique tilapia, three-striped tigerfish, and snubnose pompano) cultured in coastal brackish ponds in Taiwan (Lin 1996).

Caligus rotundigenitalis Yü – caused mortality to black porgy (Lin *et al.* 1994) and three other species (black sea bream, Malabar rockcod, and common spade fish) cultured in coastal brackish ponds in Taiwan (Lin 1996).

Caligus spinosus Yamaguti – caused outbreaks of disease on cultured yellow tail (*Seriola*

quinqueradiata) in Japan (Fujita *et al.* 1968).

Lepeophtheirus longiventris Yü and Wu – caused mortality to spotted halibut (*Verasper variegatus*) pen-cultured in Iwate Prefecture, Japan (Ogawa, pers. comm.).

Lepeophtheirus paralichthydis Yamaguti and Yamasu – caused mortality to olive flounder (*Paralichthys olivaceus*) pen-cultured in Kyoto Prefecture, Japan (Ogawa, pers. comm.).

Lepeophtheirus salmonis (Krøyer) – caused lesions to chum salmon (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*) pen-cultured in Hokkaido, Japan (Nagasawa 1993, Urawa 1998).

It is interesting to note that, so far, the sea lice problem in Asia is largely known in countries in the Far East. However, this is not an assurance that the problem will not occur in other parts of Asia.

Among the 10 species of sea lice mentioned above *C. epidemicus* is considered to be the most dangerous one. In addition to the low host-specificity, it has been reported in 15 species of fish and one species of shrimp (Ruangpan and Kabata 1984) widely distributed in Asia, ranging from Victoria, Australia (Hewitt 1971) in the Southern Hemisphere to Tainan, Taiwan (Lin and Ho 1993) in the Northern Hemisphere. Besides, *C. epidemicus* is also found in plankton samples (Hewitt 1971), indicating that it is capable to disperse without "hitch hiking" on the wild fish. Although the geographical distribution of *C. orientalis* and *C. punctatus* is not as wide as *C. epidemicus*, due to their relatively low host-specificity, they are also considered to be the potential pathogens in the development of cage aquaculture in Asia.

Conclusion

Cage aquaculture has been in practice for several years in Asia but the problem of sea lice has not yet been escalated to an alarming state. This is largely due to the fact that the establishment of cage aquaculture has not yet attained a large-scale operation like the farming of salmonids in cold-water countries. Therefore, it is utterly important to first conduct studies on sea

lice before intensive promotion of this industry is carried out.

Without doubt, the transmission of sea lice occurs from the wild fish to the farmed fish, between farms, and possibly, also from the farmed fish to the wild fish (Boxshall and Defaye 1993). Therefore, to prevent and control the outbreak of sea lice, we need, in addition to a rich information on the sea lice fauna of Asia, a thorough knowledge of the life cycle, population dynamics, and transmission mechanisms of each species. These tasks are to be carried out by the sea lice specialists. Yet there is a limited number of specialists in Asia who can lead in these essential basic research. Consequently, to prepare a group of specialists to work on the sea lice of Asia is considered as one of the most indispensable preparatory works to the modernization of cage aquaculture in Asia.

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COUNTRY PAPERS

Cage Aquaculture in Australia: A Developed Country Perspective with Reference to Integrated Aquaculture Development Within Inland Waters

G.J. GOOLEY¹, S.S. DE SILVA², P.W. HONE¹, L.J. MCKINNON¹ and B.A. INGRAM¹

¹Marine and Freshwater Resources Institute
Aquaculture Program
Private Bag 20
Alexandra, Victoria 3714
Australia

²School of Aquatic Science and Natural Resources Management
Deakin University
P.O. Box 423
Warrnambool, Victoria 3280
Australia

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Abstract

Over the last decade, cage culture practices have gained significant prominence in Australian aquaculture. Commercial use of cages within inshore coastal waters predominantly includes the farming of Atlantic salmon, *Salmo salar*, and southern bluefin tuna, *Thunnus maccoyii*, with a collective production of >12,000 tons worth almost AUD\$ 150 million per annum. To a lesser extent rainbow trout, *Oncorhynchus mykiss*, and a number of new and developing species are also now being cultured in cages at sea, including snapper, *Pagrus auratus*, black bream, *Acanthopagrus butcheri*, and mulloway *Argyrosomus hololepidotus*. Existing commercial use of cages for aquaculture within Australian inland waters is primarily restricted to barramundi, *Lates calcarifer*, farming in freshwater lakes and purposely built freshwater farm ponds. However, despite such limited application to date, and indeed despite Australia's relatively arid environment, there is considerable potential for aquaculture development within inland waters in which novel, cage culture practices may be applied on an integrated basis with irrigated farming systems. Trials utilizing relatively small floating cages as a principal culture system component, are presently underway in a range of developmental systems which demonstrate the integration of aquaculture and irrigated agriculture to enhance farm productivity and water use efficiency, and the use of otherwise wasted aquatic resources such as inland saline groundwater and industrial and domestic effluent.

Introduction

Cage culture practices have gained significant commercial prominence within the Australian aquaculture industry over the last decade. Commercial use of relatively large-scale cages within inshore coastal waters was effectively pioneered by the salmonid industry in Tasmania during the mid 1980's. At present, cage farming in Australia predominantly includes the farming of Atlantic salmon, *Salmo salar*, southern bluefin tuna (SBT), *Thunnus maccoyii*, and to a lesser extent rainbow trout, *Oncorhynchus mykiss*,

snapper, *Pagrus auratus*, mulloway, *Argyrosomus hololepidotus*, and black bream, *Acanthopagrus butcheri*. Specifically, the use of relatively conventional "Norwegian-style" cages (also referred to as "polarCirkel®-type" cages) for marine farming is integral to the success of the respective salmon and SBT industries, collectively the major finfish aquaculture sectors in Australia.

Existing commercial use of cages for aquaculture within Australian inland waters is primarily restricted to barramundi (sea bass), *Lates calcarifer*, farming in purposely built

freshwater farm ponds in north Queensland, and in the freshwater Lake Argyle in northwestern Western Australia. However, despite such limited application to date, and despite Australia's relatively arid environment, there is considerable potential for aquaculture development within inland waters in which novel, cage culture practices may be applied on an integrated basis with irrigated farming systems and within other surface waters. Indeed relatively small-scale cages (typically 1-20 m³ capacity) are presently being used for a variety of small or experimental scale pilot production trials as part of both commercial farming operations and research and development projects in many parts of the country, particularly within the Murray-Darling basin.

Status of Australian Aquaculture

By global standards, the Australian aquaculture industry, though relatively small is diverse in terms of species farmed, sites under

Development and systems employed. The total production for the Australian aquaculture industry for 1997-98 exceeded 30,700 tons and 9.3 million juveniles, together worth approximately AUD\$ 517 million. This represents an overall increase of 16.5% over the 1996-97 production, with the average annual production over the last ten years increasing by 16% in tonnage and 28% in value. Of the 1997-98 total, the finfish sector accounts for over 16,500 tons (54%), worth approximately AUD\$ 186 million (36%); a 33.2% increase in value on the 1996-97 production. This sector also constitutes the largest tonnage in Australian aquaculture production, and is second only to pearl oyster production in value (>AUD\$ 229 million), the latter being the most valuable Australian aquaculture sector (Figs. 1 and 2) (O'Sullivan and Roberts 1999). For purposes of comparison, it should be noted that at the time of preparation of this paper the AUD\$ exchange rate in US currency was approximately US\$ 0.65.

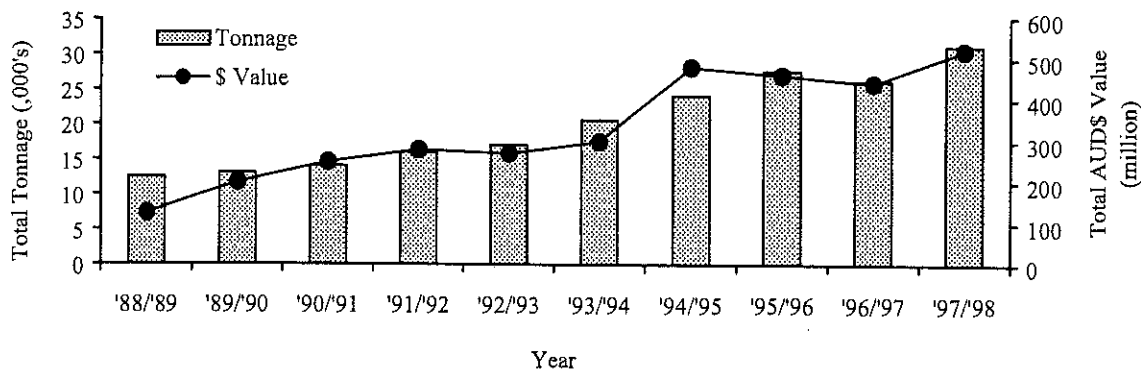
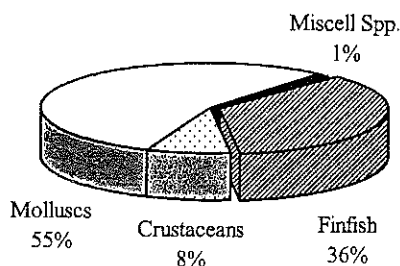


Fig. 1. Australian aquaculture production value and tonnage since 1988-89.

By Tonnage



By Value

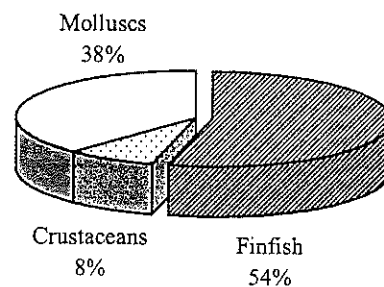


Fig. 2. Australian aquaculture production in value and tonnage by key sectors in 1997-98 (after O'Sullivan and Roberts 1999).

Table 1. Australian aquaculture production of finfish for 1997-98 (from O'Sullivan and Roberts 1999).

Species	Production (tons)	Hatchery (,000's)#	Value (\$,000)
Atlantic salmon	7,072.0	0	60,945.2
Chinook salmon	NDA	NDA	NDA
Brook trout	1.3	0	8.7
Brown trout	4.0	844.4	520.3
Rainbow trout (f/w)	2,736.1	457.2	17,445.8
Rainbow trout (s/w)	500.0	NA	3,750.0
European carp	0.5	0	0.5
Australian bass	0	396.5	111.0
Eel-tailed catfish	0	18.1	19.0
Golden perch	87.1	1,174.8	1,683.5
Silver perch	165.3	678.9	1,773.1
Murray cod	1.5	301.8	299.5
Eastern cod	0	40.0	20.0
Short finned eels	200.3	NA	2,103.0
Long finned eels	18.3	NA	237.0
Barramundi	633.4	0	6,999.1
Southern bluefin tuna	5,140.0	NA	87,223.0
Mulloway	6.8	0	50.0
Misc. marine ¹	5.0	67.1	98.6
Native aquarium fish	NA	129.6	307.8
Exotic aquarium fish	NA	5,081.1	2,477.3
Subtotal	16,571.6	9,189.5	186,072.4

Sources: Information provided by State and Territory Fisheries Departments and Industry.

#= Hatchery production not for sale to commercial farms. NA= not applicable, NDA= no details available.

1: Pilot scale culture of tarwhine, black bream, greenback flounder, snapper and Australian bass (note: production figure is from snapper).

Specific data on cage culture production are not readily available, however the major finfish species are southern bluefin tuna and Atlantic salmon, both of which are produced either predominantly (salmon) or exclusively (SBT) in cages at sea. SBT and Atlantic salmon production for 1997-98 were 5,140 and 7,072 tons worth AUD\$ 87.2 million and AUD\$ 60.9 million respectively (Table 1). Of these two species, SBT production has shown the greatest growth with an increase in value of 117% over the previous year (O'Sullivan and Roberts 1999). However, historically the Tasmanian salmon industry has exhibited an average annual compound growth rate of around 15% and at this rate, production is expected to double within the next five years (Smithies 1999). Recent industry sales revenue targets have projected the total Australian aquaculture industry to be worth AUD\$ 2.5 billion by 2010, with salmon contributing up to AUD\$ 1 billion and SBT up to AUD\$ 300 million (Hussey 1999).

Other key cultured finfish species largely reliant on cage production include marine and freshwater production of barramundi, and marine production of rainbow trout, snapper, black bream and mulloway. Specifically, sea cage production of rainbow trout in 1997-98 was 500 tons, with a value of AUD\$ 3.75 million; an increase in value of 250% over the previous year. Pilot production of marine finfish in 1997-98, predominantly mulloway, snapper and black bream, collectively was in the order of 11.8 tons, worth almost AUD\$ 150,000. Production of barramundi in 1997-98 was 633 tons, worth about AUD\$ 7 million, not all of which was from cage culture; an overall increase in value of about 35% on the previous year (O'Sullivan and Roberts 1999) (Table 1). Of the total barramundi production, the majority was produced in cages in freshwater ponds in northern Queensland (O'Sullivan and Roberts 1999; Lobegeiger 1999), although an additional 50-100 tons per annum of barramundi is also known to be produced from

freshwater cages at Lake Argyle in northwestern Western Australia.

The general location of the major cage culture production of key marine and inland species in Australia is shown in Fig. 3.

Representative examples of the major Australian marine and inland cage culture operations, systems and resources are pictorially presented in Figs. 4 and 5, respectively.

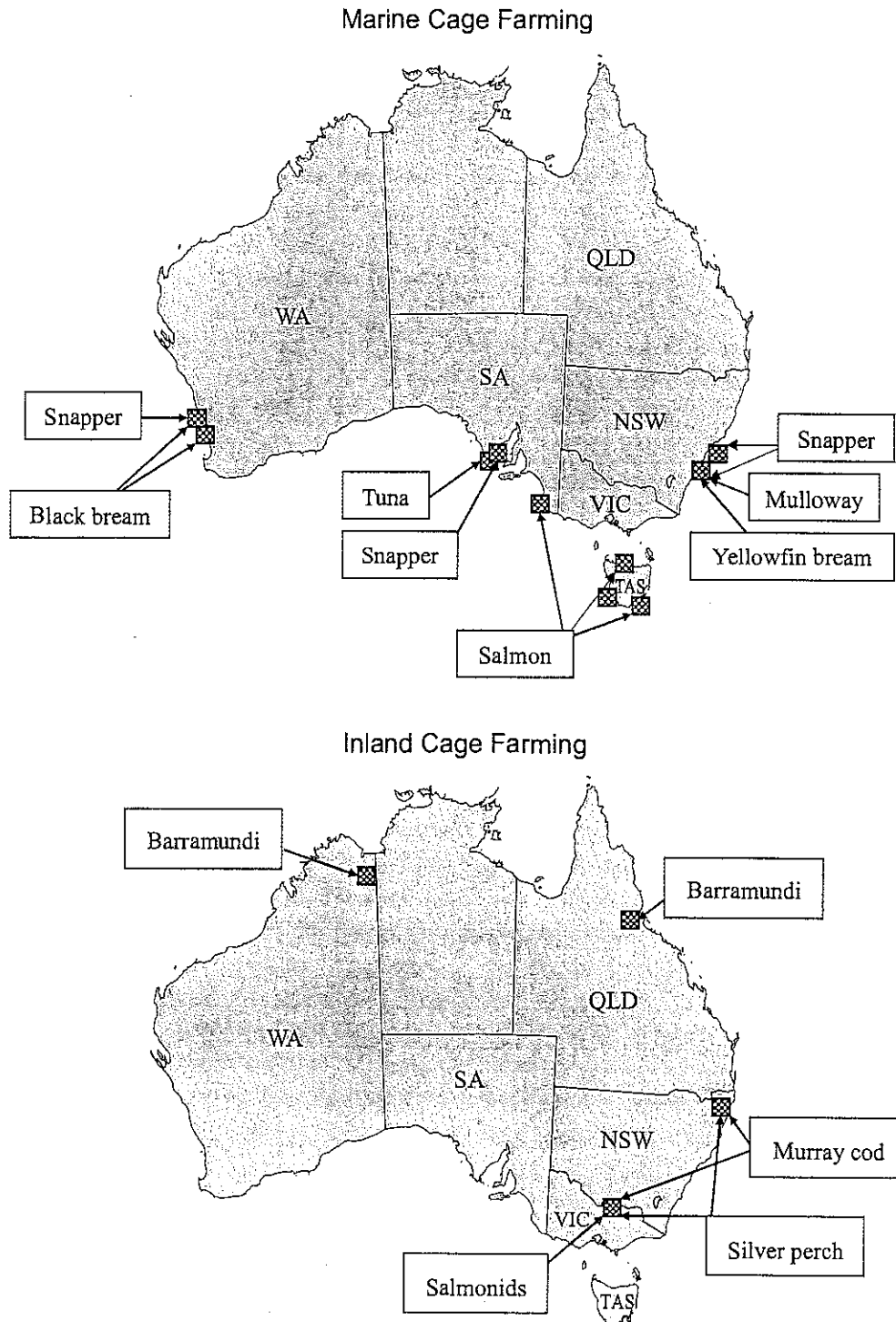


Fig. 3. General location of major marine and inland cage culture sites in Australia.

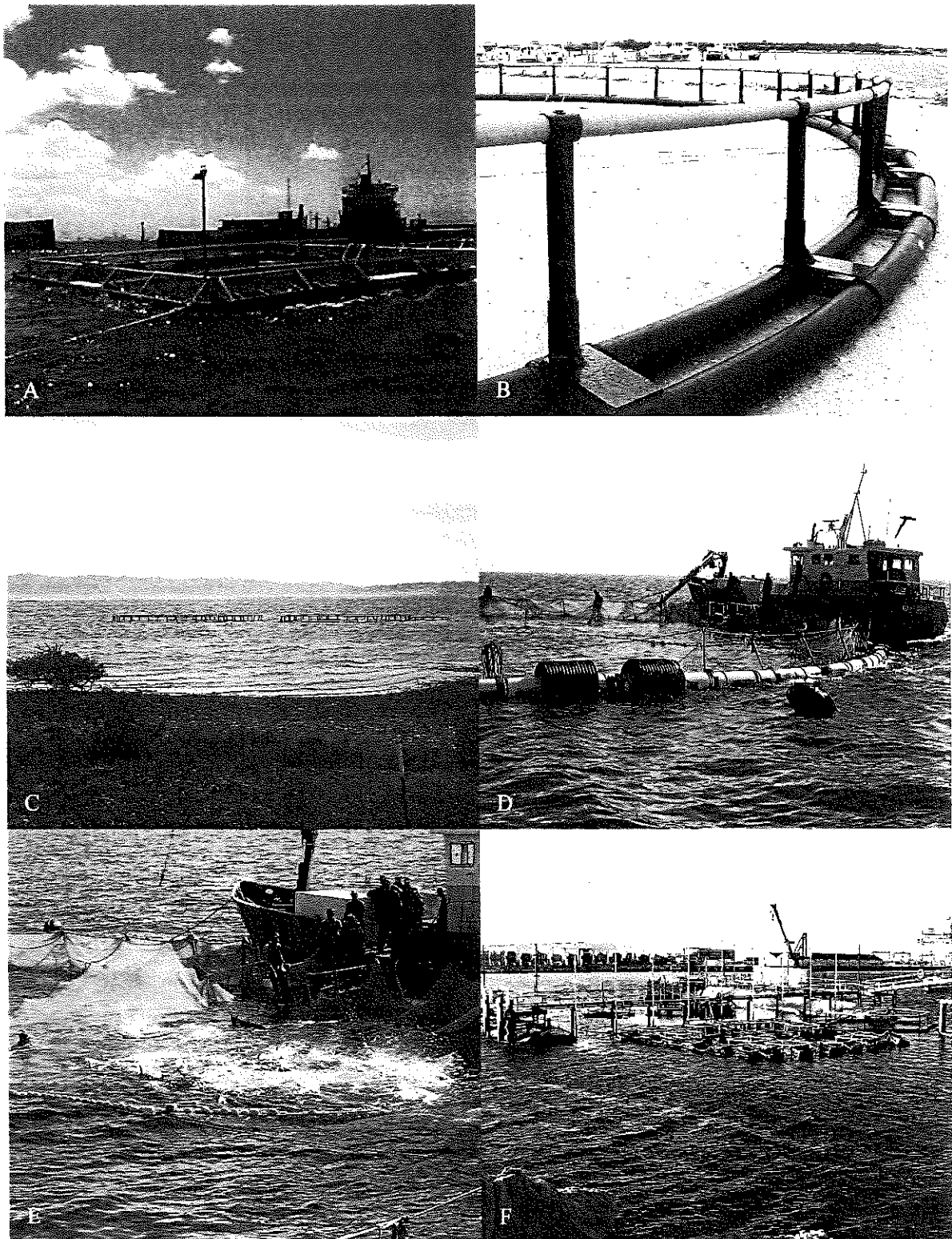


Fig. 4. Examples of marine cage culture systems in Australia. A) Snapper cages in Botany Bay (courtesy of NSW Fisheries); B) "Norwegian style" cage collars used for snapper and black bream at Jurien Bay in Western Australia; C) "Norwegian style" snapper cages in Spencer Gulf, South Australia; D), E) Tuna cages near Port Lincoln, South Australia; F) Black bream cages at Fremantle in Western Australia.

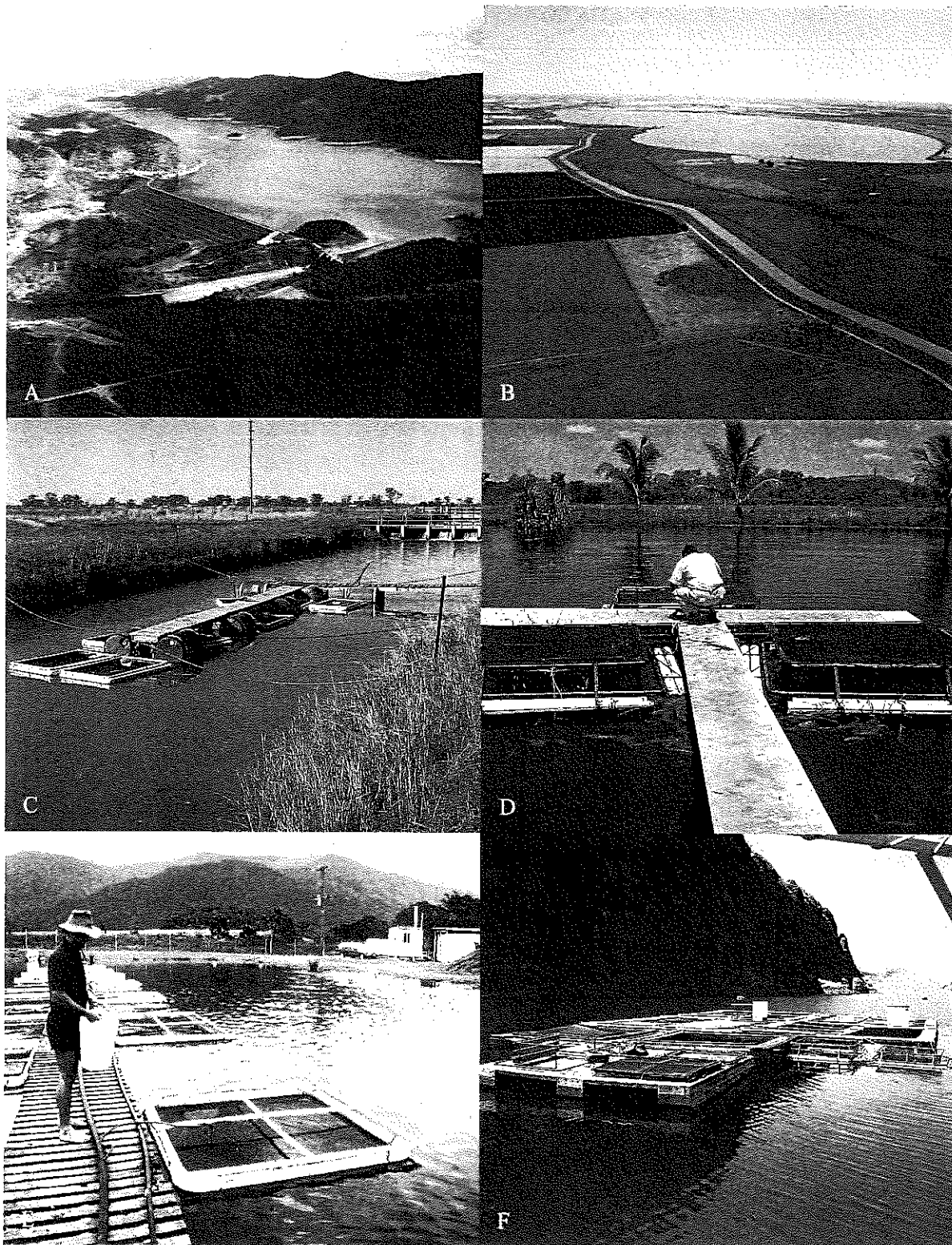


Fig. 5. Examples of inland cage culture resources and systems in Australia. A) Irrigation storage reservoir in the Murray-Darling basin, Victoria; B) Intensive irrigated agriculture in the Murray-Darling basin; C) Integrated irrigation cage culture trials in the Murray-Darling Basin, Victoria; D) Commercial barramundi cage culture in freshwater ponds in the Ord River Irrigation Area in northwest Western Australia; E) Commercial barramundi cage culture in freshwater ponds in northern Queensland (courtesy of Queensland Department of Primary Industries); F) Commercial barramundi cage culture in Lake Argyle in north-west Western Australia.

Marine Cage Culture

Salmonids

Tasmania

Majority (about 80%) of the Australian marine cage production of Atlantic salmon and rainbow trout occur in the inshore waters of the Huon and Derwent estuaries of southeastern Tasmania. The remaining production occurs in the Macquarie Harbour area on the west coast of Tasmania, although pilot scale production, has also now commenced in the Tamar River estuary on the north coast. At present, a total of 38 marine farming leases are on issue for salmonid production in Tasmania, with over 300 cages in the water. The cages range in size from 65 m to 120 m circumference, with the majority (>48%) being 80 m in circumference. The cages are located in varying depths of water from 15 m to 40 m, although the majority is located in depths of 15-30 m. Shore to cage distances range from 100 m to 1.5 km, although at one location in the Macquarie Harbour, cages are located approximately 3-4 km offshore.

All cages (also referred to as pens) are locally manufactured following a standard design, incorporating a separate floating collar and a net bag. Collars are single or double configuration, of 200-300 mm diameter pipe, constructed of foam-filled, high density polyethylene (HDPE), and with either steel or moulded HDPE stanchions. Net bags are typically 12-25 m deep and of knotless poly or nylon mesh. Predator nets, when used, are typically of larger, 100-150 mm square mesh.

Feeds are exclusively extruded pellets and FCR's of about 1.3:1 (live weight) are routinely achieved. The cages are serviced daily by boat from shore-based facilities for feeding, monitoring and mortality retrieval. Feeding occurs in a variety of methods, including boat-mounted water/air cannons and auto feeders, the latter of which may also be fitted with electronic feeding monitors. A more recent trend is towards the use of underwater video camera surveillance to monitor real time feeding response. Stocking densities range from 5 to 15 kg/m³ and the typical

production cycle ranges from 12 to 15 months for a 60-120 g smolt (in land-based tanks and raceways), followed by a further 12-15 months for a 3.5-4 kg fish ready for sale. Ambient water temperatures typically range from 8 to 18°C, although summer temperatures can occasionally reach 20°C. Currents are relatively low at <10 cm/sec and swells are typically no more than 1 m, although up to 3.5 m swells have been experienced.

Industry practice dictates that a minimum distance buffer of one km exists between farms managed by different operators, although such distances may be reduced between jointly operated farms. Cages are periodically relocated to different positions within the lease area to allow fallowing of areas within the site. Environmental evaluation of new lease areas typically involves an initial environmental assessment at fixed control sites, including extensive analysis of benthic fauna, sediment chemistry, currents and bathymetric profile. Ongoing environmental monitoring is then carried out as part of Government prescribed license conditions, including six monthly video surveillance of the adjacent benthos along set transects to determine the need for fallowing in impacted areas.

The major problems facing the salmonid industry in Tasmania include the impact of predators such as seals and, to a lesser extent sharks, which also stress fish and disturb fish feeding patterns, and occasionally juvenile jellyfish which block the gills of fish. Particularly troublesome seals have previously been captured alive by the industry under permission and relocated by road to be released in other areas around the Tasmanian coast, only to find the same animals sometimes returning to their original point of capture. One operator is presently trying the possibility of using a fully enclosed bag system of cage culture to reduce the impacts of predator disturbance.

Other salmonid production

Cage culture of Atlantic salmon has also recently commenced in one site at Robe on the southeast coast of South Australia. This is a relatively small operation which was established in

an area with a cold natural upwelling current. Water temperatures are largely moderated from surrounding ambient sea temperatures, and range from 14 to 18°C. The site is about 2 km offshore and although relatively exposed to the adjacent oceanic environment, it is located in the lee of an existing reef which offers some protection from the often huge prevailing seas. Although actual production to date is only 12 tons, projected capacity in this area is estimated at 2000 tons in the future as more sites and cages are established.

At present, there is no marine cage culture of salmonids in Victoria, although sites are being evaluated near the entrance to Port Phillip Bay. Based on the success of recent land-based, seawater tank trials, sea cage trials have now been proposed to assess feasibility for marine production of both Atlantic salmon, rainbow trout and brown trout, *Salmo trutta*, in this area. The major limiting factor for cage production of salmonids in this area is seen to be the ambient summer sea temperatures, which at times can reach 23°C.

Tuna

Cage culture production of SBT is based on the grow-out of fish taken by purse seine nets on a seasonal basis from the wild fishery in the Great Australian Bight off the southern Australian coast. Fishing for tuna occurs from as early as November and continues up to May-June. The captured fish are towed in cages from the point of capture, at a speed of <2 km/hr, a distance of up to 400 km to the cage culture facilities near Port Lincoln in the Spencer Gulf, South Australia. This process takes about one to five weeks. Fish are held at upwards of 165 tons per tow cage (generally these are either of the "Norwegian-style" or "Bridgestone"-type), and on arrival are transferred via swim-through doors to growout cages (120 m circumference/40 m diameter; 15-17 m deep) at a density of about 40-45 tons/cage (2.5 kg/m³, with a final density of 4 kg/m³). Fish are counted using a video system during the transfer and 150 fish were sampled for weight as part of the quota verification. This fishery is managed under a tripartite agreement among Japan, New Zealand and Australia with the total

allowable catch set at 11,500 tons, including the Australian quota set at 5,300 tons/annum. Up to 80 growout cages are presently in use spread across twelve, 20 ha farm leases (Lee 1998). The majority of the cages are located in about 18-25 m of water, 1-7.5 km from the mainland and 2-18 km from the main service center at Port Lincoln. Water temperatures in this area typically range from a low of 14°C during winter to a maximum of about 24°C during summer. Cages are of similar "Norwegian-style", circular, floating design and construction to the salmon cages in Tasmania. This include an outer predator net to protect the inner fish net bag, and are locally manufactured in Port Lincoln. They are moored using four-six, one ton "Danfors-type" anchors, with sea swells at some sites reaching 4 m at times.

Frozen pilchards are the main diet, although semi-moist, extruded pellets are being developed and tried. Up to 3 tons (wet weight) of pilchard feed/cage/day, six days a week, are fed out by hand. FCR's for pilchard-fed fish are typically >10:1 (live weight), although FCR's of about 8:1 have been achieved in trials using the semi-moist feed (Glencross *et al.* 1999). Cage fattening of tuna, which are initially about 16-20 kg in weight, continues for about three to eight months. The production process is based on a serial harvest basis, in which marketable fish (about 20-35 kg) are periodically harvested, ultimately leaving fewer and increasingly bigger fish, with stocking density remaining relatively constant. Harvesting of tuna from cages is carried out by running a net through to concentrate the fish. Divers then "swim" the fish individually to an adjacent boat moored to the cage where they are immediately slaughtered according to Japanese market requirements. Cages are removed from the water for maintenance and storage at the end of the season.

Environmental guidelines dictate that cages must occupy no more than 30% of the farm lease area, and that there is a minimum space of 1 km between lease sites and a minimum of 1 km from shore. The cages were moved to the present more remote locations, from the Port Lincoln harbor, where they were previously located, following a

major fish kill in 1996. This mortality occurred as a result of a cyclonic storm event which disturbed fine sediment in the benthos at the cage sites, which in turn clogged the gills of the fish. Increasingly, the industry trend is towards moving the cages to more remote oceanic locations in order to access better quality water, to further spread the farm sites for overall environmental management purposes and reduce the risk of farming all the tuna within the Port Lincoln region. The former sites at Boston Bay, which are nearer to shore, are considered to be more suitable to the more fragile, relatively lower value cage culture species such as snapper and possibly yellowtail kingfish. Routine operational problems with tuna cage farming tend to be primarily related to predator control, mostly in relation to seals and sharks, as well as the practicalities and costs associated with biofouling, including net replacement, cleaning and general maintenance.

Last year it was estimated that seal predation, particularly from the New Zealand fur seal, cost the tuna industry AUD\$ 6 million. To combat this loss farmers have developed a variety of technologies. The most promising to date is the development of above and below water electric fences. The below water fences are based on the shark nets developed off the South African beaches. While above water, the method developed is based on that used for land-based stock control. However, neither method is able to stop the seals from jumping clear over the outer structures and a considerable amount of research is therefore being undertaken on this issue. In Australia, seals are a protected species so control must not injure the seals. At present, farmers can obtain a license to trap seals and relocate them; however, they usually return to the site within weeks of being released, as has also been reported in Tasmania.

Snapper, Mulloway and Black Bream

These three species are being farmed in cages to varying degrees in a number of States, but the industry is still in the early stages of development. Specifically, snapper are being farmed in combination with black bream at one

site near the Jurien Bay, just north of Perth in Western Australia, at two farms in Spencer Gulf in South Australia, and at two farms on the central coast of New South Wales, one of which is also producing smaller quantities of mulloway and yellowfin bream, *Acanthopagrus australis*. Black bream are also being farmed commercially in relatively small-scale cages within the Fremantle Harbour, south of Perth, primarily as a nursery operation to supply hatchery-bred, young-of-the-year seedstock for stock enhancement purposes.

South Australia

The South Australian farms presently stock marine cages with weaned juveniles weighing about 5 g, for a 12 month growout cycle producing fish from 400 g to 1 kg in weight. The cages are similar in design to the circular, floating cages used by the salmon and SBT farmers, but with a diameter of up to 24 m (circumference 80 m) and a production capacity of up to 10 tons. The cage sites are relatively near shore, ranging from 100 m to 1-2 km, to provide the necessary protection to the smaller fish from high seas. Water temperatures range from 14 to 24 °C and water depth is typically 10-20 m, but with a high degree of tidal flushing. Although production to date has been relatively low, the production estimate for both farms combined in the current season is in the order of 130 tons, with both sites expanding to a projected combined level of 350 tons of product in the near future, and up to 1,500 tons within three to five years. Although there are no problems with predators, however biofouling of nets is proving to be a problem.

New South Wales

Two farms in New South Wales differ in the sense that one is utilizing a floating, circular cage (80 m circumference) at a site located approximately 3.5 km offshore in about 20 m of water, whereas the other is adjacent (about 150 m) to a jetty in relatively shallow water (5-6 m) within a protected harbour, and is using a combination of several 25-100 m² steel-framed cages. Water temperatures range from 14 to 24 °C at the more northerly site and 12.5-24 °C at the more southerly

site. Both operations are in the preliminary developmental stages of operation and projected production capacity is 30 tons and 100 tons for the inshore and offshore sites, respectively.

The major problems experienced by marine cage farmers in NSW are caused by the difficulty of gaining access to suitable sites as a result of public perceptions about the industry. Consistent with other states and cage culture operations, community perceptions about the loss of visual amenity had a significant impact on the availability of sites. The trend therefore is towards offshore sites (>4 km from shore) which are less visible but are physically more exposed, largely to alleviate community sensitivities. This however leads to various logistical problems for fish farmers associated with operating at offshore sites, such as net maintenance, security and general servicing of the site. The economics of the scale of farm operations therefore become critical.

Western Australia

The operation at Jurien Bay for snapper and black bream consists of ten, 60 m and ten, 20 m circumference, floating circular cages located approximately one km offshore in about 10 m of water. The net bags are mostly of knitted monofilament and predator nets are typically not used in the water, but some bird netting is used. The actual cage site is situated in the lee of a prominent limestone reef running parallel to the shore, which provides some limited protection to the cages. Current velocity ranges from 0.383 m/sec in winter to 0.437 m/sec in summer, and wave swells are known to reach two meters at times with wind gusts up to 100 km/h. Ambient water temperatures range from 11 to 22 °C. A tender vessel services the cages on a daily basis, weather permitting, for feeding and routine maintenance. Projected production capacity is in the order of 200 tons at a stocking density of 10 kg/m³.

Major problems experienced to date include mooring failure, resulting in stock losses, variable growth due to seasonal fluctuation in ambient temperatures, predatory seals and birds (mostly cormorants), and logistical difficulties and costs associated with fish feeding and net main-

tenance. Typically at least two nets of each size are required for routine production purposes. Accordingly, industry trends in Western Australia suggest that with limited availability of suitably protected, inshore cage sites, marine farming of finfish such as snapper and black bream for growout purposes is likely to take place either in submersible cages at relatively deep (>30 m), offshore sites, or in land-based facilities.

Industry Trends and Issues

The development of the Australian marine finfish aquaculture industry is dependent on the development of technologies that utilize either exposed offshore sites for cage culture, or land-based tanks and raceways. Australia has relatively limited sites that are considered suitable for marine cage culture, with most offshore waters being exposed and shallow. Western Australia, with over 12,500 km of coastline has probably only two to three sites, with most of these being existing marine reserves or near sensitive marine habitats. Existing developments overseas in multi-bay, exposed offshore technology are being explored for both the salmon and tuna industries. However, this technology is expensive and depends on farm sizes in an order of magnitude larger than those existing in Australia. Bridgestone cages capable of withstanding waves up to 5-6 m are being examined for the tuna industry in the Port Lincoln region. Both the salmon and tuna industries have the capability for a three and twofold increase, respectively, in tonnage capacity before existing leases are fully used. In Western Australia, the industry is exploring the development of a new local design of submersible cages similar to that used in the Mediterranean for sea bass and sea bream. It is proposed to try a pilot facility with snapper off Jurien Bay. Other farmers have visited similar ventures overseas, but at present the establishment cost and high service costs have precluded either the salmon or tuna industries from establishing a pilot facility. The development of submersible fish cages will allow farms to be sited in areas where visual amenity currently precludes fish farming.

Onshore raceway development for marine finfish farming is seen as a viable alternative for smaller species like snapper, and other new and developing species such as King George whiting, *Sillaginodes punctata*, and Westralian jewfish, *Glaucosoma hebraicum*. Several farms have submitted plans for approval to try this technology. For states like Western Australia with large exposed coastlines and few port facilities, this may offer the best opportunity for marine coastal finfish farming.

Species diversification in the tuna industry is important given the overfished status of the wild fishery. Farmers are currently trying the fast growing yellowtail kingfish, *Seriola lalandi*, with some 30,000 fish being grown out at present and with plans for 200,000 more this coming season. Fish can be grown to a market size of 2-3 kg in 18 months and are presently fetching AUD\$ 10-15/kg (gilled and gutted) on the Sydney Fish Market.

Closing the life cycle of the southern bluefin tuna has commenced with a feasibility study (Lee 1999). This is considered as an expensive and risky research venture and is expected to take 10-15 years before a commercial outcome is achieved. The development will require the establishment of a broodstock facility located somewhere on the northwestern coast of Western Australia, near the spawning grounds in the Coral Sea. This is considered as the most difficult component, as spawning tuna weigh over 100 kg and are difficult to domesticate from the wild.

Inland Cage Culture and Agri-Aquaculture Integration Systems

Despite relatively limited application to date, and despite Australia's relatively arid environment, arguably some of the greatest potentials for aquaculture development is within the inland waters in which novel, cage culture practices may be applied on an integrated basis with irrigated farming systems.

Agricultural production in Australia by comparison with aquaculture is relatively large. By some estimates, irrigated agriculture specifi-

cally accounts for over 25% of the total production in Australia worth at least AUD\$ 5-6 billion annually. Existing irrigation resources include the use of >13,000 GL of water per annum, some 2,000,000 ha of land, over 20,000 km of water supply channels, and myriad, relatively small, on-farm water storages. Associated with irrigated farming are extensive saline groundwater resources, estimated at about 2,875 GL across Australia. Within the Goulburn-Murray Irrigation District (GMID) of Victoria alone, there are approximately 490,000 ha of irrigated farmland which consume on the average about 2.6 million ML of water per annum, costing farmers about AUD\$ 60 million. This represents almost 10% of the overall dollar value of the total annual agricultural produce from the GMID, the major food producing river basin in the country (Crabb 1997).

It is becoming increasingly apparent that the scale of such resources and infrastructure which exists within the irrigated farming sector in Australia clearly offers considerable scope for diversification into aquaculture as a means of increasing the effectiveness and efficiency of valuable irrigation water resources. Improving both economic returns from this water and overall sustainability of the resource, by the development of multiple use strategies through integration of agriculture and aquaculture farming systems, therefore, has intrinsic merit for Australian primary industries and rural communities (Gooley 1999; Smith and Barlow 1999). Indeed, much of the existing and projected growth in the Australian barramundi aquaculture industry is in one form or another linked to the integration of cage culture and irrigated agriculture.

Given this potential, trials utilizing relatively small (1-20 m³ capacity) cages as a principal culture system component are presently underway in the Murray-Darling basin. These trials are evaluating a range of developmental systems which demonstrate the integration of aquaculture and irrigated agriculture to enhance farm productivity and water use efficiency, as well as the use of otherwise wasted aquatic resources such as inland saline groundwater (Ingram *et al.* 1999). Likewise, cage aquaculture in nutrient-rich food

manufacturing and domestic effluent is also being seen by the relevant industry sectors as an economically and environmentally sustainable option for offsetting waste management costs and for low value, high volume finfish import replacement purposes. Furthermore, Australia has a wide variety of warm and coldwater, native and introduced finfish species potentially available for cage culture in such waters, including barramundi, native Murray-Darling species such as Murray cod, *Maccullochella peelii* and silver perch, *Bidyanus bidyanus*, as well as various introduced salmonids such as Atlantic salmon and rainbow trout.

Barramundi

Queensland

At present, there are about 100 licensed barramundi farms in Australia producing over 600 tons annually; annual production has increased by approximately 20% since the industry began in the late 1980's (Wingfield 1999). The majority of Australian barramundi production (estimated >65%) however comes from 17 farms utilizing cage culture in freshwater ponds and estuarine waters in north Queensland (Lobegeiger 1999; O'Sullivan and Roberts 1999). At the present time, majority of this production is geared towards producing plate size fish up to 500 g in weight for the domestic market. However, based on current practices and growth trends, production forecasts for Queensland alone predict barramundi production to reach 1,200 tons, worth about AUD\$ 12 million by 2005 (Lobegeiger 1999), with an increasing emphasis on the production of larger sized, 2-3 kg fish.

As previously stated, majority of the barramundi cage culture in Queensland is from relatively small cages in private freshwater ponds. Cages are typically constructed on farm using 100 mm PVC pipe as the frame and also to provide flotation. The cages and attached net bag have a surface area of 3 m x 2 m with a depth of up to 1.5 m, and are covered to prevent bird predation. The ponds are usually about 0.2-0.5 ha in surface area and about 1.5-2 m deep. On the average, about four such cages are stocked per

0.15-2 ha pond. Ambient water temperatures range from 19 to 32°C. Mechanical aeration is provided in the ponds to generate a significant flow of water through the cages, to maintain dissolved oxygen levels and to enable relatively high stocking densities (up to 100 kg/m³ just prior to harvest). Under these circumstances, overall pond production equates to about 30-35 tons/ha/yr.

As a consequence of the high levels of production, the ponds usually become quite turbid, which in turn limits the amount of biofouling on the net bags. Off-site effluent discharge is regulated by environmental guidelines on water quality standards; however, effluent is increasingly being recycled for irrigating pasture and sugar cane crops and effectively being retained on-farm. It is estimated that the industry in north Queensland has >300 such cages in operation at the present time. In the future, it is anticipated that the industry will plan to utilize bigger grow-out cages which will enable them to produce bigger fish.

There is also a single marine barramundi farm in north Queensland located in estuarine waters. This farm uses a combination of rectangular, wooden and steel-framed cages and, more recently, floating, circular cages which are 60 m in circumference. Stocking densities are up to 30 kg/m³, which is relatively high compared with other finfish grown in such cages in Australia (eg. salmon and snapper).

Western Australia

More recently, significant production of barramundi in freshwater cages is also underway in Lake Argyle, in the northwestern region of Western Australia. Lake Argyle is a massive impoundment (surface area of 980 km²) on the Ord River, providing water storage for the downstream Ord Irrigation Scheme. Recent production capacity estimates for existing Lake Argyle operations are in the order of 50-100 tons per annum of up to 4 kg fish. However, based largely on a proposed expansion of cage culture of barramundi in the lake, future production is projected to reach at least 2,000 tons, subject to meeting prescribed environmental standards (Anon. 1999).

Cages in Lake Argyle are presently located in about 15-20 m of water. A total of 36 nursery cages (fish up to one kg in weight) are used. These are locally manufactured and the design is based on square net bags (8 m³ in capacity; 2 x 2 x 2 m deep) mostly suspended from a floating timber and steel pontoon/walkway. Three floating, circular cages (65 m circumference), similar to other "Norwegian-style" cages in Australia, are used for growout (fish up to 4 kg in weight). These are typically stocked initially with about 20,000 half kg fish and have a production capacity of about 50 tons each.

The combination of optimal water quality and the ambient tropical environmental conditions are considered to be ideal for barramundi. Ambient water temperatures range from 20 to 32 °C. Furthermore, the lake is endowed with numerous islands and the general topography and hydrology of the area is generally conducive to providing sheltered cage sites. Indeed the integration of cage culture in such a public water storage is considered to be a logical and realistic initiative which is adding considerable value to the existing water resource and extending a significant flow of economic benefits to the broader community in the region. Nonetheless, Lake Argyle is presently considered to be an oligotrophic body of water, and the major concern over an expansion of cage farming of barramundi is in relation to the potential for eutrophication and the associated impacts on water quality in the lake and on downstream water users. A nutrient modeling approach is presently being used to determine acceptable levels of cultured fish production in the lake, however it is also suggested that a comprehensive water quality monitoring program be required to address Government imposed environmental guidelines for proposed cage culture development (Anon. 1999).

