Automation of Feeding Management in Cage Culture

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Abstract

There are five types of automatic feeding management in cage aquaculture including the use of submersible camera, doppler system, Aquasmart, Ecofeeder, and Lift Up. An experiment involving the last three systems gave FCR's of 0.94 for Lift Up, 0.93 for Ecofeeder, and 1.05 for Aquasmart. The conclusion is that all three systems provide good control of feeding and help to improve feeding efficiency.

Introduction

The methods of farming Atlantic salmon (*Salmo salar*) and large rainbow trout (*Oncorhynchus mykiss*) in cages in seawater have been developed over the last 40 years. Initially, the fish were fed with moist feed, which was distributed in the cages by hand. It only became possible to mechanize the distribution of feed when dry pellets were introduced. Mechanization led to the possibility of automating the feeding process. But some farmers still believe that feeding by hands and observing the feed intake by eye is the most economic method. Due to the decrease in salmon marketing price, the farmers are pressured to reduce production costs and increase efficiency by optimizing the use of the feed. This means that automation of feeding management to optimize feeding rate is important as the feed cost currently accounts for 50-60% of the total operational cost in farming Atlantic salmon in Norway (Table 1).

If too much feed is given, there will be wasted feed, and this will give a high feed conversion ratio (FCR). If too little feed is given, more of the feed will be used for maintenance and less for growth. This will also give a high FCR. Giving the correct amount of feed is therefore important to get the lowest possible FCR.

The feed intake of Atlantic salmon varies from day to day (Fig. 1) and even throughout the day (Figs. 2 and 3). Neither the variation in appetite is consistent throughout the day as shown in Figs. 3 and 4. Therefore, a fixed feed ration

Table 1. Production costs (in NOK) for Atlantic salmon in Norway during 1997 and 1998.

Items	New Estimate 1997	Preliminary figures 1998
Smolt	2.67	2.39
Feeding	9.04	9.67
Insurance	0.24	0.25
Wages	1.60	1.45
Sundry expenses	2.54	2.51
Net interest on debt	0.74	0.81
PRODUCTION COSTS/KG	16.82	17.08

will not satisfy fish appetite, resulting in deficiency in some periods and surplus in others. The use of self-feeders has been reviewed by Alanärä (1996), but self-feeders are considered inappropriate to be used in high-sea cages due to strong wave actions. Water with high turbidity will make automatic feed control even more important as the use of the human eye to control the feed is difficult due to low visibility.

Methods

The following are automatic feeding monitoring systems being used for feeding management.

Submersible Camera

The submersible cameras have been used for a number of years. There are a number of suitable cameras on the market.