Recent Research and Development on Cage-based Integrated Agri-aquaculture Systems

Water is currently underutilized in irrigated farming systems in Australia as a result of routine, single-use only method. Long term sustain-

ability factors and water management costs to the industry and community at large indicate that farmers will need to diversify and increase total farm productivity and profitability as well as conserve water. With such increasing pressure on Australia's water resources, integration of water uses is now being considered.

Since 1994, a number of research projects based within the southern, cool temperate regions of the Murray-Darling basin have investigated various options for enhancing farm productivity and water use efficiency through multiple water use by the integration of aquaculture into existing irrigated farming systems (eg. see Ingram *et al.* 1999). Cage culture is seen to be one of the primary means by which such integration can be pursued within existing irrigation water supplies, which would otherwise be unsuitable for semi-intensive production and for which little control over the production cycle could otherwise be achieved.

These projects include the integration of semi-intensive cage culture of silver perch within existing irrigation supply channels and on-farm storage ponds (eg. see Fig. 6). Other projects include examining the potential for semi-intensive cage culture of silver perch, rainbow trout and Atlantic salmon in public lakes and reservoirs, and the cage culture of a wide variety of euryhaline finfish, such as Atlantic salmon, silver perch, rainbow trout, snapper and black bream, in saline groundwater evaporation basins as part of a serial biological concentration system (eg. see Fig. 7; Ingram *et al.* 1999). The trial cage culture production of finfish in urban and industrial wastewater treatment ponds has also recently commenced. In all trials and systems, existing infrastructure has been utilized with minimal extra capital expenditure for the incorporation of aquaculture; hence the relevance of cage culture practices to facilitate retrofitting of existing waters and to enable a relatively low cost entry for farmers.

Cages used in the trials are mostly locally made and typically incorporate 90 mm PVC flotation collars to which rigid poly and knotless poly mesh net bags are attached. Cages are square or rectangular in shape, range in size from

1 to 20 m³ in capacity, and are typically attached to a floating walkway or pontoon for feeding and general access to the fish. Larger cages are constructed of aluminum frames, to which net bags are attached, all supported by large flotation buoys at the corners of the frames.

Research results to date suggest that the integration of cage aquaculture and irrigated farming systems within the Murray-Darling basin of Australia is technically feasible and can be readily incorporated into a wide range of existing farming and water management practices. Indeed integrated cage aquaculture can be readily incorporated into the daily farming routine, and is an aspect of farming that all family members can participate in with only basic training. However, year round production at the more southerly latitudes will require access to multiple water sources and (fresh or saline), multiple species (both warm and cold-water species) and will need to be subject to rigorous environmental management guidelines. Furthermore, problems encountered to date have included physical damage

to cages and design failure from high flows in irrigation channels, disturbance by vandals, predation by birds (eg. cormorants) and water rats (*Hydromys* spp.), nuisance intrusion by nontarget, cohabitant fish species (eg. carp, *Cyprinus carpio*), and poor ambient water quality impacting on fish growth and survival.

Key issues for such use of cages, therefore, relate to the overall cost-efficiency compared with purposely built ponds and/or tanks and other farming operations, and the impacts on water quality, and therefore on other water users in relation to potential eutrophication. The use of cages in irrigation channels specifically also raises concerns over the physical restriction to flows for agricultural irrigation supplies. As to what extent the integration of cage aquaculture and industrial and domestic wastewater management systems are both practical as well as economically and logistically feasible is yet to be determined. Potential production estimates for inland cage culture within integrated irrigation aquaculture systems are presently not available.

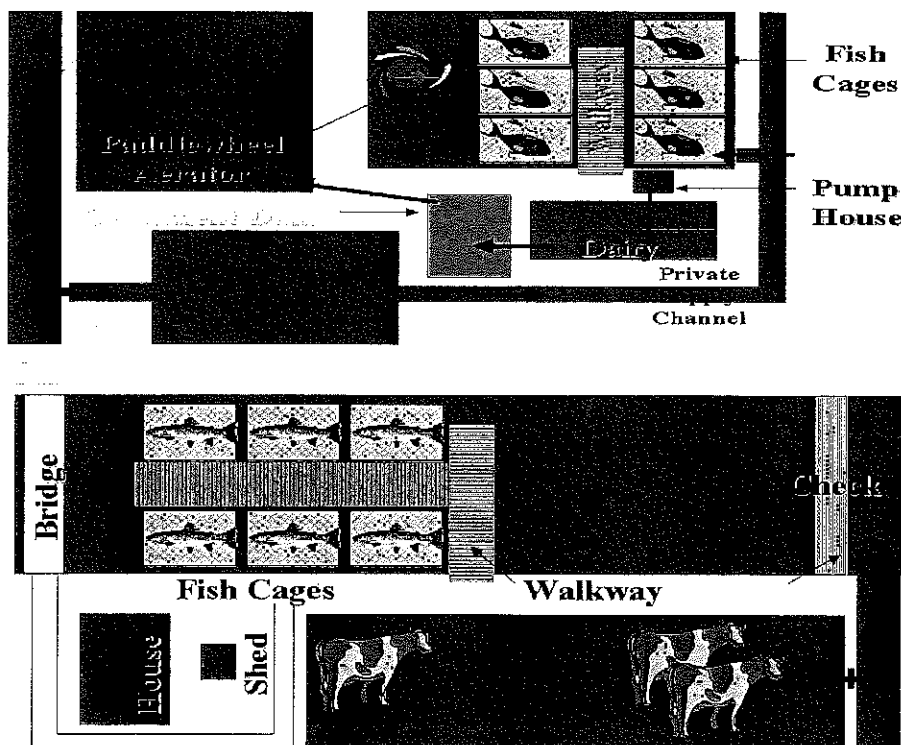


Fig. 6. Schematic diagram of conceptual, R&D scale integrated, irrigation cage culture systems in the Murray-Darling basin in Australia.

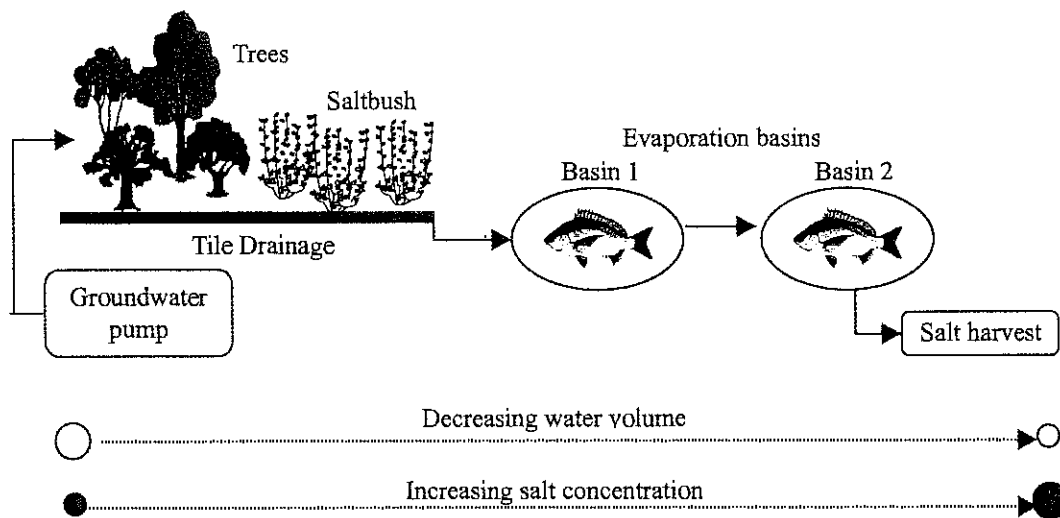


Fig. 7. Schematic diagram of the SBC system incorporating marine cage culture trials (from Ingram *et al.* 1999).

Environmental management

As for most forms of intensive/semi-intensive aquaculture development, cage aquaculture within inland waters has the potential to contribute excess nutrients to the environment, perhaps leading to eutrophication. As previously stated, this is certainly the case with integrated aquaculture systems being operated in public irrigation storages, irrigation supply channels and on-farm irrigation storages, in which the excess nutrients are deemed to constitute an environmental risk to varying degrees. The potential impact of eutrophication from integrated cage aquaculture in such waters in Australia is arguably the major issue constraining industry development in this sector. Traditionally in Australia, the environmental impacts of aquaculture development within inland public waters are typically regulated by government regulatory agencies through the imposition of water quality discharge limits on a site specific basis, in addition to real time monitoring of the quality of effluent and/or adjacent waters.

Increasingly however, resource and environmental managers in Australia are endeavouring to set such environmental limits at a catchment scale in order to regulate the cumulative nutrient impacts of multiple aquaculture

developments. Presently, catchment scale information is limited on the relative nutrient contribution of various fish farming practices, including integrated agri-aquaculture production of finfish. Gooley *et al.* (1999) proposed a simplified, conceptual, nutrient mass balance model to derive levels of nitrogen (N) and phosphorus (P) discharged from a hypothetical integrated silver perch cage culture system within an existing irrigation farming operation. The model is intended to estimate the approximate levels of N and P added to the environment for every ton of silver perch produced, based on various assumptions about FCR's, N and P content of feeds, and various nutrient dynamics within the cage culture system (eg. see Fig. 8).

This type of predictive model is a useful tool for the monitoring and regulation of integrated aquaculture development, including cage culture of finfish as part of irrigated farming systems, in particular to ensure conformity with relevant nutrient management strategies, catchment nutrient loadings and associated regulations (Gooley *et al.* 1999).

Rural communities

With the extension of integrated cage culture R&D outcomes, traditional Australian

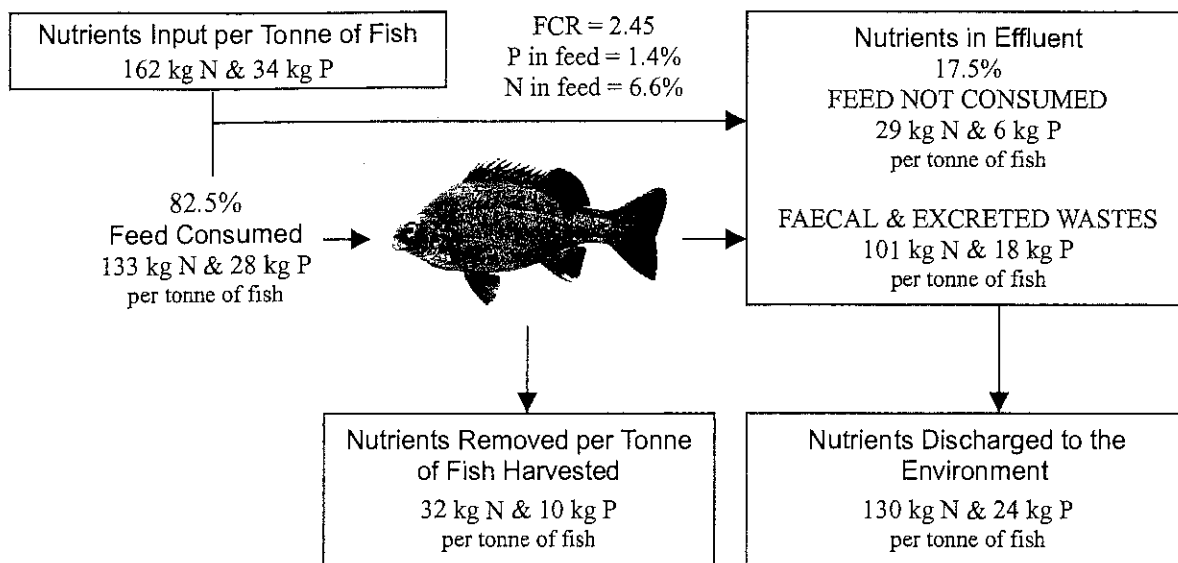


Fig. 8. Simplified nutrient mass balance model for integrated cage culture of silver perch within the Murray-Darling basin in Australia (from Gooley *et al.* 1999).

farming communities are becoming increasingly cognizant of, and receptive to, the opportunities presented by cage culture in public and private irrigation waters as a means of achieving a practical, versatile and cost effective entry to the aquaculture industry and to enhance the longer term economic and environmental sustainability the irrigation industry and Australian rural centers.

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Cage Aquaculture in Western Australia – Current Status and Future Plans

S. KOLKOVSKI¹, G.I. JENKINS² and C.L. LEE¹

¹Research Division
Fisheries WA, P O Box 20
North Beach, WA 6020
Australia

²Fremantle Maritime Centre
Southern Metropolitan College of TAFE
1 Fleet St. Fremantle, WA 6160
Australia

Kolkovski, S., G.I. Jenkins and C.L. Lee. 2000. Cage aquaculture in western Australia – current status and future plans. *In* Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia (ed. IC. Liao and C.K. Lin), pp. 39-46. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok.

Abstract

The state of Western Australia (WA) has a huge potential for the development of cage aquaculture. Being the largest state of the Commonwealth of Australia with the longest coastline, it offers the possibility of growing cold, temperate and tropical fish species in cages. It also has the largest artificial freshwater lake with potential for inland cage aquaculture.

During the last three years, Fisheries Western Australia (Fisheries WA) has been concentrating on developing the state aquaculture industry. Many stakeholders in the industry believe that the most efficient and economic way to raise fish is by using cages. Currently, cage aquaculture in WA is very limited. There are only two marine cage farms producing snapper and black bream. These farms are small and have limited production capacity of 5-10 tons/annum (mt/yr). There is a freshwater cage culture farm in Lake Argyle producing some 30-50 mt/yr of barramundi. Fisheries WA is keen on increasing production in the lake to an initial target of 2,000 mt to a maximum of 10,000 mt/yr.

A new innovative submersible fish cage called the "Cage Farming System for the Future" is currently being developed by a private company. The system includes a feed canister with an automatic feeding system and is designed to withstand all weather conditions.

Many physical and environmental factors limit the future development of cage aquaculture in WA. These are:

- Exposed sea shores – a large part of the shoreline in WA are exposed to oceanic weather and cyclonic conditions, forcing the use of expensive high seas cages such as the polar circle.
- Stringent Environment Protection Agency (EPA) regulations.
- Negative public opinions that can limit the use of potentially suitable areas.
- Lack of seed supply – currently, there is no commercial hatchery that can offer continuous supply of fingerlings for many suitable aquaculture species.

The industry stakeholders and Fisheries WA are taking up the challenge of addressing all the issues faced by the state.

Introduction

The state of Western Australia (WA) is distinguished by resources ideally suitable for the development of cage aquaculture. It is the largest state of the Commonwealth of Australia with a

coastline extending to some 13,000 km (Fig. 1). This long coastline offers enormous potential for cage aquaculture of a great variety of commercial species ranging from cold, temperate, warm water, subtropical to tropical species. In addition to its long coastline, WA has the largest artificial

tropical freshwater lake in the southern hemisphere, Lake Argyle, which has a surface area of 980 km². The lake has great potential for inland cage aquaculture. This paper presents the current and future development potentials, as well as the limiting factors for fish cage industry in WA.

Considerable commercial interest has been expressed for the development of a marine and freshwater finfish hatchery and grow out industry in Western Australia. Currently, there are licenses for the culture and sale of barramundi (*Lates calcarifer*), snapper (*Pagrus auratus*), black bream (*Acanthopagrus butcheri*), WA dhufish (*Glaucosoma hebraicum*), King George whiting (*Sillaginodes punctata*), barramundi cod (*Cromileptes altivelis*), estuary cod (*Epinephelus coioides*) and sooty grunter (*Hephaestus jenkinsi*). Companies interested in the culture of such species are mostly involved in research and development (R&D) activities and have not reached the stage of successful commercialization.

The WA Department of Training funded the establishment of a marine aquaculture research and training hatchery in the Fremantle Marine Centre (FMC), the Southern Metropolitan College of TAFE in 1992. In the last few years, the Aquaculture Development Unit (ADU) of FMC has developed a reliable and cost effective semi-intensive green-water culture regime for marine finfish. This has been proven with the "best-practice" culture of snapper and black bream. The technique has also been successful in the experimental culture of WA dhufish and King George whiting.

In 1998, Fisheries WA formalized a Memorandum of Understanding (MOU) with the FMC to carry out a collaborative aquaculture research. Three research scientists have been employed to work in close collaboration with the ADU in Fremantle. This level of government support shows the confidence placed in the potential for establishing a large marine finfish industry in Western Australia.

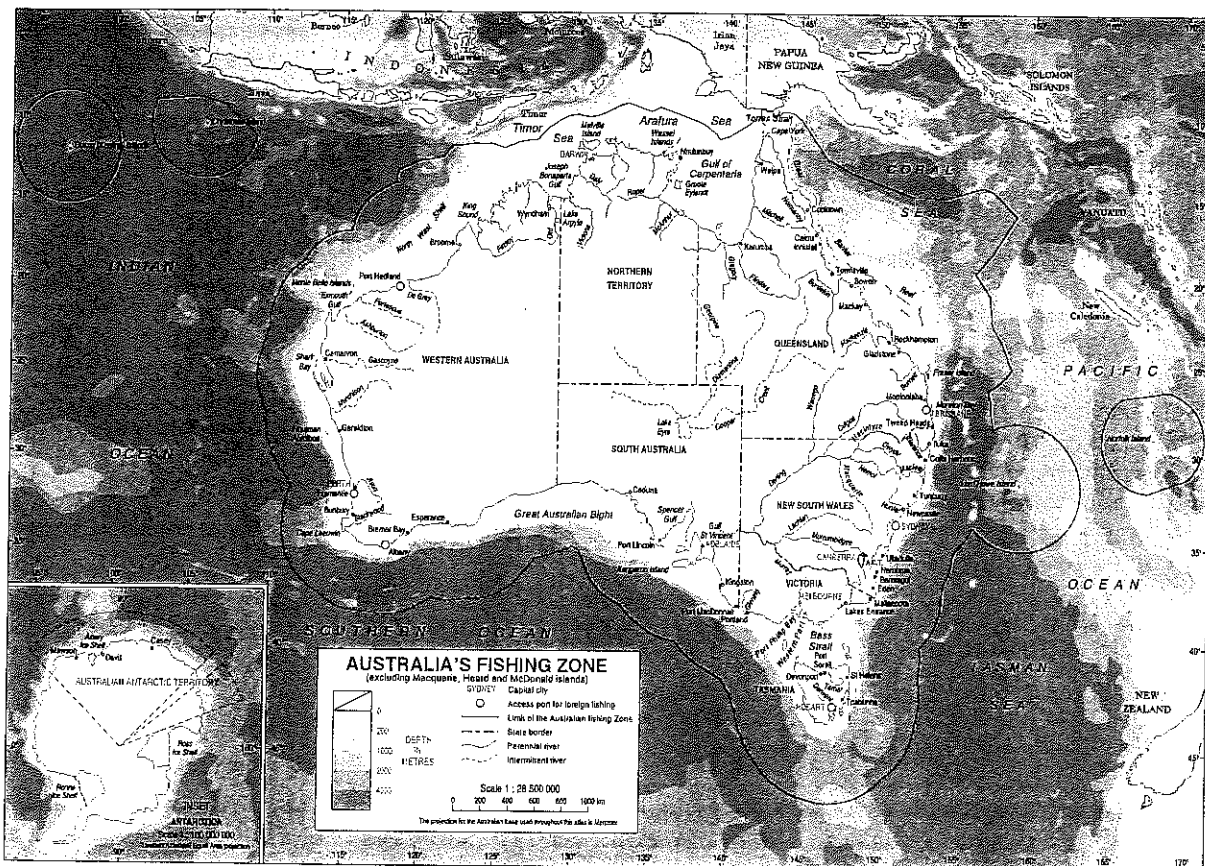


Fig. 1. WA coastline.

It is believed that the most efficient and economic way to raise fish is by using cages (Beveridge 1996). The overriding advantage of sea cages is that they make use of existing bodies of water, giving the landless sectors of the community access to fish farming as a means of income. Cage aquaculture also reduces conflicts resulting from competitive land and water use and it is also considered more sustainable than land-based aquaculture. Approximately, 60% of all marine aquaculture around the world is carried out in pens or cages (Tucker 1998) and potential for further growth is good. However, in specific exposed areas on high seas, establishment costs of sea cage farms can be fairly high and capital intensive.

Current Status and Future Plans

Cage aquaculture in WA aside from being very limited is at a very early stage of development. There are only two marine cage farms producing snapper and black bream. These farms are small and have limited production capacity of 5-10 mt/yr.

The biggest fish cage farm in WA is located in Lake Argyle in the Kimberley region, north WA. The farm consists of 36 small nursery cages and three "polar circle" type cages for grow-out (Fig. 2). Annual farm production is about 30-40 mt/yr of barramundi and production is expected to reach 200 mt/yr during the next few years. The farm includes a hatchery and barramundi broodstock that has the capability to supply fingerlings for the cages. Fish are harvested at a weight of 3 kg for fillets. At the moment, the farm can not supply the demand.

In addition to the two farms currently in operation, there are eight approved licenses for fish cage farms in WA. Most of them are small companies that will have small scale farms in sheltered water close to the shore.

In Shark Bay, a combined fisheries-aquaculture operation is planned by the Shark Bay fishermen. Part of the snapper fish catch from the wild fishery during the peak season will be put in sea cages (polar circle type) for fattening over a period of three to six months. This operation will

ensure a constant and continuous supply of snappers year round.

A new initiative involving the development of a submersible fish cage system ("Sea Haven"® MK1) has been initiated by two WA companies (Petroteam and Fish Unlimited). The submersible cage system (Fig. 3), which is a combination of a submersible cage with a remote automatic underwater feeder capable of providing feed for five to seven days, hopes to solve the problem of high waves and storms in the exposed sea off the shore of WA. This unique approach will allow continuous feeding of the fish under all weather conditions thereby reducing stress and maintaining maximum growth rates. First trial of the prototype cage will start in the next few months with stocking of 50,000 pink snapper juveniles from the Fremantle Maritime Centre, Fremantle.

In addition to marine cage aquaculture, Fisheries WA is developing a strategic plan for the development of a large cage farming industry for barramundi in Lake Argyle. The strategic plan proposes the development of a 2,000 mt/yr barramundi industry for the freshwater lake with a possible future expansion to 10,000 mt/yr.

Potential Cage Aquaculture Sites in WA

Near-Shore Cage Aquaculture Sites

The extensive coastline of WA can be divided into three different zones for consideration of cage aquaculture development.

Zone 1A: The coastal zones north of Shark Bay

The coastal areas north of Shark Bay to Wyndham are prone to regular cyclonic events and sea cage activities in these areas would involve considerable risk or deployment of high capital investment for cages capable of withstanding strong wind and rough weather conditions. It is unlikely that large scale commercial coastal cage aquaculture would be developed in this zone in the near future. However, the open-ocean off the northern coast is presently the site for numerous oil platforms in the Timor Sea and

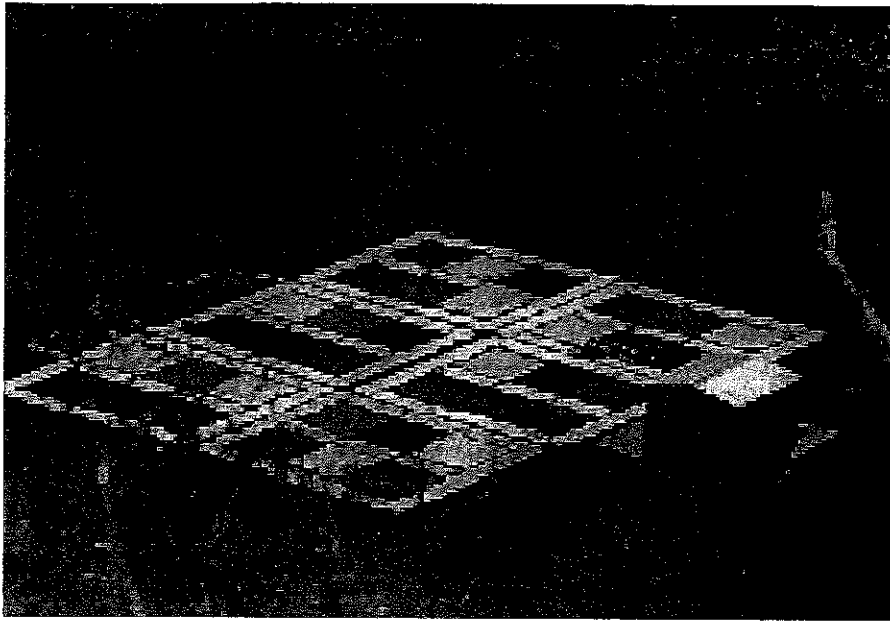


Fig. 2. Lake Argyle fish cage farm.

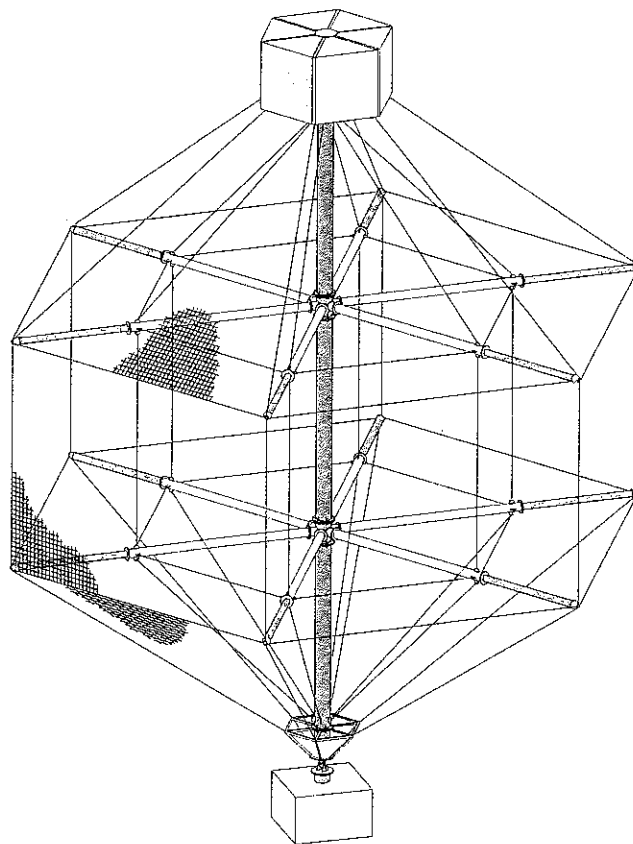


Fig. 3. Submersible fish cage system "Sea Haven"® MK1 (from Petroteam, WA-Patent pending).

the Indian Ocean. In the next millennium, when these platforms are decommissioned, they would offer ideal ocean bases for the development of cage aquaculture in the open seas.

Zone 1B: The Lake Argyle region

Away from the coastal area is the huge freshwater lake, Lake Argyle. This artificial freshwater lake occupies an area of some 980 km² at full service level with a capacity of some 10,000 Mm³. The lake is the site for the first successful cage barramundi farm in WA. It is presently under consideration for expansion into a major cage culture site producing some 2,000-10,000 mt/yr. Fisheries WA is inviting public expression of interests for developing the project in Lake Argyle. This investment opportunity is open to companies from Australia and overseas countries.

Zone 2: The central zone from Shark Bay south to Perth

Shark Bay, with numerous sheltered coves and inlets of appropriate water depths and suitable water current, offers a suitable location for the development of cage aquaculture. However, Shark Bay has been designated as a World Heritage area and as such, many of the best areas with potential for sea cages are not available for aquaculture development.

Shark Bay also hosts a large commercial prawn fishery with 27 vessels. The commercial prawn catch in 1997 was 2,700 mt/yr with a value of approximately \$32 million (FWA Annual Report 1997/8). Other Shark Bay fisheries include scallops (328 mt/yr at \$11.5 million in 1997), and snapper (approximately 2,000 mt/yr). The commercial fishing activities in Shark Bay may limit the development of a large-scale sea cage industry for marine finfish due to conflict over areas and resources.

Likewise, there are considerable interests in the recreational fisheries in Shark Bay. The Shark Bay recreational fishery is a valuable one and brings in large tourism dollars. In a recent recreational fishery draft management plan for Shark Bay, aquaculture was not recognized as being compatible to this industry and conflicts

between aquaculture proponents and recreational fishing groups need to be resolved before cage aquaculture can proceed.

Apart from the township of Shark Bay, the shoreline fronting the ocean in the Shark Bay region is typified by high coastal cliffs and is well known for shipwrecks throughout the history of Western Australia. Such areas are not conducive to near-shore sea cage technology.

The coastline south of Shark Bay to the Perth metropolitan area (a distance of some 600 km), is typified by long sandy beaches and offshore limestone reefs. The coastline is generally straight with few embayments or protected areas. The limestone reefs vary from a few meters to approximately a kilometer offshore. The area between these reefs and the shoreline is typically shallow (less than 10 m in depth) and carpeted with seagrasses. The Department of Environmental Protection does not allow sea cages over significant seagrass communities and therefore, combined with the shallow depths, these semi-protected areas behind the reefs are not generally available or suitable for near-shore sea cage operations.

Western Australia has a population of approximately 1.6 million with about 1.3 million residing in the Perth region. Coastal areas south of the Perth metropolitan area to Cape Naturalist are considered to be Perth's "holiday playgrounds" and consequently subject to high recreational use. For both visual and environmental reasons, placing a large-scale sea cage industry in this region would result in considerable conflicts between competing user groups. Furthermore, there are a few available sites in the coastal strip, north of Perth, which have protection from the prevailing weather conditions.

Zone 3: The southern region from Cape Naturalist to Cape Leeuwin and the south Australian border

The coastal area from Cape Naturalist to Cape Leeuwin is characterized by cliffs and has an exposed aspect to southerly storms and therefore not suitable for near shore sea cage operations.

The shoreline east of Cape Leeuwin to the

South Australian border (a distance of some 1,600 km) alternates between long and exposed beaches, rocky headlands and wide sweeping bays before reaching the cliffs of the Great Australian Bight east of the township of Esperance. There are also many, mainly small, off-shore islands in this region with a concentration of islands around the Esperance area. While there are some excellent sites for sea cage operations in some of the more sheltered bays and in the lee of some of the offshore islands in this region, the community perception of such operations is currently not conducive to such activities. This region is in the cooler temperate zone of Western Australia where the winter water temperatures often fall below 15°C. The target species for this region is most likely to be the southern bluefin tuna (*Thunnus maccoyii*), an excellent species with high potential for fattening and growout in cages.

Though prospects for near shore sea cage operations are limited in Western Australia, alternate marine finfish growout methods with high potentials for development in the next millennium include open-ocean sea cages, submersible sea cages and pump-ashore or recirculated land-based facilities. These developments are likely to attract higher establishments and/or increased operating costs than near-shore cages and thus market-driven species selection becomes even more critical to ensure a profitable operation (Jenkins 1999).

Open-ocean Sea Cages

During the last few years, open-ocean sea cages were developed by different companies around the world. The technology is available and there are different types of commercial sea cages capable of operating in extreme weather conditions such as those likely to be experienced in the North sea, Mediterranean, Atlantic Ocean etc. These open-ocean cages include polar circle type, semi-submersible, oil rigs, and others (Basurco 1998; Loverich 1998). Muir (1998) believes that for these cage systems to be successful, they need to meet conditions such as:

- Location: >2 km from the shore, generally within continental shelf zone with possibility of

open-ocean.

- Environment: average waves >5 m, regularly 2-3 m oceanic swells, variable wind periods.
- Access: usually >80% of the time when cages are accessible to staff.
- Operation: remote operations, automatic feeding, distance monitoring.

While offshore and open-ocean sea cages apparently have high potentials, many operators consider this form of aquaculture to carry considerable risks and highly capital intensive. Several key interrelating issues may need to be considered when open-ocean system is designed (Muir 1997):

- Can complete offshore systems be defined and developed?
- Can these be developed and operated in a cost effective manner?
- Can they be made suitable for specific/localized conditions?
- Will there be appropriate policy environment, and what should be important?
- Will there be appropriate market and investment conditions to stimulate their use?

Currently, although technology is available, open-ocean cage system is not considered to be cost effective in WA. The main reason is the lack of suitable high value fish species that can be cultured in these systems. The current fish species being reared in WA are the barramundi and the snapper which are fetching a market price of \$AU 6-7 per kg. The only valuable and high priced species that could be considered for growout in open-ocean cages is the southern bluefin tuna. Unfortunately, spawning requirements for the species is not known and juveniles for growout have to be collected from the wild. Currently, Fisheries WA is carrying out a review to determine the potential fish species that future R&D need to be focused on by the department. These species include: southern bluefin tuna, grouper (*Epinephelus* sp.), dhufish, yellow tail tuna, mahi-mahi, and others.

Obstacles

Despite the optimism surrounding the potential of this new industry, several technical and

environmental issues may hinder future development of cage aquaculture in Western Australia which include:

- despite its lengthy coastline, preliminary study has indicated that there is a lack of protected and easily accessible in-shore deep-water cage sites along the coastline of WA resulting in the need to move to off-shore sites which are more inaccessible and more expensive to manage.
- the sites considered good for sea cages are generally in high use areas or are considered to have high conservation value (Jenkins, 1999 in press) resulting in strong competition from different user groups.
- environmental concerns such as degradation of sea-bed from anchors, shading, sedimentation or eutrophication resulting from the location of sea-cages over or near seagrass beds.
- concerns over the detrimental effects of high nutrient loading on areas immediately surrounding sheltered sea-cage sites, where reduced waves and current actions may limit the effective flushing and dilution of effluent (Jenkins et al, 1999 in press).
- lack of seed supply – currently there are only two commercial hatcheries that can offer supply of fingerlings for some suitable aquaculture species.

To streamline and expedite the approval process for aquaculture development in the state, a WA Government Information Pack, released in 1996, titled "Aquaculture and the Environment", provides guidelines for the development of the marine finfish industry in Western Australia in relation to environmental issues. One of the papers titled "Industry guidelines for the environmental management of marine finfish aquaculture in Western Australia" provides the following criteria for the selection of sea cage sites:

- sites must not be near important biological communities such as seagrasses, reefs and macroalgae.
- sites must have adequate flushing, ie, currents of not less than 10 cm/sec for more than a three day period.
- sites must not be near urban drainage areas or point sources of pollution.
- sites must not have an impact on any heritage

sites.

- sites must not impair the quality of high scenic quality areas.
- sites must not be in conflict with other users (recreational, commercial or existing aquaculturists).
- sites must allow a minimum gap between the cage bottom and the sea floor, about 30% of the total water depth, provided the gap is not less than 3 m at low tide.

Discussions

The state of WA in the Commonwealth of Australia is endowed with an extensive coastline that has potentials for in-shore and open-ocean cage aquaculture. Despite its 13,000 km long coastline and potential, marine cage aquaculture development is still in its infancy stage. There are only two marine pilot cage farms producing snapper and black bream. These farms are small, restricted to in-shore area and have a limited production capacity of 5-10 mt/yr. Other developments under consideration include an innovative all-weather submersible cage production system and cage grow-out for southern bluefin tuna in the temperate waters of the state.

Preliminary studies have indicated that premium in-shore deep-water cage culture sites are limited and subject to competitive demand by different user groups. The aquaculture industry and Fisheries WA are keen in supporting the development of a sustainable cage aquaculture industry in the state. On going discussions and planning are being put in place and discussions will be conducted among all stakeholders to ensure an orderly development of cage aquaculture in WA in the next millennium.

Similarly, considerable interest has been generated in recent years on developing open-ocean cage aquaculture. The early successes achieved in Europe and elsewhere has provided impetus for WA to plan for the future. An area of considerable interest in WA is the prospect of utilizing decommissioned oil platforms off the coast as bases for future cage aquaculture development.

In addition to the marine cage culture, the

freshwater Lake Argyle has potential for development into a 10,000 mt/yr cage aquaculture project. Like the inshore marine cage sites, environmental issues and issues relating to competitive demand by different user groups will need to be resolved before the project could be successfully implemented.

The state of WA is confident that it will be a major player in cage aquaculture production in the Commonwealth of Australia in the next millennium.

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Status of Cage Aquaculture in India

S.C. PATHAK

*National Bank for Agriculture and Rural Development
Laxmi Bhawan, Panbazar
GUWAHATI - 781 001 (Assam)
India*

Pathak, S.C. 2000. Status of cage aquaculture in India. *In* Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia (ed. IC. Liao and C.K. Lin), pp. 47-51. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok.

Abstract

India which is surrounded on three sides by the Indian Ocean, Arabian Sea and Bay of Bengal, has a vast coastline of 7,100 km² with a potential resource of 20,200 km² of Exclusive Economic Zone. The country has 14,002 km² of brackishwater and 45,000 km² of freshwater to produce fish from both capture and culture. India produces over 5.4 million tons of fish annually and ranks 7th in the world. However, the annual fish catch is declining, hence the country has to increase its aquaculture production to meet the increasing demand. Efforts to enhance aquaculture activities since the 1970s have augmented total fish production in the country. However, most aquaculture practices in the country are still confined to pond culture of fishes and prawns. To utilize the full potential of India's vast open bodies of water in both inland and marine, technologies such as open water cage culture have to be developed and widely adopted. Although several attempts have been made to launch commercial cage culture in marine and freshwater areas, still it remains at experimental stages.

This paper gives a detailed review of the measures taken by research institutions and developmental agencies, and analyses of the causes of poor development of cage fish farming technology in India.

Introduction

India possesses vast areas of marine and freshwater conducive for capture fishery and aquaculture. While marine resources, viz., Arabian Sea, Indian Ocean and Bay of Bengal, surround the country on three sides covering a coastline of 7,100 km², freshwater resources are also available in all states of the country. Since the Exclusive Economic Zone (EEZ) came into being in the year 1977, India has about 20,200 km² of EEZ for exploitation, of which 85,000 km² have been identified as being farmed. All along the coastline, the country has backwaters, brackishwater impoundment, mangroves, lagoons and estuaries. A total of 14,200 km² is available for coastal aquaculture. Similarly, an immense potential also exists in India's inland waters with 14 large, 44 medium and innumerable small rivers, and irrigation canals; 29,000 km² of lakes and reservoirs; 13,000 km² of *beels* (watershed pond) and derelict water bodies, and

28,050 km² of ponds and tanks. The total area can easily give a sizeable cultivable area of 45,000 km² for fisheries activities to increase fish production.

With such resources available, India produces about 5.4 million tons of fish per annum, which ranks 7th in the world with a prominent place in the world seafood market. Although the quantity of seafood exports has been rising steadily, the country has to make concerted efforts through cultivation practices to increase production as the trend of marine fish catch has reached a plateau (Dehadrai 1996). Large scale efforts to popularize aquaculture since the early seventies have resulted to aquaculture gradually becoming a major fisheries activity contributing over 48% of the total fish production.

Current Status of Aquaculture

Most aquaculture production comes from pond culture systems in the form of polyculture,

integrated fish culture with rice paddy, poultry, ducks, pigs and sewage-fed fish culture. Culture of air breathing fish, freshwater prawn culture and shrimp farming are also common. However, cage aquaculture, which is commonly practiced for fish production in many countries did not become popular in India. Open water aquaculture activity was taken up by adopting extensive and semi-intensive methods with low but sustainable levels of fish production while freshwater aquaculture production mostly ranged from 500 to 8,000 kg/ha/year. Shrimp farming grew rapidly with an average annual growth rate of 36.5% between 1990-91 as it received considerable support from financial institutions because they were economically viable. However, shrimp farming has received a major setback due to issues raised by the environmentalists. The recent reduction in shrimp farming has affected the total aquaculture production and therefore it is highly attractive to pursue cage and pen aquaculture. This would not only supplement production but also overcome the resistance of environmentalists who believe that coastal aquaculture activities are affecting agricultural lands.

Cage Aquaculture

In India, cage aquaculture experiments were undertaken by research institutions, agricultural universities, fisheries colleges, state fisheries departments, state fisheries corporations and a few private entrepreneurs. However, most of these trials were of exploratory in nature and have not led to large-scale commercial cage aquaculture. Most of those cages were set up in four types:

1. Surface cages resting at the bottom occupying the full water column
2. Cages floating on the surface
3. Submerged cages suspended in the water column with floats and anchors or resting at the bottom
4. Cages fixed with bamboo, angle-iron, etc.

The design of the cages depends on the behaviour of the cultured fishes. Cages can be circular, square or rectangular. Circular cages with a metallic frame and nylon nets are preferred in culturing pelagic fishes, which have circular

movements, whereas rectangular cages appear to be more suitable for culturing sedentary fishes.

Cage Culture in Coastal Areas

In estuarine areas culture trials were carried out with milkfish (*Chanos chanos*), grouper (*Epinephelus* sp., *Eutroplus suratensis*), seabass (*Lates calcarifer*), mullet (*Liza macrolepis*) and *Lutjanus* sp. The coastal areas of Chilka Lake, Tuticorin, Mandapam, Kakdwip, Cochin and Saurashtra were used for cage culture. The Central Institute of Brackishwater Aquaculture (CIBA) of the Indian Council of Agricultural Research uses rectangular cages of 50 m² for rearing sea bass fingerlings with greater than 70% survival. Local improvisation has also been made by progressive farmers to raise fishes in cages. For example, farmers successfully raised catfish in cages made of used 1-2 tons syntax water storage tanks with perforation to facilitate water exchange. Availability of synthetic cages enthused fish farmers who are making attempts to renew cage aquaculture in the coastal areas of Gujarat, Karnataka and Goa on the West Coast, and Orissa, West Bengal, A & N. Islands, along the Bay of Bengal. However, the results and production from cage culture are still insignificant.

Cage culture experiments to raise food oysters, pearl oysters, green mussels and seaweed were also conducted by The Central Marine Fisheries Research Institutes (ICAR), Tamil Nadu Fisheries Development Corporation and Fisheries Department of Tamil Nadu, Central Institute of Freshwater Aquaculture (ICAR). Some of the experiments show that few technologies are technically or economically feasible. Thus, it is still not ready for commercial development due to various reasons including lack of acceptability, lack of foolproof technology, lack of knowledge, non-availability of seed for stocking and threat of poaching. In addition, state governments are also reluctant to lease open water for cage farming as it may interfere with the other activities and cause conflicts with other users of the common water resources.

Freshwater Cage Culture

In the freshwater sector, cages are used for

nursing fish fingerlings and culturing table fishes. Cage culture has also been modified into running water culture in cement cisterns and pen culture. Some of the technologies adopted for freshwater cage culture are as follows:

Fry rearing

Rearing of commercially important fish fry is often done in net cages with 6-10 mm mesh size, where fish fry of 3-4 cm size are stocked at 100-500 per m² for 45-50 days and fed with phytoplankton and zooplankton. After this period, each cage produces fingerlings of 70-100 mm with 60-65% survival.

Table size fish culture

In raising adult table fishes, healthy fingerlings of 50-60 g size are stocked in cages of 16-20 mm mesh size at 30-50 fingerlings/m³ and fed with natural and supplementary feed for 6 months to reach an average weight of 400 g, with an extrapolated productivity of 30-300 tons/ha.

Air breathing fish culture

Besides carp culture in cages, several trials have been made for rearing air breather fishes in rectangular cages of 1-2 m². These experiments were carried out in Assam, West Bengal, Andhra Pradesh and Karnataka States. These culture experiments were mostly taken up to utilize weed choked *beels*, swamps and other derelict water bodies to produce fish, such as *Clarias* sp., *Heteropneustes* sp., *Anabas* sp. and *Channa* sp. Because of their capacity to inhale oxygen directly from the air, these fishes are ideal for culturing in cages installed in oxygen deficient water bodies.

Running water cage culture

Research experiments are being conducted in several research organizations including the Central Institute of Freshwater Aquaculture (ICAR) Bhubaneswar to raise fingerlings as well as adult fishes by installing cages in cement cisterns with flowing water. With high velocity and continuous water exchange, these cages can produce fish as high as 150-300 tons/ha. However, this system is still in the experimental stage and

needs further standardization.

Some Case Studies on Freshwater System

Rearing and fattening trials in cages were carried out with carps and air breather fishes (Pathak *et al.* 1978; Chitranshi 1987; Sivakani *et al.* 1987). The air breather fish (*Clarias* sp., *Batrachus* sp., *Heteropneustes fossilis*, *Anabas testudineus* and *Channa punctatus*) were reared in rectangular bamboo cages of 2 m² in *beel* areas of Assam with production ranging from 2.2 kg to 12 kg/m² and survival ranging from 48 to 72% in 120 days. Sivakani *et al.* (1987) cultured silver carp (*Hypophthalmichthys molitrix*) in 6.25 m² cages in the lakes of Karnataka and got a maximum production of 16 kg/cage with survival ranging from 11 to 27%.

Similar experiments on cage aquaculture were also carried out by many scientists in the Central Inland Capture Fisheries Research Institute, Barackpore; the Central Institute of Freshwater Aquaculture, Bhubaneswar; fisheries colleges, and state fisheries development corporations. Said trials were conducted to raise fingerlings, grow-out of fishes and feeding trials with a varying degree of success. The most common species used were catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinas mrigala*), common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), silver carp, tilapia, climbing perch (*Anabas* sp.), *Kalbasu* sp., *Murrels* sp., *Magur* sp., *Pangassius* sp., *Heteropneustes* sp., *Wallago* sp., and *Mystus* sp.

In Allahabad, net cages were used to stock fish hatcheries at a density of 8,500 fry for 21 to 28 days to a size of 30 to 45 mm with 25% survival. In another case, fry stocked at 700-2,500/m² reached 10 to 12 cm size in 90 days. Those fry were fed with powdered soya bean, groundnut cake and rice bran in equal proportions (Parmeswaran, personal communication).

Similarly, carp fry were reared in Getalsud reservoir in cages of 2.4 m x 1.5 m x 1.5 m size at a stocking rate of 300-700 fry/m² for catla and rohu. Experimental results obtained from trials in Tamil Nadu, Karnataka and Orissa showed

varying degrees of success and survival rates ranging erratically from 5 to 90%.

Advantages of Cage Aquaculture

Cage aquaculture has the following advantages:

- Aquaculturists need not own bodies of water for culture purposes and therefore even landless farmers can engage in cage farming.
- Large bodies of water can be used for aquaculture.
- Cage farms can be increased or decreased depending upon the capacity of farmers.
- Floating cages can be transferred to suitable areas or conditions should such need arise.
- Feeding, growth and health of stocked fishes can be monitored on a daily basis without much disturbance.
- Cultured species are well protected against predators.
- Compared to open water culture systems, there is less risk of environmental hazards.
- Harvesting of cultured material would be easier and cost-effective.
- Cage aquaculture has an excellent scope as it promises increased production and higher return on investments through intensive stocking and feeding.
- Excellent job opportunities would be created through cage aquaculture and other ancillary activities.

Conclusion

Despite many attempts made in India, cage aquaculture has remained at the research stage. It has not been attractive to farmers due to a number of reasons:

- conflicting use of common water resources and related social issues
- permitting culture areas in short-term lease
- fluctuating water levels causing poor water quality especially in shallow bodies of water
- stocking at high density and crowding caused low survival rates, injuries of cultured fish
- short life span of cages and high depreciation of cage material

- poaching problem

These factors have reduced the economic viability of cage aquaculture in India and credit for supporting the system is not forthcoming. Compared to cage aquaculture, pen culture by cordoning portions of natural bodies of water has shown better success, particularly in the eastern and northeastern regions of the country. In several experiments conducted during the last one and a half decades, pen culture has been shown to yield 3-5 tons/ha. These results are comparable with production in pond aquaculture and is economically viable.

India has large areas of surface water, but has not been judiciously exploited for fish production. Its present level of fish production of 5.4 million tons is grossly under the country's production capacity. Despite under-utilization of these resources, environmental issues are being raised against existing efforts. We are facing a situation wherein fish production is decreasing while demand for fish consumption is increasing. What India immediately needs is a well planned, widely acceptable National Aquaculture Policy for the optimum use of its aquatic resources. If this could be implemented immediately, the fisheries sector is capable of contributing to greater food security and to the national economy (Pathak 1994).

Acknowledgment

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Cage Culture in Japan Toward the New Millennium

F. TAKASHIMA and T. ARIMOTO

Tokyo University of Fisheries
Konan, Minato
Tokyo 108-8744
Japan

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Abstract

The history of cage culture in Japan dates back to about 200 years ago with the primitive wooden frame net cage for anchovies or sardines as the bait for skipjack pole and line. This type of net cage was employed for yellowtail farming and developed in various areas of western Japan. Recent development of cage culture in Japan can be summarized with the statistical data of marine species such as yellowtail, red sea bream, coho salmon, horse mackerel, striped jack, flatfish, and puffer. Total production of these fish was about 250,000 tons worth 282 billion yen in 1997. Some technical matters for the cage structure regarding size, materials, and shapes as well as the feeding systems will be illustrated, together with the recent research and development projects on the new concepts of the large-scale cage for tuna farming and the submersible cage for abalone farming. Two projects by the Marino Forum 21 are also introduced; the farming platform and the air bubble curtains and acoustic guiding for behavior control in marine ranching. For purposes of live fish marketing and price control, highlights are given on the net cage attachment to the large set-net fishing gear, and on the cage-combined set-net as the latest challenge in the coastal fisheries. Finally, recent developments on the conservation issues or responsible aquaculture are also discussed.

Introduction

About 200 years ago, bamboo or wooden framed cage, about 5 m in diameter and 3 m in depth were originally used in Japan, for stocking live anchovies or sardines as baits for skipjack pole-and-line fishing. This type of cage was later employed in many regions of Japan for yellowtail farming. Modern cages utilize a frame of steel pipes coated with zinc to which a net is attached. These net cages were initially used in shallow coastal areas for farming of marine fishes such as yellowtail, and later applied for carp farming in freshwater lakes and ponds. Improvements in the materials used in the cages paved the way for the construction of larger cages in deeper areas which are capable of tolerating strong waves and winds. One of the largest types, currently in use for yellowtail and tuna farming, are about 50 m in diameter and 20 m in depth.

There are two other styles of fish farming,

i.e., the inlet enclosure and the partitioned cage. The former, which is applied to small inlets with sluice and netting, was developed by Mr. Noami about 40 years ago in the Seto Inland Sea area for yellowtail farming. The latter type, the partitioned cage consists of a net cage supported by stalks standing at the bottom of shallow lakes and ponds. Both are now the minority, since net cage farming is the most popular in marine fish aquaculture for various types of species all over Japan.

Historical Background of Fish Farming

Fig. 1 shows the transition of fisheries production in Japan. Total production including freshwater fisheries and aquaculture showed a steady increase until its peak in the mid '80s and then the sudden drop starting 1989. This drastic change is attributed to the drop in high-seas fisheries in the '70s by 200 EEZ and oil crisis and

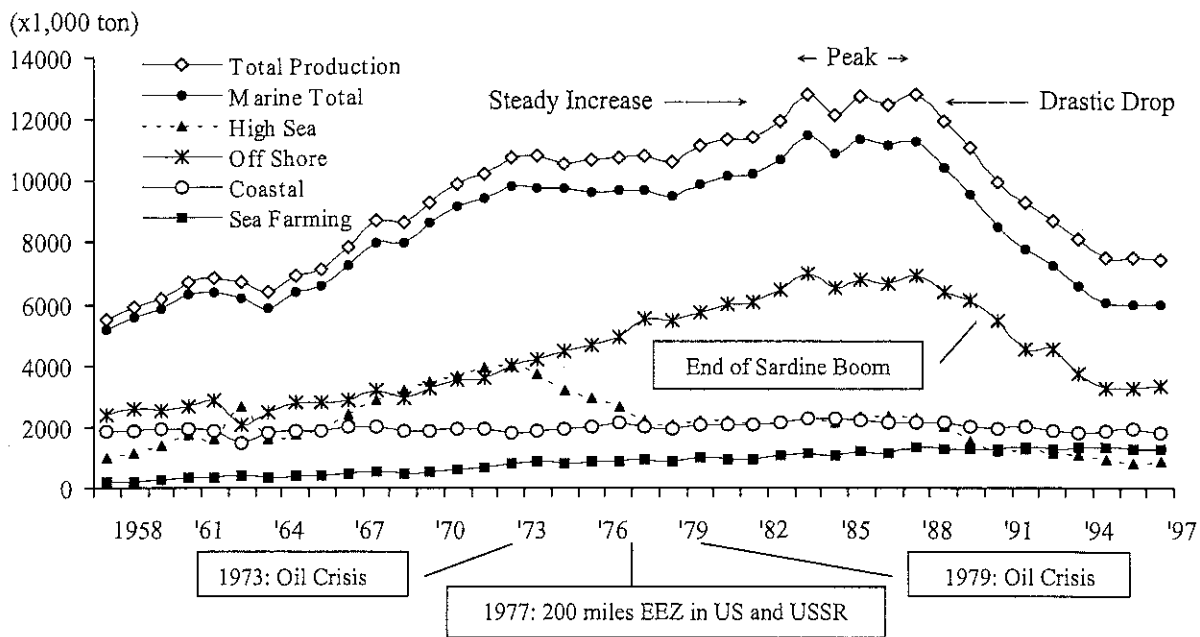


Fig. 1. Fisheries production in Japan.

of the offshore fisheries due to the end of the sardine boom around the late '80s. The production of sea farming, however, shows a steady increase until now and occupied 17.2% to the total production in 1997, which was only 4.9% in 1960 and 10% in 1980.

The majority of sea farming production is occupied by the sea algae and shells, so that the amount of fish farming is around 250-300 thousand tons as 20% in total of 127 thousand tons, as shown in Fig. 2.

Fig. 3 shows the species statistics of fish farming. Yellowtail shows a stable level of 150 thousand tons since 1978, even with the primitive techniques using the wild juveniles as seeds. This implies a matured balance between the demands and supplies. The red sea bream shows the steady increase after the success in the early 70's on the mass production of artificially raised seeds. The salmon and flatfish species are still on the minor level compared with yellowtail and red sea bream, and are acquiring a new status as the farming species. Salmon farming was initiated by the R&D projects on site decision as the so-called "off-shore" cage farming, as well as by the feasibility studies to develop new types of flexible

and framed cages that can tolerate high current and waves. Fig. 4 shows the number of farmers and cages for yellowtail and red sea bream respectively. Even with the stable production level of yellowtail in figure 3, the number of farmers and cages are declining after the peak around 1980 implying the higher productivity per farmer/cage. In the case of red sea bream the number of farmers are slightly declining from 3,000 to 2,500, while the number of cages remained in the same level of 20,000, which implies an increase in the number of cage per farmer since 1990.

Present Status of Net Cage Culture

Net cage farming is the major technique in marine fish aquaculture for the various species according to the local characteristics of sea conditions, such as yellowtail (*Seriola quinqueradiata*), red sea bream (*Pagrus major*), coho salmon (*Oncorhynchus kisutch*), horse mackerel (*Trachurus japonicus*), striped jack (*Pseudocaranx dentex*), flatfish (*Paralichthys olivaceus*) and puffer (*Takifugu rubripes*). Freshwater fish like carp (*Cyprinus carpio*) are farmed in net

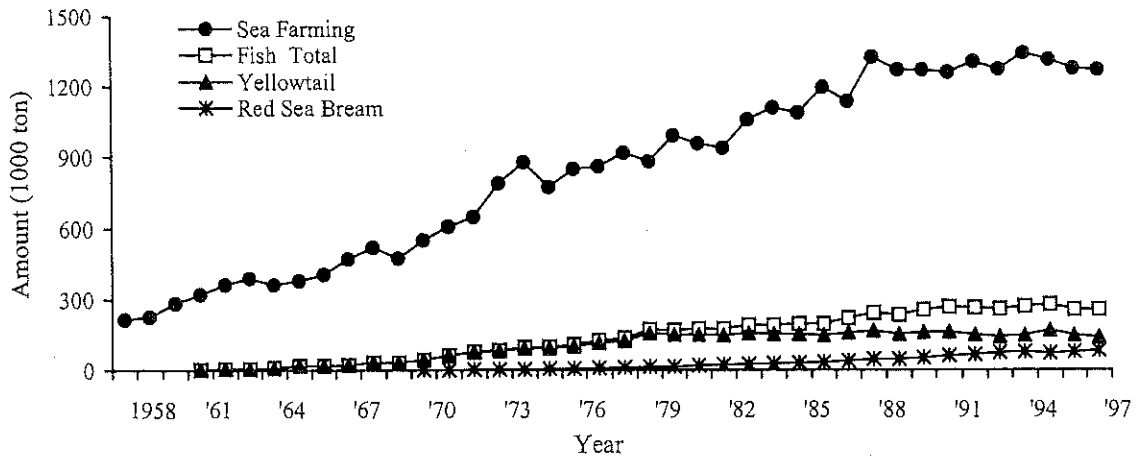


Fig. 2. Sea farming production in Japan

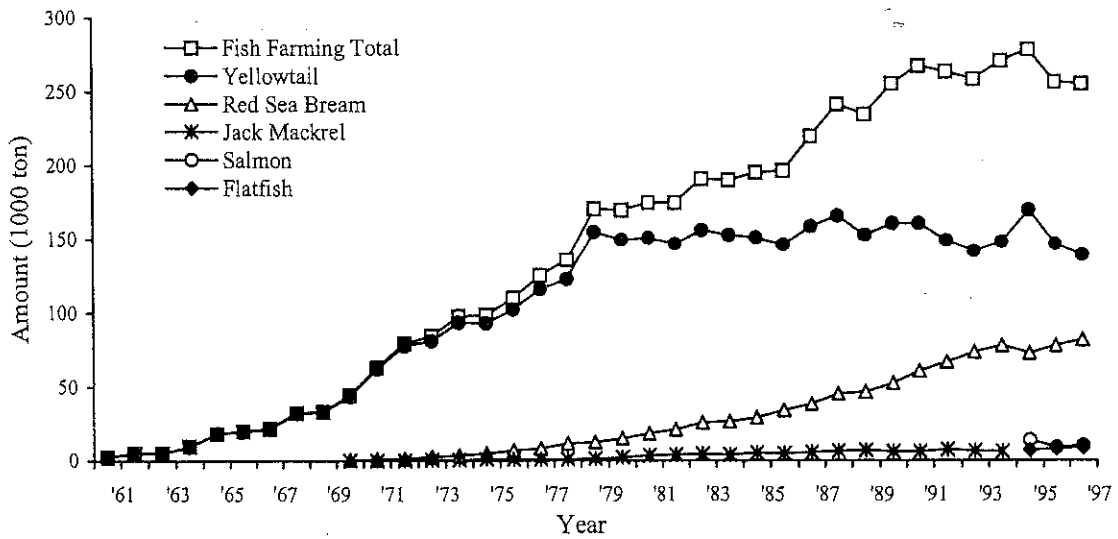


Fig. 3. Fish farming production for major species in Japan

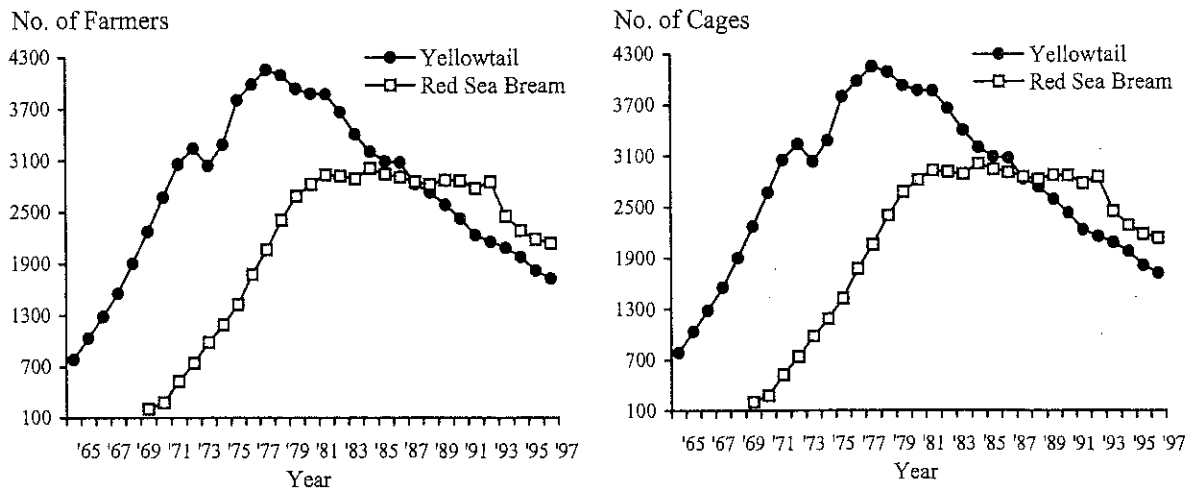


Fig. 4. Number of farmers and cages for yellowtail and red sea bream in Japan

cages in some areas, but not popular. The production and value of fish farming in net cages in 1997 are shown in Table 1.

The total fish production of net cage farming was about 250,000 tons in 1997, which represents more than 98% of the total production of fish farming in Japan. In terms of value, the production was almost 282 billion yen, or nearly 90% of the total value of fish farming in Japan.

In the case of yellowtail, 1,724 fish farmers owned 15,898 cages which produced 138,000 tons of fish in 1997. The total area for farming was 1,869 x 1,000 m², of which 99.6% was comprised of net cages. In the case of red sea bream, 2,137 farmers produced 80,903 tons using 18,741 cages in an area of 1,845 x 1,000 m². The area for the farming of this species besides net cage was only 22 x 1,000 m².

Table 1. Production and value of net cage cultured fish in 1997.

Species	Production (tons)	Value (billion yen)
Yellowtail	138,376	147.5
Red sea bream	80,903	82.7
Coho salmon	9,927	4.4
Horse mackerel	3,526	-
Striped jack	2,217	-
Flatfish	8,583	19.1
Puffer	5,961	-

Structure and Function of the Net Cage

There are three types of net cages currently used in Japan, i.e., floating, fixed, and submersible. The floating type consists of a floating frame to suspend the net cage. Most nets are made of synthetic fiber or nylon-coated steel. The common shape of the net cage is square, while other types of polygonal or round shapes are also popular depending on the cage size and strength of the tidal currents where the net is deployed.

The size of the net cages used for yellowtail is most often around 10 x 10 x 6-7 m deep with 12 floats (buoyancy 300 kg), while for carp, they use net cages measuring 11.5 x 11.5 x 2.5-3 m deep with 9 floats as in the case of Lake Suwa.

The price of a net cage varies according to the sizes and materials used. The most popular one costs 3 million yen (about US\$ 30,000) including the frame, net, floats, sinker, and ropes. The average life span of a net is three years while the frame is five years. After submersion in the sea, fouling organisms such as algae, insects and worms, shells and bacteria may grow on the net and cause a decrease in the rate of water exchange. Maintenance works are frequently required especially in warmer areas for the net is cleaned-up by drying and washing, or changed once a year due to the bio-fouling. The nets can be treated before setting with anti-fouling chemicals which contain copper or organic sulfur compounds that possess none or extremely low toxicity that could affect vertebrate animals.

The stocking density in the cage depends on the oxygen demand of each species, the water currents, and the amount of dissolved oxygen in the water. The minimum level of dissolved oxygen for normal life determines the minimum stocking density (*A*; kg/l) as shown in the following equation:

$$K(C_s - C) + v(C_i - C)/V = A \times K_f + K_p$$

where, *K*= dissolving rate of oxygen; *C*= dissolved oxygen at a given time (mg/l); *V*= volume of the cage (l); *v*= amount of inflow water per hour; *C_s*= saturated dissolved oxygen (mg/l) at a given temperature; *C_i*= actual amount of dissolved oxygen (mg/l); *K_f*= oxygen consumption of the fish (mg/l/hr); *K_p*= oxygen consumption of other organisms besides fish in the cage (such as zooplankton; mg/l/hr). This equation roughly suggests that stocking density depends on the amount of inflow water and tidal and current speeds in the farming ground.

In Japan, oxygen consumption and its changes along with growth are experimentally determined for each species in relation to the rearing temperature in order to clarify the optimum stocking density for net cage farming.

New Net Cages for the Next Millennium

Some projects on advanced farming technologies are now on-going toward the establishment of a new strategy in marine aquaculture and marine ranching as well as the combination with the coastal set-net fisheries in the region.

For the farming of bluefin tuna, the large-scaled round net cages (40-50 m in diameter and 20 m in depth) are being developed. The shape and construction differs in the farming sites and growth stage of tuna species. Several projects on the experimental bases of tuna seedling, or on the commercial base for farming are going on in Okinawa, Kagoshima, Kochi and Wakayama Prefectures, and in Ogasawara Islands of Tokyo.

The Japan Marine Science and Technology Center has developed a technology on the use of broad undersea space for aquaculture. A type of submersible platform has been developed and evaluated for the purpose of abalone farming. The concept of the platform is simple and comprises an artificial sea floor, rectangular in shape (36.4 m x 20 m). This is normally kept in the middle of the water column and can be brought to the surface when necessary. The abalone are kept in cages of steel net attached to the platform, so that the upper part of the cages can be positioned slightly above the sea surface when the platform is lifted. To bring the platform to the surface, an operator starts a diesel generator in the machinery room and operates two drainage pumps. The pumps stop automatically after about 70 minutes when the platform has reached the surface. For submerging, which takes about 25 minutes to complete, the operator simply opens two flood valves. Feeding (sea-algae) is given to the abalone when the cages are opened at the surface. This system is still on the experimental base while the data from the viewpoint of commercial application is not yet available. However, this system could be beneficial in areas where the sea can be vertically exploited.

Marino Forum 21 is the semi-governmental agency which promotes the new challenges of the technological advances in good collaboration with the companies who provide the funding and

technology. One project is the farming platform, which was installed in Kumamoto Prefecture. The platform which is attached to several net cages can offer the automated support for daily farming activities such as feeding, water quality monitoring and information transmission to the land-based office.

Stock enhancement by artificial seedling and releasing is also challenged as the marine ranching project to establish the upgraded techniques of fish behavior control by means of keeping juveniles in the enclosure through air bubble curtains, and guiding them to the safer nursery ground by acoustic conditioning.

In considering the combination with the coastal fisheries, the keeping cage is attached to the trap net. The idea is to keep the captured fish for a while, for the purpose of live fish marketing and price control. Another challenge to set-net fisheries is the simple construction of the gear by combining the two net cages as the traps. The idea is that the final trap can be easily detached for keeping the captured fish, and can be towed to the best site for keeping or farming purposes until marketing.

Environmental Conservation in Relation to the Cage Farming

In 1999, the Japanese government enacted a new law for sustainable aquaculture in open water areas. The major purpose of this law is to keep the environment in and around fish-farm areas clean and healthy. For this purpose, the density and arrangement of the cages in the concerned area should be analyzed by the fisheries cooperatives and, if necessary, be re-arranged under the approval of the local government. In addition, prophylactic and therapeutic measures must be taken to avoid the spreading of certain diseases. In some cases, diseased fish inside the cage and the net itself must be disposed by the order of the local governor.

This action can set the new trend for aquaculture toward sustainable production, in accordance with the recent moves of responsible aquaculture steered by FAO and SEAFDEC.

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Cage Aquaculture in Korea

I.-B. Kim

Pukyong National University
599-1 Taeyon-dong
Nam-gu, Pusan
The Republic of Korea 608-737

Kim, I.-B. 2000. Cage aquaculture in Korea. In *Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia* (ed. IC. Liao and C.K. Lin), pp. 59-73. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok.

Abstract

This paper presents the general status of cage aquaculture in Korea. Except for the sporadic use of cages to hold live fish caught from the wild, cage aquaculture to grow fish to marketable size dates back to two decades ago in inland waters and only a little more than one decade in marine waters. The inland water cage farming was once thought to be the most important and profitable aquaculture business, but it is now totally banned by the central government due to the clean water policy after long social conflicts. Marine cage farming has instead been growing at a steady pace and now some 400 farms are under operation. Annual output from marine cage farms is now more than 40,000 tons of fish, well rivaling one of the other types of marine fish culture, land-based tank aquaculture.

Introduction

Total aquaculture production in Korea is about one million metric tons in the late 1990's, occupying about 30% of total fisheries production including seaweeds. But the aquaculture production of finfish occupies only a fraction, still being about 100,000 metric tons. For the production of finfish, nevertheless, cages in inland waters and protected coastal seas have contributed not to an insignificant extent, while bringing in some social conflicts in inland waters leading to complete closure of inland water cage culture. The central government disclosed in May 1997 that all inland water cage farms must be dismantled after the original licensed term, mostly 10 years, expires. At present, almost all inland water cage farms have already been removed leaving only a few cage farms which will also be eliminated in a couple of years. On the other hand, in the marine environment, cage fish farming has been growing at a steady pace and, in 1998, it produced some 38,000 metric tons of black rockfish (*Sebastes schlegeli*), in addition to other fishes including sea bass (*Lateolabrax japonicus*), mullet (*Mugil cephalus*), yellowtail

(*Seriola quinqueradiata*), red sea bream (*Chrysophrys major*), puffers, etc. At the beginning of marine finfish aquaculture development in the early 1990's, land based tank aquaculture played a major role, but now the situation is gradually changing, with a significant increase in cage farm production as well.

History of Cage Farm Development

The people of Korea have rapidly developed aquaculture industry for the last four decades, and the production from aquaculture increased from less than 100,000 metric tons in 1960 to about 1,000,000 metric tons including seaweeds in the late 1990's, comprising about 30% of the total fisheries production. However, the production of finfish occupies only a fraction. In 1998, less than 100,000 metric tons were produced; of which, about 40,000 metric tons came from cage farms.

Inland Water Cage Farm Development and Its Fall

The first trial of inland water cage aquaculture

in respect to business development was made in 1976 to grow common carp in a dammed lake, near Chunchon, some 80 km east of Seoul (Kim 1983). The carp was one strain of scaleless European carp, which was introduced from Israel in 1973. This trial once led to a prosperous business development of nationwide inland water fish farming in net cages until the complete termination of cage farms by the end of 1990's by the government action for a sustainable clean water policy.

The total number of inland water cage farms reached 221 in the early 1990's producing about 30,000 tons of common carp but the number began

to decrease upon termination of their original licensed terms, thus being completely wiped out by year 2001 (Fig. 1).

During the heydays of cage aquaculture in inland waters, common carp of mainly Israeli strain, which were almost exclusively reared in the cage farms, occupied more than half of the total freshwater aquaculture production (Fig. 2). Though the figures in the official statistics ranged only some thousand metric tons of common carp, it was generally agreed that at least 30,000 metric tons of carp were produced, as estimated from the consumed feed and fish farmers' own assumptions.

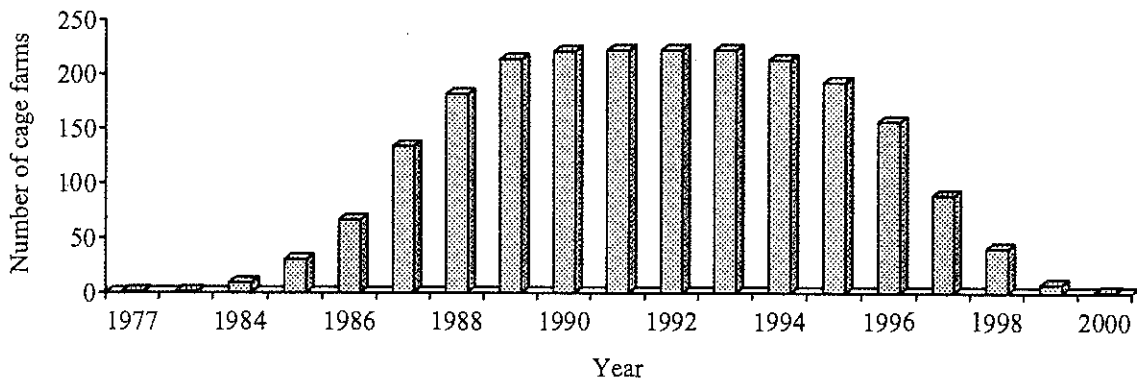


Fig. 1. The rise and fall of inland water cage farms in Korea.

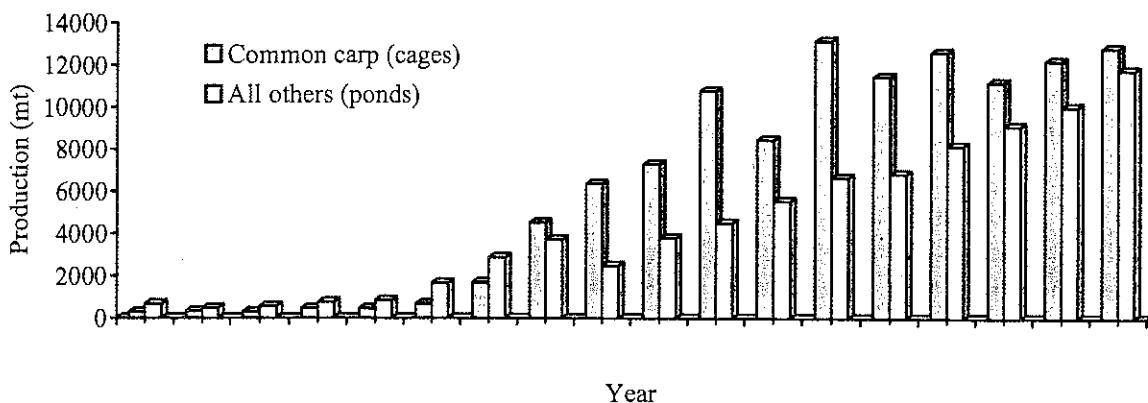


Fig. 2. Production of common carp and all other fishes combined in inland waters in Korea from 1980 through 1997. The common carp were almost exclusively produced from cage farms. The figures were drawn from the official statistics. Real size of production has generally been agreed at least triple the official figures.

Marine Cage Farm Development

Marine fish cages may have first appeared in 1964 at Samchok, Pohang and Kampo, along the east coast of Korea to hold live fish which were caught in the sea. Some cages were also set up in the areas of Hansan and Sanyang, in Tongyeong area, Kyongsangnam-do of the south coast (Yi, pers. comm.). In spite of an effort by the government agency, Fisheries Research and Development Agency to further develop cage aquaculture in 1968, this did not lead to any expansion of the industry because of a highly limited demand for cultured fish and economic conditions to afford the aquacultured products which needed feeding.

In 1975 and thereafter, a relatively large number of cages were set up at Yokji, Sanyang, Koje, Konri, Pongam, and Hansan, in Tongyeong area, Kyongsangnam-do, Yosu and Komundo, in Chollanam-do. In the beginning, the cage farmers stocked fishes, which were caught from the wild, some for a limited period until the price of fish rises and others for further growing to some extent. The species of fish included yellowtail, puffer, and red sea bream. Among them, yellowtail topped all of the others and some three thousand tons of yellowtail were grown in 1985.

However, these trials did not develop further and began to shrink.

With the advent of olive flounder *Paralichthys olivaceus*, and black rockfish into the aquaculture arena by the end of the 1980's, which led to a rapid growth of mariculture business in the 1990's, the marine cage systems have been actively employed to grow these fishes. The cage system now plays an important role in the development of marine aquaculture business in addition to other types, such as land-based tanks and large impounded ponds (Fig. 3).

Though it is hard to exactly trace the development and size of the cage farms in the past years, it is apparent that the cages were used to grow yellowtail for several months in summer. The other species of marine fishes, which were caught from the wild, have been held in cages only for a short time as a means of live holding. One can trace back the time, from the official statistics, to early 1970's, when yellowtail farming was sporadically carried out (Fig. 4). Yellowtail farming prospered around the middle of the 1980's, but toward the end of 1980's and early 1990's, yellowtail production was drastically reduced. Anyway, yellowtail aquaculture can be considered as the history of marine cage culture in the early days in Korea.

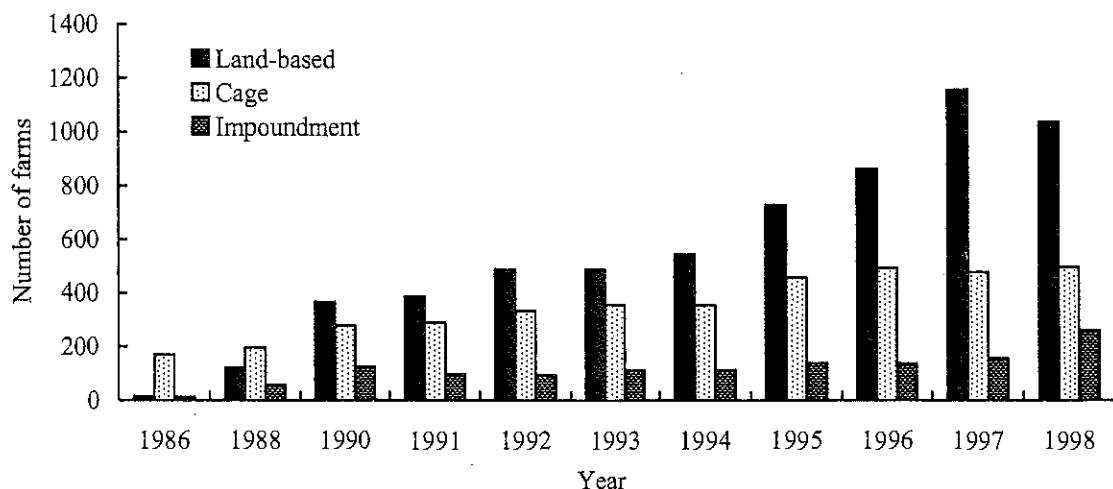


Fig.3. Development of marine fish farming which has consisted of three types of farming in Korea, such as land based tanks, net cage farms, and large impounded pond farms.

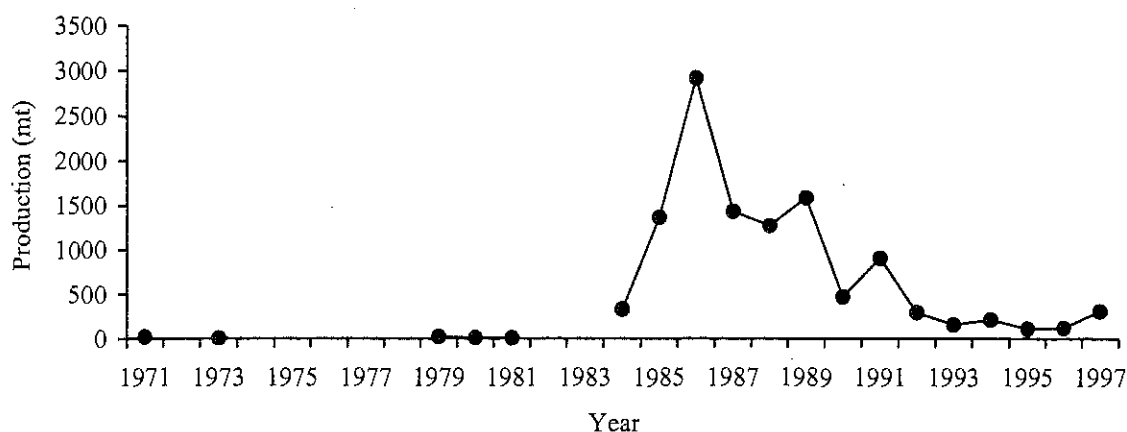


Fig. 4. Official record of yellowtail farming which has existed from the early 1970's. For yellowtail rearing marine fish farmers have always employed net cages.

Growth of the Farmed Marine Fish Production

Fish farmers then shifted their target fish from yellowtail to other species, first flounder and then black rockfish. These two species played a major role in marine fish culture business of both the cage and land based systems for several years up to very recently. The production of these two species reached more than 70,000 metric tons out of a total of 83,800 metric tons in 1998, estimated by a local office of the Ministry of Maritime and Fisheries (Yi, pers. comm.).

Of these two major marine aquacultured species, black rockfish are almost exclusively reared in cage farms. The other species, olive flounder were once reared in cage farms until recently, now only a few cage farmers still grow this species but to a limited extent.

Indirect Estimation of Production Size of Farmed Fish in Early Days

During the early days of fish farming it was difficult to figure out the real amount of output from aquaculture farms. General trend of production growth could be figured out based on the official statistics but real output could be indirectly estimated by the amount of feed consumed and size of the fish farms. Flounder feed consumed in 1995 was 21,680 metric tons of manu-

factured compound powder feed released from domestic feed mills plus some imported feeds. This powder feed is only a part of moist pellet feed, which is prepared on farm sites. Most farmers used powdered feed at a ratio of 10% of the total ingredients of the moist pellet feed, some 20%, and very few up to 50%. Therefore, the amount of moist pellet feed consumed by these marine-farmed fish must have been more than five times the ingredient of powdered feed. According to an estimate discussed at an appraisal meeting, olive flounder harvested in 1995 (NFRDA 1996) was said to have amounted to 17,000 metric tons and black rockfish, about 10,410 metric tons. These two species occupied 95% of a total of 28,730 metric tons, in contrast to the officially released figures of 8,360 metric tons of total marine-farmed fish in 1995. These figures suggest that marine-farmed fish production in Korea has developed at a much faster rate than that of the officially released figures.

Present Status of Cage Aquaculture

Inland Water Cage Aquaculture

As stated in the history of aquaculture in Korea, freshwater cage farms are no longer existing except for a few whose licenses are still valid for 10 years, and we can not expect the return of

cage farms in the inland waters of Korea in the future.

Marine Cage Aquaculture

In the marine environment in Korea, more than 400 cage farms were under operation in 1998. The cage farms had a total licensed area of 1,224 ha, 20% of which was allowed to install net cages. The marine cage farms contribute to the production of almost all farmed black rock-fish. More than 39,000 metric tons of black rock-fish was reported in 1998, in addition to other minor species from the cage farms (Park and Yi 1999, pers. comm.).

Marine cage farms are located mainly along the southern coastal seas of Korea, with some located in a few places of the west coast and a fraction located in the east coast. Of the total cage farm area of 1,046 ha in 1995, 52% was located in Chollanam-do, 33% in Kyongsangnam-do, and these two provinces span the whole southern coast of Korea (Fig. 5). The remaining 7% in Chungchongnam-do province, west coast of Korea, and 5% in Kyongsangbuk-do province, east coast, leaving only 3% for the other four provinces (Fig. 6).

Along the coast of Chollanam-do, the largest cage farming province, marine cage farms are further distributed into sub-areas, Yosu area in the east and Wando area in the west. Between these two areas, small areas are further distributed.

Marine Cage Farm Establishment

Most of the data in this section is based on information from two local officers who are practically engaged in the field affairs of marine aquaculture of two major farming regions of Korea (Y.H. Yi and Y.J. Park, pers. comm.). The author also gained information through personal visits to the most important cage farming areas in the nation.

To be able to establish a cage farm in the marine environment, one must obtain cage fish farm license from the government authorities. After obtaining license, the farmer is allowed to install fish rearing cage installations within 20% of the licensed area. If one hectare or 10,000 m²

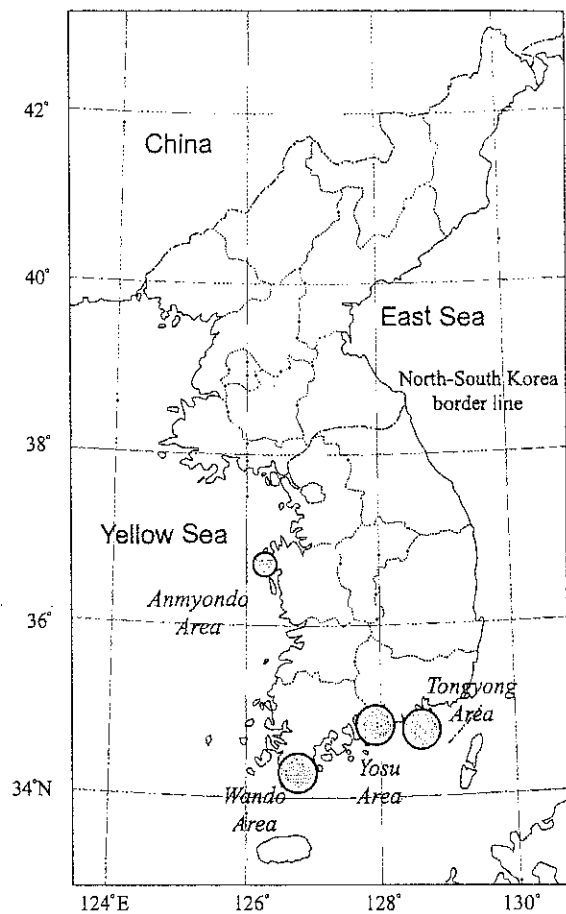


Fig. 5. Map showing the main areas of marine cage aquaculture in Korea.

Total area: 1,046 ha

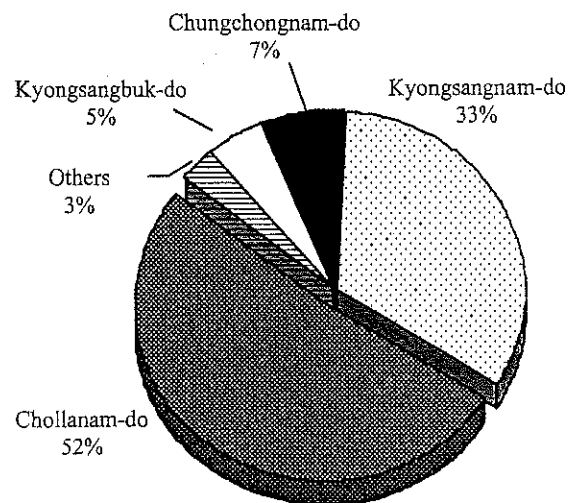


Fig. 6. Distribution of marine cage farms by province in Korea, 1995.

is licensed, the farmer can construct 2,000 m² of net cages leaving the remaining area to facilitate water movement and to protect the habitat. The distance to the neighboring cage farm must be at least 300 m.

In Korea, it has been customary to designate 100 m² of fish rearing cage as one set of the cage. Normal size of a set of rearing cages is 10 m x 10 m (Fig. 7). In many cases, one unit of a cage is further divided into four cells, which is still one set of cages. But some fish farmers make their cages of 14 m x 14 m, occupying two sets of cage areas, while others make 12 m x 12 m cage installations.

In addition to the installations of fish rearing cages, farmers need to set up auxiliary facilities. They include a working platform, a quarter house for the personnel, cold storage, moist pellet (MP)

manufacturing machines, and a general storage to keep unused nets and other necessities. Cold storage is essential to keep feed materials such as raw fish as the ingredient of MP feed and processed MP feed before being fed. For these additional installations, the farmer must obtain a separate permit from the respective government authorities. The cage fish rearing system consists of frameworks, floats, and net enclosures. The cage systems are supported by floats and moored to anchors. Though some cage farmers use polyethylene pipes for the frameworks, most use wooden material imported from tropical regions. The wooden frameworks can better stand against rough weather on the sea than other materials. Besides rigid frames, some farmers use rope frames, which are flexible and can withstand well against storms.

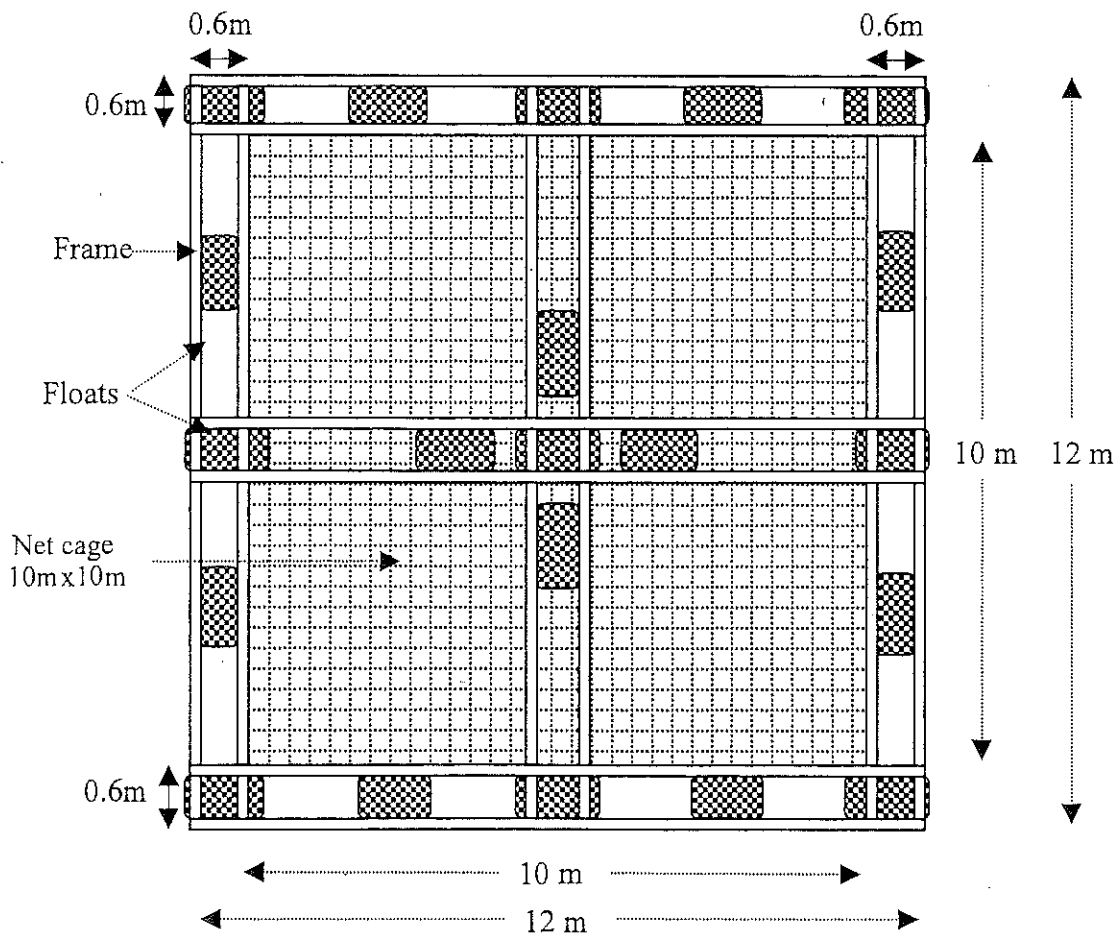


Fig. 7. One set of cage structure, which contains one net enclosure of 10 x 10 m.

Most farmers use iron anchors, but some use rocks and concrete structures. Mooring lines are of polypropylene rope and the length of mooring lines is more than five times the depth of water. At relatively shallow waters, some farmers use piles to fix cages.

The cages used for growing small fish are further divided into four sections to make small net cages of 5 m x 5 m for fingerling rearing. In some regions the cage farmers exclusively use these small units of net cages throughout their farming operations. Of the four net cages of one set, only three net cages are stocked with fish leaving one empty. In the farm environment, fouling of cage nets is a common phenomenon and frequent cleaning of nets is required. When cleaning a net cage, fish in this cage are transferred into the empty net cage right next to it. This facilitates the handling of fish for staggering cleaning of cage nets.

The materials required to construct one hectare or 2,000 m² cage farm are shown in Table 1. This record is based on a fish farm, Nammyon, Yochon-gun, in Yosu area, Chollanam-do around the middle of the southern coast of Korea (NIFRDI 1999).

Selection of Species to be Reared in Cages

The species reared are determined by first, marketability, which greatly influences profitability, and second, susceptibility to diseases. Some farmers once tried to grow coho salmon, *Oncorhynchus kisutch*, which could have expanded their production to a large extent, but the farmers had difficulty in marketing the products due to the prevailing low price then. At present it is generally agreed that local salmon farmers can not compete with imported salmon. Olive flounder generally commands a very good price but they are very susceptible to many disease pathogens compared to other species, such as black rockfish, black porgy *Acanthopagrus schlegeli*, rock bream, etc. Therefore, in recent years, cage farmers in Korea have gradually reduced the size of flounder production, but increased black rockfish production.

Stocking Fish Seeds

Most fish seeds are obtained from fish hatcheries except for yellowtail, the fingerlings of which are caught at sea. The size of fish ranges

Table 1. Materials required to construct a one hectare cage farm (for a cage net area of 2,000 m²).

Item	Specification	Unit	Amount	Remarks
Lumber	12 cm x 15 cm x 10 m	Number	240	—
Float	0.4 m ³	Number	420	—
Anchor	Iron, 75 kg	Number	26	—
Anchor line	40 mm PP rope	m	1,170	15 m water depth
Rearing net	Mozi net, 105	Roll	5	5 m x 5 m x 5 m (for small fish)
Rearing net	Knot-less, 8 mesh	Roll	40	5 m x 5 m x 5 m (for small fish)
Rearing net	Knot-less, 12 mesh	Roll	40	5 m x 5 m x 5 m (for small fish)
Rearing net	Knot-less, 18 mesh	Roll	10	10 m x 10 m x 10 m (for large fish)
Rearing net	Knot-less, 20 mesh	Roll	10	10 m x 10 m x 10 m (for large fish)
Rope to tie floats	PE rope, 10 mm	m	1,400	—
Bolts and nuts	33 cm x 18 mm	Number	1,440	—

from 5 to 7 cm when they are stocked. Cage fish farmers prefer to stock larger fingerlings in the peer group of the batch produced at the hatchery.