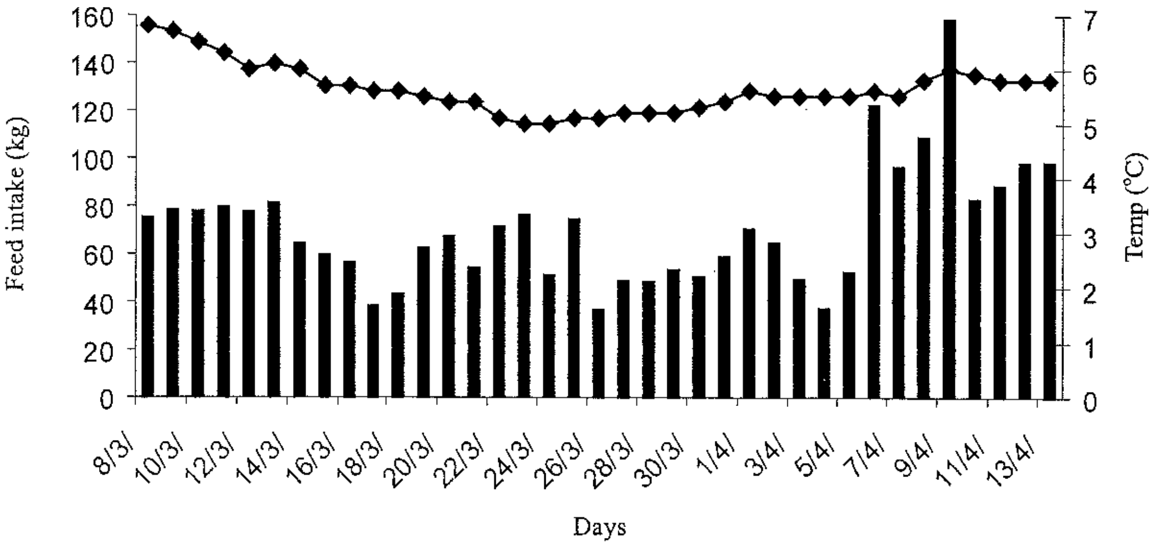

Fig. 1. Variation in daily feed intake (Diamond line shows temperature and vertical bars show feed intake in kg for each day).

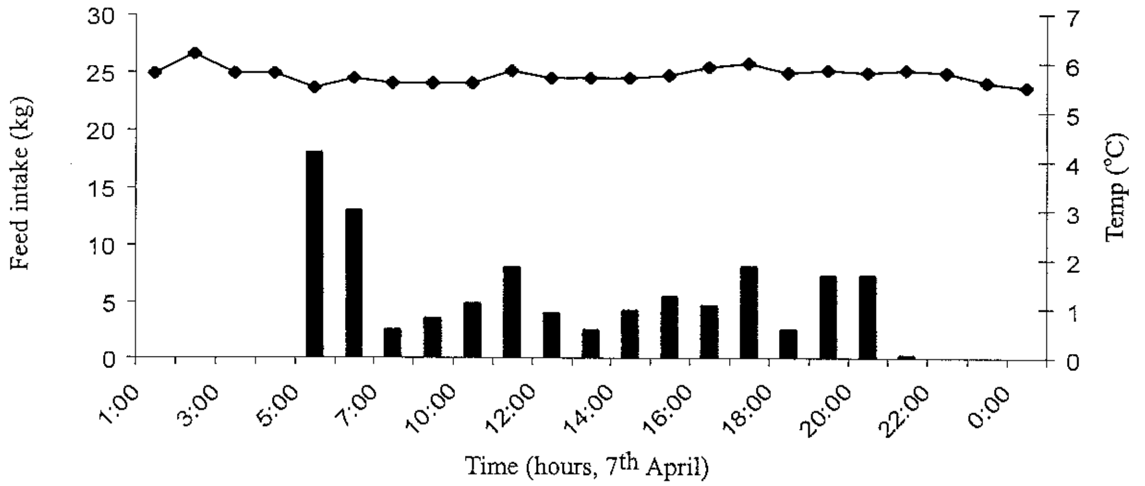

Fig. 2. Variation in feed intake for one day on 7th April 1999 (Diamond line shows temperature and vertical bars show feed intake in kg for each day).

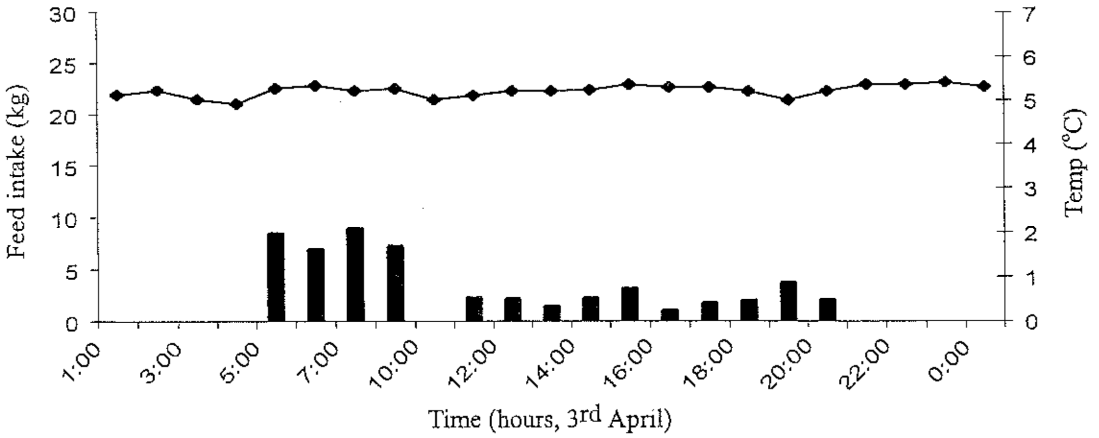

Fig. 3. Variation in feed intake for one day on 3rd April 1999 (Diamond line shows temperature and vertical bars show feed intake in kg for each day).