The fish seeds of black rockfish are stocked in late spring or early summer in the Tongyong area and elsewhere in the southern coast of Korea. Normal stocking rate is 500,000 for a one-hectare farm with a 2,000 m² cage enclosure. This means that one standard 10 m x 10 m cage can be stocked with 25,000 fingerlings on the average. In the case of 14 m x 14 m x 7 m (depth) cages, 50,000 fingerlings are stocked. The other pelagic species, such as sea bass, sea bream, etc. also follow this guideline.

In the case of flounder, much larger seeds from 100 g to some 200 g or larger fish, which have been grown up at land-based tank farms have been stocked.

Total size of fish seed production in the nation is hard to estimate but it is estimated that the number of rockfish seeds produced by 150 hatcheries in the Tongyong area, eastern south Korea, may have been over 100,000,000 in 1999. This estimation was made based on the outcomes of three major hatcheries that actually produced 37,000,000 fingerlings. The average production size of each hatchery is 500,000 fingerling seed fish. Extra fish seeds produced in this area are shipped to other regions while some are released into natural waters.

Rearing Manipulation of Fish in Cages

Two months after initial stocking, the fish are graded and the number of fish is reduced by about one-half. Manual grading has been a rule until recently when farmers began to use graders and this method is now gaining popularity.

Once fish have been stocked, routine works include feeding, preparation of quality feed, changing of nets and net cleaning, and control

and prevention of diseases. Management of these factors is highly artistic rather than scientific, because the conditions of fish are highly influenced by natural variables such as seawater temperature, wave actions caused by stormy weather or typhoon, and red tide attacks.

Production Capacity by the Size of Cages

Production from a cage varies with the fish species reared. Personal capability also affects the performance, but in general larger cages have much larger capacity to grow fish in a given area of cages than the smaller cages. One standard fish cage of 10 m x 10 m can grow up to 8,000 kg of black rockfish or 6,000 kg of yellowtail, but in the case of a demersal fish like flounder, only 2,000 kg can be produced at harvest time. It is also generally recognized that a 14 m x 14 m cage which has an area twice the standard 10 m cage can produce as much as 2.5 times fish that could be reared from the standard cage (Table 2).

Major Species Culture Strategy by Region

Recently, there has been a trend of species specialization between the regions in the nation. This trend is caused by the differences in water characteristics including temperature ranges and physical and chemical parameters by locality and topography of the region.

At present, major species reared in cage farms in the southern seas of Korea is black rockfish. The other species are yellowtail, sea bass, olive flounder, sea breams including black porgy, and other rock fishes. In addition, a few farmers grow groupers including seven-band grouper *Epinephelus septemfasciatus*, greenling *Hexagrammos* sp., black scraper *Navodon modestus*, and others in the southern cage farming areas. The

Table 2. Production capacity of cages.

Size of cage	Demersal species	Pelagic species	
	Flounder (kg)	Rockfish (kg)	Yellowtail (kg)
10 m x 10 m	2,000	8,000	6,000
14 m x 14 m	5,000	20,000	15,000

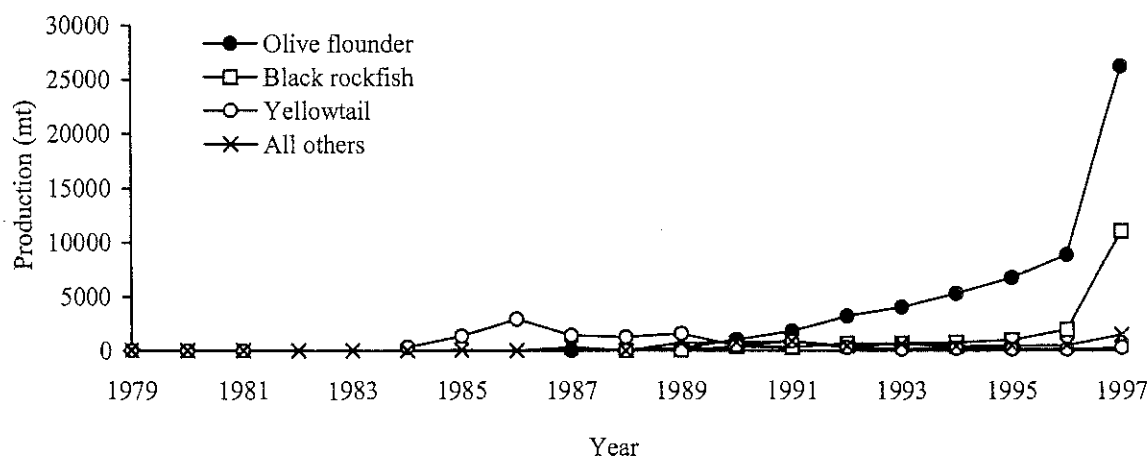


Fig. 8. Development of mariculture production of major fish species in Korea. Data in this figure were based on official statistics and real figures before 1997 should have been much higher, estimated by other methods such as the amount of feed consumed and of farms.

species, which have been added to the candidate of cage culture, is increasing quite rapidly in recent years owing to successes of marine fish hatchery operations in Korea.

On the other hand, in the western areas the variety of species are rather restricted, and the farmers there prefer to grow such species as black porgy and rock bream, which better survive hot summer water temperatures in their highly protected seas.

Culture Strategy in the Southern Area of Korea

Black rockfish

Black rockfish, the main species produced in cage farms, came into marine aquaculture systems almost at the same time with olive flounder at around the end of the 1980's, but production remained far less than the flounder until around 1995 (Fig. 8). The black rockfish are reared in the same way with olive flounder but the main production areas are in the southern coast of the main land, while that of olive flounder are spread all around the nation including Cheju-do, which is a separate island in the south.

Black rockfish are quite hardy and could better tolerate the winter cold than olive flounder and other farmed fishes, but they are more vul-

nerable to warm water during summer. Black rockfish grow well during the cool season when water temperature remains below 20°C, but during the summer season when the temperature increases above 23°C, their growth is retarded. The optimal water temperature of their growth appears to be from 15 to 20°C.

Feeds offered are moist pellets for their main growing season and extruded pellets during hot season and for fingerlings.

Fingerlings of black rockfish in the Tongyeong area are generally stocked in the cage in early July. They are then fed extruded pellets which are available from feed manufacturers until the end of October, and during the fast growing season. From the beginning of November the feeds are replaced with moist pellets. From early July to the end of October the following year, the fish are again offered extruded pellets. Thus, the fish are grown on extruded pellets during summer seasons when their health conditions shrink, and on moist pellets during winter seasons when they resume their vigorous growth. After two years of feeding, the black rockfish weighs 500 g, the size suitable to be sold in the market.

Olive flounder

Though olive flounder have mainly been

farmed at the land-based tank farms throughout the nation, they are still reared by some cage farmers in the southern areas of Korea. Despite having joined the Korean aquaculture quite late compared to yellowtail, the flounder soon began to capture the great interest of the fish farmers in the early 1990's.

Olive flounder are bred during cold seasons, that is, fall and winter seasons in Korea. But they are also bred much earlier than the natural spawning seasons through the manipulation of temperature and light-dark rhythms. Recently, all female flounder, which grow much faster than males, have also been developed by techniques of genetic manipulation and they are now grown by some fish farmers.

Though most olive flounder require a little more than one year to grow to one kilogram size or larger, some fish farmers are able to grow them up to 1 kg or even to a bigger size within one growing season, which is normally less than one year. The larger flounder command a much higher price than the smaller ones.

In cage farms, much larger fish seeds, which had been grown in the land-based tanks, are being stocked. The initial size to stock cage farms varies by farmers. Table 3 shows one example of cage growing of olive flounder in the Wando-area, Chollanam-do, western south Korea.

Depth of flounder cages varies according to the clarity of water. Net cages for growing flounder are normally 10 m x 10 m and the depth varies from place to place, but are normally 3 to 4 m, and 1.3 m in the areas where water is quite turbid due to suspended particles caused by the wave actions in shallow seas. Clarity of coastal water in Korea varies from place to place to a significant extent. Water is very clear in the east and southeast areas, but quite turbid in the west and southwest. It has been known that in the

clear seas of Tongyong, Kyongsangnam-do, strong solar radiation adversely affected the well being of this demersal flatfish. Therefore cage farmers in clear water areas make their cages quite deep. On the other hand, in the Changhung and Wando areas, Chollanam-do, western south Korea, the cage farmers have made their cages very shallow, only 1.3 m or so for flounder rearing until recently when they gradually stopped flounder farming. If radiation does not affect the fish, flatfishes do not require deep cages unlike other pelagic species.

Other species

Yellowtail, red sea-bream, common seabass and other rockfishes are produced in cages in the southern seas. Yellowtail, which was once the hope of fish farmers in Korea around the middle of the 1980's, has shown decreasing production. Red sea-bream has also been one of the targeted fishes for a long time but the production is still negligible. Black porgy and the grouper have also been recently added to the aquaculture yield, and production shows a sign of increase but at a slow pace.

Yellowtail are still reared in cages in the Tongyong area but to a limited extent. They grow well during the warm season in Korea and they exhibit retarded growth during winter when water temperature cools down to below 20°C. The optimal temperature for this species is considered to be 22 to 26°C.

The moist pellet feed, in the Tongyong area, prepared for this species for summer feeding contains 80 kg of raw fish and 20 kg of powdered dry compound feeds as the major ingredients. Some farmers add 4 kg of high quality fish meal to make a total amount of 104 kg. The fish show the best growth and good feed coefficient on this feed. Feed coefficient normally ranges

Table 3. Growth of olive flounder in the cage farms in Wando county, Chollanam-do province.

	Initial		Time after stocking (month)										
	0	1	2	3	4	5	6	7	8	9	10	11	12
Length (cm)	15	17	19	21	23	25	27	30	33	35	36	37	38
Weight (g)	50	70	100	110	120	190	310	390	430	510	590	600	700

between 1.8 and 2.1.

With the onset of cooling of water temperature in October, fishmeal is replaced with feed oil in the above mentioned moist pellets and this feed is fed for one month before winter. During winter, the fish may be fed but only in a very small amount.

Just like the yellowtail in the Tongyong area, the red sea bream also grow well during the season when water temperature increases and grow poorly as the water temperature decreases. In this area, some farmers grow red sea bream and yellowtail in the same farm.

Culture Strategy in Anmyondo Area, Chungchongnam-Do, West Coast

Anmyondo area is located somewhere in the middle of the West Coast of south Korea. This region is highly protected by a long island and is only capable of restricted exchange of water through a very narrow channel with open sea water. The water temperature in the cage farm area fluctuates between 3°C in winter and 30 or

32°C in summer. The cage aquaculture is not large in the size of production but the business has a very good profit potential because the farmers have established their specific rearing and marketing strategies (Tables 4 and 5).

In the beginning, around the first half of the 1990's, the farmers tried to grow black rockfish and other types of fish until recently, but they gradually changed the species to environmentally more sustainable and economically more profitable fish. During the last few years, most cage farmers have been growing black porgy and rock bream together with some other minor species.

It is generally agreed that black rockfish have difficulty in withstanding the hot summer water temperature of above 30°C in this area. In contrast, black porgy and rock bream can easily withstand the high temperatures but have some difficulty during winter due to low temperatures in this area.

Black porgy is one of the high valued fishes in aquaculture in this area. Black porgy is more tolerant to low temperature down to 3-4°C, but much higher temperature is preferred for wintering.

Table 4. General status of black porgy and rock bream cage culture in a west region of Korea, 1999.

	Black porgy	Rock bream or parrot fish
Marketable size	400 g	200 g
Age at marketable size	2 seasons (summers)	1 season (summer)
Time of harvest	Mid October-Mid January	Mid September-Mid December
Time of seed-fish stocking	End of July	First of May
Size of seed-fish	5 cm	5-7 cm
Price of seed-fish	350 won/fish	350 won/fish
Feed supplies	Extruded pellets	Extruded pellets
Origin of feed	A few domestic feed manufacturing companies	
Price of feed	1,150-1,350 won/kg or roughly 1 US\$/kg	
Feed conversion	Mostly around 1.5 but some 1.2 or bellow	
Distribution of cage farms along the West Coast	Majority (70-80%) of marine cages on western coast are located both at northern and southern ends of Anmyondo Island	

Table 5. Price fluctuation of aquacultured fish in Korea, 1996-1999.

Year	Olive flounder	Black rockfish	Sea bass	Mullet
	500-700 g	500-600 g	700-800 g	700-800 g
1996	13,000	12,000	13,000	6,000
1997	12,500	10,000	13,000	6,500
1998	12,000	9,500	12,500	5,500
1999	13,000	12,000	14,000	6,000

Therefore, farmers in this area, where water temperature increases to above 30°C, have preferred to grow them in their cages instead of black rockfish. However, they must be overwintered because they require two growing seasons to reach the desired market size of 500 g or larger. In this case, one problem is that the cold temperature in the cage area during winter is too low for the black porgy to overwinter. Therefore, the porgy farmers move the fish to land-based fish tanks during the winter season after one growing season. One setback for black porgy is that they are highly vulnerable to stress caused by handling during the transfer of the fish from cages to land-based tanks. Accordingly, farmers have been trying to set up their wintering facility near their cage farms.

While many farmers have constructed wintering land-based tanks, a few farmers improved their own wintering floating basins, which are insulated and covered by a greenhouse roof. The basin measures 7 m x 7 m x 1 m deep, and has polyurethane foam sandwiched between fiberglass reinforced plastic sheets. The cost to build one wintering basin is said to be seven million won, equivalent to about US\$ 5,800. It is said that water temperature in this wintering basin is kept at about 12°C while that in the outer sea water cools down to 3°C in winter.

This floating basin is moored near the cage site and fish are easily transferred without causing much stress. One basin can hold 10,000 black porgy, weighing 50g each. Thus, the farmers in this area can produce marketable black porgy, which require overwintering to reach the desired market size after two seasons of growing.

Feed and Feeding

Feeds supplied to fish in the cage include moist pellets and extruded pellets. Moist pellets are prepared on site while extruded pellets are purchased from commercial feed mills.

Preparation of Moist Pellets

For the preparation of moist pellet feeds, raw fish, which is used as the primary major

ingredient, must be obtained beforehand and preserved in the cold storage room with temperature of at least -20°C. Many kinds of fishes, such as mackerel, horse mackerel, sand eels, sardine, and other trash fish that are cheap yet fresh could be used as ingredients of moist pellets. The other major ingredient, powdered compound feed, released from the feedmills normally contains protein, which ranges from 36 to 48% of the mass. The main nutrient additives are premixtures of vitamins and minerals, which are commercially available.

The first two major ingredients, raw fish and powdered compound feed, are put together in the hopper of feed processing machine, and are press-passed through the auger of the machine, resulting in cut moist feed pellets. Some farmers pass the moist pellets through the machine twice to mix the ingredients more evenly. Additives such as additional vitamins and other micronutrients are added during this process. Prepared feeds are normally kept in the cold storage until they are fed.

Feeding Regime

As a general rule, routine feeding is twice per day, but for small fish feedings, three to four times feeding daily is widely practiced. Extruded pellets are generally supplied to small fingerlings up to 100 g. For more omnivorous fishes such as mullet, rock-bream, black porgy, and black scraper, extruded pellets are supplied from the first throughout their on-growing stages by some farmers in the Tongyong area.

Feed conversion ratio ranges from 1.0 to 2.4 on the dry feed basis depending on feed ingredients, processing skill, water stability, feeding regime, and age and species of the fish reared.

In addition to the general nutrient additive, some farmers add so-called tonic food additives such as ginseng, aloe, cactus, herbal medicine, etc. when fish are stressed by sudden changes of water quality caused by unstable weather conditions. Fish farmers have experienced that fish are normally weakened after a typhoon, other stormy weather, or red tide, which suddenly changes the water parameters such as turbidity, temperature,

etc. Fish then get diseased which sometimes lead to heavy mortality. To avoid this, some farmers use, rather regularly, these tonic additives for several days with intervals of two to three weeks. Still some farmers continually use Obosan™, one of the herbal medicine compounds, at a rate of 0.3% active ingredient of feed. Many marine fish farmers in Korea depend on some kinds of additives such as these fish tonic ingredients.

Disease and Hazard Problems

With the increase in the number of cage fish farms, disease outbreaks have become a critical problem for the survival of the cage culture business. This problem is more serious in the regions where cages are densely installed, than in sparsely installed areas. Commonly occurring bacterial diseases are vibriosis by *Vibrio anguillarum*, streptococcosis by *Streptococcus* sp., edwardsiellosis by *Edwardsiella tarda*, and pseudotuberculosis by *Pasteurella piscicida*. Parasites mainly infesting caged fish are *Scuticociliate*, skin-flukes *Microcotyle sebastisci*, and gill-flukes.

To control the bacterial diseases, antibiotics including oxytetracycline are commonly administered by mixing in the moist pellet feed. Parasites are controlled by immersion of the infested fish in freshwater or in 9% hyper-saline salt water for 55 to 65 seconds.

In general, the most serious problems for all marine finfish culture including land based tank and impounded pond culture, have been persistent outbreaks of diseases, when water temperature rises, generally beyond 24°C for olive flounder and black rockfish. Once a disease out-

break occurs, farmers lose quite a large portion of their fish, normally 20 to 30%, sometimes more or less than 50% and medication can only help a little after the outbreaks. To cope with this problem, the management of water quality and feeding regime is considered as the most critical factor.

In recent years, another problem which frequently affected not only cage farms but also land based tank farms has been red tides in the south and southeast coastal seas of Korea. For the last decade, red tide attacks have been frequent phenomena with losses of hundreds to thousands metric tons of fish under aquaculture in some years. Heavy red tides occur after heavy rains following an extended drought during summer and early fall. To protect the fish under rearing from loss, control measures against the effects of red tide are practiced. These include heavy aeration of water to prevent depletion of dissolved oxygen level in the fish rearing boundary and spray of loess, one kind of yellow earth, which has been proven to have an effect of quickly precipitating the red tide organisms. These techniques have been practiced only during the last several years.

Marketing

Almost all fish produced in the cage farms in Korea are marketed as live fish mainly before winter, and the price varies primarily with the size of fish and season of the year. The average farm price of black rockfish of 500 g is around 9,000 won or US\$ 7.50 per kilogram. But the price this year along the western coast has been much higher than ten US dollars (Table 6).

Table 6. Sizes and prices of black porgy and rock bream cultured in the western region of Korea.

	Black porgy	Rock bream or parrot fish
Marketable size	400 g	200 g
Price in 1999 (won/kg)	17,000	15,000
Price for larger size (230 g)	-	17,000 won/kg
Predicted price at end of season	14,000 won/fish	14,000 won/kg
Time of harvest	Mid October-Mid January	Mid September-Mid December

The fish are first sold to live fish dealers who transport the fish to nationwide raw fish restaurants, where they are served as sashimi at sashimi restaurants and Japanese food restaurants. Recently, the fish are exported to Japan and China but are still restricted to specific fish species, flounder.

Fish are live-hauled in the live-fish hauling container mounted on the truck bed. The amount of live fish transported on a five ton truck is about 1,000 kg.

The general price of cage cultured fish species of 500 g to 700-800 g are shown in Table 5. Converting the price into US dollars, the prices of olive flounder and sea bass of about 600 to 800 g have ranged more or less than 10 US dollars per kg and that of black rockfish remained a little less than 10 US dollars. On the other hand mullet grown in cage farms commanded about 5 US dollars per kg.

On the other hand, black porgy and rock bream produced at the West Coast command much higher prices but harvesting season is strictly restricted to September through December or January. The size of production is very small compared to that of the South Coast cage farms, which are predicted to produce some 40,000 metric tons or more per year.

Discussions

Though marine cages have existed for more than three decades now, cage farming at a business level has a very short history, less than ten years. While the types of cages do not vary by region and with time, management of the fish in cages and species have been quite versatile according to the respective meteorological and hydrological parameters of the region. For a couple of years recently, species of fish grown in each region have been changing, new species have been added each year, and production size of both hatcheries and grow-out farms have also been increasing. Many small scale hatcheries have served to provide seed fish at profit, but as the large hatcheries have become providers of cheap high quality fish seeds, small inefficient hatcheries began to change their type of pro-

duction to grow-out farming. Future trends seem to be continuous growth in both the size of production and diversification of species.

Specialization in Management

To date, most marine fish farmers have used moist pellets to grow their fish, but very recently some fish farmers have began changing their attitude of sticking to moist pellets. Some farmers now use more dry pellets for some specified stage of fish growth, or for the entire rearing stages of some species, such as mullet and some other species. Most farmers have found that moist pellets give fish an accelerated growth. However, persistent problems in managing the water quality in and around the farms and frequent recurrences of fish diseases are partly attributed to the use of moist pellets. First, moist pellets are more apt to disintegrate and scatter into the water of their farms leading to heavy pollution of water. Second, the primary ingredient, raw fish, has become more scarce aside from the fact that quality is not consistent. For sustainable fish growing, the use of dry pellets that are formulated and processed based on scientific findings and developed technology is thought to be preferable to the use of moist pellet.

Constraints and Sustainable Cage Aquaculture

For the attainment of a sustainable cage aquaculture even in the marine environment, extra effort should be exerted to reduce the negative impacts on the protected environment, by avoiding heavy stocking and employing high quality water-stable feeds and employing proper feeding techniques. For the drastic expansion of marine cage farming, the final solution may be through the introduction of open water cage system.

Another problem seems to be on how to reduce the cost of production through health manipulation, which is heavily influenced by the selection of proper feeds and command of wise feeding regime. Reduction of disease outbreaks leads to significant savings on drugs and manpower, and accelerated growth rates of fish to a very large

extent as already shown through the experiences of some cage farmers in the Tongyong area.

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Cage Culture in Malaysia: An Overview

M. SHARIFF¹ and N. GOPINATH²

¹Faculty of Veterinary Medicine
Universiti Putra Malaysia
43400 Serdang, Selangor
Malaysia

²FanLi Marine & Consultancy
11th, Third Floor, SS2/67
47300 Petaling Jaya
Malaysia

Shariff, M. and N. Gopinath. 2000. Cage culture in Malaysia: an overview. In *Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia* (ed. IC. Liao and C.K. Lin), pp. 75-81. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok.

Abstract

The cage culture industry is a relatively recent development in Malaysia with large scale farming in marine waters taking off only in the 1980's and in inland waters in the 1990's. In 1997, total production from cage farms amounted to 7,314 tons or 8% of the total aquaculture production. However, cage farm output amounted to US\$ 29 million or 18% of the total aquaculture value. Production was oriented largely towards production of high valued finfish for the live trade.

In 1997, there were 58,500 marine cages in the country with a total area of 680,893 m². Production amounted to 5,621 tons valued at US\$ 26.4 million. Unit production from marine cage farms averaged about 8.5 kg/m². The average wholesale price of cage farmed marine finfish in 1997 was US\$ 4,696/tonne. The main finfish reared is the sea bass (*Lates calcarifer*), which in 1997 accounted for 50% of the total finfish production and 35% of wholesale value. Other fishes reared include the groupers (*Epinephelus* sp.) and mangrove jacks (*Lutjanus* spp.). Though groupers account for only 14% of the finfish production, they accounted for 28% of the total value. The snappers (mangrove and red snappers) and tilapia which accounted for just 5% of the total cage culture output in 1992, accounted for nearly 50% in 1997. Major constraints include seed supply, congestion of existing sites and lack of new sites for expansion.

In inland waters, the number of units rose to 200% over 1992-1997, from 2,152 to 6,516 units. As with marine cage culture, the emphasis is on the production of live fish for the restaurant market. However, the value of the freshwater fish output (average wholesale value US\$ 1,426/ton) is generally lower than that of cage farmed marine fish. Production increased to 250% from 484 tons in 1992 to 1,693 tons in 1997, while its contribution to overall freshwater fish production increased from 3% in 1992 to 5% over the same period. Unit production rates ranged from .18-23 kg/m². The main species cultured include the tilapia (*Oreochromis niloticus*), sultan fish (*Leptobarbus hoevenii*), mystid catfish (*Mystus nemurus*) and striped catfish (*Pangasius sutchii*). Smaller quantities of Javanese carp (*Barbodes gonionotus*), common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) were also produced.

The future for cage culture development in Malaysia is promising, especially for freshwater cage culture. There are over 206,000 ha of reservoir area in the country suitable for inland cage culture. However, the market for freshwater fish is more limited. On the other hand, the scenario facing marine cage culture appears to be more limited. Though markets are not constraining, the limited resource base, disease, feeds and seed supply are serious impediments to the continued growth of marine cage farming.

Introduction

Though cage culture has antecedents in Asian aquaculture going back to the 16th century (Hora and Pillay 1962), it is a relatively recent development in Malaysia. The first attempts at

marine cage culture were made in Singapore in the early 1970's (Chen 1979). In 1973, it was introduced to the Malaysian aquaculture industry with the first experimental cage farms in Teluk Kumbar and Jelutong, P. Pinang (Chua and Teng 1977). However, it was only in the early 1980's,

when seed became available from Thailand, and as farmers became more familiar with the rearing techniques and cage culture grew. By the late 1980's, cage farming, particularly in marine waters, began to establish itself as a major force in the local aquaculture industry (Gopinath and Chin 1998).

The growth of cage farming in inland waters was slower compared to those in marine waters. Large-scale cage culture in freshwaters was first attempted in the Kubang Aji ox-bow lake and Chenderoh hydroelectric impoundments, Perak in the early 1980's. At its height, there were 1,248 cages in the state. However, due to a combination of factors, including pollution, limited market demand and lack of suitable feeds, the industry collapsed and by 1984, there was no cage production to speak of (Gopinath 1984, unpubl). In the 1990's, the industry was re-established in a larger scale, with cage farms developing in mining pools, hydroelectric and water supply impoundments. With continuing pressure on land resources for commercial agriculture, housing and industry, inland cages have taken on a more important profile and are seen as the major means by which the country's need for freshwater fish could be met (Tan 1998).

As with the other subsectors of the Malaysian aquaculture industry, there is a distinct vertical differentiation in the cage culture industry, with both seed production and grow-out culture being undertaken separately. Hatchery and nursery operations are basically land based with grow-out being undertaken in floating cages. Most farms specialize in one activity or the other and vertically integrated operations where both hatchery and grow-out are undertaken simultaneously are rare.

Cage culture in Malaysia is largely oriented to the production of high valued finfish species

for the live fish trade. Live fish are generally consigned to the restaurant trade where it fetches a premium price. Unlike its counterparts elsewhere in the world, cage farming in Malaysia is not directed towards catering for a broad consumer market.

Current Industry Status and Trends

Overall Status

The Malaysian cage culture industry is a substantially important part of the nation's aquaculture industry. In 1997, total production from cage farms, both inland as well as marine, amounted to 7,314 tons or 8% of the country's total aquaculture production. Production focused mainly in high value species. The fact that the output value from cages amounted to RM 109.5 million or 18% of the total aquaculture value (Table 1) exemplifies this.

The growth of the cage culture industry in Malaysia has generally been slow in relation to other subsectors in the same industry. Output value of cages rose from RM 39.6 million in 1992 to RM 109.5 million in 1997, an increase of 177% over the 5-year period. This contrasts against the 194% increase in overall industry value over the same time frame (Fig. 1). The contrast has been particularly pronounced after 1995, when overall aquaculture production and value climbed significantly.

A major reason for this was the shortage of sites for further development of the marine cage industry. Though the resource base for freshwater cage culture is not limiting, the investment in this area is still relatively small. This has led to a situation where cage culture is, at present, unable to match the rapid growth seen in other subsectors of the Malaysian aquaculture industry.

Table 1. Aquaculture production in Malaysia, 1997.

	System (tons)	Production value (RM '000)
Cage culture of marine finfish	5,621.37	100,304.51
Cage culture of freshwater finfish	1,692.63	9,180.22
Total aquaculture production	107,819.40	608,320.55

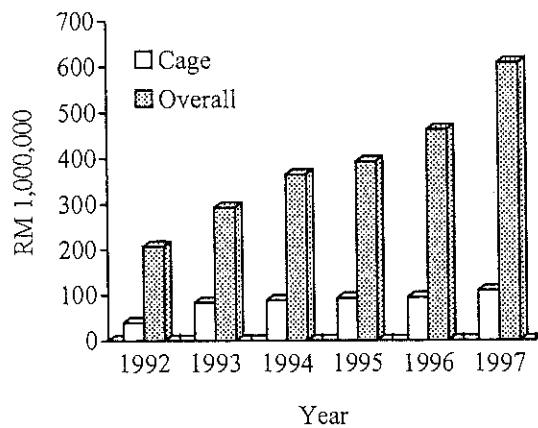


Fig. 1. Trends in wholesale value from cage farms and overall aquaculture value from 1992-97 (Source: DoF 1993-1998).

Marine Cage Culture

Marine cage culture has been the mainstay of the industry since the 1980's when commercial culture was first established. In 1997, there were 58,500 cages in the country with a total area of 680,893 m² (Table 2). Most of the cage farms were located in Penang (41% of total cage count), Perak (28%) and Selangor (11%). All three states have prosperous and developed hinterlands, which provide the market catchment for the farmed fish. In addition, significant quantities of live fish are exported to Singapore and Hong Kong. In the case of Sarawak, much of the output is consigned to Brunei Darussalam.

Most of the cage farms are small (average size 33 cages/farm). The level of technology

Table 2. Status of marine cage culture in Malaysia, 1992-1997.

Year	No. of farmers	Production (tons)	Cage farms	
			Number	Area (m ²)
1992	1,013	3,369	42,188	397,799
1993	885	4,601	63,306	668,260
1994	923	5,629	62,756	679,439
1995	1,182	5,762	64,262	715,152
1996	1,233	5,379	54,845	658,489
1997	1,779	5,621	58,499	680,870

Source: DoF 1993-1998.

applied in the cages is relatively low. Gopinath and Chin (1998) provide a detailed description of the industry.

The cages are of braided polyethylene hung from 4 m x 4 m x 5 m hardwood rafts floated by plastic containers. The net cages tend to float and have to be weighed down by suitable weights such as bricks. In some cages, a galvanised iron framework maintains the cage shape. During harvesting, the cages are untied from the framework and raised. The cages are connected in rafts of four, and a row can contain up to four series. Each row is moored using suitable drag anchor or grapples. The cages last for about five years.

The low level of technology has confined the cage culture to sheltered lagoons, protected coastal areas and estuaries having a water depth of around 5-8 meters. The shortage of such site, however, has stymied the growth of the industry. Though the number of marine cages grew from 42,188 in 1992 to 58,499 in 1997 (an increase of 39%), most of this occurred in Sabah and Sarawak. At present, almost all cage culture sites are fully occupied and any expansion of the industry in its present form does not seem tenable.

This appears to be reflected also in the production trends of the industry. From 1992 till 1997, production increased by 40% in tandem with the increase in productive assets. However, output plateaued since 1994 at a level of 5,400 to 5,700 tons.

Despite intractable disease problems faced by many farms (Shariff and Premala 1996), unit production from cage farms averaged about 8.3-8.5 kg/m². The stability of the present level implies that some kind of upper limit may have been reached where production efficiencies are concerned.

Increasing the wholesale value of the farmed products further enhanced the viability of the industry. The average wholesale price of cage farmed marine finfish in 1992 was RM 10,741/ton. By 1997, this had increased to RM 17,845/ton, an increase of 66% in just five years. It is significant to note that despite the fluctuations in production, the overall wholesale value of farmed marine finfish continued to increase every year.

The main finfish reared is the sea bass (*Lates calcarifer*), which in 1997 accounted for 50% of the total finfish production and 35% of the wholesale value. Other fish reared include the groupers (*Epinephelus* sp) and mangrove jacks (*Lutjanus* spp). Though groupers account for only 14% of finfish production, they accounted for 28% of the value. In particular, the snappers (mangrove and red snappers) and tilapia appear to be taking on a more significant profile (Fig. 2). Though accounting for just 5% of the total cage culture output in 1992, by 1997, they accounted for nearly 50%.

Despite the importance of the marine fish farming subsector, seed production remains a major constraint. Seeds for the grouper are still procured from the wild. While snapper and sea bass are hatchery-bred locally, supply is still inadequate and substantial quantities of marine fish fry continued to be imported, mainly from Thailand (Ali 1994).

Production technology is at a relatively low level, a full description of which is provided by Gopinath and Chin (1998). Initial stocking density is about 300 m⁻². As they grow in size they are graded and distributed to other cages. The final stocking density is about 40 m⁻². Net cages are rotated every two weeks because of biofouling. The fouled nets are cleaned using high-pressure pumps before being dried and stored for reuse. The fish are fed on trash fish (trawler by-catch) which consists predominantly of small anchovy (*Stolephorus commersoni*), clupeids (*Sardinella finbriala*, *Illisha melastoma*) and a

wide range of other species. The use of formulated feeds is uncommon.

Freshwater Aquaculture

Despite the late development of cage culture in inland water, progress in the development of the industry has been rapid. The number of units rose by 200% from 2,152 to 6,516 units, from 1992-1997. Most of the cages were located in reservoirs (Negeri Sembilan, Sarawak), rivers (Terengganu) and mining pools (Perak). The location of most reservoirs close to their respective catchment has focused freshwater cage culture in less developed areas in the respective states. However, the need for infrastructure such as roads and power represents major constraints for farms operating in more isolated areas.

The growth trend in cages is due to a number of factors. The resource base is large and farmers are able to easily get concession because there are no other competitors for the water and cages themselves. The water management authorities are also encouraged by the fact that cages are a nonconsumptive system. However, the most important reason is that the quality of cage reared fish are generally higher and free from off-flavors. As with marine cage culture, the emphasis is on the production of live fish for the restaurant market. However, the value of freshwater fish output (average wholesale value RM 5,422/ton) is generally lower than that of cage farmed marine fish. Though some are exported to Singapore, most cage farmed freshwater

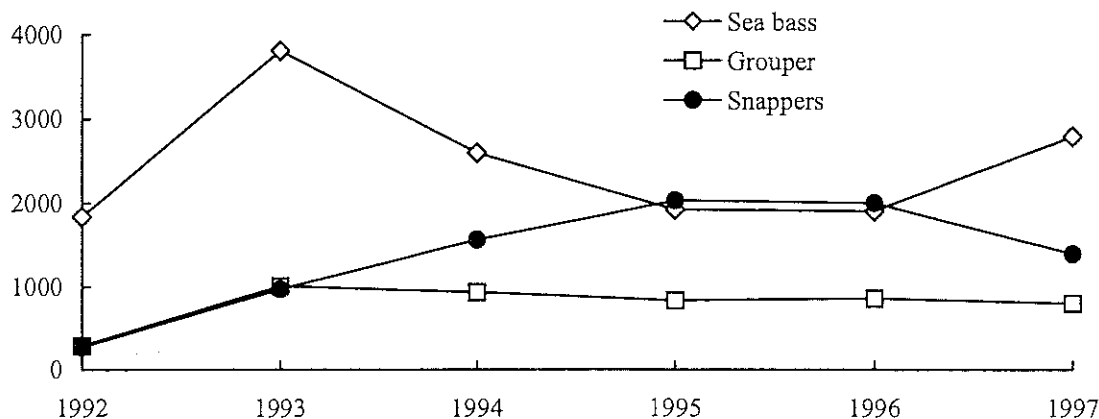


Fig. 2. Trends in output profile of marine cage culture, 1992-1997.

fish are consigned entirely to the domestic market.

Most cages are made of braided polyethylene or netlon hung from 4 m x 4 m x 5 m hardwood rafts or galvanized iron frames floated by plastic containers. As with marine cages the cages are untied from the framework and raised for harvesting. However, newer cage designs have been developed to enable harvesting to be undertaken much more easily (Padmasothy 1994)

Output from cage farms increased by 250% from 484 tons in 1992 to 1,693 tons in 1997 while its contribution to overall freshwater fish production increased from 3% in 1992 to 5% over the same period (Table 3). Unit production rates ranged from 18-23 kg/m². The main species cultured include the tilapia (*Oreochromis niloticus*), sultan fish (*Leptobarbus hoevenii*), mystid catfish (*Mystus nemerus*) and striped catfish (*Pangasius sutchii*). Smaller quantities of Javanese carp (*Barbodes gonionotus*), common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) are also produced.

Table 3. Status of freshwater cage culture in Malaysia, 1992-1997.

Year	No. of farmers	Production (tons)	Cage farms	
			Number	Area (m ²)
1992	321	483.5	2,512	29,046
1993	568	786	2,819	48,693
1994	868	1,413	3,864	56,796
1995	883	1,534	4,110	79,633
1996	1,779	1,550	6,053	85,816
1997	1,287	1,693	6,516	140,709

Source: DoF 1993-1998.

Most of the seed stock is supplied by local hatcheries and seed does not pose the kind of problem that is faced by the marine cage culture industry. The use of pelleted feed is universal and, as a rule, raw feeds are not employed in cage farms. Culture densities vary according to the

species being cultured and site specific conditions. However, tilapia is generally reared at 44-60 m⁻² while the catfish and sultan fish are raised at lower densities ranging from 200-400 m⁻².

Future Outlook

The future outlook for cage culture development in Malaysia is promising, especially for freshwater cage culture. There are over 206,000 ha of reservoir area in the country, mostly in the form of hydroelectric impoundments and to a lesser extent, in irrigation, flood mitigation, and water supply infrastructure (Ubaidillah 1984). As pointed out earlier, the development of cage culture carries several major advantages. The resource base is large and there are no other competitors for the water and cages. The water management authorities are also encouraged by the fact that cages are a nonconsumptive system. However, the most important reason is that the quality of cage reared fish are generally higher and free from off-flavors.

On the other hand, the scenario facing marine cage culture appears to be more limited. Both from the standpoint of resource base and production technology, there are serious impediments to the continued growth of marine cage farming. This is partly due to the fact that marine cage farming is much more mature than freshwater cage culture and thus faces problems that would ultimately be common to both.

The most serious constraints, current and potential, faced by the cage culture sector include: seed supply, disease, feed, limited resource base and sustainable husbandry practices.

Seed Supply

Although there have been advances in seed production, seed supply for certain species is still dependent on collection from the wild or on imports. Sea bass, exotic major carps, red tilapia, catfish, eels and red snapper fingerlings are imported from the far east or the neighbouring countries. Though the problem is more acute in the marine cage culture industry, further intensification of production in freshwater aquaculture

would also face seed supply problems. It is thus important that adequate seed production infrastructure is in place so as to facilitate the growth of the industry.

Disease

Disease has been identified as the major cause of concern to the cage culture industry. Disease problems relate to the importation of infected fingerlings (Shariff 1995), as well as poor environmental conditions exacerbated by overcrowding of cages and the employment of unsustainable farming practices (Shariff and Premala 1996).

Anecdotal information indicates that as much as 20% of cultured stock in marine cage farms is lost through disease and mass mortalities involving millions of ringgit have been reported in the past. It is important that the existing quarantine infrastructure be strengthened to provide further protection from imported diseases. Farmers should also be forced to comply with Good Culture Practice protocols to prevent environmental degradation.

Feed

Cost of feed can range from 40 to 55% of production cost, depending on the management and environmental conditions (Shariff *et al.* 1997). In particular, continued reliance on trash fish on the basis of cost, however, is untenable. Trash fish is extremely variable in quality and polluted watercourses. The use of formulated feeds is however, limited, by cost. There is an urgent need, therefore, to develop low cost feeds that can lower the cost of production and make cage farming a more viable prospect.

Limited Resource Base

The present sites for marine cage culture are largely exhausted and there appears little potential for increase in productive assets. There has been an effort in recent years to shift offshore but the production systems, which have been developed in Norway for salmon, are very new and have yet to be proven under local conditions. Though freshwater cages do not, at present, face

physical limitation on their resource base, environmental degradation can set in if development of the industry is not managed.

Related to this would be the need for government management agencies to ensure that cage culture development is predicated on sound resource management regimes. The use of sophisticated GIS techniques to identify suitable sites, and at the same time, protect valuable habitats would be an important part of this effort. Water quality considerations would also be critical. Such considerations need to take into account the present level of nutrients in the water, the flow or dilution rates and quality of effluent from the cages. The need to ensure optimal water quality cuts both ways. For instance, it is also important to protect aquaculture development areas from industrial and agricultural outfalls.

Sustainable Husbandry Practices

A major concern in aquaculture development is its sustainability. Though many countries have actively pursued aquaculture as a tool in development planning, very few can claim a tangible measure of success without associated environmental problems.

While some of this has no doubt been due to the over optimistic expectations of the planners themselves, a significant bottleneck has been the use of unsustainable husbandry practices by producers.

It is critical that farmers employ sustainable farming practices such as appropriate stocking densities, pelleted feed and sanitation. It is also important that farmers be educated on the need to ensure that their husbandry protocols are in consonance with environmentally sustainable norms, and they do not bring about deleterious consequences to themselves and other users of the same resources. To ensure this, it may be necessary to provide for sustainable legislation to compel farmers to be environmentally responsible.

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Recent Developments in Freshwater and Marine Cage Aquaculture in the Philippines

C.L. MARTE¹, P. CRUZ² and E.E.C. FLORES³

¹*Southeast Asian Fisheries Development Center
Aquaculture Department,
Tigbauan, Iloilo 5021
Philippines*

²*Cruz Aquaculture Corporation
Bacolod City
Philippines*

³*University of the Philippines in the Visayas
Miag-ao
Iloilo
Philippines*

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Abstract

Fish production from freshwater cages and pens, and marine cages and pens constitute 19% of the total foodfish produced from aquaculture in the Philippines. In 1998, production from freshwater cages and pens contributed about P 2.5 billion or about 10% of the total revenues from aquaculture. Freshwater cage and pen culture is practiced in most of the major lakes and reservoirs in the country. The most important species cultured in freshwater cages are tilapia and bighead carp (*Aristichthys nobilis*) while milkfish (*Chanos chanos*) is farmed in freshwater pens at Laguna de Bay. Small water impoundments intended for the irrigation of upland farms are also being used to culture tilapia and other freshwater fish in cages. The unregulated expansion of cages and pens, use of high stocking densities, and excessive feeding has resulted in the deterioration of the water quality in many areas. This has prompted the more informed local government authorities to adopt measures limiting further expansion of cage and pen culture activities beyond the carrying capacity of freshwater bodies to prevent periodic occurrences of mass fish kills.

While cage mariculture of groupers has been practiced in the Philippines since the 1980's, it was only in the early 1990's that much of the growth and expansion of the industry occurred with the popularization of milkfish mariculture. In the last five years, no less than 1,000 cages with an aggregate capacity in excess of 10,000 metric tons a year have been invested in milkfish sea farming. The species now accounts for about 90% of the production from marine cages. In recent years, a drop in milkfish prices has motivated the industry to focus its attention on other fishes, primarily grouper (*Epinephelus* spp.), snapper (*Lutjanus* spp.), sea bass (*Lates calcarifer*) and siganid (*Siganus* spp.). Currently, imported species such as red tilapia, yellow-wax pompano (*Trachinotus blochii*) and red drum (*Sciaenops ocellatus*) are also being tested by the private sector. A high production cost due to low feed conversion efficiency and high seed cost is presently the greatest concern of marine cage farmers. In some areas, unregulated expansion has already led to problems in water quality.

Introduction

Total aquaculture production in the Philippines in 1998 was 954,000 mt (DA-BAS 1998); about 67% were seaweeds and 32% or 312,077 mt were fish and shellfish. Most of the fish produced from aquaculture came from brackish-

water and freshwater ponds and from pen culture in freshwater lakes. Freshwater cages and pens contributed about 16% or 52,500 mt while 7,765 mt or 2.5% were produced from marine cages and pens (Table 1). In terms of value, freshwater cage and pen production contributed about P 2.5 billion (US\$ 62.5 million) while production from

marine cages and pens contributed P 492 million (US\$ 12.3 million) to the economy.

Cage culture of tilapia and freshwater pen culture of milkfish have grown rapidly since their introduction in the early 1970's. Marine cage and pen culture in the Philippines, on the other hand, are comparatively recent introductions. The rapid proliferation of marine cages in protected coastal areas and the dramatic increase of milkfish production from marine cages in recent years indicate strong interest among fish farmers in this new farming system. With the increased demand for high value and exotic species in the export market, fish farmers are now beginning to venture into rearing non-traditional species of fish and crustaceans. We present in this paper the current status of freshwater and marine cage and pen culture, the problems and constraints confronting the industry, as well as the prospects for further development of the industry in the Philippines.

Freshwater Cage and Pen Culture

Tilapia (*Oreochromis niloticus*, Cichlidae) is the major species cultured in cages while milkfish (*Chanos chanos*, Chanidae) and bighead carp (*Aristichthys nobilis*, Cyprinidae) are the main species produced in freshwater fishpens. Cage and pen culture is practiced in all of the large freshwater lakes and reservoirs in the country. Major freshwater cage and pen farming

areas are located in the Southern Tagalog Region, Bicol Region, and Central Mindanao. Tilapia cage culture has also been introduced in small water impoundments and dams intended for irrigation in upland areas.

Fish Production from Freshwater Cages and Pens

Tilapia production from freshwater cages steadily increased since its introduction in 1970 with an average annual growth of 9% and an average increase in price of 1.9% until 1995 (Agbayani 1998) (Table 2). From about 7,000 mt produced in 1985, production increased to over 35,000 tons in 1993 (DA-BAS 1998). Production however remained below the 1993 level in succeeding years except in 1997 when peak production of 42,600 mt was attained. While tilapia production from fishpen exceeded fish cage production in the 1980's, production in fishpens has considerably dropped in recent years. The number of fishpens have been greatly reduced after the successive mass kills experienced in Laguna de Bay and other lakes in the 1980's.

Bighead carp production from cages and pens remained relatively stable at about 4,500 mt from 1985 to 1991 (Table 3). Peak production of 6,700 mt was reported in 1992 but went down by more than 50% in the following years. Increased production in 1998 mostly from fishpens indicate a resurgence in bighead carp fishpen farming apparently because of an increased demand by

Table 1. Aquaculture production (mt) from freshwater cages and pens and marine cages and pens in the Philippines, 1985-1998.

Year	Freshwater cage	Freshwater pen	Marine cage	Marine pen
1985	7,441	51,979		
1986	9,373	41,296		
1987	17,789	35,588		
1988	18,260	23,814		
1989	19,502	24,102		
1990	20,931	24,379		
1991	23,939	25,931		
1992	31,292	33,395		
1993	35,632	29,403	64	334
1994	32,285	40,721	46	252
1995	34,281	20,445	10	213
1996	31,282	16,240	87	68
1997	42,680	19,952	320	165
1998	29,678	21,856	2,647	4,995

Source: DA-BAS 1998, 1999.