Doppler System

This system was developed by the Norwegian company Akva A/S. The system as shown in Fig. 4 is capable of detecting uneaten and falling pellets when the automatic distribution of feed is disengaged.

Aquasmart

The Aquasmart system was developed by an Australian company and is marketed worldwide. As shown in Fig. 5, when uneaten pellets fall through a detector at the bottom of the funnel, the food distribution is reduced or stopped, depending on the preset program.

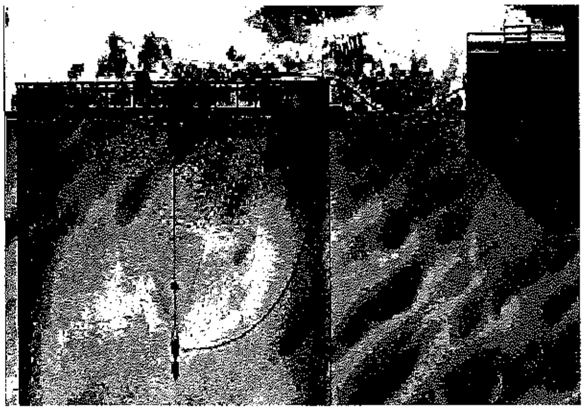

Fig. 4. Doppler system from Akva A/S.

Ecofeeder

The Ecofeeder is marketed by Storvik A/S, a Norwegian company. The system is shown in Fig. 6. Feed pellets are distributed by a water current to the center of the cage. Uneaten pellets

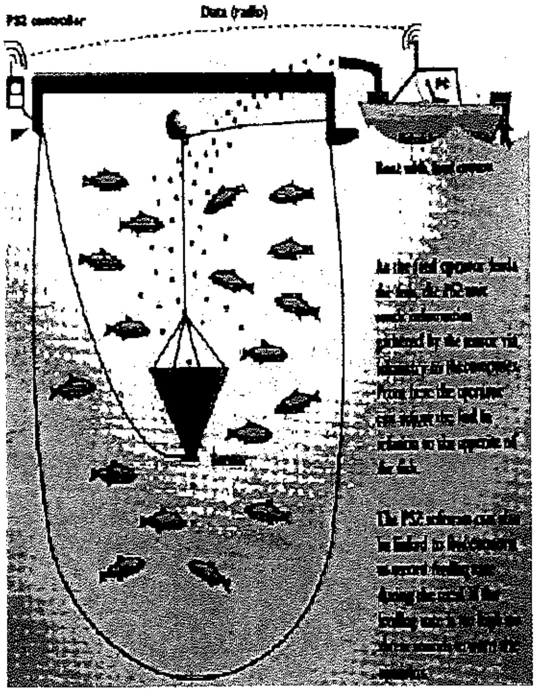

Fig. 5. Schematic illustration of aquasmart.

are collected in the funnel and transported by water back to the feed hopper where the pellet detector is located. The uneaten pellets are returned to the cage again. When pellets are detected, the feeding may be reduced or stopped according to the preset program.

Lift Up

A Norwegian company, Lift Up Akva A/S, developed the system which consists of a cone hanging in the cage with a float. From the bottom of the cone, an airlift operated water current brings uneaten pellets to the surface where they are collected in a screen. This allows fish farmers to regulate the feeding rate according to the number of pellets appearing on the screen. This system is called "mini" Lift Up (Fig. 7).

An experiment comparing Lift Up, Ecofeeder and Aquasmart was conducted at an experimental farm, Salmofood S.A. in Chile. The feed used was standard salmon feed with 30% oil. The species was Atlantic salmon.

Results

One of the suppliers of submersible cameras, Datronik AS, has estimated that the FCR is reduced from 1.2 to 1.1 or 8.3% by using cameras.