Table 2. Tilapia production (mt) from freshwater cages, pens, and ponds in the Philippines, 1985-1998.

Year	Cage	Pen	Pond
1985	7,187	9,387	13,674
1986	8,921	16,313	14,064
1987	16,823	14,264	46,751
1988	17,249	9,470	30,149
1989	18,449	9,246	30,900
1990	18,220	3,948	35,169
1991	21,048	4,092	37,358
1992	29,554	5,843	48,006
1993	35,563	4,939	47,893
1994	31,866	9,779	38,867
1995	33,350	4,876	38,411
1996	30,788	3,714	40,097
1997	40,615	4,272	39,005
1998	29,544	3,748	32,780

Source: DA-BAS 1998, 1999.

Table 3. Bighead carp production (mt) from freshwater cages, pens and ponds in the Philippines, 1985-1998.

Year	Cage	Pen	Pond
1985	254	4,286	1,376
1986	452	4,099	962
1987	966	3,588	3,083
1988	1,011	2,402	2,438
1989	1,053	3,157	3,010
1990	2,711	1,427	642
1991	2,891	1,390	616
1992	4,738	1,990	746
1993	na	8	72
1994	16	4,177	56
1995	62	2,507	273
1996	48	1,747	209
1997	64	1,510	291
1998	81	4,379	295

Source: DA-BAS 1998, 1999.

food processors following the introduction of carp surimi and other by-products derived from carp.

The milkfish pen culture industry in Laguna Lake has undergone a cycle of boom and bust since its introduction in 1971. At peak production, as much as 82,000 mt of milkfish were produced from about 30,000 ha of freshwater pens in 1983-84 (Bagarinao 1998). In the 1980's, milkfish yields from freshwater pens reached as much as 6-7 mt/ha/yr. Most farmers then, relied

on the natural productivity of the lake and occasionally fed their stocks with supplemental feeds. Mass fish kills due to overcrowding with consequent deterioration in water quality, industrial pollution, storms, and dismantling of illegal fishpens has drastically brought production down to 13,062 mt in 1995. The present production of about 20,000 mt from an estimated 4,000 ha of the remaining fishpens approach yields obtained during peak production in the lake but only with feeding.

Cage farming of other species is also being practiced although to a very limited extent and in specific localities. A number of fishfarm operators in Taal Lake and other areas have cultured sea bass (*Lates calcarifer*, Centropomidae) but very few fishfarmers are continuing to culture this fish because of the low rate of return and scarcity of fingerlings. Successful trials at rearing Cavalla (local name: maliputo; *Caranx ignobilis*, *C. sexfasciatus*, Carangidae) in Taal Lake, Luzon and Cross-barred grunt (local name: pigeek; *Mesopristes cancellatus*, Teraponidae) (Macabalang, S. *et al.* 1984, and pers. comm. 1999), a highly valued fish in Mindanao, have been conducted by the Bureau of Fisheries and Aquatic Resources. Some cage operators have also started trial cultures of both species because of their high market prices. However, production for both species, is very limited since fingerlings are difficult to source from the wild.

Cage and Pen Design and Construction

Depending on the depth and location of the farm, cages in freshwater lakes and reservoirs are either fixed or of floating types. Fixed cages are usually installed nearshore or in shallow lakes like Laguna de Bay where water depth is less than 5 m. In fixed type cages, synthetic net cages are attached to bamboo poles staked to the bottom for support. Sizes of the cages range from 5 x 5 m to 15 x 10 m with net mesh sizes of 5-15 mm (Guerrero 1998). Floating net cages are typically suspended from bamboo rafts with or without plastic drum floats (Fig. 1) and anchored to the bottom using concrete sinkers. Cages have a net mesh size of 15 mm and vary in size from 15 x 10 m to 20 x 15 m with a depth of 5-6 m.



Fig. 1. Tilapia cages in Sampaloc Lake, Luzon using bamboo rafts as floats.

Culture Practices

Tilapia fingerlings (3-5 g) purchased from nearby hatcheries are stocked at densities of 20-120/m³. Cage-reared tilapia are fed supplemental feeds such as rice bran and copra meal, but in more intensive cage farms, commercial tilapia feed containing 24-30% crude protein is usually fed twice per day at 3% body weight ration. Survival rates during the grow-out culture vary from 60 to 90% and harvest sizes of 100 to 300 g are attained depending on the stocking density and how well the cage farm is managed. In Taal Lake, yields of 1,000 to 3,000 kg in 250 m³ cages (10 m x 10 m x 3 m) or 4-12 kg/m³ are obtained after 4-5 months of culture depending on the water condition and farm management (Yap, W. pers. comm. 1999). Lower yields however are obtained in other areas like Lake Sebu and other nearby lakes in Central Mindanao where about 150 ha of tilapia cages are in operation. In these lakes, 250 m³ cages (5 m x 10 m x 5 m) are stocked with tilapia fingerlings at 20 pcs/m³ with survival of about 90% obtaining yields of 2-4 kg/m³ (Adora, G. pers. comm. 1999). In eutrophic lakes like Laguna de Bay, culture period may be as short as four months even without

feeding but this may be extended to 10 months in less productive lakes and reservoirs.

Land-based hatcheries are the sources of tilapia fingerlings for cage grow-out in most lakes and reservoirs. In Laguna de Bay however, many cage farm operators at present find it more profitable to produce tilapia fry and fingerlings in cage hatcheries and nurseries (Basiao, Z. pers. comm. 1999). Fine-meshed hapa nets (3 m x 8 m x 1 m; 1 mm mesh) are stocked with 100 females and 25 males or about 6 fish/m². The fish are fed with commercial pellets at 3% of their biomass to supplement the lake's natural productivity. For each spawning cycle 20,000 fry can be obtained from each broodstock cage. Fry are reared to fingerlings in nursery cages of 50-300 m² at 500 fry/m². Fingerlings for the grow-out cages are obtained in 3-4 weeks.

Carp were introduced in the Philippines as early as 1915-1918 and have been stocked in swamps, rivers, and lakes in various parts of the country as part of government programs to increase fish production in freshwater bodies. Of the different Asiatic carp species introduced in the Philippines, only the bighead carp has significantly contributed to fish production from aquaculture mainly because of the development

and adoption of breeding techniques for this species. Bighead carp hatcheries around Laguna Lake supply carp pen and cage farmers with seedstock. The species is usually polycultured with milkfish and tilapia in pens and cages. Without feeding, bighead carp juveniles can grow to 1.5-2 kg after 4-6 months in pens or cages in the eutrophic lake.

Socio-economics of Freshwater Cage/Pen Culture

Tilapia and carp cage farms are usually small family run businesses but big commercial operations control the milkfish and carp pen culture industry. Cage farming require little investment in terms of facilities and labor since

cages are constructed using low cost materials and operations are family based. About 80% of the operating costs go to purchase of seedstock (6.6%) and feeds (73.6%) (Table 4). Because tilapia cage culture is highly profitable, the industry also attracted bigtime operators in the 1980's resulting in the proliferation of cages in small lakes such as Sampaloc Lake in Luzon . As much as 33 hectares of cages were being farmed in the 104-hectare lake from 1986 to1992. The massive fish kills experienced in 1993 from water quality deterioration due to heavy application of feeds (about 6,000 tons of feed annually from 1986-1992; Santiago 1994) forced the local government to dismantle the cages and reduce the culture area to five hectares.

Table 4. Cost and return for tilapia cage culture in Taal Lake, Philippines*.

Assumptions:

- 2 units of 10 x 10 x 5 m cage
- Effective cage volume= 500 m³/cage
- Grow-out cropping cycle= 4 months
- Stocking density= 25,000/cage
- Harvest size= 250 g
- Survival rate= 70%
- Production= 4,375 kg/cage/crop; 8,750 kg/crop for entire facility
- Biomass loading= 8-12 kg/m³/crop
- Wholesale selling price= US\$ 1.375/kg
- US\$ 1= P 40

* Excludes Fixed Cost

Item	Qty.	Unit cost	Variable cost/yr	Percent production cost
Fingerlings (@ 25,000/cage x 2 cages)	50,000	0.010	500	6.60
Feeds (@ 8,750 kg tilapia/crop x FCR=1.7)	14,875	0.375	5,578	73.66
Cage personnel (@ US\$75/mo x 4 mos)	1.0	300	300	3.96
Harvesting expense (labor, ice, fuel, etc.) (@ US\$0.1/kg)	8,750	0.075	656	8.67
Equipment maintenance (@ US\$10/cage/mo)			160	2.11
Miscellaneous (@ 5%)			378	5.00
Total Variable Cost/Crop			\$7,572.80	100.00
Total Variable Cost/kg Tilapia			\$0.87	
Gross Sales/Crop			\$12,031.25	
Gross profit/crop			\$4,458.45	
R.O.R.			58.87%	

At present, the local government has imposed a ban on bringing in bamboo poles within the lake vicinity for cage construction or repair to discourage farmers from expanding their farm operations. Cage farmers in this lake are now limited to operating four to six tilapia cages per family. Big commercial operations in Luzon however have moved to bigger lakes like Taal Lake where some farmers operate more than 70 cages. The Philippines has limited freshwater bodies for cage or pen culture and in all major lakes, tilapia cage culture is a flourishing industry. Recently, cage culture has also been introduced in small farm reservoirs in upland areas where this is being integrated with other agricultural activities. Communities living far from the coast have little access to fresh fish and growing tilapia in these impoundments offer a source of protein as well as additional income to the farmers.

Problems, Constraints and Industry Prospects

Pollution, whether from industrial, agricultural, and domestic effluents or self pollution from unregulated expansion of cage and pen culture activities in lakes and freshwater reservoirs is the major problem of cage farm operators (see also Yambot, A., this proceeding). The rise and fall of the milkfish pen culture industry in Laguna de Bay has been well documented. Annual occurrences of mass fish kills are reported from major culture areas in the country. Because of the rapid population increase and increasing need for freshwater for domestic, agricultural, and industrial uses, conflicts in the use of multi-use resources such as lakes and reservoirs particularly near urban areas are now becoming acute. While freshwater cage culture of tilapia, milkfish and carp remain viable, the profitability of these activities is also threatened by technical and other factors such as poaching, lack of or insufficient capital particularly for the small-scale grower, lack of or inadequate technical know-how, typhoons, flooding, etc. Marketing problems also plague the industry. From the farm, the produce usually passes through several intermediaries before it reaches the consumer

(Agbayani 1998). In addition, low farmgate prices, erratic supply particularly of seedstock, poor quality, and spoilage because of poor farm to market roads are persistent problems.

Nevertheless, freshwater cage culture of tilapia and to a lesser extent, pen culture of carp and milkfish in shallow lakes will remain as major contributors to fish production in the country. Further expansion of culture activities in the major lakes will be limited because of increasing awareness by farmers and local government officials for the need to maintain the quality of the freshwater environments in order to sustain culture activities and to satisfy other needs of the community for their limited freshwater resource. The development of new and faster growing strains of tilapia, improvements in culture techniques such as the development and adoption of cost-efficient feeds and training on effective feeding management techniques however, can further increase farm productivity. With the increasing interest among farmers to try other species for culture, freshwater cage culture in the Philippines will diversify into other species but only when hatchery produced fry of these species become available. Research on breeding and seed production of a few candidate species such as *Caranx spp.* and *Mesopristes sp.* is included in the proposed programs of some government regional research stations.

Marine Cage and Pen Culture

Significant marine fish culture activities in the Philippines can be traced back to the mid-1980's with the production of live groupers in cages in Roxas City. These are grown for export mainly to Hong Kong, Taiwan, and Singapore. It was only in the early 1990's, however, that the rapid growth of the industry was realized with the successful culture of milkfish in marine cages and pens. During this period, stagnant production from traditional brackishwater ponds, and freshwater pens in Laguna Lake, brought milkfish wholesale prices to reach as high as US\$ 2.5/kg (US\$ 1: P 40) for fish weighing 400-500 g. This made possible the heavy use of artificial feeds for mariculture growout. Also instrumental to the

growth of marine fish culture was the collapse of the shrimp farming industry which prompted the aquafeed manufacturers to shift their focus to the production of fish feeds.

Major Species Cultured and Production

Milkfish represents over 90% of the marine fish culture industry with the remainder consisting of orange-spotted grouper (*Epinephelus coioides*, Serranidae) and black-spotted grouper (*E. malabaricus*). Minor species under cultivation include, siganids (*Siganus* spp., Siganidae), sea bass (*Lates calcarifer*, Centropomidae), snapper (*Lutjanus* spp., Lutjanidae), and salt-water tolerant tilapia. Recently, several hatchery-bred species from Taiwan have been brought into the country by the private sector to evaluate their commercial culture in cages. These include the yellow-wax pompano (*Trachinotus blochii*, Carangidae), cobia (*Rachycentron canadum*, Rachycentridae), and red drum (*Sciaenops ocellatus*, Sciaenidae).

Current monthly marine cage and pen production of milkfish is estimated at 900-1,200 mt with 600-800 mt coming from the province of Pangasinan. This production level is 55-65% lower than the 1997 estimates when milkfish prices were more attractive. During this period Pangasinan alone is believed to have produced monthly peak production of 1,300 mt. Table 5 gives the government estimates on marine cage and pen production.

There is no data available on the recent total cage-farmed grouper production. Based on a total farming area of around 20,000 m² (2,350 cage units x 9 m² per cage) and assuming an average yield of 7.5 kg/m² and 1.5 crops/yr, aggregate capacity of existing facilities is in the vicinity of 150 tons annually. Latest government estimates, however, peg production at only 60 mt/yr (Table 5). This large shortfall in yield potential is being attributed to seedstock shortage and disease problems currently plaguing the industry.

Farming Centers

The province of Pangasinan, which is the pioneer and leader in milkfish mariculture in the

Philippines, now accounts for about 70% of the total marine farmed fish production. The single biggest concentration of farms is in the western side of Lingayen Gulf, in the municipalities of Bolinao and Sual. Aside from providing fairly good shelter from rough sea conditions and typhoons, Bolinao and Sual offer the key advantages of being within half a day's travel to Metro Manila, and having numerous suppliers of fingerlings for direct stocking. Pangasinan milkfish has also been traditionally regarded as superior in quality compared to fish coming from the Visayas and Mindanao fetching an 8-10% higher price in the wholesale market. Other milkfish cage and pen farming centers can be found in the provinces of Cavite, Cebu, Negros, Iloilo, Samar, and Davao.

The bulk of grouper cage farms are located around Roxas City, Capiz where there are presently no less than 2,000 cage units. At least 350 more cages can be found scattered in the provinces of Pangasinan, Cavite, Palawan, Samar, Bohol, and Surigao.

Table 5. Aquaculture production in 1998 from marine cages and pens.

Species	Culture system	Volume (mt)	Value ('000 P)
Milkfish	Cage	2589	156,933
	Pen	4957	303,812
Grouper	Cage	33	156,933
	Pen	27	10,227
Red snapper	Cage	1	600
	Pen	1	225
Rabbitfish	Cage	1	261
	Pen	2	340
Mud crab	Cage	7	900
	Pen	30	4221
Lobster	Cage	9	10,000
	Pen	1	1,250
Shovel-nosed Lobster	Cage	6	3,000
Black tiger prawn	Cage	1	450

Source: DA-BAS 1999.

Site Characteristics

Because of threats caused by typhoons and monsoon rains throughout the archipelago, fish

mariculture activities in most parts of the country are limited to well sheltered coves, sounds, and estuaries that are free of major river tributaries. During torrential rains, large river systems bring large quantities of debris from upstream, cause tidal runs, and prolonged salinity stratification.

Actual cage sites for milkfish culture normally have depths of 7 to 15 meters and are located 50-100 meters from the shore. Cage sites usually have steep drop-offs. Cages are rarely placed adjacent to shallow coasts due to the difficulty of hauling supplies during low tide. For grouper culture, cage sites are shallower with depths of four to eight meters.

Cage/Pen Design and Construction

Bamboo has always been a popular cage construction material because of its ready availability and low cost. Cage dimensions typically range from 3-4 m x 3-4 m x 2-3 m for grouper to 4-6 m x 4-6 m x 4-5 m for milkfish. For pens, the size range is from 500 m² (25 m x 20 m) to 1 ha (100 m x 100 m) (de la Vega 1998). In recent years, however, experience has shown that even relatively well sheltered sites can be exposed to abnormally strong winds and currents. For this reason, many milkfish farmers in Luzon have shifted to steel cages. These usually have dimensions

of 6 m x 6 m x 6 m to a maximum of 12 m x 12 m x 12 m. Fish farms located in Luzon tend to have bigger cage dimensions than those in the Visayas and Mindanao due to larger volumes of harvest that can be accommodated in Metro Manila.

From 1995-1997 when milkfish prices were at its highest and the exchange rate was less than P 28: US\$ 1, large imported all-weather cages were the trend for serious farmers particularly in the typhoon prone regions of Luzon and the Visayas. Close to a hundred cages ranging from 1,000-3,500 m³ volume were brought in from Europe and US. During this period it was possible to amortize a US\$ 15,000-20,000 cage investment within two crops, or a little over a year. The Asian crisis that followed however and the drop in milkfish prices due to overproduction has since made the use of imported cages prohibitive. Recognizing the need to modernize the cage farming industry and to decongest sheltered farming centers, in 1997 a local firm and the Philippine Department of Science and Technology – Technology Application and Promotion Institute (DOST-TAPI) collaborated in the development of sea cages for exposed and semi-exposed sites (Cruz 1998). The effort has so far yielded two cage designs for food crops and cash crops (Figs. 2 and 3).



Fig. 2. Circular milkfish cages for exposed and semi-exposed sites.

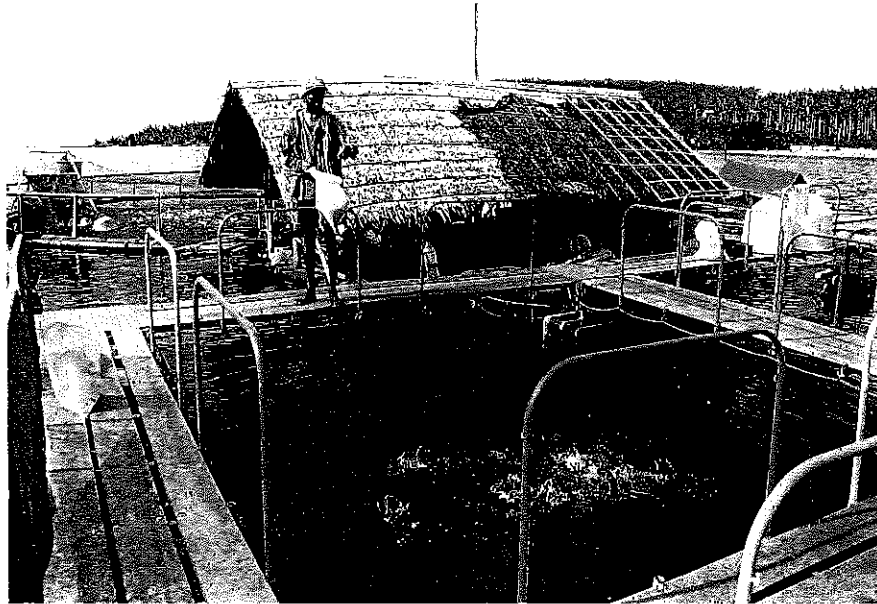


Fig. 3. Modular cage system for the culture of high value crops.

Cage nets are constructed mainly of knotted polyethylene. Use of knotless nylon nets is uncommon at present due to its high cost. For high value species, however, there is growing interest to use the less abrasive nylon. The Philippines has two large net manufacturers and exports a substantial quantity of knotless nylon nets to the Australian tuna farming industry.

The use of storm mooring systems is very new in the country and is likewise being promoted by a private sector-DOST collaborative project. Proper mooring is now widely recognized as crucial in marine cage farming after a "freak" storm in August 1998 struck Pangasinan province damaging up to 25% of the cages in Bolinao and Sual. Imported cages that were inadequately anchored were similarly damaged, clearly demonstrating that mooring is as important as the cage structure.

Seedstock

Locally produced hatchery-bred milkfish seedstock are now well accepted by farmers. Imported fry, however, are not highly regarded due to some previous bad experiences by the industry. There are now three local hatcheries in commercial operation and several more are under development. Seabass fry is also being produced

in two or three hatcheries. Supply of grouper, siganids, and snapper fry is still mainly from the wild although some private hatcheries are already starting production in small quantities.

Milkfish fingerlings are normally stocked in cages and pens at 5-10 grams. These are grown and stunted in land-based nurseries mainly during the second quarter when large quantities of wild fry appear. Fingerling price is between US\$ 0.075-0.125/pc. For farms adjacent to nursery ponds, milkfish fingerlings as big as 50-100 grams are sometimes used. Grouper fingerlings on the other hand are grown in small cages in ponds. Cost of 3-4 inch fingerlings is US\$ 0.75-1.0/pc. There are a number of farmers who specialize in producing fingerlings but only for milkfish. Commercial nurseries for grouper, sea bass and other species are mainly dependent on fingerling catch from the wild. Grouper "tinies" are often sold directly to farmers but survival rate is often below 40% due to lack of experience and appropriate technology.

Efforts to develop sea-based nursery systems have so far failed due to high mortality rates. Such is being attributed to net abrasion during tidal runs, inadequate nutrition, and water quality deterioration due to the rapid fouling of fine-meshed nets. Run-offs and salinity stratifi-

cation during heavy rains is also seen as a major cause of mortalities.

Feeds and Feeding Management

Only milkfish has an established mariculture feed market with a total consumption of 35,000-40,000 mt annually. There are at least 20 feed manufacturers located mainly in Luzon, with the top five companies accounting for 80% of the total market. Eight companies offer both extruded (floating and slow-sinking) and pelleted diets while the rest produce only pelleted feeds. Use of extruded feeds is increasingly becoming popular and was introduced in the market only in the last three years. Current cost of milkfish feeds is US\$ 0.35-0.42/kg with floating feeds costing US\$ 0.04-0.05/kg higher than sinking feeds. The subject of feed resources is exhaustively discussed in the Aquaculture Feed and Fertilizer Resource Atlas of the Philippines (Cruz 1997).

Culture of grouper, sea bass, and snapper is dependent on trash fish which costs US\$ 0.1-0.2/kg. Hence all farming centers for these carnivores are limited to areas where low cost fish is available. Recently, one of the country's largest feedmills has launched feeds for grouper and sea bass at a cost of US\$ 0.6/kg.

Feeding is still done largely by hand although solar-powered automatic feeders manufactured by a local firm are already being used by some of the larger farms. Current feed conversion ratios (FCR) obtained for marine fish culture are relatively high despite careful feeding management. For milkfish cages and pens, FCR ranges from 2.4-2.8 and 2.3-2.5, respectively, as compared to 1.8-2.0 for intensive pond culture. To address this problem of poor feed conversion efficiency, three feed companies have recently introduced new feed product lines specifically for milkfish mariculture containing improved protein quality and higher energy level.

Growout System

Stocking density for milkfish cages is typically 30-60 pieces/m³ and at a survival rate of 70-80%, yield is 15-25 kg/m³. For fishpens, stocking is from 50,000-100,000 pieces per hectare.

Survival rate in pens is normally better than in cages at 80-90%; production is from 25-50 tons/ha/crop. Most stocking activities take place during the third quarter of the year in order to harvest the crop at peak local prices from November to March. Because of the high feed expense in milkfish mariculture (i.e., due to the high FCR), farmers are forced to grow their crop to bigger sizes of 500-700 g where market price is higher. Culture period to this size range is from six to eight months from 5-10 g fingerlings.

In grouper cage farming, stocking density is from 10-20 pieces/m² with a yield of 6-12 kg/m². Harvest size is from 400-700 g after a production period of 6-8 months from three to four inch fingerlings. Survival rate is commonly above 85% when there are no health or disease problems. In Roxas, Capiz, however, where cage farm sites are already congested, survival is typically 60-70%.

Oxygenated plastic bags are commonly used for transporting fingerlings but among milkfish farmers in Pangasinan, there is a growing trend towards the use of a transport boat called "pituya" which was originally designed for stocking freshwater fish pens in Laguna de Bay. Fish are released inside the hull with pond water. Seawater is gradually introduced from a small hole beneath the hull as the boat travels from the pond site. As the hull fills up during transport, water is pumped out. At the same time, the fish becomes gradually acclimated to pure seawater. With this system, a large quantity of fish can be transported with minimal handling stress. Acclimation is often not possible with the use of plastic bags due to the sheer number being handled. With the use of the "pituya" transport related mortalities are below 5% as compared to 15-30% using plastic bags.

In Luzon, harvesting of a cage or a pen is normally completed in less than a week. In the Visayas and especially in Mindanao, harvesting takes much longer due to the small market volume. Stress due to protracted harvest operations contributes to poorer FCR's obtained by farmers in these regions. For more details on growout systems, the reader is referred to Vol. 20, No. 5 of SEAFDEC Asian Aquaculture.

Socioeconomic Profile of Cage/Pen Farmers

The abrupt drop in milkfish prices in 1997-1998 resulted in the bankruptcy of many small fish farms. The huge collectibles of feed companies effectively prevented the selling of feeds on credit which forced inadequately financed operations to close. The typhoon that hit Luzon in August, 1998 made the scenario worst for small entrepreneurs in Pangasinan province, ultimately displacing this farmer group. At present, the remaining farms in operation are relatively big and well capitalized ventures. Two of the biggest farms in the Philippines located in Pangasinan province operate around 80 units of circular-type Norwegian-made cages for milkfish with a combined volume of 160,000-180,000 m³. These farms are responsible for 25-35% of the national marine cage and pen output. Other milkfish cage ventures are much smaller usually with 4-8 cage-units (1,000-2,000 m³/cage) or 2-6 pen-units (0.5-1.0 ha/pen).

It is interesting to note that for marine pen culture, many farmers at one time or another operated freshwater pens in Laguna de Bay.

Compared to milkfish culture, a greater number of grouper farms in Roxas are classified as small with six cages or less. Investment cost for equipment is below US\$ 1,000. Most of the production however comes from big well financed farms with 24-36 cage units.

Cost and Returns for Major Species

Table 6 summarizes the cost and return for milkfish cage culture. With a production cost of US\$ 1.4/kg for milkfish, and a wholesale selling price of US\$ 1.75, profit is around 25%. Considering that wholesale prices can drop to US\$ 1.25/kg, many investors are actually finding milkfish mariculture an increasingly risky investment. Only during the months of December and March is cage culture attractive with wholesale prices reaching US\$ 2/kg. It does not come as a surprise therefore that many farmers program their stocking to harvest during these months of peak prices.

Table 7 presents cost and returns for grou-

per culture. With the current farmgate price of around US\$ 7/kg and direct cost of production of US\$ 3.22/kg, it is evident from the data that farming of grouper is highly attractive in the Philippines with a profit margin in excess of around 118%. This is only for the live market. Wholesale prices for the wet market is often lower than the production cost.

Depending on the cage construction and the support facilities (e.g., service boat, floating work platform, etc.), fixed cost for milkfish and grouper on the average is between US\$ 0.05 and 0.1/kg fish produced.

Problems and Constraints

Compared to milkfish producing countries in the region, milkfish feeds in the Philippines cost higher. This is attributed to a number of factors including lower import volumes of raw materials, multiple handling and shipping cost (between islands), higher power cost, higher cost of money, and absence of government subsidy. This high feed cost coupled with the currently high feed conversion ratios of 2.4-2.8 make cage- and pen-farmed milkfish vulnerable to a drop in the local market prices which is inevitable during the summer months when sea catch is high and milkfish production in traditional ponds is at its peak. In 1997, an oversupply of milkfish brought down wholesale prices to as low as US\$ 1.2/kg (Navotas fishing port) which is below production cost. This has resulted in the closure of many facilities. For milkfish mariculture to be economically sustainable in the long run, there is an immediate need to reduce the feed expense component which is close to 70% of the variable cost (Table 5).

Improved feeding management is seen as a major step in reducing production cost. Farmers who have adopted feeding rates relative to demand, and have employed the use of automatic feeders for regulated and uniform feeding, typically report 8-12% better feed conversion (Abesamis, pers. comm.). But the greatest impact in production cost will come from an improved feed formulation suited to the marine environment. It is important to note that the current feed conversions of 0.9-1 in the Norwegian salmon

industry started in the 70's with FCR's in excess of two. A 10% improvement in FCR alone in local feeds will already bring down production cost by around 7%.

The challenge of reducing farm production cost applies to the entire milkfish industry as well. In recent years, high milkfish prices have actually caused a drop in per capita consumption compared to poultry and pork meat. This has also allowed the entry of frozen milkfish from countries like Taiwan and Singapore. Part of the problem is the marketing channel which passes through at least three levels of traders which increases retail price by 25-35%.

The limited availability of ideal sites for mariculture has resulted to congestion of cage farms in many farming centers (Fig. 4). Ectoparasitic and gill diseases have been reported in milkfish in Bolinao and Davao del Sur although

this has diminished lately with the closure of a significant number of farms due to low fish prices. In Roxas, a rising incidence of health problems and diseases is being observed among groupers and this is being attributed to overdevelopment. With the Fisheries Code of 1998 which empowers local governments to manage their own coastal waters, some of the more progressive municipalities have already started to adopt and implement policies at guiding and regulating mariculture development. This has already resulted in the dismantling of numerous cage and pen structures in the Lingayen Gulf. While environmental consciousness is becoming evident among fishfarmers, they need adequate information from the scientific community on environmental carrying capacities and guidance in establishing sound and sustainable husbandry practices.

Table 6 . Cost and return for milkfish cage culture in Bolinao, Pangasinan, Philippines*.

Assumptions:

- 1 unit of 15 m diameter x 8 m deep cage
- Effective cage volume= 1,000 m³/cage
- Stocking density= 50,000/cage
- Harvest size= 500 g
- Survival rate= 80%
- Grow-out cropping cycle= 7 months
- Production= 20,000 kg/cage/crop
- Biomass loading= 20 kg/m³/crop
- Wholesale selling price= US\$ 1.75/kg
- US\$ 1= P 40

* Excludes fixed cost

Item	Qty.	Unit cost	Variable cost/yr	Percent production cost
Fingerlings (@ 50,000/cage)	50,000	0.095	4,750	17.06
Feeds (@ 20,000 kg milkfish/crop × FCR= 2.5)	50,000	0.38	19,000	68.24
Cage personnel (@ US\$ 75/mo × 7 mos)	1.0	525	525	1.89
Harvesting expense (labor, ice, fuel, etc.) (@ US\$ 0.1/kg)	20,000	0.10	2,000	7.18
Equipment maintenance (@ US\$ 25/cage/mo)		175	0.63	
Miscellaneous (@ 5%)		1,391	5.00	
Total Variable Cost/Crop			\$27,841.27	100.00
Total Variable Cost/kg Milkfish			\$1.39	
Gross Sales/Crop			\$35,000.00	
Gross Profit/Crop			\$7,158.73	
R.O.R.			25.71%	

Table 7. Cost and return for grouper cage culture in Roxas, Philippines*.

Assumptions:

- 8 units of 3 m x 3 m x 3 m cage
- Effective cage volume= 27 m³/cage
- Stocking density= 625/cage
- Harvest size= 500 g
- Survival rate= 80%
- Grow-out cropping cycle= 8 months
- Production= 250 kg/cage/crop; 2,000 kg/crop for entire facility
- Biomass loading= 9-10 kg/m³/crop
- Wholesale selling price= US\$ 7/kg
- US\$ 1= P 40

* Excludes fixed cost

Item	Qty.	Unit cost	Variable cost/yr	Percent production cost
Fingerlings (@ 625/cage x 8 cages)	5,000	0.40	2,000	31.09
Trash fish (@ 2,000 kg grouper/crop x FCR= 4)	8,000	0.20	1,600	24.87
Cage personnel (@ US\$ 75/mo x 8 mos)	2.0	600	1,200	18.65
Harvesting expense (labor, ice, fuel, etc.) (@ US\$ 0.38/kg)	2,000	0.38	750	11.66
Equipment maintenance (@ US\$ 3.75/cage/mo)			240	3.73
Miscellaneous (@ 10%)			643	10.00
Total Variable Cost/Crop			\$6,433.27	100.00
Total Variable Cost/kg Grouper			\$3.22	
Gross Sales/Crop			\$14,000.00	
Gross Profit/Crop			\$7,566.73	
R.O.R.				117.62%

Industry Prospect

Accelerated developments in the local hatchery industry and the availability of seed-stock for high value species from Taiwan hatcheries now provide a variety of species for mass propagation which was not available before in the aquaculture industry. With growing consumer preference for maricultured fish due to its more consistent and higher quality, marine fish farming in the coming years will likely dominate over pond culture in opening up the export market. Production cost in marine cages at present is 15-20% higher than in intensive pond culture. This difference is however expected to narrow down as newer feeds and feeding technologies become available.

The need to decongest farming centers and regulate newly opened sites will inevitably mean moving cages further offshore. This development will likely bring large mariculture projects further south of the country where the threat of typhoons is less. For mariculture to have its impact in the alleviation of poverty in the countryside, local governments should give small farmers priority in the sustainable use of sheltered sites as this will not require costly all-weather cages and other support facilities. In areas with little protected coastline, a government-run "community mooring system" can be established which small farmers can rent at a reasonable cost. Of the emerging new species, salt-water tolerant tilapia appears to be the most promising for small farmers because of its simple hatchery system,



Fig. 4. Grouper cages in Bambang, Roxas City showing congested site.

lower fry cost, lower feed cost, and efficient feed conversion. At least four private and government groups are already undergoing genetic improvement studies to develop a suitable salt-tolerant tilapia strain.

At present, fish cultured in marine waters accounts for only 2-2.5% of the total farmed fish production. Assuming 0.1% of the country's 26,000,000 ha of coastal waters (BFAR 1998) is suitable for marine fish culture, an area of as much as 26,000 ha is theoretically available for cage and pen farming. With a yield of only 50 tons/ha/yr, such an area has the potential to produce up to 1.3 million mt of fish annually, or four times the present annual fish production from aquaculture. Considering the country's vast coastline, the potential for mariculture to contribute significantly to food security, livelihood, and aquaculture exports is enormous. For this to be realized, however, the industry must first strive to lower the production cost and embrace sustainable culture practices to avert the threat of diseases and environmental problems.

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Potential of Marine Cage Aquaculture in Taiwan: Cobia Culture

M.S. SU¹, Y.-H. CHIEN² and IC. LIAO¹

¹Taiwan Fisheries Research Institute
Keelung 202
Taiwan

²Department of Aquaculture
National Taiwan Ocean University
Keelung 202
Taiwan

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Abstract

Currently, there are about 1,500 cages, ranging from 216 m³ to 1884 m³, operated in the coastal waters off Penghu, Pingtung, Ilan, and Hsinchu Prefectures in Taiwan. Over 80% of these cages are devoted to cobia culture. Cobia attains maturation at 9-10 kg and spawns spontaneously from March to October. Incubation takes 30 hours at 24-26 °C. Larval rearing takes about 45 days for the fry to reach 8-10 cm. Nursing takes another 25-30 days to reach 30 g. The fish are then transferred to marine cages for growout culture. They can reach 6-8 kg in cages in one year. About 1,500 mt of cobia was produced in Taiwan in 1999. Of which, over 450 mt of 6-8 kg whole fish was marketed to Japan at cage-side prices of 150-180 NT\$/kg (US\$ 5-6/kg). The preliminary success suggests that there is a great potential for marine cage aquaculture of cobia in Taiwan.

Introduction

Cage aquaculture in the open sea is believed to be the most potential aquaculture system in the future. In 1981, the production of rainbow trout and salmon together in Norway was only 8,000 mt. However, in 1998, salmon production alone has reached 343,000 mt (Hjelt 2000). The success of the salmon farming industry in Norway has promoted the development of marine cage aquaculture in the whole world.

To prevent further adverse environmental impacts from the over expansion of pond culture, the development of offshore cage aquaculture has drawn much attention in Taiwan. Currently, about 1,500 cages of various sizes, ranging from 216 m³ to 1884 m³, are being operated in coastal and offshore waters off Penghu, Pingtung, Ilan, and Hsinchu Prefectures (Fig. 1). The production was merely 103 mt in 1990. It was increased more than 7 folds to 837 mt in 1997 and again by more than 3 folds to 2,673 mt in 1998. The main

cultured species include: amberjack (*Seriola dumerili*), cobia (*Rachycentron canadum*), red-spotted grouper (*Epinephelus coioides*), red snapper (*Lutjanus erythropterus*), gray snapper (*L. argentimaculatus*), spotted snapper (*L. stellatus*), red seabream (*Pagrus major*), speckled drum (*Nibea diacanthus*), and pompano (*Trachinotus blochii*). The fry used are all artificially propagated by the local farmers. Comparing the culture performance and the potential markets among these species, it has been recognized that cobia is the most promising one for marine cage aquaculture in Taiwan. At the present, over 80% of marine cages are devoted to cobia culture and about 1,500 mt was produced in 1999. It is foreseeable that cobia culture in marine cages will become a very important sector of aquaculture in Taiwan.

Current State of Development

The schedule of cobia culture is outlined in Fig. 2.

Larval Rearing

The cobia cultured in marine cages in coastal waters of southwest Taiwan attains sexual maturity at the age of 15 months. Brooder around 9-10 kg are selected from cages and transferred to land-based spawning ponds in January. The fish are then fed with raw sardines, mackerels, and squids to satiation once per day. They become mature in late February and spawn spontaneously from March to October. The fertilized eggs are collected and transferred to larviculture ponds for larval rearing. The ponds, ranging from 200 to 300 m³, are built with concrete dikes and sandy bottom. A water depth of 1.0-1.2 m is maintained and the pond water is moderately aerated. The stocking density of fertilized eggs is 1-2 million per pond. Eggs hatch 30 hours after spawning at 24-26°C. The newly hatched larvae are 3.4-3.6 mm. The larvae open their mouths and reach 5.0-5.2 mm at day 3. Rotifer, copepod, and microparticulate feeds are subsequently fed to the larvae. The green algae water from nearby growout ponds is pumped into the larviculture ponds to control water quality and transparency. The larvae grow rapidly into fry, reaching 8-10 cm at day 45. The fry are then

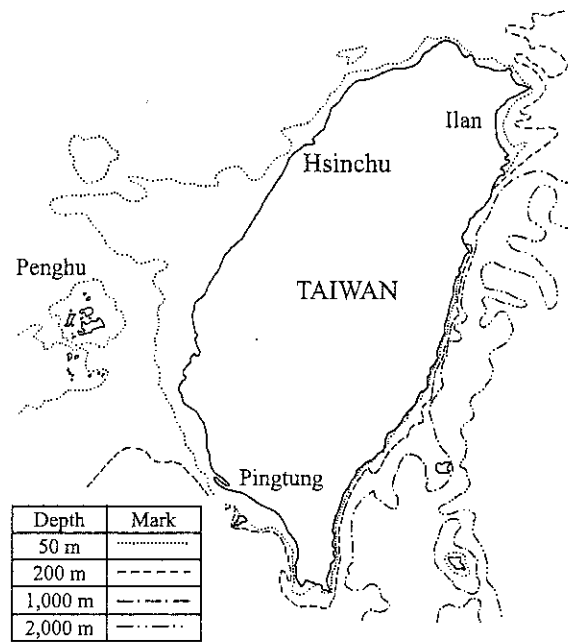


Fig. 1. Water depth contour lines around Taiwan prefectures having marine cage aquaculture.

collected and transferred to nursery tanks or ponds. About 5 million cobia fry were produced in Taiwan in 1999. Survival rates in larval rearing ranged from 5-20% from fertilized eggs through day 45 fry.

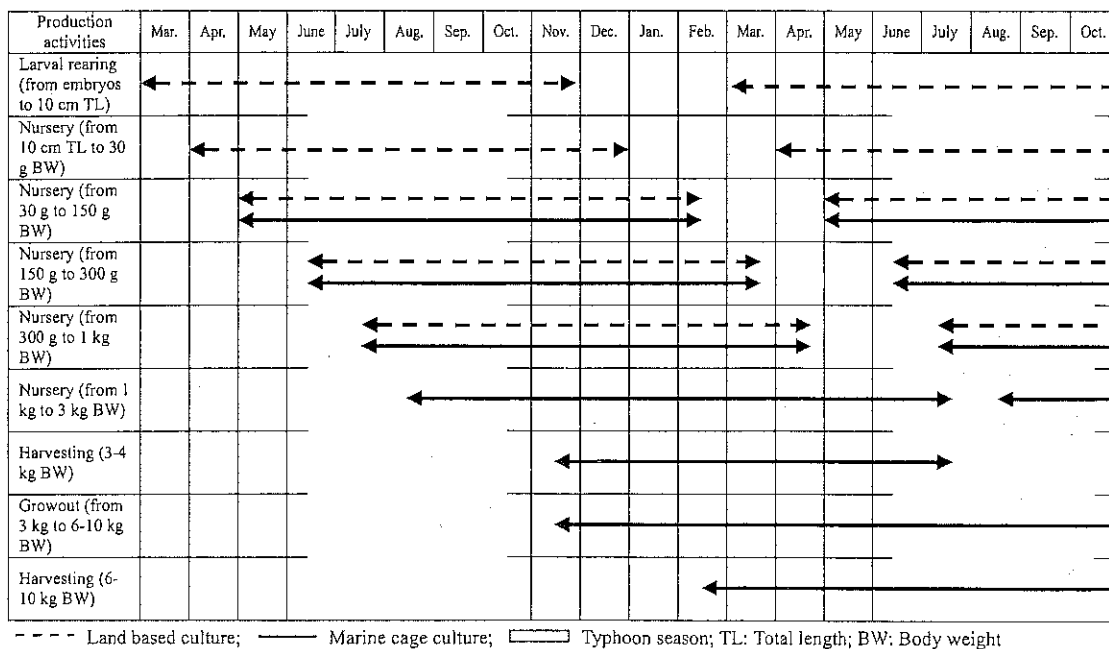


Fig. 2. Schedule of cobia culture in Taiwan.

Nursery

Growth disparity is apparent in cobia fry. Larger fry usually show sibling cannibalistic behavior over smaller ones. Cannibalism occasionally leads to mortality in both prey and predators because the cannibals can choke to death on their prey. Therefore, fry should be graded before being transferred to the nursery tanks. Continuous grading at 10 to 14-day intervals is necessary during the nursery culture. Fish can be injured and weakened from catching and handling stress during grading, which often causes diseases and mortality. Medication using furazolidone before or after grading is necessary. Table 1 shows the relationship between sieve size of a grader, the sizes and corresponding body weight of cobia passing through the grader, and the feeds for fish of different size classes (Chang *et al.* 1999). The graded fish are stocked into fiberglass reinforced plastic (FRP) or concrete tanks in circular or race way shape with a working volume of 5-60 m³. Pellet feed of appropriate size (1.0 mm in diameter) is first introduced for 4-cm fish. Palatability and nutrition are essential considerations for a weaning diet. At size over 8.5 cm, all fish usually have been weaned onto pellet feed. The fish are fed 4 times at daytime using automatic feeders. Pellet sizes are increased gradually from 1.0 to 1.5 mm as the fish grow. Fish are fed daily at a rate equivalent to 8-10% of the tank biomass. Fish grow from 1.5-3.5 g (8-10 cm) to 28-32 g in 25-30 days. The fish over 30 g can well acclimatize to the oceanic environment and then be transferred

from land-based tanks or ponds to offshore cages for growout cultivation.

Cage Systems

Taiwan is leading in fishing net industry. The export value reached US\$ 230 million in 1999. To meet the fast development of offshore cage aquaculture, several companies have devoted to develop cage systems in recent years. The accrued experiences in manufacturing fishing nets have facilitated the development of cage systems, especially the flexible submerged cage system. Ropes and buoys, which are quite flexible against wave and current, are used to support bags and their cover nets of the cages. The cage is submerged 1-2 m below the sea surface from the cover nets. The mooring ropes are fixed onto 5-15 mt concrete blocks. Cage bags vary in size: 10 m x 10 m x 8 m, 6 m x 6 m x 6 m, and 3 m x 3 m x 3 m. Although these cages cost fairly low to construct and can withstand strong wave and current, they are inconvenient in operations such as feeding, net changing, and checking fish in the cages. To improve the cage-construction techniques, over 60 modern floating or submergible cages from Norway have been introduced to Taiwan since 1996. The collars of these cages consist of two concentric pipes linked together with some special hinges. The pipes are made of high-density polyethylene (HDPE). There are different sizes of cage bags: 12 m diameter x 6 m depth, 16 m x 8 m, and 20 m x 8 m. The farmers can walk on the collars to check fish in cages. Feeding and net changing can be done easily, too.

Table 1. The relationship between sieve size of grader, the size and body weight of cobia passing through the sieve, and the feeds for different size class of cobia (Chang *et al.* 1999).

Sieve size of grader (cm x cm)	Total length of cobia passing through sieve (cm)	Corresponding body weight of cobia (g)	Feeds for cobia
0.33 x 0.51	4.06-5.33	0.12-0.28	Copepod, Microparticulated feeds
0.51 x 0.61	5.08-6.81	0.33-0.67	Copepod, Microparticulated feeds, Subadult artemia
0.61 x 0.66	6.06-7.83	0.51-0.91	Microparticulated feeds, Adult artemia, Small shrimp
0.66 x 0.80	6.60-8.17	0.74-1.47	Microparticulated feeds, Adult artemia, Small shrimp
0.80 x 1.00	8.40-11.03	1.45-3.33	Microparticulated feeds
1.00 x 1.13	10.98-13.84	4.27-6.88	Microparticulated feeds

Several local manufacturers have successfully produced HDPE circular cages, which have been well accepted by the farmers.

Cage Aquaculture

Cobia over 30 g is ready to be transferred to marine cages. The fish are stocked in small square cages ranging from 3 m x 3 m x 3 m to 6 m x 6 m x 6 m at various densities. After reaching 600 g-1 kg, the fish are transferred to large square cages of 10 m x 10 m x 8 m or circular cages ranging from 12 m x 6 m to 20 m x 8 m. The stocking density is 4-6 fish/m³. The fish are fed with raw fish and moist and dry pellets. Raw fish include sardines, mackerels, sand lance, etc. Farm-made moist pellets are prepared by mixing minced raw fish with a formulated powder diet at a ratio of 1:1 or 2:3. Dry pellets are made by feed mills. Feeding is done by hands. Dry pellets have several merits over raw fish and moist pellets, such as stable and controllable food quality, easy to transport, store, and feed; and less contamination, feed loss, and pollution to the water. For these reasons, the use of dry pellets has been strongly recommended. Table 2 shows the feeding regimes and FCR of a commercial extruded pellet feed fed to cobia in a private cage farm in the southwestern Taiwan. The study was conducted by Tungking Marine Laboratory (TML), Taiwan Fisheries Research Institute, in 1999. Feed size ranged from 1.5 to 18.0 mm in diameter and increased with fish size. Daily feeding rate

Table 2. The feeding regimes and food conversion ratio (FCR) of a commercial extruded pellet feed fed to cobia in cages. The study was conducted by Tungking Marine Laboratory in 1999.