Akva A/S, who supplies the doppler system, claims that the system gives better control of feeding and as customers do increase the number of systems they purchase, the doppler system works. The result of the use of Aquasmart in Norway is given in Table 2.

Fig. 6. Illustration of ecofeeder from Storvik A/S.

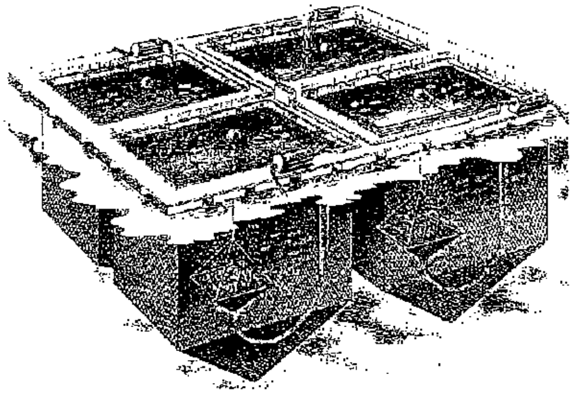

Fig. 7. Diagram of cages with "mini" Lift Up systems.

Table. 2. Comparison of FCR before and after using Aquasmart for feed control among salmon farmers (Data provided by the Company).

Company number	Before Aquasmart	After Aquasmart	Control	Prognosis for 1999
1	1.10	0.83	1.06	0.9
2	1.12	0.86		0.9
3	1.30	0.87		0.95
4	1.20	1.02	1.17	0.95
5	1.15	1.05		1.0
6	1.16	1.02		1.0
7	1.30	1.10	1.20	1.05
8	1.17	1.13		1.08
9	1.05	0.82	0.95	0.90
10	1.30	0.94		1.0
11		1.06	1.15	
Average	1.21	0.97		0.97

Table. 3. Comparison of equipment types in relation to salmon growth and FCR in cage culture (Data Provided by Salmofood).

Cage no.	Equipment type	Initial weight in grams	Final weight in grams	Accumulated FCR
17	Lift Up	460	2,760	0.92
18	Ecofeeder	426	2,645	0.93
19	Aquasmart	443	2,578	1.05
20	Lift UP	418	2,596	0.96

Table. 4. Some VF3 and biological FCR's from five Norwegian salmon farms (from Endal 1998).

Farm	Temp (°C)	Final weight	VF3*	FCR_{BIOL}**
A	10.0	4,110	2.12	0.94
B	10.0	4,328	2.27	1.16
C	9.1	3,676	2.05	1.23
D	8.8	4,447	2.81	1.10
E	6.2	4,688	3.66	1.23

VF3 is the thermic growth factor: $^{*}\mathrm{VF} = 1000 \times \dfrac{V_t^{1/3} - V_0^{1/3}}{\text{day degree}}$

The biological FCR is: $^{**}FCR_{BIOL} = \dfrac{\text{Feed given}}{\text{Weight increase - Weight increase of dead fish}}$

The results of the experiment with Aquasmart, Ecofeeder and Lift Up are given in Table 3.

Discussion

It is difficult to do experiments on an industrial scale and at the same time have the required scientific design. The number of cages and feeders required, make such an experiment difficult or close to impossible to do. This can be illustrated in the results shown in Table 4, which indicates a large variation of FCR among five Norwegian fish farms in 1996 and 1997 (Endal 1998). However, it is obvious that there are large savings made by the Norwegian fish farming industry to start using feed control systems. As fish cages are increasing in size, technical devices which can assist with feed control be come more and more important.

Acknowledgments

I would like to thank Salmofood S.A. for providing me with data from their experiments and the equipment suppliers who have helped me with the information.

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Derived Data for More Effective Modeling of Solid Wastes Dispersion from Sea Cage Farms

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Abstract

A focus of research is modeling the nutrient loading from cage aquaculture in order to predict impacts to allow more effective environmental management. At present, waste dispersion models for marine cage sites rely on scant data on settling velocities of food and fish feces that do not take into account pellet sizes, environmental conditions (temperature, salinity), feed formulation and the re-suspension and degradation of settled food and fecal pellets.

The present work presents empirical data that allows more effective modeling of solid wastes dispersion. The data has been used to refine existing models predicting the fate of nutrients from marine cage farms using mass balance and spatial vector techniques. In this study we first briefly review the environmental impacts of cage aquaculture and waste dispersion modeling. We then outline the methods of determining settling velocities of commercial feeds for sea bass and sea bream, nutrient leaching rate for a range of salmon feeds under defined laboratory conditions and general sedimentation rate of the solid waste from *in situ* cage farm. Data for incorporation into solid wastes dispersion models are summarized.

Introduction

Cage fish farming is dependent on the environment to provide a wide range of environmental goods and services, including the steady supply of dissolved oxygen and the removal and assimilation of wastes (Beveridge *et al.* 1997). Over recent years, there has been increasing concern about the environmental impacts associated with cage-based production systems. As cages are essentially ecologically open systems, there are inevitably wastes produced that are released into the surrounding environment.

Wastes from intensive aquaculture systems primarily consist of uneaten food, metabolic waste (faeces and urine), chemical wastes and feral animals (Beveridge 1984; Lumb 1989; Ackefors and Enell 1990, 1994; Beveridge *et al.* 1991; Blyth *et al.* 1993; Henderson *et al.* 1995; Beveridge 1996; Black *et al.* 1996). Unlike land-based aquaculture systems, marine cage systems discharge their wastes directly into the environment, the bulk of which are solids or bound to particulate material, and thus subject to sedimentation. Sedimentation is dependent on the settling velocity of solids which in turn is dependent upon their physical properties (i.e. food pellet shape and density), current velocity, water turbulence and depth at the sea-cage sites (Hansen *et al.* 1991; Silvert 1992; Gowen *et al.* 1994). In general, impacts from these wastes occur over several spatial and temporal scales: internal, local, and regional (Silvert 1992; Sowles *et al.* 1994; Beveridge 1996). Internal impacts are negative feedback mechanisms in which a particular farm causes detriment to itself (e.g. fish within the cages) and its immediate environment, generally on a scale of a few hundred meters with fluctuations over time measured in minutes or even seconds. However, some internal impacts, such as those associated with fouling, can operate over much longer time scales. Local impacts can affect nearby farms and wild populations within distances of the order of a few hundred meters to a kilometer. Regional impacts involve an entire inlet or larger water body (e.g. a whole bay or fjord and associated rivers) with a spatial influence of many kilometers and time scales ranging from a single tidal cycle to an entire season. An obvious form of local impact, and one receiving much scientific attention, is the deposition of uneaten feed and faecal matter on the seabed under sea-cages (Gowen and Bradbury 1987; Hargrave *et al.* 1993; Wu *et al.* 1994; Johannessen *et al.* 1994; Tsutsumi 1995; Findlay *et al.* 1995; Black *et al.* 1996; Hevia *et al.* 1996; Hargrave *et al.* 1997; Yokoyama *et al.* 1997).

Most studies of the environmental impacts of cage aquaculture have shown an increase in the levels of suspended solids and nutrients (ammonia, organic nitrogen and carbon), and a decrease in dissolved oxygen levels around cages. High rates of waste deposition, in the sediments below cages, can lead to accumulation of organic detritus in the sediments that overwhelm the assimilative capacity of the benthos and result in the formation of anaerobic bacterial mats and anoxic conditions. This in turn leads to the anaerobic generation of hydrogen sulfide and methane. The effects are known to affect both the fish farm and the environment, with visible changes to sediment quality and recognizable changes in benthic communities in the vicinity of fish farms.