Fish size (g)	Feed size (mm)	Daily feeding rate (% of fish body weight)	FCR
30	1.5	7.8	1.02
100	2.5	6.4	1.18
200	5.0	6.1	1.23
500	8.0	5.0	1.46
1,000	12.0	5.2	1.48
3,000	18.0	4.8	1.76
5,000	18.0	4.3	1.80

FCR=Feed weight/Fish growth weight.

ranged from 4.3% to 7.8% of the cage fish biomass and decreased with fish size. FCR ranged from 1.02 to 1.80 and increased with fish size.

Harvesting and Marketing

The harvestable sizes for cobia are 6-8 kg for the Japanese market and 8-10 kg for domestic market. Prior to harvesting, fish are starved to evacuate their guts. This practice is necessary to prevent the fish from contamination with its gut contents and excreta during processing. The harvesting process is simple. The cage net is hoisted until the fish are concentrated in a small body of water and then the fish are netted to the boats with dip nets. Fish are bled on boat by severing the blood vessels in gill arch. The cut fish are placed in tanks and flushed with clean and cold water until the water run clear. After bleeding, fish are packed whole between layers of ice in insulated boxes and dispatched as soon as possible to ensure the freshness of the product. About 450 mt of cultured cobia (whole fish with 6-8 kg body weight) was exported to Japan in 1999. The flesh quality and texture of cobia have been well accepted by Japanese consumers, although cobia is a new seafood item for them. Proximate composition and fatty acid contents of meat in various parts and viscera of cobia are shown in Tables 3 and 4 (Shiau 1999). Variation in moisture and fat makes the texture, appearance, and flavor of meat in various parts different, and enables the consumers prepare several kinds of dishes from one fish, such as sashimi, broiled, fried, stewed, and soup. The meat of cultured cobia has higher fat and EPA and DHA content than other cultured fishes and most food fishes caught from the wild (Shiau 1999). Since the beneficial effects of EPA and DHA from marine fishes on human health have been well known, rapid increase in demand of cobia is anticipated because of its richness of EPA and DHA.

Prospects of Future Development

Integrated Research and Development

Since most cultured cobia are destined for export, both the price and quality have to be

competitive with other fish such as salmon. Therefore, the focus should be placed on the reduction of production cost and increase of quality. Integrated research and development (R & D) in all relevant disciplines should be implemented in the whole industry (Fig. 3). As such, each sector of the industry from broodstock cultivation to distribution of the final products will benefit. Through the strong support of this integrated R & D, the cage culture of cobia can be operated intelligently, that is, the work and resources can be well organized, the work environment can be made positive, and the technologies can be correctly chosen. In this manner, the competitiveness of the whole industry will be substantially increased.

Stepwise Culture Strategy

The stepwise culture has been practiced successfully in pond culture of eel, tilapia, milkfish, and mullet in Taiwan. The stepwise culture for cobia is proposed in Fig. 4. The advantages of stepwise culture for cobia include: (1) reducing fish loss in typhoon reason, which prevails from late June to early October; (2) effectively curing the fish infected by pathogens before they

are stocked into cages; (3) easing fish grading and improving feeding management; (4) shortening the growout period in offshore cages and concomitantly decreasing the risks of cage aquaculture. Beyond the size of 1 kg, cobia can grow over 1 kg per month. Stocking fish over 1 kg into cages has been seriously considered by many farmers to take the advantage of the fast growing period of the fish. However, the obstacle lies on the difficulty to transport large fish over 1 kg from ponds to cages. An advanced technology of live fish transportation still needs to be developed.

Innovation of Cage Systems

Disaster loss due to typhoon is always a major risk in open sea cage aquaculture. The development of typhoon-proof cage systems should be placed on the top priority. Theoretically, it is possible to design a cage system, which can be manipulated easily and safely to submerge several meters below the sea surface to escape from the strong waves and currents caused by typhoons. By offsetting the disadvantages caused by typhoons, there are several advantages of developing cage aquaculture in exposed locations.

Table 3. Proximate composition (%)^a of various tissues in cobia (Shiau 1999).

	Moisture	Protein	Crude Fat	Ash
Dorsal Meat	71.55±3.60	18.87±1.30	7.73±3.56	1.48±0.23
Ventral Meat	64.86±7.21	17.64±1.23	16.27±7.73	1.42±0.21
Dark Meat	64.02±8.82	16.47±1.18	19.14±8.81	1.03±0.19
Viscera	49.11±15.69	11.87±2.24	38.56±16.93	1.08±0.31

^aExpressed as mean ± standard deviation (n=6).

Table 4. Fatty acids (mg/100 g of wet wt)^a of various tissues in cobia (Shiau 1999).

	Dorsal meat	Ventral meat	Dark meat	Viscera
C14:0	154.2±83.3	283.5±169.5	322.9±143.9	716.2±231.6
C16:0	974.1±446.9	1,794.5±1,040.6	2,230.9±7,63.4	5,928.4±3,515.0
C18:0	219.9±122.0	4,12.1±2,42.9	528.3±211.5	1,343.2±794.1
C18:1	766.5±804.1	2,027.0±1,275.9	2,498.8±999.8	7,221.5±4,961.5
C18:2	577.1±390.2	1,130.6±9,71.7	1,326.6±828.7	3,577.7±2,437.4
C18:3	78.6±44.8	151.6±118.5	166.5±84.4	470.0±282.5
C20:0	43.3±23.6	75.3±45.1	82.9±34.5	222.8±67.2
C20:5	279.6±131.4	484.9±245.7	547.2±214.0	1,509.7±457.0
C22:6	327.9±93.3	506.5±277.9	600.9±185.0	1,479.5±765.2
Unknown	438.4±199.1	733.9±434.8	898.8±287.5	2,312.2±1,252.9

^aExpressed as mean ± standard deviation (n=6).

Exposed sites are usually deeper and have strong currents (Lindbergh 1998). Greater depth and strong current disperse solid wastes more effectively, hence, reducing or eliminating sediment

buildup and allowing for higher stocking densities. Current in exposed open water can flush excess nutrients out of the rearing area and reduce the chance of toxic phytoplankton growth.

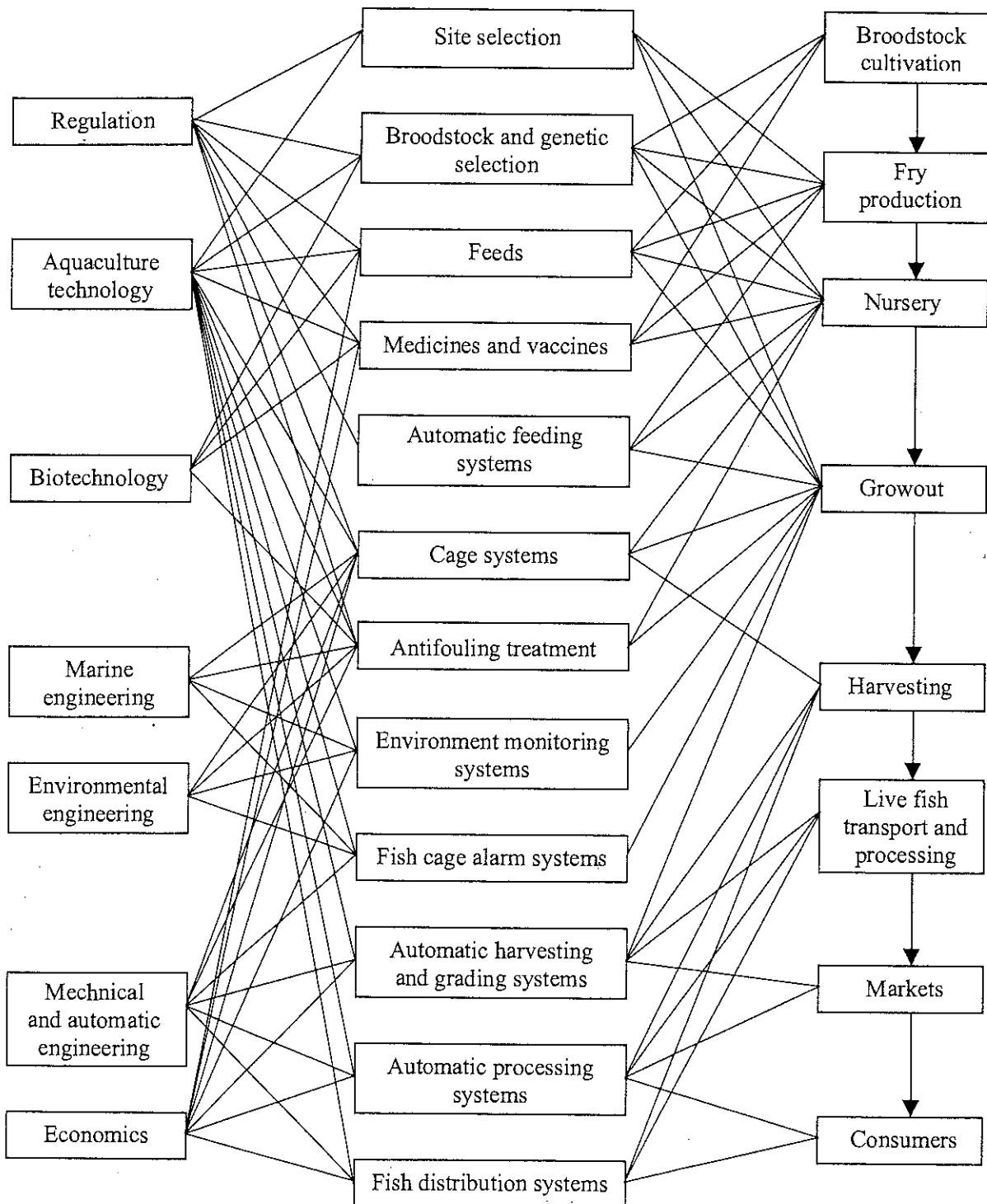


Fig. 3. Recommended integrated research and development for offshore cage aquaculture of cobia.

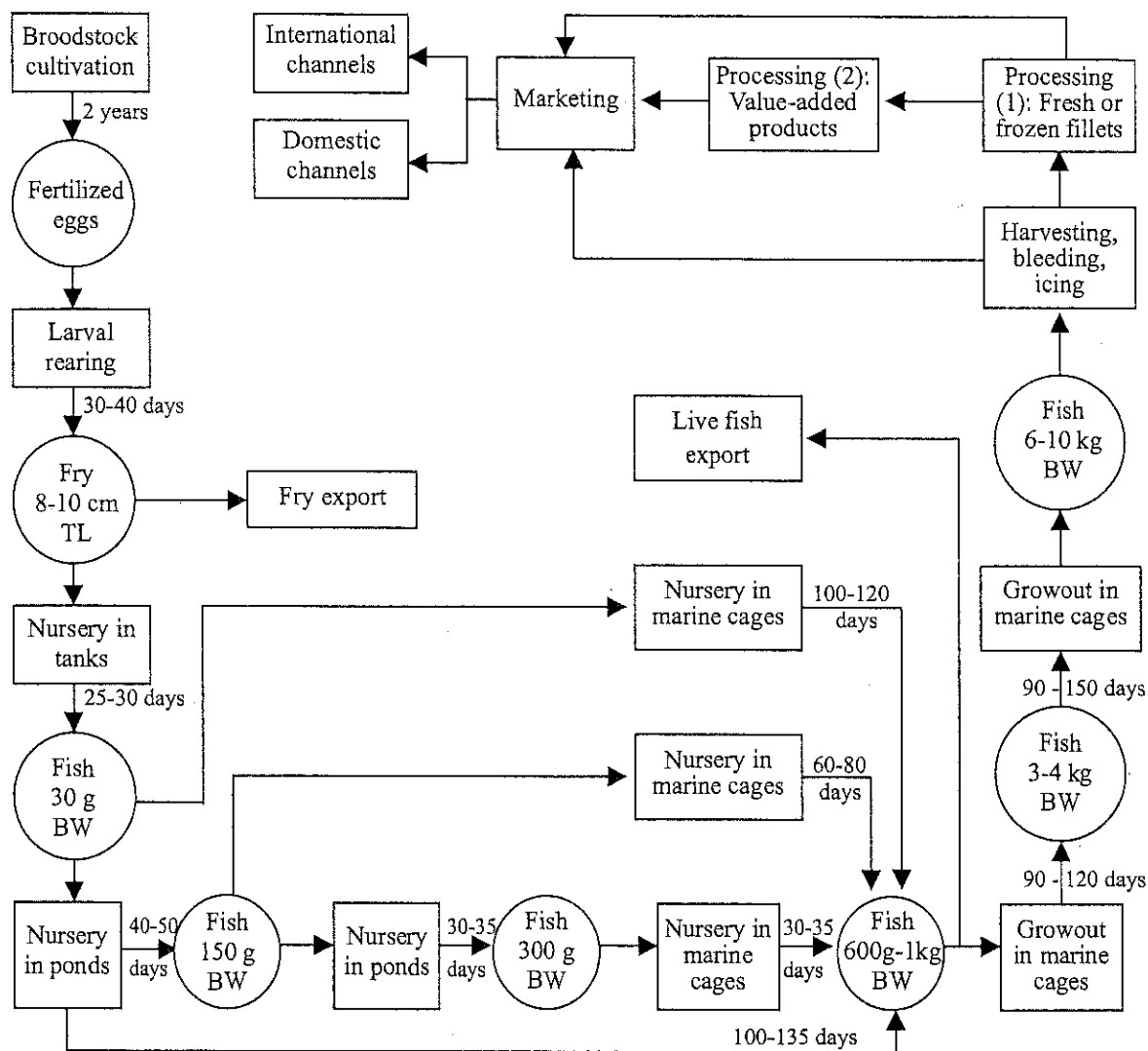


Fig. 4. Stepwise culture of cobia.

Consistent water flow through cages brings sufficient oxygen and flushes out the metabolic wastes. Current can also dilute the concentration of pathogens and reduce the infection to the fish.

Improvement of Feeds and Feeding

Development of effective extruded pellets and establishment of automatic feeding system for cobia culture should be addressed. In Norway, almost all salmon farms use extruded pellets (Dahle 1998). The feed development has not only resulted in the FCR close to 1, but also increased the growth rate of the cultured salmon. An ideal feed should be cost-effective, nutritionally balanced, and environment-friendly and

yield fast growth, low FCR, and high quality fish flesh. The FCR of dry pellets for growing cobia from 1 to 6 kg in offshore cages ranges from 1.48 to 1.80. As compared to the FCR of salmon feed, there is still ample room for the improvement of cobia feed used at the present. Currently hand-feeding in cobia cage culture is labor intensive, hard to conduct and risky especially during rough sea condition. Small distribution area and uneven feed distribution can lead to heterogeneous growth of fish and feed loss. In salmon culture, central automatic feeding systems are very popular. Pellets are distributed through HDPE pipes to the cages. All cages can be fed individually according to the fish size distribution and

biomass in each cage and water temperature, oxygen level, time of day, and other in-situ factors (Dahle 1994). Recently, a computer-integrated central feeding system has been developed by TML, satisfactorily tested for nursery culture of cobia. After some refinements, this system can be used for growout in offshore cage as well.

Application of Vaccines

It has been proven that a major factor attributed to the sustainable development of salmon culture industry is the use of vaccines to curb the disease. Almost complete elimination on the use of antibiotics since 1994 (Dahle 1998) also lessens the environment concern over and health hazard from antibiotics. Although cobia in general is found to be hardier than other fishes, probably on disease resistance, too, it is however not sure if disease outbreak may be encountered in the future. The development of vaccines for cobia should be initiated now to secure the industry.

Automation of Cage Aquaculture

Automation in cobia production processes is needed so that the production scale can be enlarged and cost can be greatly reduced. These processes include grading, net cleaning, fish, environment, safety monitoring, feeding, harvesting

and post-harvesting. It has been considered to import some of the automation equipments used in salmon industry and modify them for the use in cobia industry. By doing this way, not only the effort and time to reinvent the wheel can be saved but also technologies can be advanced during the adaptation and modification processes.

Economic Production Scale

Cobia production was about 1,500 mt in 1999. The cage-side price ranged from 120-230 NT\$/kg (1 US\$ = 30 NT\$) and 150-180 NT\$/kg for Japanese markets. Favorable price has prompted farmers to expand their production scales. However, if supply exceeds demand or is unable to meet the demand in each link of the production processes, orderly production and stable profit for both sectors of each link cannot be assured. Therefore it is important to estimate the supply ability and demand capacity in each link far in advance and lay out short-to-long term development strategies for the whole industry. The sectors include hatcheries, nurseries, grow-out farms, feed ingredient suppliers, feed producers, equipment and facility material producers and suppliers, processing plants, traders, and the end users, which are consumers or market. Based on current practice and experience, we estimate the demands for fry (Table 5), feed (Table 6), and

Table 5. Estimated number of cobia fry required at stocking in cages to obtain various projected production through various survival rates.

Survival rate ^a (%)		40	50	60	70	80	90
Projected production		No. of fry at stocking ^b (x 10,000)					
Volume (mt)	No. of fish						
5,000	830,000	208	166	138	119	104	92
10,000	1,670,000	418	334	278	239	209	186
20,000	3,330,000	833	666	555	476	416	370
30,000	5,000,000	1,250	1,000	833	714	625	556
40,000	6,670,000	1,668	1,334	1,112	953	834	741
50,000	8,330,000	2,083	1,666	1,388	1,190	1,041	926
70,000	11,670,000	2,918	2,334	1,945	1,667	1,459	1,297
100,000	16,670,000	4,167	3,334	2,778	2,381	2,084	1,852
110,000	18,330,000	4,583	3,666	3,055	2,619	2,291	2,037
150,000	25,000,000	6,250	5,000	4,167	3,571	3,125	2,778

^aFrom fry (10-cm TL) to harvest (6-kg BW in average); ^bNo. of fish produced/survival rate.

cages and farming area (Table 7), and the value (Table 8) by various projected production. Based on these estimates, it is assumed that if the international and domestic market can accommodate all the cobia produced in Taiwan, 150,000 mt, at a reasonable price, 140 NT\$/kg, the annual

production would be valued 21 billion NT\$. This value is closed to the value of total land-based pond culture production in Taiwan in 1998, 23 billion NT\$. It is clear that offshore cage culture of cobia can play an important role in reconstructing the aquaculture industry in Taiwan.

Table 6. Estimated extruded pellets feed required to obtain various projected cobia production when the feed attain various FCR.

FCR ^a	1.8	1.6	1.4	1.3	1.2	1.1	1.0
Projected production (mt)	Feed required ^b (mt)						
5,000	9,000	8,000	7,000	6,500	6,000	5,500	5,000
10,000	18,000	16,000	14,000	13,000	12,000	11,000	10,000
20,000	36,000	32,000	28,000	26,000	24,000	22,000	20,000
30,000	54,000	48,000	42,000	39,000	36,000	33,000	30,000
40,000	72,000	64,000	56,000	52,000	48,000	44,000	40,000
50,000	90,000	80,000	70,000	65,000	60,000	55,000	50,000
70,000	126,000	112,000	98,000	91,000	84,000	77,000	70,000
100,000	180,000	160,000	140,000	130,000	120,000	110,000	100,000
110,000	198,000	176,000	154,000	143,000	132,000	121,000	110,000
150,000	270,000	240,000	210,000	195,000	180,000	165,000	150,000

^aBased on Table 2; ^bBack-calculated from dividing the projected production by FCR.

Table 7. Estimated number of cages and farming area (in parentheses) required to obtain various projected production based on various fish density at harvesting.

Fish density (kg/m ³) at harvest ^a	10	12	15	18	20	22	25
Projected production (mt)	No. of cage ^b & farming area ^c (ha) required						
5,000	199 (62)	166 (52)	133 (42)	111 (35)	99 (31)	90 (28)	80 (25)
10,000	398 (125)	333 (104)	265 (83)	221 (69)	199 (63)	181 (57)	159 (50)
20,000	796 (250)	663 (208)	531 (167)	442 (139)	398 (125)	362 (114)	318 (100)
30,000	1,194 (375)	995 (323)	796 (250)	663 (208)	597 (187)	543 (171)	478 (150)
40,000	1,592 (500)	1,326 (416)	1,061 (333)	884 (278)	796 (250)	724 (227)	637 (200)
50,000	1,990 (625)	1,658 (521)	1,326 (416)	1,105 (347)	995 (313)	904 (284)	796 (250)
70,000	2,786 (875)	2,321 (729)	1,857 (583)	1,547 (486)	1,393 (438)	1,266 (398)	1,114 (350)
100,000	3,979 (1,249)	3,316 (1,041)	2,653 (833)	2,211 (695)	1,990 (625)	1,809 (568)	1,592 (500)
110,000	4,377 (1,374)	3,684 (1,145)	2,918 (916)	2,432 (764)	2,189 (688)	1,990 (625)	1,751 (550)
150,000	5,969 (1,874)	4,974 (1,562)	3,979 (1,249)	3,316 (1,042)	2,984 (937)	2,713 (852)	2,388 (750)

^aBased on standing crop per volume of water.

^bProjected production (kg)/fish density (kg/m³)/cage volume (m³) per cage. A volume of 2,513 m³ per cage, a cage of 20 m in diameter and 8 m in depth.

^c10 x cage area (m²) per cage x no. of cage/10,000 (m²/ha), 314 m² per cage.

Table 8. Estimated production value by various cage-side price.

Cage-side price (NT\$)	180	160	140	130	120	110	100
Projected Production (mt)	Value (million NT\$)						
5,000	900	800	700	650	600	550	500
10,000	1,800	1,600	1,400	1,300	1,200	1,100	1,000
20,000	3,600	3,200	2,800	2,600	2,400	2,200	2,000
30,000	5,400	4,800	4,200	3,900	3,600	3,300	3,000
40,000	7,200	6,400	5,600	5,200	4,800	4,400	4,000
50,000	9,000	8,000	7,000	6,500	6,000	5,500	5,000
70,000	12,600	11,200	9,800	9,100	8,400	7,700	7,000
100,000	18,000	16,000	14,000	13,000	12,000	11,000	10,000
110,000	19,800	17,600	15,400	14,300	13,200	12,100	11,000
150,000	27,000	24,000	21,000	19,500	18,000	16,500	15,000

1 USD = 30 NT\$.

Conclusions

The preliminary success of cobia culture in marine cages has evoked a booming development of marine cage aquaculture in Taiwan. The technologies of larval rearing, nursery, and grow-out for cobia have been established in Taiwan. From the juvenile size, cobia can grow up to 6-8 kg in cages in one year. Its flesh quality has commanded good acceptance by consumers in Japan and US. Cobia is considered a very promising culture species in marine cages. Sustainable growth of this industry relies on the development of the following technologies: (1) typhoon-proof cage systems to prevent disaster loss; (2) high quality extruded pellets to increase growth rate, decrease FCR, and improve flesh quality; (3) nursery systems to increase survival rate in cages; (4) automatic feeding systems to reduce operational labor and risk and increase productivity; (5) vaccines to curb diseases; and (6) other automatic equipment to increase productivity and reduce production cost. Regarding the non-technology aspects, refining the laws and regulations related to offshore cage aquaculture

and coordinating all sectors involved in the industry must be given priority as well.

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Present Status of Fish Cage Culture in Thailand

P. MENASVETA

*Department of Marine Science
Chulalongkorn University
Bangkok
Thailand*

Menasveta, P. 2000. Present status of fish cage culture in Thailand. *In* Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia (ed. IC. Liao and C.K. Lin), pp. 107-109. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok.

Abstract

Fish cage-culture in Thailand has been developed for more than three decades, starting with freshwater fishes and extended to coastal waters. Most cages are boxshaped and made of wooden planks, floated along the river banks. The predominant cultured species are river catfish (*Pangasius pangasius*), marble goby (*Oxyeleotris marmoratus*), and serpent-head (*Ophicephalus* sp.), which are produced in large quantities. Production, however, has declined significantly during the last decade due to dam construction in several rivers. This resulted in the reduction of flow rate making the areas unsuitable for cage culture. Coastal fish cage culture has been practiced for more than two decades during which the production increased steadily. Sea bass (*Lates calcarifer*) and groupers (*Epinephelus* spp.) are the two major groups of fish being cultured in the coastal areas. In the future, net-cage culture of tilapia species will play an important role, especially in reservoirs. This is because the investment cost is comparatively lower than the culture of other groups of fishes and there is a large market demand.

Introduction

Fish cage culture in Thailand has been developed for more than three decades. From freshwater fishes, this practice was later applied to the coastal species. In most cases, cage culture has always aimed to produce high-priced fishes such as marble goby, sea bass and grouper. This paper reviews the development and present status of cage fish cage culture in Thailand.

Present Status

At present, cage cultures in Thailand are mostly used to raise eight groups of fish, namely tilapia (*Oreochromis* spp.), Thai silver carp (*Puntius gonionotus*), river catfish (*Pangasius* spp.), marble goby (*Oxyeleotris marmoratus*), giant gouramy (*Osphronemus goramy*), sea bass (*Lates calcarifer*), and grouper (*Lates calcarifer*) (Table 1). The first six groups are freshwater species while the latter two belong to brackish and marine water.

Most cage culture in freshwater are conducted

along the river banks. River catfish, marble goby, and serpenthead were produced in large quantities. But the production has been declining during the past ten years (Table 2), perhaps due to dam construction in several rivers. The reduced flow rate makes the areas unsuitable for cage culture.

Coastal cage cultures started about two decades ago, and production has increased steadily (Table 3). Sea bass and groupers are the two predominant groups of fish being cultured in cages in coastal areas. Most sea bass cages are located in estuarine areas and coastal lagoons. Grouper cages are located in more marine environment, such as bays or enclosed coastal areas protected from storms and strong wave action.

Development and General Practice

Development and practices of cage culture are species specific. This paper presents three groups of fish as examples, marble goby for the freshwater species, grouper for the coastal species, and tilapia for the new development.

Table 1. The production of major cage-cultured fish in Thailand in 1996.

Fish groups	Yield (tons)
Freshwater	
Tilapia	19
Thai silver carp	3
River catfish	1,438
Marble goby	15
Giant gouramy	897
Coastal	
Sea bass	2,998
Grouper	723

Table 2. Production of major species of freshwater fish from cage culture. Unit: tons

Year	Tilapia	River catfish	Marble goby	Serpent-head
1987	4	486	117	325
1988	no data	no data	no data	no data
1989	1	1,010	493	281
1990	1	739	522	5,475
1991	2	987	67	1,629
1992	0	340	39	755
1993	1	118	21	641
1994	4	267	97	456
1995	1	143	66	370
1996	19	1,438	15	0

Table 3. Production of marine fish from coastal cage culture (tons) during 1987-96.

Year	Sea bass	Grouper
1987	No data	No data
1988	654	357
1989	1,114	441
1990	1,002	416
1991	1,461	347
1992	1,967	916
1993	1,347	666
1994	1,675	609
1995	3,060	616
1996	2,998	723

Marble Goby

The marble goby is highly esteemed as food fish by people in the Southeast Asian region, where market demand for this fish is growing steadily. In 1979, the export of marble goby from

Thailand to other countries amounted to 165 metric tons, valued at 1.5 million U.S. dollars. The local demand within Thailand is also increasing.

Marble goby is indigenous to the Southeast Asian region and its natural habitats are rivers, canals, marshes, swamps and man-made reservoirs. As it normally dislikes intense light, the fish usually hides at the pond bottom during the day and becomes active during the night. Marble goby is a carnivorous species, feeding on small shrimp, small fish and insect larvae. Mating and spawning occur during the rainy season.

As its supply from natural catch cannot satisfy market demands, the marble goby has been raised by many farmers in captivity. The most successful culture technique for this fish is to grow them in floating cages in rivers with good running water (Menasveta and Higuchi 1983). In 1979, cage culture of sand goby in Thailand was concentrated in two areas – the Nan River in Nakhon Sawan Province and Suphan Buri Province. At the peak of operation, there were about 1,000 cages situated along the lower part of the Nan River. Fish were cultured intensively in box shaped floating cages made of wooden planks with two bunches of 50 bamboo poles as buoys. The capacity of cages varied from 1 to 30 m³ and the initial stocking density was 100 fish/m² of 100-gram size juveniles. The fish were fed with chopped marine fish for about eight months to reach the market size of approximately 500 grams. The fish yield depended on the survival rate. With 90% survival, the production could reach as high as 45 kg/m² (Menasveta and Higuchi 1983). Being situated in running water, the cages were well aerated and wastes could be washed out any time. Furthermore, turbid river water due to large amounts of suspended solids created a favorable dim condition for the fish.

From 1978-1980, the cage culture of marble goby in the Nan River faced serious problems. The construction of a dam in the upper section of this river discouraged many operators in the area (Hiranrat 1980). The dam reduced water flow rate causing oxygen depletion in the water and lowered water turbidity. Poor water exchange rates in fish cages might have also been related

to the subsequent disease outbreak.

Due to the insufficient supply of fish seed from the wild, attempts were made to produce them in captivity and successful breeding was achieved. (Menasveta *et al.* 1983).

Grouper

Grouper species have been cultured in Thailand for a number of years. The fish are usually found in coastal waters, especially along the rocky patches around islands. This fish grows fast and are easily handled. Grouper culture has been proven to be commercially viable, depending on the export market in the region. The price for live fish weighing 1.2-1.5 kg is US\$ 9-10 each or US\$ 7-8/kg.

Most fish farmers culture grouper in floating net cages in sheltered coastal areas protected from strong winds and waves, with salinity ranging from 12 to 30 ppt.

Due to unreliable and limited hatchery production, majority of the grouper seedstock are obtained from the wild. Grouper fry at the size of 1.0-2.5 cm are usually collected from the coastal areas of Songkhla and Pattanee Provinces from October to March. These fry are reared up to the size of 7-10 cm prior to stocking in grow-out cages. Majority of these seedstocks were exported to other countries. Seedstocks of sizes longer than 10 cm are collected using traps and the fish are stocked in grow-out cages directly without nursing. Fish farmers prefer this type of seed to the reared fry because of shorter grow-out period and better survival.

According to Boonchuwong and Lawapong (1999), on the average, each farmer in the Andaman Sea coast of southern Thailand owns four cages (4 x 4 x 4 m³ each). The average production is 210 kg/cage (175 fish), the size ranging from 1.0-1.2 kg in a culture period of 9-12 months. The production cost is US\$ 3.5/kg fish, of which 75% is accounted for the feed cost. Most farmers start to harvest fish after nine months of culture at a selling price of US\$ 7.3/kg.

Tilapia

Tilapia species have been introduced and cultured in Thailand for more than three decades now. The fish are commonly cultured in ponds integrated with chickens. This farming practice produces fish at low cost. But fish size is usually small, consumed largely in rural areas. Recently, large size tilapia are in demand by restaurants or export trade. A new development was initiated by CP Aquaculture Group to culture a strain of red tilapia in cages. Several areas have been chosen for tilapia-cage culture, for instance the old shrimp ponds in the coastal area, man-made and natural reservoirs. With this new culture practice, the fish product apparently has less off-flavor problem. Tilapia cultured in cages has shown good growth performance and condition factor, as well as an attractive external appearance. The production cost is somewhat higher than those produced in pond culture. However, the higher retail price compensates the higher production cost. The fish produced from cage culture is steadily increasing and its future appears to be promising.

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Status of Cage Mariculture in Vietnam

L.A. Tuan¹, N.T. Nho^{1,2} and J. Hambrey^{2,3}

¹University of Fisheries
Nha Trang
Khanh Hoa
Vietnam

²Asian Institute of Technology
PO Box 4 Khlong Luang
Pathumthani 12120
Thailand

³Econeco
Strathpeffer
Ross-shire
Scotland

Tuan, L.A., N.T. Nho and J. Hambrey. 2000. Status of cage mariculture in Vietnam. *In* Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia (ed. IC. Liao and C.K. Lin), pp. 111-123. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok.

Abstract

In Vietnam, cage culture started in the Mekong Delta in the 1960s, and significant expansion took place in the early 1990s with the appearance of marine cage culture. The major cultured species are: catfishes (*Pangasius bocourti*, *P. hypophthalmus* and *P. micronemus*), bleeker (*Clarias macrocephalus* and *C. gariepinus*), lobsters (*Panulirus ornatus*, *P. hormarus*, *P. timpsoni* and *P. longipes*), and groupers (*Epinephelus bleekeri*, *E. akaara*, *E. sexfasciatus*, *E. malabaricus*, *E. coioides*, *E. merra* and *Cephalopholis miniata*). There are approximately 18,000 cages of which more than 6,000 are located in coastal waters, mainly in Nha Trang Bay in the South, and Ha Long Bay in the North. These marine cages yield 540 tons of fish and shellfish valued at more than VND100 billion (ca US\$ 7.2 million) in 1998. However, this contributed only a small part (less than 1%) of the total export value of the fisheries sector of the country. This paper reviews the current status of marine cage aquaculture, and identifies major technical, economic and social constraints to further development. It addresses in particular the potentials of small-scale marine cage culture for poverty alleviation in the coastal zone.

Introduction

Cage culture was developed in Vietnam in the late 1960s, mainly in the Mekong delta. The development of cage aquaculture underwent different stages in relation to the political and economic circumstances of the country. In 1974 there were 10,000 cages in the Mekong delta producing more than 42,000 metric tons of catfishes (*Pangasius bocourti* Sauvage 1880, *P. hypophthalmus* Sauvage 1878, *P. micronemus* Bleeker 1862, *Clarias macrocephalus* (Gunther 1864) and *C. gariepinus* (Burchell 1822). Between 1975 and 1985, the number of cages declined to less than 1,000 but soon recovered in 1992. By 1996, there were 12,000 cages for

culturing freshwater fish, of which 3,876 were in the provinces of An Giang and Dong Thap. The production of *Pangasius* in the two provinces was 27,000 metric tons with an export value of US\$ 1 million (Phuong 1998).

Mullet, milkfish and sea bass have been cultured in ponds since the 1960s (Son 1996b). Marine cage culture began to develop in the early 1980s when the Department of Fisheries (DOF) in Binh Tri Thien province (Thua Thien-Hue Province now) initiated shrimp culture (*Metapenaeus ensis*) in pens in the Tam Giang lagoon. However, actual marine cage culture developed in the form of lobster culture in Khanh Hoa province based on the study conducted by Ho Thu Cuc (UoF) in collaboration with Khanh Hoa

of the DOF. By 1998 there were more than 6,000 marine cages in the whole country. The main culture areas are Quang Ninh, Phu Yen, and Khanh Hoa provinces (Fig. 1). The main species cultured are lobster (*Panulirus ornatus*, *P. homarus*, *P. timpsoni*, and *P. longipes*), and groupers (*Epinephelus bleekeri*, *E. akaara*, *E. sexfasciatus*, *E. malabaricus*, *E. coioides*, *E. merra* and *Cephalopholis miniata*). In addition, some other species such as sea bass (*Lates calcarifer*), yellowtail (*Seriola dumerilli*), sea bream (*Parargyrops edita*), snapper (*Lutjanus* spp.), sea horse (*Hippocampus*), pearl oyster (*Pinctada maxima*, and *P. martensii*), and ornamental fishes are also cultured in cages (An 1993; Tuan 1998).

Marine cage culture has great potentials to develop in Vietnam. There is a 3,200 km-long coastline, an exclusive economic zone (EEZ) of one million square kilometers, more than 4,000 islands, and many lagoons and bays, which are suitable for cage culture (MOF 1994a). In the future when Vietnam can already produce hatchery seed, cage culture is predicted to develop strongly.

Cage Aquaculture Systems

Culture Areas and Species Cultured

The coastline of the Vietnam sea can be divided into five regions as follows: Mong Cai-Do Son, Do Son-Lach Truong, Lach Truong-Hai Van, Hai Van-Vung Tau, and Vung Tau-Ha Tien. There are two monsoons: winter monsoon (Northeast monsoon) and summer monsoon (Southwest monsoon). Although conditions are generally favorable for cage culture, waves and wind, especially during the winter monsoon, are significant constraints, with implications for siting, anchoring, construction, and design. To date, marine cage culture has only been carried out in sheltered lagoons and bays, although there is probably potential for offshore production in larger cages in those areas not subject to frequent typhoon. Areas particularly suitable for cage culture are Ha Long Bay, and the Central Sea from Thua Thien-Hue province to Ninh Thuan province, where there are many lagoons and bays (Fig. 1). The culture areas and species are summarized in Table 1. Khanh Hoa and Quang Ninh

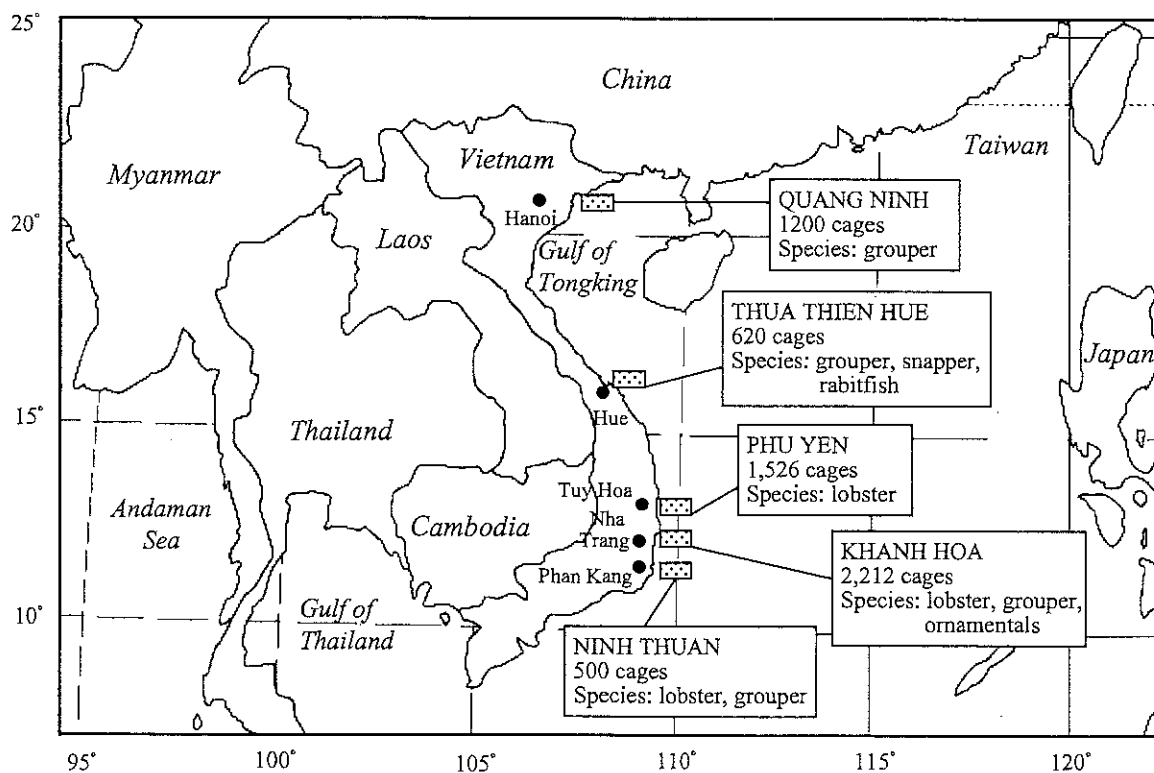


Fig. 1. Major cage mariculture areas in Vietnam.

are the biggest suppliers of cage mariculture products.

Approximately thirty species of groupers were reported to be distributed in the Vietnam seas (An *et al.* 1994). However, a recent study showed (Phan 1997) that there are 11 genus and 48 species in the grouper family (*Serranidae*) in Vietnam. Grouper species cultured in Ha Long Bay and the Central sea are *Epinephelus akaara*, *E. malabaricus*, *E. merra*, *E. coioides*, *E. sexfasciatus*, *E. bleekeri*, *E. fuscoguttatus*, *E. tauvina* and *Cephalopholis miniata* (Son 1996; Tuan 1998). The seed was mainly taken from the wild. During 1994-1995 the Research Institute for Marine Products (RIMP) successfully produced grouper seed in Ha Long Bay. After three-months of rearing, fingerlings reached approximately 13 cm in length and 50 g in weight (Son 1996a). However, production is still experimental.

Yellowtail (*Seriola dumerili* and *S. nigrofasciata*) are distributed along the coast, mainly in the surface and middle layers of the water. They feed on crustaceans and small fish. They have rapid growth. For example, two year old fish may reach 2-3 kg/pc (RIMP, unpubl. data). The seed is taken from the wild.

Asian sea bass (*Lates calcarifer*) is distributed in the Ton Kin Gulf, the Central Sea, and the coastal sea of Ho Chi Minh City. The breeding season varies according to location. In Can Gio, and Ba Ria (South Vietnam) the fish breeds mainly in March and April, whereas in Nha Phu lagoon (Central Vietnam) breeding is mainly from April to August (Tham 1995). In cage culture, after one year the fish may reach a weight of 0.6-1 kg/pc, and 2-3 kg/pc after two years. The seed supply is still from the wild. At present, experiments on seed propagation of Asian sea bass are being carried out in the marine finfish hatchery of the University of Fisheries (UoF). Some success has been recorded.

Sea horses are used for the treatment of some diseases in Oriental Medicine. In the Central Sea, there are four sea horse species including black sea horse (*Hippocampus kuda*), three-dotted sea horse (*H. trimaculatus*), thorn sea-horse (*H. histrix*), and short-mouth seahorse (*H. spinosissimus*). After eight months of rearing, sea

horses may reach a length of 132-156 mm, and weigh 12-15 g/pc. Sea horses reach sexual maturity at seven months, and can breed year round. In nature, sea-horse fry feed on zooplankton, mainly copepods. Sea-horse juveniles feed on small crustaceans such as *Mysidacea*, *Palaeomonidae*, *Amphipods*, *Lucifer*, etc. To date, sea horses in captivity have only accepted live food. This is a significant constraint to commercial culture. The Institute of Oceanography (IO) has successfully produced artificial seeds of two species: *H. trimaculatus* and *H. histrix*. The Institute has also tried to culture the sea horses in fixed cages in estuaries and lagoons with a cage size of 3 x 6 m, and mesh of 1 mm (Ky 1994).

Lobsters are distributed mainly in the Central sea from Quang Binh province to Binh Thuan province. Among the nine identified species in the region, three have rapid growth, large size, bright color, and high export-value. These are *Panulirus ornatus*, *P. homarus*, and *P. stimpsoni*. *P. longipes* is also cultured, but in small quantities. In general, each species has its own distribution area. For example *P. ornatus* is found mainly in the Ninh Thuan Sea and *P. stimpsoni* in the Quang Binh-Quang Tri Sea (Thuy 1996; Thuy 1998). There have been some studies on seed production of lobster (*P. ornatus*, *P. homarus*) in the Research Institute for Aquaculture No. III (RIA III) in Nha Trang, but the results have not been published. At present, lobster seed is sourced from the wild. In the past the seed was abundant, but between 1995 and 1998 the seed supply became limited, and was imported from neighboring provinces to meet the demand in Khanh Hoa province. Unfortunately the quality of this seed was poor. However, at the beginning of 1999, lobster seed was again abundant at the size of 2 cm, and the price fell to half that in 1988.

Production Systems

Cages are designed in various ways depending on cultured species and characteristics of culture areas (Table 2).

Floating cage

The bag of the floating cage is usually supported by a frame with buoys. This kind of cage

Table 1. Summary of the commonly cultured species in Vietnam.

Scientific name and synonyms	Common names	Distribution	Habitat	Seed fishery	Hatchery	Cage culture
<i>Cephalopholis miniata</i>	Coral hind	Southern Central Sea	Well-developed exposed coral reefs, clear water	Khanh Hoa		Khanh Hoa
<i>Epinephelus akaara</i>	Hong Kong grouper, Red spotted grouper, Red grouper	Ton Kin Gulf, Southern Central Sea	Marine, demersal; common in rocky areas	Quang Ninh, Phu Yen, Khanh Hoa		Quang Ninh, Phu Yen, Khanh Hoa
<i>E. bleekeri</i>	Duskytail grouper, Yellow spotted grouper	Ton Kin Gulf, Southern Central Sea	Shallow rocky banks	Quang Ninh, Phu Yen, Khanh Hoa		Quang Ninh, Phu Yen, Khanh Hoa
<i>E. coioides</i>	Orange-spotted grouper	Ton Kin Gulf, Southern Central Sea	Marine and brackishwater	Quang Ninh, Phu Yen, Khanh Hoa		Quang Ninh, Phu Yen, Khanh Hoa
<i>E. fuscoguttatus</i>	Brown marble grouper, Flowery cod	Ton Kin Gulf	Marine, shallow coral reefs and rocky bottoms, clear water; juveniles found in sea-grass	Quang Ninh,		Quang Ninh,
<i>E. malabaricus</i>	Malabar grouper, Estuarine grouper	Ton Kin Gulf, Southern Central Sea	Marine and brackishwater, coral, rocky reefs, sandy and muddy bottoms, tidepools, estuaries, mangrove; juveniles occur in shallow coastal waters and estuaries	Quang Ninh, Phu Yen, Khanh Hoa		Quang Ninh, Phu Yen, Khanh Hoa
<i>E. merra</i>	Honeycomb grouper	Ton Kin Gulf, Southern Central Sea	Shallow-water coral reefs in lagoons and bays	Quang Ninh, Phu Yen, Khanh Hoa		Quang Ninh, Phu Yen, Khanh Hoa
<i>E. sexfasciatus</i>	Sixbar grouper	Ton Kin Gulf, Southern Central Sea	Silty sand or muddy bottoms	Quang Ninh, Phu Yen, Khanh Hoa		Quang Ninh, Phu Yen, Khanh Hoa
<i>E. tauvina</i>	Greasy grouper, Green grouper	Ton Kin Gulf	Marine clear oceanic water and coral reefs, hard bottoms; juveniles in reef flats and tidal pools	Quang Ninh		Quang Ninh
<i>Hippocampus histrix</i>	Thorn seahorse	Southern Central Sea		Khanh Hoa	Khanh Hoa	Khanh Hoa
<i>H. kuda</i>	Black seahorse	Southern Central Sea		Khanh Hoa	Khanh Hoa	Khanh Hoa
<i>H. spinosissimus</i>	Short-mouth seahorse	Southern Central Sea		Phu Yen, Khanh Hoa		Phu Yen, Khanh Hoa
<i>H. trimaculatus</i>	Three-dotted seahorse	Southern Central Sea		Khanh Hoa	Khanh Hoa	Khanh Hoa

...cont.

Table 1. cont.

Scientific name and synonyms	Common names	Distribution	Habitat	Seed fishery	Hatchery	Cage-culture
<i>Lates calcarifer</i>	Seabass, Baramundi	Ton Kin Gulf, Southern Central Sea		Khanh Hoa	Khanh Hoa, Ho Chi Minh	Khanh Hoa
<i>Panulirus hor-marus</i>	Spiny lobster	Southern Central Sea	Rocks, coral reefs	Phu Yen, Khanh Hoa		Phu Yen, Khanh Hoa
<i>P. ornatus</i>	Yellow ring spiny lobster	Southern Central Sea	Rocks	Phu Yen, Khanh Hoa		Phu Yen, Khanh Hoa
<i>P. stimpsoni</i>	Hair spiny lobster	Northern Central Sea	Rocks, coral reefs	Phu Yen, Khanh Hoa		Phu Yen, Khanh Hoa
<i>Rachycentron canadum</i>	Black kingfish; cobia			Quang Ninh		Quang Ninh
<i>Seriola dumerili</i>	Amberjack, Dumeril's amberjack	Southern Central Sea Lat. 14°34'N to 17°32'N; Long. 109°30'E to 108°22'E	Intersecting water with floating seaweed	Da Nang		Da Nang
<i>S. nigrofasciata</i>	Black-banded kingfish, Black-banded trevally	Southern Central Sea Lat. 14°34'N to 17°32'N; Long. 109°30'E to 108°22'E	Intersecting water with floating seaweed	Da Nang		Da Nang

is commonly located in waters with a depth of 20-50 m e.g., Nha Trang Bay (Khanh Hoa), Son Tra Sea (Da Nang), Ha Long Bay (Quang Ninh), etc. Grouper cages in Khanh Hoa belong to this kind (Fig. 2).

Wooden fixed cage

The framework is made of salt-resistant wood. Wooden stakes, 10-15 cm in diameter and 4-5 m in length are embedded every two meters so as to create a rectangular or square shape. The bottom area of a farm is normally 20-40 square meters, but may be as much as 200-400 square meters. The cage size is also varied. Each cage has a cover. This kind of cage is suitable for sheltered bays and behind islands. They are common in Khanh Hoa province.

Bamboo fixed cage

This is common in the Tam Giang lagoon, in Thua Thien-Hue Province. The bamboo sticks are 1 cm thick, 3-4 cm wide, and 1.5-2.0 m long tied with nylon lashings of diameter of 0.18 cm. The distance between two lashings is 20 cm, and 1.2 cm between two sticks. The bamboo sticks are woven closely into the cage bottom. The upper surface has an opening of around 60 x 60 cm for checking (Fig. 3).

Submerged cage

The framework is made of iron with a diameter of 15-16 mm. The bottom shape is either rectangular or square with an area of 20-50 m².

Table 2. Summary of commonly used cages in Vietnam.

Candidates cultured	Cage			Culture area	
	Type	Shape and size (meter)	Frame		
Fish as seafood: Grouper, Yellowtail, Black kingfish, Seabass, Snapper, Seabream, etc.	Floating	Bottom: rectangular; Various size: 2x1.5x2, 2x2x2, 4x2x2, 10x5x2, 3x3x3, etc.	Salt-resistant wood and buoys	Net	Sites with depth of 20-50m in bays (Quang Ninh, Da Nang, Phu Yen, Khanh Hoa)
Ornamental fish: Butterfly fish, anemone fish, etc.	Floating	Bottom: rectangular; Various size: 2x1.5x2, 2x2x2, 4x2x2	Salt-resistant wood and buoys	Net	Sites with depth of 20-50,m in bays (Khanh Hoa)
Fish as medicine: Sea-horse	Fixed	Bottom: rectangular; Size: 3x6x1	Salt-resistant wood	Net with mesh size 1mm	Estuaries, lagoon (Khanh Hoa)
Crustacean: Lobster	Fixed	Bottom: rectangular, square; Various size: 2x1.5x2, 2x2x2, 4x2x2, 10x5x2, 3x3x3, etc.	Salt-resistant wood	Net	Shallow sites in bays (Phu Yen, Khanh Hoa)
	Submerged	Bottom: rectangular, square; Bottom area 20-50, height 1-1.5	Iron	Net	Shallow sites in bays (Phu Yen, Khanh Hoa, and Ninh Thuan).
Shrimp	Fixed	Cylinder shape; bottom diameter 2.5-2.8, height 1.5	Bamboo	Bamboo	Lagoon (Thua Thien-Hue)

Source: An 1994; Son 1996a, b; FBC of Thua Thien-Hue province 1998; Luong 1998.



Fig. 2. Floating cages for grouper culture.



Fig. 3. Fixed cages used for lobster culture.

The height is 1.0-1.5 m. The cage has a cover. This type of cage is common in Khanh Hoa, Ninh Thuan and Phu Yen provinces, and mainly used for lobster culture.

Materials for making cages such as wood, iron, net, etc. are available in Vietnam. The marine cages are often of small size suitable for family-scale operation.

Feed Supply

Feed and feeding applied in the culture of commercially important species in Vietnam are summarized (RIMP, unpubl; Ky 1994; FEC, Ninh Thuan province 1996; Trai 1997; Deng 1998; Hoa 1999) in Table 3.

Lobsters are fed exclusively with fresh whole or chopped fish and shellfish. The most commonly used species/groups for feeding lobster are lizardfish (*Saurida* spp.), red big-eye (*Priacanthus* spp.), pony fish (*Leiognathus* spp.), pomfret, snails, oyster and cockles, small swimming crab, other crabs and shrimps. Finfish comprises about 70% of the diet, with 30% shellfish. The preferred fish (comprising 38% of fishes in the diet) was lizardfish.

Farmers showed active selection of the

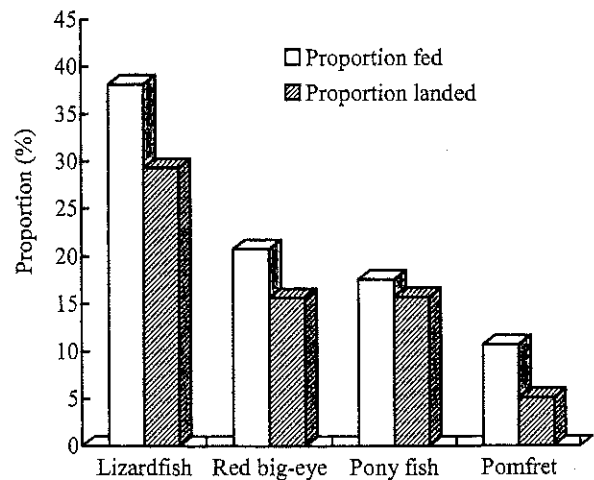


Fig. 4. Preferential selection of trash fish species by lobster farmers.

preferred fish species, using a consistently higher proportion than the present in typical trash fish landings (Fig. 4), and a higher proportion of lizardfish in particular, despite the significantly higher price (average VND 5,000/kg) associated with this species. Food conversion ratio for lobster using this diet is high at around 28 (fresh weight basis).

Previous studies (Trai 1997) have shown

that only whole fresh trash fish are used, and that food conversion ratio in cage culture, averaging 5.9 (fresh weight) is significantly higher than that for pond culture of grouper whose average FCR was found to be 4.3. Feed costs comprise about 18% of the farm gate price of grouper.

Seed Supply

Total grouper seed production in Khanh Hoa is approximately 200,000 pieces per year, sufficient to meet local demand in the short term, but insufficient to allow for further expansion of the industry (Tuan 1998). Knowledge of the fishery is still inadequate to be able to determine the maximum sustainable yield, and this information is unlikely to be available in time to be useful for management purposes. However, price gives a reasonable indication of the relation between supply and demand, and this has increased significantly in recent years for all sizes of fish, suggesting a shortage of supply and the possibility of over-exploitation (Fig. 5). Given the ineffective coastal fishery management regime (there is widespread over-exploitation of reefs and mangrove, and use of destructive or harmful fishing gears) over-exploitation, if not yet a problem, is

likely to become so in the near future. Some further research on catch-effort for the fishery should throw further light on the status of the fishery. The potential supply of lobster seed is also being assessed roughly from first principles, using area of suitable habitat and natural productivity as indicators of potential seed production. Total lobster seed production in Khanh Hoa is around 300,000 pieces per year in recent years. The price is between VND 20,000 and 120,000 (ca US\$ 1.4-8.6), which is higher for larger seed. The price has also increased steadily through time.

Recently, the central government has paid more attention on seed supply. The government had a decree on seed management (MOF 1996a).

Social and Economic Aspects

Fishermen used to collect lobster less than 300 g/pc, and sell them at low prices, if they were able to sell them at all. However the price for lobsters, especially live lobsters, increased rapidly in the early '90s. The price of live lobster of more than 300 g was VND 300,000/kg in 1992, whereas the price of dead lobster was VN

Table 3. Feeds and feeding in marine cage culture in Vietnam.

Cultured species	Feeds and feeding
Groupers	Trash fish; FCR = 4-17; feeding 3-5% body weight;
Asian sea bass	Trash fish
Black kingfish	Trash fish
Yellowtail	Trash fish and crustacean.
Seahorses	<ul style="list-style-type: none"> ♦Sea horses only feed on live food. ♦Fry: zooplankton, mainly on <i>Copepods</i>; feeding 10-15% body weight, twice/day: 8 am and 4 pm. ♦Juvenile (>30mm body length): small crustacean such as <i>Mysidacea</i>, <i>Palaemonidae</i>, <i>Amphipods</i>, <i>Lucifer</i>, etc.; feeding 5-8% body weight; twice/day: 8 am and 4 pm.
Lobsters	<ul style="list-style-type: none"> ♦Preferred feeds are shellfishes such as mollusks, and crustacean. Among trash fishes, lobsters prefer Red big-eye, Pony fish, Lizardfish. FCR = 28-29. ♦Small-sized lobster: fed 3-4 times/day. Feed amount increased in the evening. Trash fish chopped into small pieces and mollusks' shells excluded. ♦Large-sized lobster (> 400 g/pc): 2 times/day. No need to chop trash fish and exclude mollusks' shells. Feeding intensity of lobster increases strongly just before moulting. In last few months of a culture cycle, the proportion of shellfish (mollusks, crustacean) is increased while trash fish decreased.

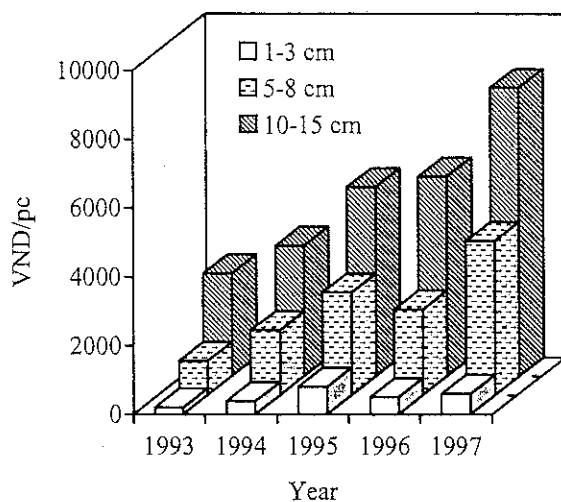


Fig. 5. Price trends for grouper seed in Khanh Hoa Province, Vietnam (Trai 1997). (1US\$ = ca. VND 11,500)

70,000/kg. Fishermen therefore began to culture lobster in cages. After six months, the lobsters reached a weight of 400-500 g/pc and were sold at a price of VND 350,000-400,000/kg. Since then many fishermen have invested in lobster cage culture. In the first year of lobster culture one farmer gained a profit of VND 25,000,000 (Luong 1998).

The estimated production of marine cage culture in the whole country in 1998 was 540 tons with a value of more than VND 100 billion (US\$ 7,200,000). The cages belong mainly to the private sector (99%). State-owned, joint venture, and foreign-owned farms are few, and mainly grouper cages. The products from marine cage culture (lobster, grouper, penaeid shrimp, crab-eater, yellowtail, etc.) are commercially important. More than 70% of the total live products are exported to China, Taiwan, Hong Kong, and Japan and over 20% of the products are sold to hotels and restaurants in big cities such as Ha Noi, Ho Chi Minh City, Da Nang, Hai Phong and Nha Trang. The rest (less than 10%) are locally consumed. Only small-sized or dead products are consumed by farmers.

Although the value of marine cage culture production comprised a small part (less than 1%) of the total value of the Vietnamese fisheries sector (export value in 1998 of about USD 850

million), marine cage culture has played a significant role in helping the poor coastal people to escape the "poverty trap".

One thousand laborers are employed in cage farms in the whole country annually. More than 10,000 people were involved in marine cage culture in 1998. Most of them were formerly small-scale fishermen. Cage culture farmers receive support from the authorities in terms of land use right, technical assistance, and bank loans. A recent survey in Khanh Hoa Province showed an average return to labor on small scale cage culture of grouper of VND 66,000 (US\$ 5) per person per day, which is substantially higher than that from agriculture or small scale fishing (Trai and Hambrey 1998). With improved technology and greater investment, returns can be much higher.

Institutional Aspects, and National Policies and Programs Related to Cage Aquaculture Development

The Central Government is the highest executive body in the country. It is responsible for issues related to politics, economics, culture, society, national defense, and foreign policy. The government administers all affairs related to national fishery development, mainly through the Ministry of Fisheries (MOF).

The MOF controls all the institutions in its sector in order to fulfill the annual, five-year, and long-term plans, which are set by the national assembly or the central government. It has the right to issue legal documents in order to implement decisions made by the national assembly and the central government. The MOF's stipulations affect all ministries, people's committees, institutions, and citizens in the whole country (National Institute for Administration 1995).

The Central Government in general, and the MOF in particular, has paid much attention on cage culture. According to Circular No. 709-TS/QLNL (MOF 1994a), there were five fisheries extension programs in which the cage culture program was considered to be important. The program's target is that by the year 2000, the total production of cage culture, including fresh-

water and marine culture, should reach 105,000 metric tons with an export value of USD 30-60 million, and create 60,000 employment (MOF 1994b). For marine cage culture, the target is 10,000 cages with a yield of 80-90 kg per cubic meter, corresponding to a production of more than 1000 metric tons by the year 2000.

Based on the MOF's direction, provincial DOFs, especially in coastal provinces were making plans for the development of aquaculture in general, and marine cage culture in particular, in each province in order to fulfil their tasks by the year 2000.

In summary, there have been many advantages for the development of the national economy in general, and marine cage culture in particular, since the "Open door" policy was initiated in 1986 by the Vietnamese Communist Party. However, at the local government level, there have been some constraints such as:

- DOF does not have enough powers to manage all issues related to the development of aquaculture and fisheries in its province. The DOF is not the final decision-maker. It serves as a consultancy unit for the Provincial People's Committee. The documents it sends to districts are not mandatory.
- There is no fishery office at the district level. Only one person in the agriculture office is responsible for fisheries. Therefore, there is a shortage of manpower to implement DOF's plans at the district and commune levels.

Opportunities for Development

Water Areas

Vietnam has an EEZ of one million square kilometers and more than 4,000 islands, many bays and lagoons suitable for cage culture. There are approximately 6,000 marine cages occupying an area of about 150 ha. According to the Ministry of Fisheries (MOF 1994a), about 250,000 ha of water area is suited to cage culture.

Candidates for Culture

In addition to commonly cultured species, some other species can be cultured in cages, and

have been experimentally tested in Vietnam. They include snapper (*Lutjanus* spp.), black kingfish (*Rachycentron canadum*), sea horse (*Hippocampus* spp.), Asian sea bass (*Lates calcarifer*), pearl oyster (*Pinctada* spp.), scallop (*Chlamys nobilis*) and abalone (*Haliotis* spp.) (Can Tho University 1994; Ky 1994; Chinh 1996; MOF 1996b; Son 1996a; Son 1998; Thu 1998).

The main constraint is seed supply. However, the government has paid more attention to this problem recently. According to the MOF's Decision No. 865-QD/NC dated 23 October, 1996 on "Planning, rearrangement of hatcheries in the 1996-2000 period", hatcheries will be systematically rearranged, invested, and upgraded; seed management will be reformed; studies on seed will be promoted; and human resource relating to seed production will be developed.

Technologies

Over the ten-year period during which cage mariculture has developed, farmers have received technical assistance through the extension activities of MOF, research and academic institutes, DOF, etc. At the same time farmers have learned a great deal from experience. At present there are three handbooks explaining the experience of cage mariculture in Vietnam up to now.

Market

Markets for cage mariculture's products are mainly international markets such as Japan, Taiwan, Hong Kong, and China. At present, Europe and the USA are emergent markets. Domestic markets are increasing through time, especially in big cities such as Hanoi, Ho Chi Minh City, Da Nang, Nha Trang, Vung Tau, etc. It is predicted that the cage mariculture's products such as grouper, yellowtail, snapper, black king fish, lobster, tiger shrimp, abalone, etc. will not meet the demand in ten more years.

Constraints

Some major constraints to marine cage culture industry in Vietnam are as follows (Fishery Department, MOF 1997; FEC, Thua Thien -

Hue province 1998; Khoa 1998; Luong 1998; OARD of Van Ninh District 1998; Thanh 1998; Toan 1998; Hoa, in press):

- Marine cage culture developed spontaneously in Vietnam. There has been no research on cages in terms of size or type suitable for each culture area, nor has there been significant research on feed and nutrition for different species.
- There has been no comparative economic assessment of various kinds of cages or alternative species.
- In grouper cage culture disease can cause high mortality. However, little is known about grouper diseases in Vietnam.
- Coastal cage culture is based almost exclusively on wild seed. The seed supply may not be sufficient to support current levels of production on a sustainable basis, and is very unlikely to support a significant increase in production. Wild seed is in any case unsatisfactory in terms of seasonality, quality and cost. Artificial production of marine finfish seed is necessary.
- The market for cage mariculture products is unstable, depending on the state of the economies in the major markets.
- Although banks for the poor have been developed, however, there are still some constraints such as small loans (VND 10-15 million/household) within a short time (6 months). It is hard for the poor to invest in cage mariculture because the production cycle lasts more than six months, and developing a skillfully sustainable enterprise may take several years. Besides, the poor have no valued assets (collateral) to deposit so that they can borrow even a small amount from the banks.

Conclusions and Recommendations

Vietnam has great potential to develop marine cage culture. There are approximately 250,000 ha of seawaters, including creeks, bays and lagoons, suitable for cage culture. The Quang Ninh-Hai Phong (Ha Long bay region) and Thua Thien Hue-Binh Thuan regions (Southern Central region) are particularly

suitable in terms of natural conditions. The Vietnam government, particularly the MOF, considers marine cage culture as an important element in the national policy on fisheries sector development. A Program of Cage Aquaculture was issued in 1994.

In Vietnam, cage aquaculture developed in freshwater areas and in the sea since 1960, and 1992, respectively. Marine cage culture was profitable, so it developed rapidly. From 1995-1998, the number of marine cages increased nearly ten times. The total number of marine cages in 1998 was more than 6,000. Farmers have learned a great deal from experience, and the culture techniques have improved through time.

At present, the species cultured include lobster (*Panulirus* spp.), groupers (*Epinephelus* spp. and *Cephalopholis miniata*), yellowtail (*Seriola dumerili*) and pearl oyster (*Pinctada* spp.). Species which are not currently cultured commercially, but which have potential and are under investigation include black king fish (*Rachycentron canadum*), Asian sea bass (*Lates calcarifer*), sea horses (*Hippocampus* spp.), scallop (*Chlamys nobilis*), and abalone (*Haliotis* spp.).

Sea pens are used for the culture of various species (penaeid shrimps, groupers, rabbitfish, etc.) in the Tam Giang lagoon (Thua Thien - Hue province). There are two main types of cages used in marine cage culture: fixed cages (including submerged cages), are used for lobster culture. Floating cages are used for the culture of marine finfish, such as grouper, yellowtail, black kingfish, etc.

Seed for cage culture is sourced mainly from the wild. In the long-term this is unlikely to be sustainable. There have been some successful experiments on seed propagation of grouper and black kingfish in RIMP, and Asian sea bass in UoF recently. However, much work remains to be done.

The feed used in cage culture is mainly trash fish, and small shellfish. The sustainability of this feed supply for the long-term development of the cage culture industry is also questionable. Compound feeds, using a higher proportion of nonfish protein need to be developed.

There has been no plan for the cage culture industry in terms of location and density of activity. There are therefore risks of pollution, declining water quality and diseases as the industry grows.

Marine cage culture is carried out mainly by fishermen who used to be poor. They have clearly benefited from cage culture and has become richer. Some of them now earn as high as VND 80-100 million per household annually.

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Cage Design in CARE-CAGES Project, Bangladesh

A.K.M.N. KABIR and S.M.Z. HUQUE

CAGES Project
CARE - Bangladesh, House 65
Rd. 7 A, Dhanmondi, Dhaka- 1209
Bangladesh

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Abstract

Bangladesh is a riverine country. An enormous variety of water bodies, including rivers, canals, flood plains, beels (large depression), and ponds, are dispersed throughout the country, providing considerable potential for cage aquaculture. To ensure access and utilization of these water bodies, the CARE-CAGES (Cage Aquaculture for Greater Economic Security) project has been developing cage designs suitable to the needs of the resource poor farmers in rural Bangladesh. The cage design must consider certain physical properties, including the ability to hold fish securely, which should also be within the financial means of the potential cage operators. It is argued that much of the historic failure of cage aquaculture in Bangladesh is due to the inability of the local people to afford the large, expensive cages both in terms of capital cost (cages were over-engineered for their purpose) and the cost of inputs (seed and feed) required for successful culture. The cages presently used by the CAGES project are small in size (1-8 m³), inexpensive, and simple to construct. The main cage types used in the project as well as their advantages and disadvantages are discussed in detail in this paper.

Introduction

The Cage Aquaculture for Greater Economic Security (CAGES) project of CARE Bangladesh is the first aquaculture development project in Bangladesh to focus exclusively on cage aquaculture systems. This DFID funded project started in September 1995 and has been going on in six districts across the country, developing and promoting cage aquaculture among the resource poor rural people, including women.

Since cage culture has a limited history in Bangladesh, the technology although based on the experiences of other Asian countries, had to be made suitable to the social, economic and cultural aspects of Bangladesh. During the development of cage culture production systems, cage design was a key component. This paper describes some of the cage designs used by the project, and the lessons learned in the process.

Brief History of Cage Design in Bangladesh

The first attempts to introduce cage culture to Bangladesh failed for several reasons, but all of them involved large, over-designed cages, which were a result of direct technology transfer from other Asian countries. In the mid 1980's, work in the Kaptai Lake used cages measuring 7 x 7 x 2.5 m, while later work in the Dhanmondi Lake, Dhaka used cages measuring 7 x 4 x 2.5 m (Karim 1998). These large cages were not suitable for adoption in Bangladesh as they were unsuitable to the resource profile and knowledge base of potential cage operators. Cage culture is a new technology in Bangladesh and unlike the more traditional pond aquaculture, it requires a pro-active management approach to obtain good results. In these larger cages, good management and experience in cage culture are vital.

In 1991-92 the DoF/ODA supported the Northwest Fisheries Extension Project (NFEP) in conjunction with CARE in Rangpur, in North-West Bangladesh to work with women groups in cage culture. The cages used were much smaller than those previously used in Bangladesh, made of locally available materials,

and more appropriate to the resources of potential cage farmers. Although the venture ultimately failed due to high levels of stocking mortality, NFEP (now NFEP-2) has continued to develop cage culture technologies as part of their Project activities. A wide variety of cage sizes, types, and materials used have been tested, all of which have been developed so as to be accessible to the resource poor groups.

The CARE-CAGES Project – Early Cage Design Used

CAGES staff made a study tour of the Philippines in 1995. The cage designs observed were brought to Bangladesh and tested on the CAGES research farm located 45 km away from Dhaka. The cage consisted of three rectangular shaped cage-bags (2 m x 1.3 m x 1.9 m) placed side by side with a gap in between within a rectangular shaped bamboo raft (4.75 m x 2.75 m). Cage bags were made from knotless black polyethylene nets (8 mm mesh). Iron sinkers were attached to the bottom line of the cage bag to maintain the shape of the netting. Rafts were made from bamboo, with three bamboos tied together in each of the four sides. Nets were hung on horizontal bamboo poles approximately 0.6 m above the water level. These bamboos were supported by tree branches (ipil-ipil). Cage bags were arranged in such a way that an average of 0.6 m of netting remained above the water, with 1.3 m beneath the water surface, creating an effective average water volume 1.68 m per cage. Concrete anchors were used to maintain the unit's position (Roy *et al.* 1996). The total cost required to construct this cage unit was around Tk. 5,000 (US\$ 100).

These types of cages were found to be not suitable to poor farmers principally due to high material and construction cost. During storms, further difficulties were encountered with cage bags failing to maintain their shape, while during severe storms some cage bags were lost. In addition it is difficult to move these cages from one location to another during annual flooding. As a consequence this cage design is no longer used in the CAGES project.

Since 1997, farmers were advised that a simple 8 m³ (2 m x 2 m x 2 m) cage approximately effective water volume of 7.4 m³ may be more appropriate. These fixed cages were quickly adopted by cage farmers due to the substantially reduced costs of approximately Tk. 1,000 (US\$ 20) per cage. To date, this design continues to be practiced by some farmers. Farmers can easily construct these cages using net, bamboo, rope and twine. The netting used is imported black polyethylene netting, with a mesh size of 8 mm. However, as will be described later, this has implications for sustainable use. A top cover is usually provided on the cages to reduce the risk of escapees, especially in areas prone to flash floods, where water levels rise very quickly. A small opening is kept at one edge or at the middle of the top covering to allow the application of feed. A feeding platform made of fine mesh net is placed near the bottom of each cage to place feed on and minimize feed loss. To maintain cage position, four bamboo poles are fixed into the substrate and the four top and bottom corners of the cage bag are tied to the bamboo poles stretching the cage netting into shape.

To minimize installation cost and to reduce daily management labor, farmers sometimes fixed their cages in series. Cages are installed in rows with a narrow space in between the adjacent cages. The small opening are positioned so that access is provided for feeding and cleaning of the cages when the farmers place their boats between cages. Hence farmers are able to feed and clean the cage on either side.

Key Problems with Fixed Cages

Management

Moving fixed cages when the monsoon comes is often problematic, and commonly results in fish losses, either through escapees, or through physical damage to fish causing mortalities. Additional daily management including the checking of fish, and net cleaning activities are difficult due to the fixed position of the cage.

Crab Cutting

Fixed cages are also vulnerable to crab cutting,

a major reason for fish escapees in Bangladesh cage culture. To reduce crab cutting, farmers fix inverted earthen funnel to each of the fixed poles below the cage bag. This prevents crabs from coming into contact with the cage netting (SUS 1998).

Fish Growth and Mortality

A recent trial has shown that fish in fixed cages exhibit poorer growth and higher mortality rates compared to fish in floating cages, with rigid cage frames (Talukder *et al.* 1998). It is thought that this is due to reduced water exchange in fixed cages, as the netting is not taut. The floating 1 m³ cages, however, can be stocked at higher density since the larger surface area: volume ratio allows a greater water exchange.

Trend Towards Using Floating Cages

Farmers in the project use both fixed and floating cages. In general, fixed cages are installed in those bodies of water where water depth is relatively low, hence cage farmers are able to fix the bamboo poles into the substrate. Floating cages do not have this limitation and can also be deployed in deeper water. Farmers have found that floating cages are easier to manage, both daily and when cages need to be moved during seasonal flooding, and this ease of management is the key reason for switching from fixed to floating cages.

Floating Cages

The proportion of floating cages to static cages used in the CAGES programme has increased dramatically (Table 1). The size of the cage is usually 1 m³ (1 m x 1 m x 1 m) having an effective volume of 0.85 m³, and follows the model of low-volume high-density cages similar to the 1 m³ cages used in China (Schmittou 1997). A top net is always used to minimize escapees, as the top of the cage is only a few centimeters above the water surface. The top of the cage has a hinged opening to allow the application of feed, removal of waste and the checking

and harvesting of fish. A fine mesh net layer is also placed at the bottom of the cage, and 10 cm around the base of each side. Previous trials have shown that the use of fine mesh dramatically reduced feed loss (Nabi 1997). In some areas, however, where water has a high turbidity, the use of fine mesh netting is not recommended as it becomes clogged, causing structural stress on the cage frame. In these areas, feeding trays are used as an alternative to fine mesh bottoms.

Buoyancy is achieved by using four plastic floats (buoys), which are tied to the four horizontal poles of the cage frame, approximately 10 cm from the top of the cage.

Table 1. Number of cages used from 1996-1999.

Year	No. of fixed cages	No. of floating cages
1996	Nil	27 (bamboo raft)
1997	502	18
1998	767	276
1999*	1,050	1,500

*estimated.

Frame Materials

A variety of different cage frames have been used and continuously being tested in the project. The principal types of cage frame materials used are iron bar, PVC poles and bamboo.

Iron Frame Floating Cage

This is constructed by welding the iron bars to form a cube. This relies on the access of the cage operator to a welder, though in practice this is not a major constraint as welders are available in every small town in Bangladesh. Once the cage frame is welded, it is painted with coal tar or paint to minimize rusting and improve its durability in the water.

PVC (Polyvinyl Chloride) Frame Cage

The cage frame is made of PVC pipes and angles. Corners of all PVC made cages are manufactured in a plastics factory in the Jessore region. Due to this factor, PVC cages are more

prevalent in this area. The PVC pipes are hollow and approximately 1.5 cm in diameter. Eight three hole L-bow type angles are then needed with the pipes fixed into the holes to form a cube shape. Small nails are used to fix the pipe into the arms of the angles. Before deployment, several holes are made in the pipes at the bottom edge of the frame, to allow water to enter and keep the cage submerged.

Bamboo Frame Cage

Cage frames made from a bamboo, locally named Mirtinga (*Bambusa tulda*) are increasingly being used. Found in the Sylhet region, this bamboo is strong and relatively thin (approximately 2 cm diameter). Construction of the bamboo cages is very similar to that used to construct a PVC frame cage, also relying on PVC corners to fix the cage frame together. To make a 1 m³-cage frame, twelve one-meter long bamboo sticks and eight three hole L-bow type angles are required.

Comparison of Costs of 1 m³ Floating Cage Frame Materials

Table 2 shows the economics of the 3-principal cage frame materials used. It can be seen that bamboo cage frames cost less in terms of materials and on construction costs (due to short time required for construction). As a result, bamboo cages are cheaper than any other cage type.

Ease of management is an important factor. Farmers reported that iron bar cages are heavy and are difficult to manage and transfer from one location to another. Both bamboo and PVC piping act as floats in the water and hence requirement for floatation is minimized (Talukder *et al.* 1998)

Strength and durability are also important in

choosing a cage frame material. Trials revealed that PVC frames are prone to deterioration upon exposure to sunlight, compared to the other frame types tested (Talukder *et al.* 1998; SRDS 1998). Furthermore, iron bar and bamboo could last for three years, PVC piping however lasted for only one year. Growth and mortality of fish were similar in all cage types.

It is clear from this analysis that Mirtinga bamboo is presently the preferred frame material for floating cages. This is reflected in the increasing number of this cage type being used in Bangladesh.

Key Problems with Small Floating Cages

Poaching

Farmers have observed that floating cages are at more risk from poaching than fixed cages. This is due to the easy access to the lifting lid, the high density of culture and the fact that fish can simply be "tipped out" of the cages and into a waiting boat. This is not the case with fixed cages, the added difficulty in handling and access is a deterrent to thieves.

Cage loss

During flash floods, floating cages may be washed away with the water currents if not adequately fixed in position. Cages though initially intact, quickly break up when dislodged, and all the fish are lost.

Some Other Cage Designs Tried and Under Trial

Many other cage frames continue to be tested at farmer level including cage frames made of locally available wood, round cages and "loop cage".

Table 2. Cost of cages made using different materials for the frame. Unit: TK

Costs	Frame	Net	Tire cord	Construction cost	Other	Total
Iron bar	220	135	20	100	18	493
PVC piping	140	135	20	100	-	395
Bamboo	60	135	20	50	-	265

Loop Cage

This cage design was tested in the CAGES research farm though it has not yet been adopted by farmers. The dimension of these cages are 2 m x 1.3 m x 1.9 m with a water volume of approximately 5 m³. A top net is always present, and a fine mesh net is usually used to minimize feed loss. Buoyancy is maintained by four plastic floats (buoys). At the base, a rectangular frame made of PVC pipe filled with sand is fixed to keep the net bag submerged and evenly spread under the water. Eight loops of nylon rope, two in each corner (top and bottom) are made in the eight outer corners of the cage. Four vertical bamboo poles are used to fix the cage bag in the water, passing the pole through the loops supplied along each edge. Although fixed in one location, the cage is able to rise and fall with fluctuating water levels, hence a floating cage (Nabi *et al.* 1998). Although trials have been generally promising, poor net spreading has been observed in some cases.

Wooden Frame Cage

The cage frame is made from cylindrical wooden rod, with dimensions 1.5 m x 1.5 m x 2 m and a water volume of approximately 4.5 m³. These cages are fixed due to the buoyant properties of the wood, which would otherwise lift the cage out of the water. Wood is treated with coal tar to increase longevity. This cage design is being tried by the farmers in the Barisal district, located in the southern part of Bangladesh and as yet the result is yet to be reported. Cost of the frame is Tk. 155, considerably more than the Mirtinga bamboo, although longevity may be greater.

Cylindrical Cage

This cage is cylindrical in shape. Three iron rod made rims (diameter 1 m, depth 1.5 m) are used. The rims are then sewn into the netting at the top, middle and bottom of the cages. This cage design is currently being tested and early results indicate that it enables fish to be easily

managed and can be stored efficiently between culture cycles. The cost (approximately Tk. 200) is again more expensive than bamboo, but larger size and easy storage may add appeal to some farmers.

Specialist Cage Designs

Nursery cage

Nursery raising in hapas is another system which offers very good returns, as well as a potential entry point to rural poor groups in Bangladesh (McAndrew *et al.* 2000). These cages are made of fine mesh netting. In Bangladesh, several types of fine mesh netting are available, all of which differ markedly in their quality. Nursery hapas are usually fixed. In testing the floating hapas, it was found out that cleaning of hapa walls were difficult considering the taut sides of a floating hapa and required the use of brushes. The action of these brushes damage the netting, tear the material apart and allow small fry to escape. Fixed hapas have enough slack to allow the rubbing together of the netting by hand.

These fine-mesh cages are very susceptible to algal deposition and hence regular net cleaning is essential to ensure adequate dissolved oxygen for caged fish. Dimensions are typically 1.5 m x 1.5 m x 2 m and when fixed in water, a cage volume of approximately 1.7 m³ is achieved. To install this cage, the four bottom and top corners are tied with four bamboo poles fixed in the substrate in the same way as a grow-out fixed cage. The fine mesh is maintained at least 10 cm above the water to prevent fish escapees. These cages are used by the farmers for fry raising and in some cases for acclimating fish before stocking in traditional cages. To be more profitable, nursery hapas should be located in shallow, eutrophic bodies of water.

Cage for hapa breeding of tilapia

This unit consists of three cages, which are used for tilapia breeding. Cages are made from fine mesh nylon net with one larger (3 m x 2 m x 1 m) breeding unit and two smaller (1.5 m x 1 m x 1 m) nursery units. These breeding and nursery

hapas have effective water volumes of 3.6 m³ and 1.8 m³, respectively. To set hapas, ponds with green water are preferred minimizing the feed requirement for brood fish. In rivers or lakes however, farmers need to apply quality supplemental feed to both brood and fry.

Netting materials used

The cage frames are as important a consideration as the nets used. Until recently, only imported black polyethylene netting was used. Recently however, the CAGES project has tested a range of different net materials, which are locally available. The following are indigenous low cost net materials currently being tested and used by cage farmers.

Tirecord net

Knotted tire cord was recently tested and was found to have good strength and durability lasting for three years in water without any damage (Kabir, unpubl. data). Net cost for a 1 m³ cage is approximately Tk. 175, and hence considerably cheaper than the previously used imported nets, which cost around Tk. 250. Tire cord netting is currently being used in all the districts of the project with promising results.

Nylon net

Locally made nylon nets are suitable for one cycle cage culture, after which they deteriorate making cage culture difficult (Kabir, unpubl. data). Nylon nets are also vulnerable to crab cutting, though if treated with coal tar this risk is reduced. In constructing a 1 m³ cage, net costs around Tk. 100 and is therefore the cheapest netting available.

Future Priorities

Reduced Risk

Cage culture is by nature a high-risk activity. However, appropriate cage design can help minimize failure, and maximize gains to resource poor groups. More than one cage per household greatly reduces the chance of an individual los-

ing all fish as the risk is spread. This practice is now being encouraged by many of our partner NGOs. The small cage size and low cost start-up, makes this option a possibility. It is also a less risk prone strategy for the resource poor to have two small cages, rather than have one large cage. Placing many cages together in clusters reduces the risk of poaching, which can again result in complete loss of all fish. Individual farmers can form groups, which will guard the fish at all times, considerably reducing potential poaching threats.

Sustainability

It is important that the cage culture systems set up by the project are sustainable for local farmers/NGOs in Bangladesh. An important part of the CAGES projects activities in the remaining 18 months of project life will be to set up linkages between potential and participating cage farmers and suppliers of inputs, feed, seed, and netting. Only by doing this can cage culture be self-sustaining after March 2001 when project activities cease.

As the largest input cost of cage culture, it is only by making the cage design appropriate to the social and economic resources of potential cage operators, as well as providing local linkages for cage materials and other inputs, that cage culture could be sustainable for the resource poor farmers in Bangladesh. The CARE-CAGES project believes that we are now doing this, and that cage culture is an appropriate technology for some groups of resource poor people.

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Engineering Risk Analysis for Submerged Cage Net System in Taiwan

C.-C. HUANG

*Department of Marine Environment and Engineering
Sun Yat-Sen University
Kaohsiung
Taiwan*

Huang, C.-C. 2000. Engineering risk analysis for submerged cage net system in Taiwan. *In* Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia (ed. IC. Liao and C.K. Lin), pp. 133-140. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok.

Abstract

The decline of fishery resources of near ocean and coastal zones and the sinking problems caused by manual fishery has caused marine cage net aquaculture to become a new direction for the future development of the Taiwanese fishery industry. Unfortunately, each year, typhoons and a long period of winter monsoon cause severe damage on the integrity of cage net structures. Most fishermen are strongly concerned about the safety of marine cage aquaculture. Mooring system risk analysis becomes a very important issue. To do so, we have to find two probability distributions. One is the mooring line stress response probability distribution during stormy conditions; the other is the probability distribution of mooring line material strength that can be obtained by manufacturing data. With these two distributions, we could evaluate the risk of mooring system by calculating the interlacing area of the two curves. The calculation results indicate that the risk of mooring system is rather low (0.15%), but owing to the serious deformation of the cage net volume, the average mortality is pretty high. This is an urgent problem that the marine cage aquaculture industry should overcome.

Introduction

The reasons for marine cage aquaculture to be the fishing industry's future development strategy in Taiwan include the following: (1) decline of marine resources due to overfishing; (2) worsening marine environment; and (3) resource limitations for land based aquaculture development. Considering the fact that about four typhoons pass through Taiwan area each year, any presence of marine cage aquaculture engineering structures in the ocean is potentially highly dangerous. Thus, the survivability of marine cage aquaculture after typhoon attacks has become an important issue. With survivability being dependent on marine cage system, the importance and urgency of risk evaluation for marine cage engineering is obvious. The intention of this article is to analyze the risk of mooring system during typhoon attacks based on engineering statistic analysis.

Offshore Cage Structure

Most cages, which vary according to the function, are constructed with nets, sinkers, floating collars, distance floats, mooring cables and anchors. To facilitate the study, we classify the offshore cage structures into three systems, i.e., mooring system, floating collar system, and cage net system (Fig. 1).

Mooring System

The main function of the mooring system is to stabilize the cages in the designated area and try to prevent them from drifting as a result of high waves, wind and current. Therefore, the stability and endurance of the material for the mooring cables (usually nylon, PE, PP and chain etc.) is the priority. The material most commonly used by the local fishing industry is nylon. The intention of combining nylon and chain is planned for the future. The purpose of the chain

is to increase the resistance to abrasion with sea bottom especially in rocky areas. The cables may create instant tension when they encounter big waves during typhoon attacks and result in cable breakage. In order to reduce the impact, distance floats are being installed along the cables. Most of the anchors used in marine cage aquaculture are made out of concrete for easy installation and cost effectiveness.

Floating Collar System

The main function of the floating collar system is to support the cage net and to connect the mooring system. It is also occasionally used as a working platform. In the past, the materials used were PVC tubes plus glass fiber. Recently, the trend is to use the HDPE (high density PE) floating collar instead. Since the floating collar systems are often affected by current, wind and waves, the collar systems are constantly degenerated into a series of floats, merely supporting the cage net. As a result, lifting the net cover manually during feeding and harvesting has become mandatory requiring a lot of time and energy. To overcome the waves without losing working efficiency, there is a trend to develop a submergible floating collar system in the near future.

Cage Net System

Since the space inside the net is expected to be filled up when the fish grow, the deformation of the net resulting from typhoon attacks will have a strong impact on the safety of the fish. For large-scale marine cage aquaculture, a shielding effect usually occurs between nets, which influences the water exchange and therefore causes net deformation unevenly. In order to cope with the situation, some practitioners have installed sinkers or iron frames at the bottom of the net to maintain a space inside the net as large as possible.

Risk Analysis

Major Environmental Forces

To effectively discuss the risk of marine cage aquaculture during typhoon attacks, this paper focuses on the submerged cage net system installed along the Fung Kuang offshore area in Ping Tong county (Fig. 2). The major environmental impacts for marine aquaculture cages are wind, waves, and tide current. These factors are closely related to the geographic environment. The fact that Taiwan does not have bays for sheltering from typhoon, all the cages are installed in the open sea and suffer directly from

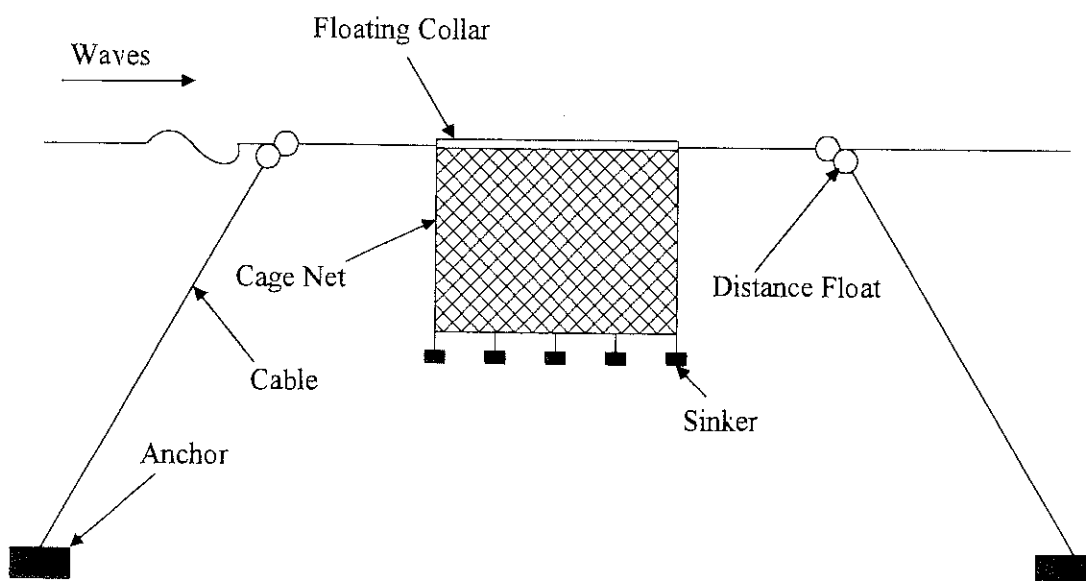


Fig. 1. A typical cage diagram.

typhoon damage. As a result, the resistance for wave and current impacts during typhoon season is a major consideration when designing cages. Having recognized the impact on the ocean environment should cage damage occur, such as water pollution if fish die in bulk or upsetting the biological balance if fish escapes, the 50 years return period of typhoon waves and two knots current are used as design criteria.

Since each component size of cage structure is relatively small compared with the design wavelength (approximately 150 m), it is reasonable to regard that the flow field will not be affected by the presence of cage structures. Therefore, for the preliminary planning and design, we will use Morison equation, Eq. 1, to calculate the wave forces on the structure.