To develop cage aquaculture as a sustainable industry it is vital that production processes use natural resources wisely and not exceed the carrying capacity of the environment, while still being profitable. To this end, appropriate control should be enforced to ensure such rational use, which are based on adequate knowledge of the impacts of developmental alternatives and possible means of mitigating the adverse effects of selected uses (Pillay 1992). In general, there are two approaches of monitoring sediment quality: first, by using long-term infrequent surveys (e.g. annual or biannual) to assess the extent of waste accumulation and dispersal beneath the cages; second, by waste dispersion modeling using limited physico-chemical, hydrographical and biological data collected from cage farms for implementation and initial validation. Because the former is costly, i.e. time- and labor-consuming, modeling is often chosen for its cost-effectiveness and rapidity of assessment. There are two components to modeling waste dispersion from cage aquaculture; (1) determination of the quantity and quality (i.e. form) of wastes entering the environment, and (2) determination of where the waste is going, and in what quantity, in terms of two or three dimensional coordinates. To quantify waste entering the environment from uneaten food and fecal material either simple mass balance models or direct measurement can be employed. However, at present, models to calculate dispersion of solid waste rely on scant data sets or assumptions on settling velocities and dispersal behavior of food and fish feces that take no account of particle size, environmental conditions (temperature, salinity), feed formulation and the re-suspension and degradation of settled food and fecal pellets.

To this end, we have carried out a series of investigations to minimize the assumptions in existing dispersion models. Following from a previous study on physical characteristics of diets for Atlantic salmon (*Salmo salar* L.) (Chen *et al.* 1999b), work is presented here in relation to two other principal species of marine fish cultured in Europe, i.e. sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*). Chemical characteristics of nutrient leaching rate for salmon diets were also determined, in order to illustrate the methodology and the implications for modeling waste dispersion. In addition, to provide data to help verify existing models, field work was carried to obtain the sedimentation rate from an *in situ* salmon cage farm to allow comparison between measured and modeled outputs. Although the species investigated in the present study differ from those farmed in cages in Asia, the methodology and approach used to derive data for more effective modeling of solid wastes dispersion is of universal applicability. The examples serve to illustrate the merits of this approach to modeling of cage farm wastes everywhere.

Materials and Methods

Settling Velocity of Feed Pellets

A 1.25 m length of 10 cm diameter perspex tube was chosen for determination of pellet sinking velocity using sea water as the test medium (Chen *et al.* 1999a, b). The transparent tube was marked every 10 cm and either secured in a vertical position or fixed with a support stand that could be moved as required to different environmental conditions (e.g. different temperatures).

The settling rates of sea bass and sea bream diets listed in Table 1 were determined at 20 (± 1) °C and three salinities (20, 33, 40 psu) which approximate a range of *in situ* aquaculture environments. Thirty pellets of each type were taken at random, weighed, and their maximum lengths and diameters measured using digital calipers (digiMax, model m2000; precision 0.1 mm). The settling velocities were determined by timing the descent between two marks, 100 cm apart, the first of which was 5 cm below the water surface (c.f. Robison and Bailey 1981). A supply of water was stored at each temperature, and the water in the tube changed prior to testing each pellet type. Pellets that came into contact with the wall of the tube or those observed to have air bubbles entrained on their surface were excluded from calculations.

Nutrient Leaching Rate of Feed Pellets

Leaching of carbon and nitrogen compounds from fish diet pellets were simulated in the laboratory using 500 ml beakers and an automatic shaker (IKA Labortechnik HS250). Pellet samples (each ~3 g wet weight) from the six commercially available salmon diets from Ewos (2 mm, 6 mm, 6 mm HE) and Trouw (6 mm, 14 mm, 6 mm HE) were assigned at random to six leaching periods: 0, 2.5, 5, 10, 15, 20 min. Samples were suspended in 200 ml of artificial sea water (33 psu) made from a commercial sea salt concentrate (Coralife) at 10 (±1)°C for different immersion period as above, or left in the open air as a control. During immersion, water in the beakers was moving at a constant velocity of 12 cm s^{-1}, similar to the mean settling velocity of the feed pellets (Chen *et al.* 1999b).

After immersion, samples were dried at 105°C for 24 h in a drying oven (Gallenkamp OVE 300). The dried material was carefully ground by pestle and mortar, homogenized, and three replicate sub-samples from each sample taken for determination of total carbon and total nitrogen, as a percentage of total dry-weight, as determined by Perkin Elmer 2400 Elemental Analyser.

Table 1. Sea bass and sea bream pellets used (+) in settling velocity trials.