Table 1. A typical size of cage system

Mooring system	Concrete Weight : 16-18 tons Cable (below water) Diameter: 50 mm Material character: PP Length: 70 m Cable (above water) Diameter: 60 mm Material character: Nylon Length: 60-150 m
Distance float	Buoy size Diameter: 400 mm Material character: PE Amount: 10 unit Buoyancy: 25 kg/unit
Floating collar	Buoy: 92 unit Buoyancy: 5 kg/unit
Cage net	Cage size: 10 m x 10 m x $\sqrt{8}$ m Sinkers: 60 kg x 8 unit

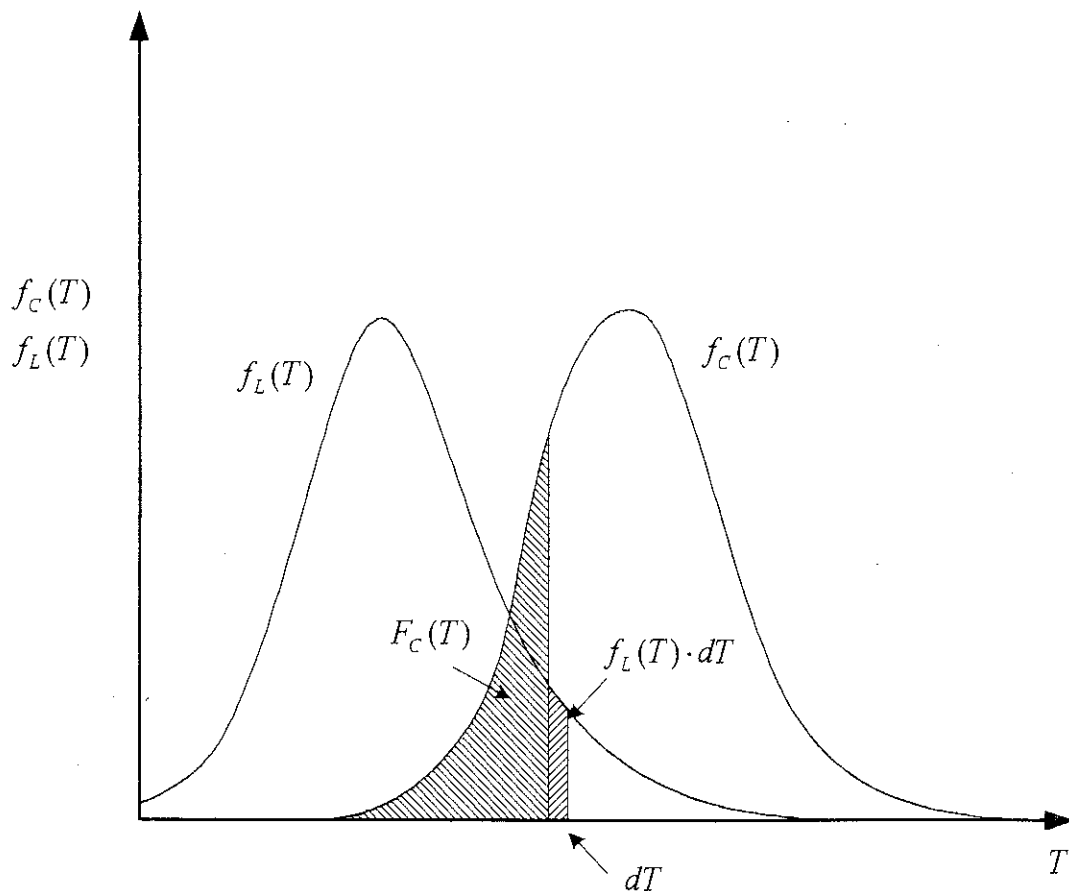


Fig. 2. Risk calculation diagram.

$$\vec{F} = \frac{1}{2} \rho_w \cdot C_D \cdot A \cdot \vec{V} \cdot |\vec{V}| + C_M \cdot \rho_w \cdot \nabla \cdot \frac{\partial \vec{V}}{\partial t} \dots\dots\dots 1$$

- ρ_w : Density of seawater
- ∇ : Volume of displaced water
- C_D : Drag coefficient
- C_M : Inertia coefficient
- \vec{V} : Water particle velocity
- $\frac{\partial \vec{V}}{\partial t}$: Water particle acceleration
- A: Projected area

Equations of Motion

Cables are used to connect parts of the cages and to restrain cage movement, therefore, cable tension has to be taken into great consideration. The cage external forces include buoyant force, weight, drag force, and inertia force. Damping force is neglected due to its small magnitude when compared with other forces.

Based on the lumped mass model, the equations of motion can be written as:

$$\left(\sum_{j=1}^5 m_{ij} + \rho_w \sum_{j=1}^5 K_{mj} \cdot \nabla_{ij} \right) \ddot{X}_i = \sum_{j=1}^5 T_{xij} + \sum_{j=1}^5 I_{xij} + \sum_{j=1}^5 D_{xij} \dots\dots\dots 2$$

$$\left(\sum_{j=1}^5 m_{ij} + \rho_w \sum_{j=1}^5 K_{mj} \cdot \nabla_{ij} \right) \ddot{Z}_i = \sum_{j=1}^5 T_{zij} + \sum_{j=1}^5 I_{zij} + \sum_{j=1}^5 D_{zij} + \sum_{j=1}^5 B_{zij} + \sum_{j=1}^5 W_{zij} \dots\dots\dots 3$$

where

- K_{mj} : added mass coefficients
- m_{ij} : the *i*th lumped mass
- ∇_{ij} : the displaced water volume of *i*th lumped mass
- i*: the *i*th node
- j*: the object type
- cable *j* = 1 distance
- float *j* = 2 floating
- collar *j* = 3
- cage net *j* = 4
- sinker *j* = 5

The initial value problem Runge-Kutta numerical method has been applied in this study. With this numerical method, the displacement of

each lumped mass and its associated maximum tension can be computed.

Risk Evaluation Concept

A risk analysis of a particular component of cage structure indicates that such a particular component may be damaged during typhoon attacks. High waves may cause the external forces so large that the component internal stress is unable to endure the waves attack. Therefore, to do the risk estimation for a particular component, we have to find the relationship between the strength density function of such a particular component and the external loading density function due to waves. Let *C* as the capacity of strength density function and *L* as an external loading density function; while the risk function *P_f*.

$$P_f = P(L > C) \dots\dots\dots 4$$

Assume the cable strength density function is *f_C*(*T*) and the external loading density function is *f_L*(*T*). Since cable strength and external loading are statistically independent, the whole system risk may be evaluated by the direct integration method, Eq. 5.

$$P_f = \int_{L > C}^{\infty} F_C(T) \cdot f_L(T) dT \dots\dots\dots 5$$

where *F_C*(*T*) is the cable strength cumulative probability function; *f_L*(*T*) is the external loading probability density function.

Case Study on Submerged Cage Net System

Most cage aquaculture installations in Ping Tong county are based on specifications designed by Joint Force Engineering Consulting Company (as shown in Fig. 3a and b). In their design, floats are implemented to replace floating collars and cage nets are sunken about 1 m below water. This enables the cages to move in accordance with the waves and have higher wave resistance than a conventional floating collar system. This system has become the mainstream for cage aquaculture in the last few years. The submerged cage system

in Fung Kuang is used as a case study (please refer to Fig. 4). A dynamic numerical model was developed to simulate the maximum tension in the mooring system and the chances for cable breakage.

The Cable Tension Probability Density Function Under External Loading

The wave height probability density function follows the Rayleigh probability distribution.

$$f(H) = \frac{2H}{H_s^2} \exp\left[-\frac{H^2}{H_s^2}\right] \dots\dots\dots 6$$

As for the energy spectra of sea waves, the spectral characteristics have been fairly well established through the analyses of a large number of wave records taken from various waters of the world. The spectra of fully developed wind waves can be approximated using the following standard formula by Mitsuyasu (1970).

$$S(f) = 0.257 \left(\frac{H_s}{T_s}\right)^2 f^{-5} \exp[-1.03(T_s \cdot f)^4] \dots\dots 7$$

with the given significant wave height H_s and its correspondent T_s , we may immediately compute the energy spectrum of $S(f)$ whose unit is $m^2 \cdot s$.

Through the relationship of wave amplitude and wave energy per unit water surface, $E = 1/2 \rho g |H/2|^2$, we may come up with the following equation:

$$S(f) = \frac{H^2}{8 \cdot \Delta f} \dots\dots\dots 8$$

The maximum wave height is confined by two conditions. One is the limitation of extreme value of statistics, $H_{max} = 2H_s$ (Goda, 1985); while the other is restrained by the water depth, $H_{max} \leq 0.78d$, where $d = 30$ m. Therefore, the H_{max} can be determined by the equation 9:

$$H_{max} = \min\{2H_s, 0.78d\} = 19 \text{ m} \dots\dots\dots 9$$

$\Delta f = 0.1$ Hz is used in equation 8 to compute the component wave height H if $S(f)$ is given. Besides, an important assumption was made as follows. The interval value of the Rayleigh probability density function $f(H) \Delta H$ is equal to the interval value of the probability density function of the cable damage strength, $f_L(T) \Delta T$ within the corresponding external loading T . Finally we may result in the relationship between the probability density function $f_L(T)$ and T .

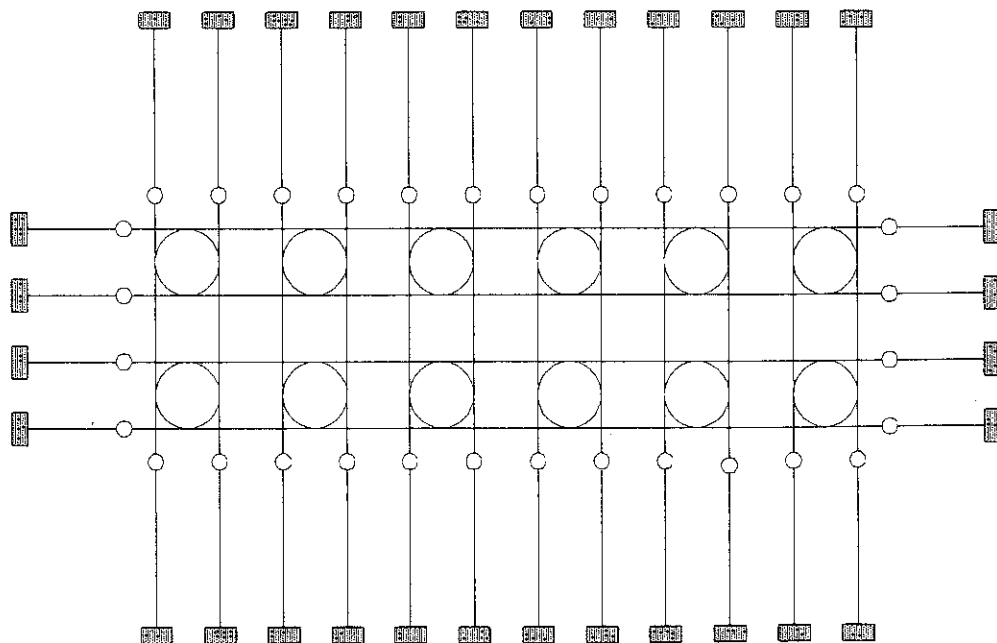


Fig. 3a. The top view of cage system.

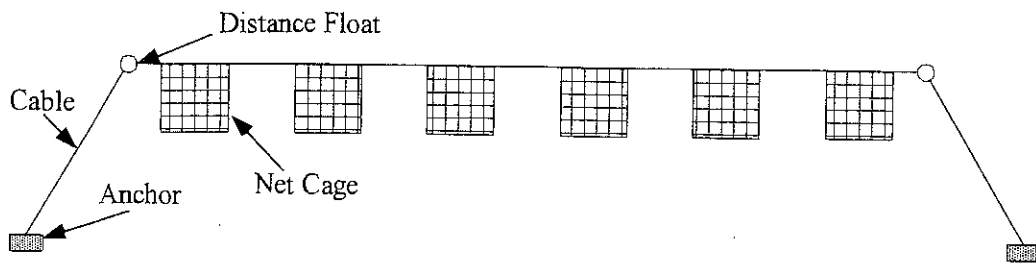


Fig. 3b. The side view of cage system.

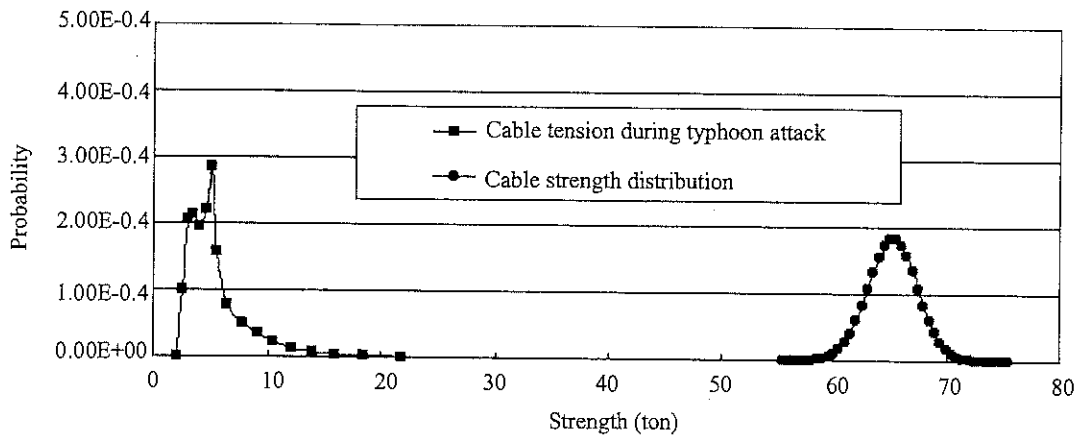


Fig. 4. The risk diagram of mooring line after the installation.

The Cable Break Strength Probability Density Function

Before the cable products are sold in the market, the manufacturer has to test the breaking strength of samples that are randomly selected from the same batch of products. If there is any failure in the testing, the whole batch of products must be returned to the factory. An example is shown in Table 2. For simplicity, we may assume that the probability density function of cable break strength is normally distributed.

The Risk of Cable Damage Right After the Installation

Putting these two probability functions together and following Eq. 5, the failure risk of the mooring cable is quite slim, almost 0%. The result is obvious since the cable break strength is far above the damage strength due to the designed

typhoon external loading. Thus, we may conclude that the mooring system is safe right after the cage is installed.

Table 2. Cable breaking strength test data.

No. of test	Nylon 65 mm (white)	
	Breaking strength (kg)	Elongation (%)
1	75,500	32.0
2	78,200	35.0
3	80,230	31.6
4	76,230	20.4
5	81,900	21.4
6	77,200	21.9
7	81,900	21.4
8	87,240	23.8
9	75,170	30.0
10	79,610	35.0
Mean	78,418	27.25
Standard deviation	2,457	6.01

The Risk of Cable Damage After 5 Years Aging

The aging cable strength can only be predicted based on reasonable assumption due to the difficulty in getting information on a precise aging process. Through numerous discussions with the manufacturer and based on the understanding of cable material from experience, it is suggested that the cables be replaced every five years. Assuming the cable material aging and destabilization time frame is five years and breaking strength has decreased to 1/3 of the original strength (this is based on the twine fatigue value being 1/2 of its dry condition and 1/3 when soaked in water), the relation between the breaking strength and time is demonstrated as follows:

$$T_1 = T_0/3 + A \cdot e^{-B \cdot t} \dots\dots\dots 10$$

where T_1 is the breaking strength after t years; T_0 is the original strength; A and B are coefficients. After arithmetic manipulation, A is 43514 while B is 1.385. Another assumption here is that the standard deviation of an aging cable strength is the same as the original, in other words, the shape of the 5-year aging cable strength is like the one that just came out from the manufacturer. The damage risk slightly increases to 0.15%

(Fig. 5), which is still low compared with the common structural products.

Conclusions and Recommendations

Previously we thought that mooring cable at anchor would be under the highest impact and most easily damaged. This case study results proved otherwise. The numerical model used to simulate 2-cages showed that cables between distance floats and the first cage have the highest instant tension which is 8,700 kg, while the highest tension at anchor is 7,600 kg. Similarly, results of a 6-cage simulation showed that the middle section of the main cable between the first and the second cages has the highest instant tension, 11,400 kg, while the highest instant tension at anchor is 8,600 kg.

Therefore, the location for the highest tension is dependent on the structure size and the number of cages. However, a great deformation occurs in the cage net space during high waves, which causes fish mortality due to the scratches between the fish and the net. Other conclusions and suggestions are as follows:

- In this case study of submerged cage net system, the damage rate of mooring cables is 0.15%.

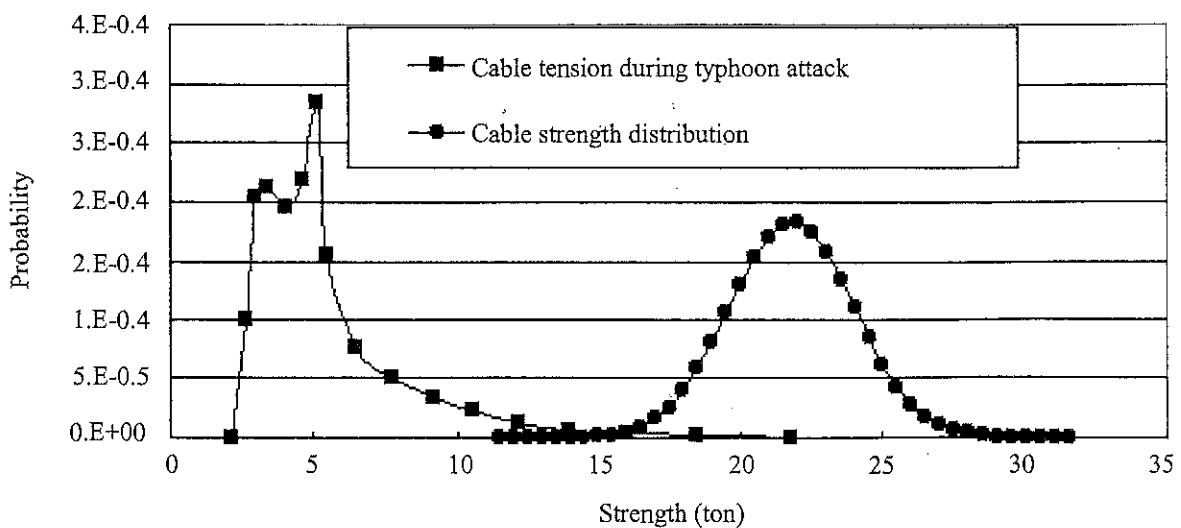


Fig. 5. The risk diagram of mooring line after five years aging.

This reveals that the mooring cables used in practice are strong and not easily damaged.

- Algae grows easily on cage nets submerged in the water for extended duration, thus increasing the net weight and reducing the net's mesh size. It also affects water exchange and increases net drag forces both of which affect fish survival rates. Therefore, it is recommended that practitioners clean the nets or apply anti-algae agents every 3-6 months.
- Whether the calculation method of cable tension aging process is applied properly or not, it should be explored further since the assumption is based only on the experiences of the manufacturers.
- Based on other studies, the information shows that the volume of cage net may decrease up to 70% under severe wave attack. This low survival space may cause fish mortality due to fish jamming or scratching inside the net. This phenomenon has been observed as a consequence of the typhoon Zeb (10/15/1998). Therefore, the capability to maintain the survival space during high waves is an important issue in marine cage aquaculture industry.

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Offshore Cage Systems

E. LIEN

*SINTEF Fisheries and Aquaculture
Pir-senteret
Trondheim
Norway*

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Abstract

An overview of the typical cage systems is presented in this paper. The general aspects regarding work conditions for the different systems are also discussed. Systems described are: traditional hinged steel cages and PEH-cages, submerged and partly submerged systems such as Farm Ocean Cages, submergible PEH cages and vertically moored cages (TLC's). An overview of the benefits for the different systems and their mechanical behaviour is given.

Cage Systems

Overview of Cage Types

The first cages used for breeding of salmon were the wooden cages (Fig. 1). These were of hexagonal shape with a circumference of about 40 m. Flexibility was provided by the wooden planks. They may be characterized by low investment costs and good work areas. These cages are still in use but the tendency to move cages into more exposed areas have now forced the replacement of polyethylene rings. There are many manufacturers of these cages, but the layout is quite similar.

Two PEH-rings are connected with brackets made of either PEH or steel (Fig. 2). Their strength is approved by thousands of installations. The drawback is the working conditions. Slippery tubes, absence of freeboard and low rest buoyancy make the cages a tough work place.

The tendency now is to use more and more hinged steel cages. They represent very good working conditions, and are often connected to a work platform with either an automatic tube feeding system or by individual feeders on each cage unit (Fig. 3). The central frame unit is designed to carry loaded forklifts. Even if there are many different concepts, one may say that they

generally have problems with fatigue. A general misconception is that they represent a mechanism due to the hinges (Fig. 4). When all hinges are placed horizontally, the flexibility is limited. Large horizontal displacement will force bending of the frame units (Fig. 5).

A common failure of design and maintenance of these types of structures is to reinforce the structural parts where the fatigue problems occur instead of implementing sufficient flexibility in the structure. In case this horizontal flexibility is not integrated in the initial construction, you will only move the fatigue "areas" around the construction by performing this type of reinforcement.

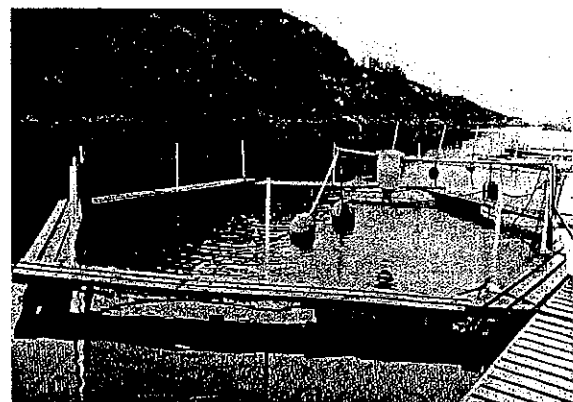


Fig. 1. Wooden cage.

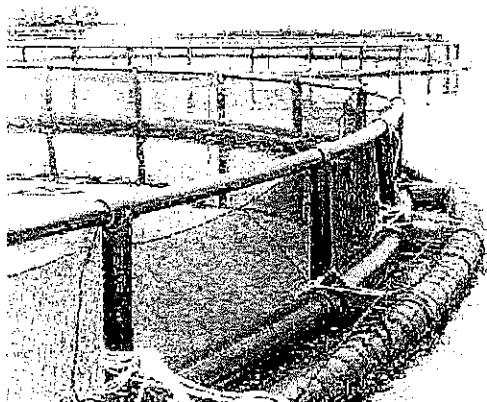


Fig. 2. PEH cage.



Fig. 3. Automatic feeders.

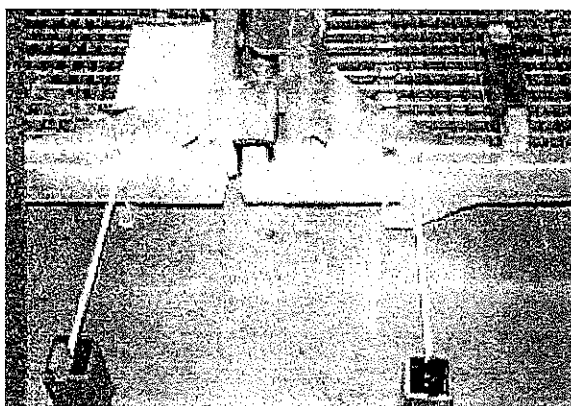


Fig. 4. Hinge.

Farmocean System

The Swedish Farmocean system is a “semi-submersible” hexagonal steel cage system with a computer controlled automatic feeding system mounted at the top of the cage. The system,

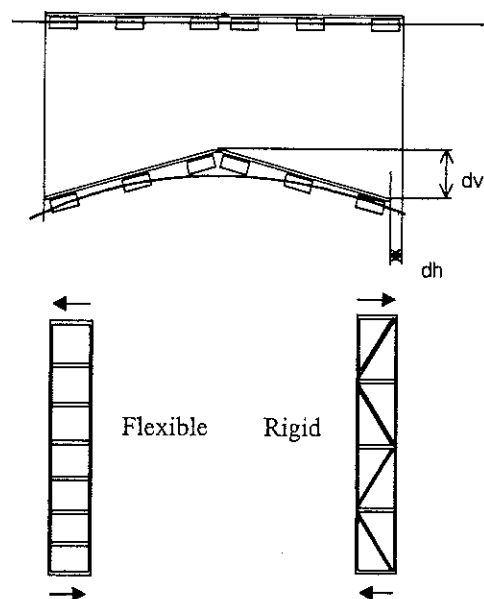


Fig. 5. Illustration of second order deformation.

shown in Fig. 6, is taken from Svealv (1991). The system has one net suspended by a “sinker tube”. Ballast water is allowed to enter six ballast tanks to lower the structure from a high “working” position into a partly submerged operational position. The Farmocean 3500 (m^3) has a feeding capacity of three tons.

The system can be operated without manpower, and several systems can therefore be spread over a large area. They represent large investment costs. More information may be found in Gunnarson (1993).

The Seacon System

The Norwegian Seacon system design is a rigid platform structure with upper and lower decks made of concrete. Houses, cranes and other necessary gear are located on the upper deck. One system has been built in Spain and is located in the Mediterranean, but it did not turn out to be any success. The system is now out of operation.

The nets were rigidly fixed to the structure. This caused strong forces on the nets due to the relative motions between the net panels and the wave particles. The “effective” volume in the nets is by the same reasons, dramatically reduced in a storm condition.

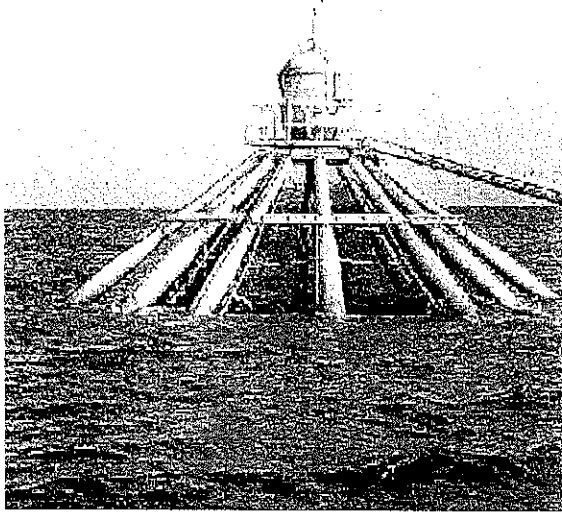


Fig. 6. Farm ocean cage.

Bridgestone Hi-Seas Cage

The Japanese company Bridgestone Corporation is mainly known as a producer of rubber tires for cars and trucks, but they also have a wide range of products for other purposes. One of these products is in fact a rubber cage for offshore fish farming. The cages had been passing tests for more than two years before the first unit was sold in 1982.

The Hi-Seas cages are square, hexagonal or octagonal in shape, and have a rubber hose string at each side mounted together with steel corner joints. The basic philosophy is that the frame should only keep the shape of the net, and not carry the net weight. The net is made with a float line which have enough buoyancy to carry its weight.

Although the cages are claimed to be expensive, more than 250 cages have been installed since 1982. The experience is very good, and only minor changes have been made since the first unit was installed. More information about this system can be found in Gunnarson (1993) and Loverich *et al.* (1997).

Submersible Systems

The reasons for developing submersible systems may be to:

- submerge the cages during storms and hurricanes
- avoid ice
- avoid burglary

The wave motions rapidly decrease with increasing depth, and submersion will therefore be a very effective method to reduce the structural loads during storm conditions. This topic is not discussed further in this paper.

We can divide the submersible systems into two different types.

- Manually operated systems, where one regulates the buoyancy by pumping either air or water
- Self submersible systems, where the mooring and rest buoyancy force the structure to be submerged due to the increasing forces from waves and current under harsh conditions.

Both the Sea Station (Fig. 7) (Loverich *et al.* 1997) and the Tension Leg Cage (Fig. 8) (Lien 1994) represent the self submersible systems which are pulled down by the anchor line forces of the current. Fig. 9 is a submersible PEH-cage. This type is operated manually by use of compressed air.

Net Pen Deflection

The effective volume of a net pen is reduced by deflection due to current forces and effect of water oscillating through the meshes in wave conditions. In over exposed, areas this may cause very high fish densities and may result to unfavorable stress and damage on the fish. We have developed computer programs to analyze the deflection due to pain net dimensions, solidity of the mesh (fouling), clump weights, and current velocity. In the recent year, we have performed full scale tests measuring the deflection on towed cage systems in order to verify the program. Based on these studies, the risk of propeller damage on the net system is discussed.

Deflection of the net pen provides less room for the fish:

- the actual volume decreases due to deflection
- the net pen are lifted towards the surface where

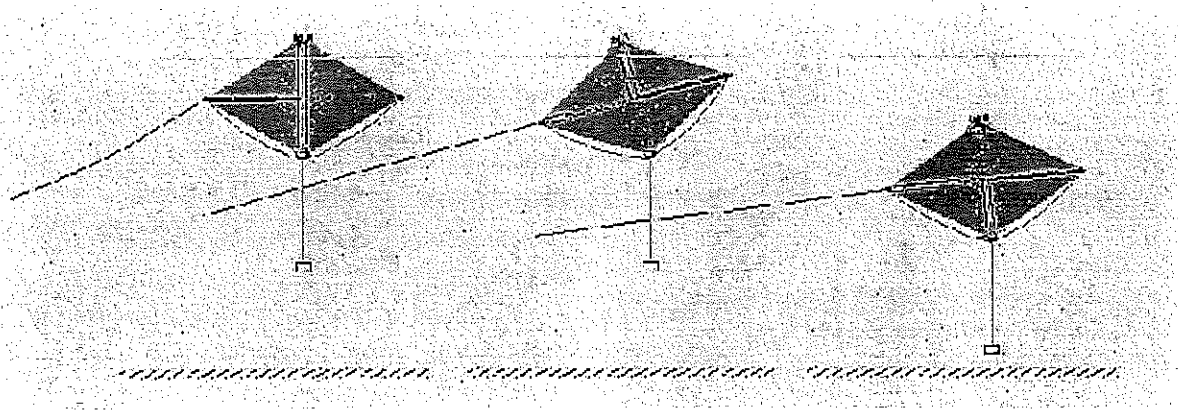


Fig. 7. Sea station – submerges due to increasing current.

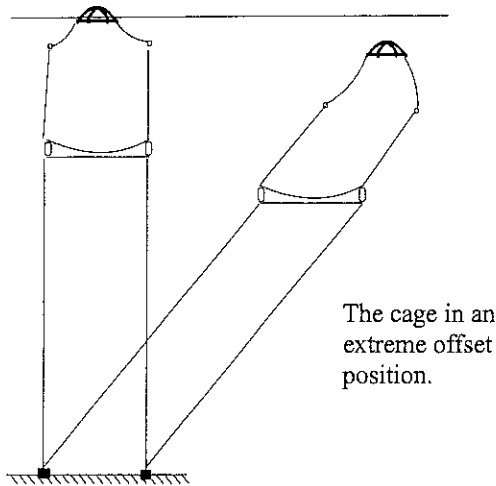


Fig. 8. Tension leg cage.

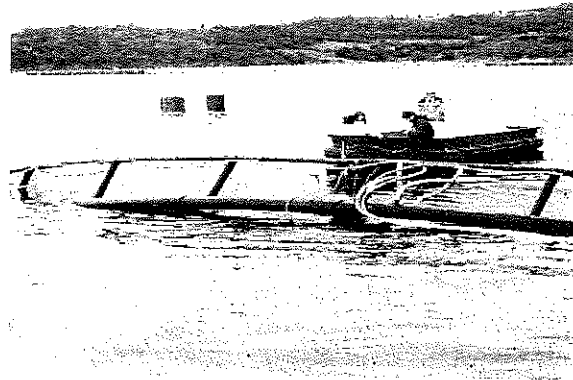


Fig. 9. Submersible polar circle.

the wave motions are more violent
 • the orbital wave motions cause an oscillating flow of water through the net mesh, this causes an even less available volume for the fish

Volume reduction due to the static deflection is well studied. Both theoretical studies and full scale measurements are performed.

In 1998-99, we have performed full scale tests on cage systems in order to verify out net deflection computer programs. The net pen was monitored using pressure gauges in order to calculate the deformation.

Fig. 10 shows the resulting deformation of a 70 m meter circumference net pen with a depth of 20 m with current velocities varying up to

0.43 m/s. The total bottom weight was about 500 kg (concrete in air) and the net was moderately fouled.

The effect of the net pen deflection is shown on Fig. 11, where the wave motion is plotted from the surface down to 14 m depth. The effect of lifting the net pen towards the surface causes the fish to be forced to a more hostile area.

Mooring Systems

Traditional mooring systems cause unnecessary high loads on the cage structure. Parametric variations of the main segment lengths on a mooring line shows that a force reduction of

more than 50% may be achieved by simple modifications. A central point is the position and type of buoys (floats) attached to the mooring lines. If a buoy is to act as a component giving flexibility to the mooring systems, it must have the capability to submerge and thereby give a geometric flexibility to the cage, which normally, systems are not capable of. We have looked into new mooring layouts and use of other buoyancy materials.

A new system now used in Norway is a single point moored system (Fig. 12) which have been studied. This system seems promising with respect to cost and operation. By using this type of mooring layout we also have a possibility to install devices to reduce the current velocities inside the net pen.

The mooring frames are normally placed at a depth between 2 and 5 m. At SINTEF Fisheries and Aquaculture, we have recently developed computer programs, making it possible to perform mooring analyses on such systems.

Analyses of existing systems have revealed unexpected conditions where collision between frame ropes and net pen occurs in some current situations. One situation to be considered is where the leeward frame line wears the net pen. A complete analysis including the flexibility of all mooring lines including the frame lines must be performed.

The layout of mooring systems are studied intensively. The "standard" layout says line lengths of approximately 15 m from the cage to the buoy + lines with a length of 3-5 times the water depth between the buoy and the mooring. It is well documented that this standard is a complete failure. There is no effect from the buoy; it contributes nothing to the flexibility (see Fig. 13). The farmers invest considerable cost in large buoys. They could also be kept on shore (Lien *et al.* 1996). On a sheltered location, they normally do not cause any damage, but on exposed sites the mooring layout should be revised.

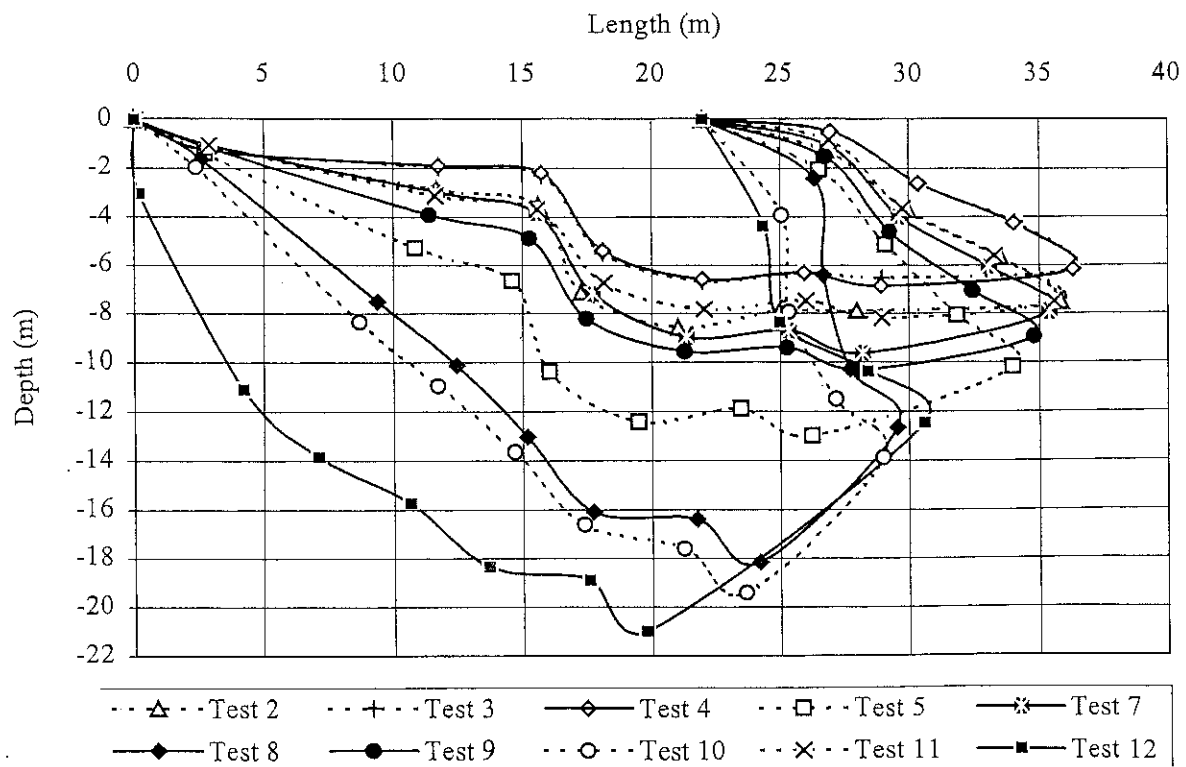


Fig. 10. Deflection of net pen, full scale tests.

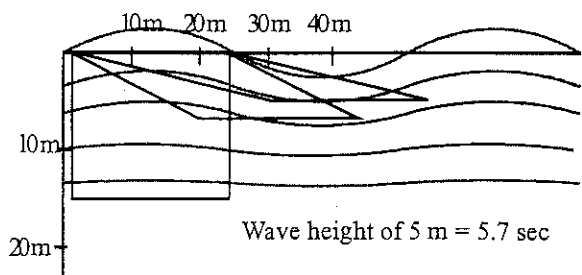


Fig. 11. Wave motion in the water column.

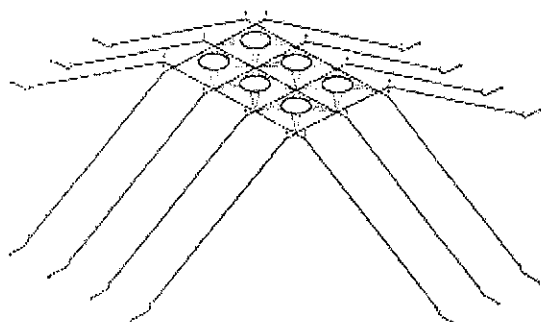


Fig. 12. System mooring.

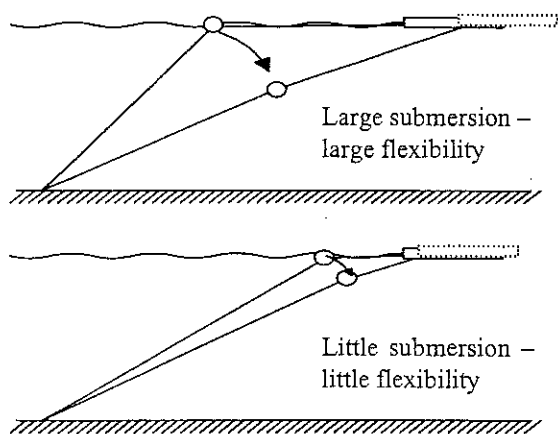


Fig. 13. Variable flexibility due to variation in segment lengths.

Sway Mooring System

One of the most common causes of the escape of fish from cages is propeller damage of the net (MARINTEK Report). Very often moored cage has a very difficult accessibility.

Take for instance a system moored cage. There are many submerged lines which cause maneuvering problems for a skipper.

An access on the leeward side is often desirable because the risk of being stuck is reduced. Current direction and orientation on the locality is often unknown to the skipper.

A deformation of a net pen is shown on Fig. 14 (NFR Project), from full scale measurements on a typical net pen. As we see from the figure, there is an imminent risk of getting in contact with the net pen and the propeller.

A mooring method that can reduce this risk is by using a single anchor line. A Norwegian company, Frøyaringen, has very good experience with such a system. This system is described in Fig. 15.

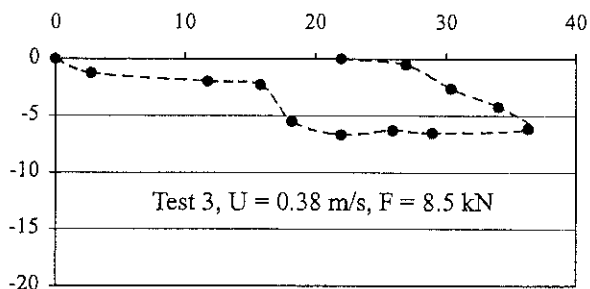


Fig. 14. Example of net pen deflection.

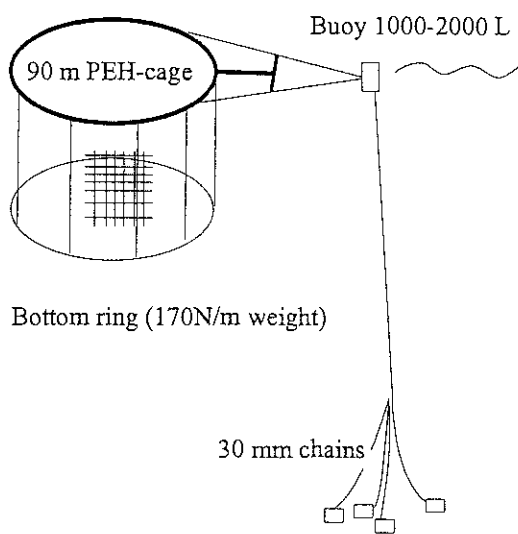


Fig. 15. Frøya Ringen, mooring method.

They use a combination of sway mooring and a net pen with a loaded bottom PEH-ring instead of several clump weights to give a bottom load on the net pen. Insurance companies (to reduction of propeller damage) have approved this system.

By accessing the cage from the leeward side and berth on the side of the cage, the risk of propeller damage will be minimized.

The cages are equipped with a T-buffer in order to avoid contact between the cage net and the vertical mooring line from the seafloor to the float. This eliminates the risk of contact during tidal changes.

Using only one mooring line may be discussed. Anyway, by having only one line, the mooring line and the mooring may be over dimensioned to reduce the risk of breakage. They use a 64 mm braided rope with an enormous breaking capacity in combination with several clump weights each connected with heavy chains. The cage collars are also reinforced in the front, by increasing the PEH- tubes from a PN4 to PN6 size class.

At SINTEF Fisheries and Aquaculture, we intend to develop further this system in order to make it adaptable to exposed locations and also to locations with large current flows.

As can be seen from the figure, the concept uses a very short horizontal distance on the mooring line. This limits the capacity to withstand high current speeds as the front of the cage, the terminal point, will be pulled down.

From previous studies, we have found that replacing single buoys with multiple floats gives a much smoother dynamic response on anchor lines (MARINTEK Report; Lien *et al.* 1996). By developing this method, we may combine these characteristics with the concept of occupying less area with even long mooring lines (see Fig. 16).

By using a combination of rope with multiple floats, pure ropes, and clump weights, we may occupy a very small area in calm conditions. The system will get a long elongation when exposed to current. A system of cages may, therefore, be put closer together than a system not using clump weight.

In order to analyse such systems, we have developed a new computer program where we may combine an arbitrary number of line segments, clump weights, and floats (Fig. 17, Tables 1 and 2).

As can be seen from Tables 1 and 2, the horizontal stiffness are quite similar, but the new system gets far less vertical forces on both the anchor and the cage.

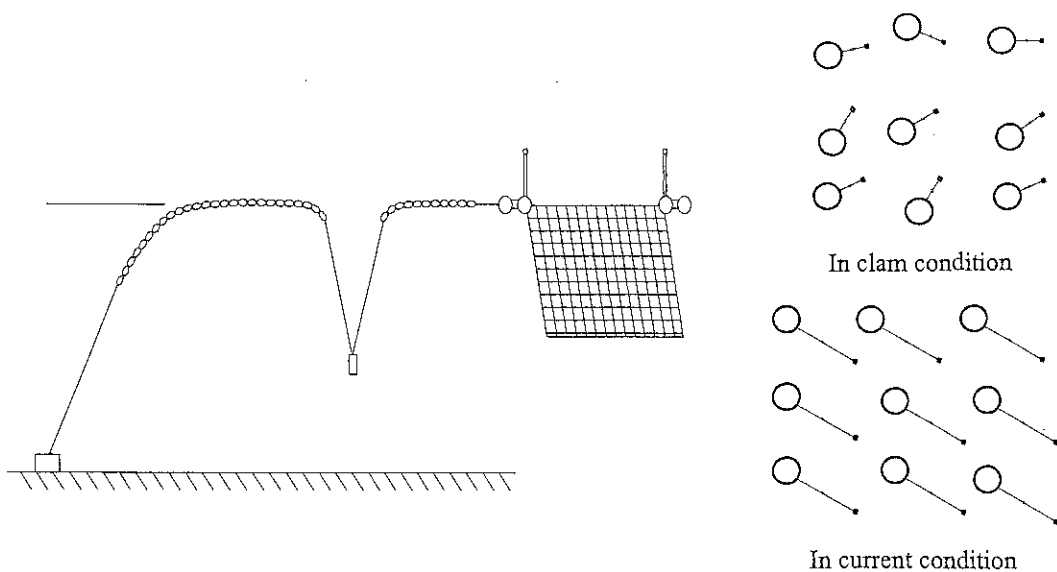


Fig. 16. Combination of multiple float segments and clump weight.

Line no:

Line lengde, s (m):

Y-koord. ende 1 (m) (origo i overflata):

Y-koord. ende 2 (m) (mot merd):

E-modul (N/m²):

Diam (mm):

EA (N):

Vekt (N/m): <0: gir oppdrift
=0: stavelement

Bruddstyrke (kN):

Velg line data:

Velg Bøye/Klumpvekt: (på ende 2)

Lagre system: System navn (*.lic):

Les system:

Line	Lengde[m]	y1 [m]	y2 [m]	Vekt [N/m]	EA [N]	Bruddst. [kN]	Bøye
1	15	-30.00	-21.90	0	1.00E+10	735	(None)
2	25	-21.90	-13.00	-200	9.56E+05	169	(None)
3	20	-13.00	-10.20	0	2.31E+06	404	LODD_2000
4	20	-10.20	-3.74	0	2.31E+06	404	None
5	20	-3.74	-1.00	-200	2.31E+06	404	None

Horisontal proj. av line, x (m):

Værndyp (m):

Høi. komp. av linestrek, H (kN):

Inkluder elastisitet

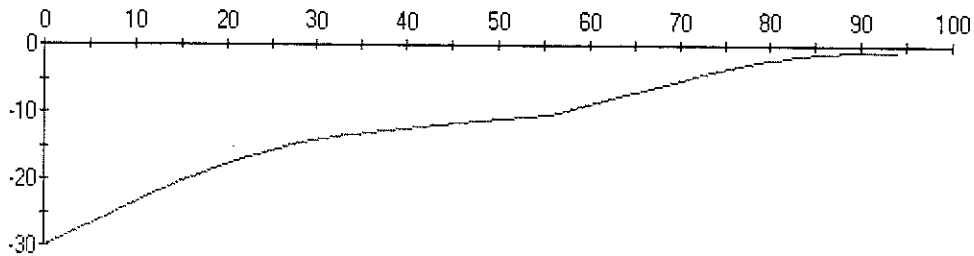


Fig.17. Computer analysis of an arbitrary number of line segments, clump weights, and floats.

Table 1. Effect of horizontal force 10 kN (small current), on a cage at a depth of 30 m.

	System 1 (existing)	System 2 (new)
Vertical force on cage (kN)	2	0
Vertical force on anchor (kN)	17	6
Horizontal stiffness (kN/m)	2	3

Table 2. Effect of horizontal force 20 kN (large current), on a cage at a depth of 30 m.

	System 1 (existing)	System 2 (new)
Vertical force on cage (kN)	10	2
Vertical force on anchor (kN)	26	10
Horizontal stiffness (kN/m)	9	10

A vertical force of 10 kN on the cage will pull the front end of the cage down in the sea, which is undesirable. The reduction of the vertical component of the anchor force also reduces the size of mooring weight.

We have not been able to perform any full scale test on this concept. A sway mooring system can never be an overall solution. The main disadvantage is that the system can not be combined with an automatic feeding system from a central station. An automatic feeding system must be connected directly to the cage unit.

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