Diet/Diameter (mm)	1	2	3	4.5	5	7
Sea bass[1]		+	+		+	+
Sea bream	$+^2$		$+^2$	$+^3$	$+^2$	

[1] Sea bass formulations contain 21% total lipid, 47% protein.
[2] Sea bream formulations (3 and 5 mm) contain 17% total lipid, 44% protein.
[3] Sea bream formulations (4.5 mm) contain 12% total lipid, 45% protein (steam-treated diets).

Sedimentation Rates of Solid Wastes from Cage Farm

The sedimentation trap system was designed and modified from the trap system described by Leftley and MacDougall (1991). Three sediment traps were deployed at a depth of approximately 20 m at three locations away from fish cages (position of the center of the cage area: 57°15'10.0" N, 05°30'00.8" W) along a south-easterly transect line (the direction of primary residual current flow) at distances of 10 m, 20 m, and 30 m (Loch Duich marine fish farm, Marine Harvest McConnell Ltd., Letterfearn, Kyle, UK). The sediment traps were deployed during two experimental periods for lengths of time ranging from three days (3-6 September, 1999) to seven days (6-13 September, 1999) to ensure collection of sufficient and representative samples. The mouths of the traps were located approximately 3 m above the sediment surface. Sedimentation samples were taken by disconnecting the sediment collectors from the bottom of each set of traps. The sediment collectors were brought back to laboratory and the contents poured into appropriate measuring cylinders. After 20 min the sediment samples had stratified and settled in the measuring cylinders, the upper stratum of water was then carefully poured off to reduce the water volume and the sediment samples were then placed into pre-weighed foil trays. The sample dry weights were then determined after drying in an oven for 24 h at 105°C to obtain a stable weight. After drying, each sample was prepared for analysis of carbon and nitrogen content as described above. The gross sedimentation rates (GSR), defined as the total amount of material sampled in a sediment trap with a known cross-sectional area over a known length of time (Gremare *et al.* 1997), was calculated as dry weight (DW) $g \cdot m^{-2}d^{-1}$ while nutrient loadings from sedimentation were expressed as $g\ C \cdot m^{-2}d^{-1}$ and $g\ N \cdot m^{-2}d^{-1}$.

Results

Settling Velocities of Feed Pellets

Settling velocities for sea bream and sea bass pellet types are shown in Fig. 1 and Fig. 2, respectively. A two-way ANOVA indicated significant differences ($p < 0.05$) in settling velocity of sea bream and sea bass diets both between different pellet sizes and within each set of environmental conditions (salinity level). The settling

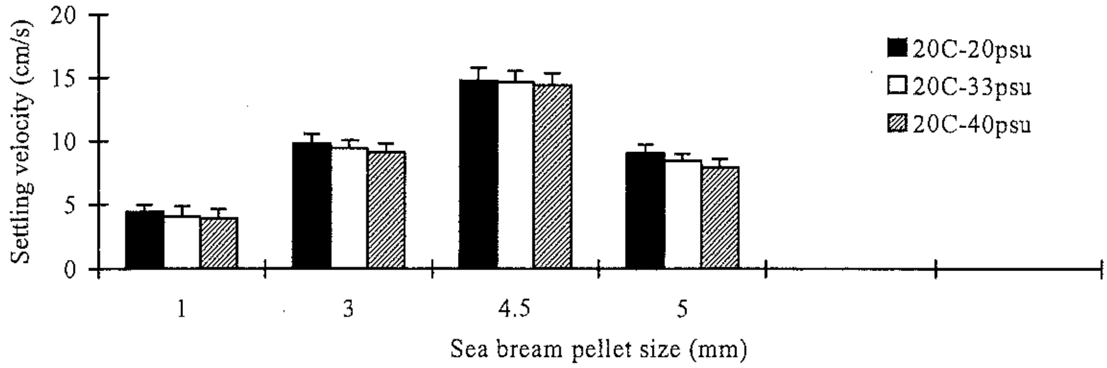

Fig. 1. Settling velocities of a range of sizes of sea bream feed pellets under a range of environmental conditions. Error bars represent 1 standard deviation.

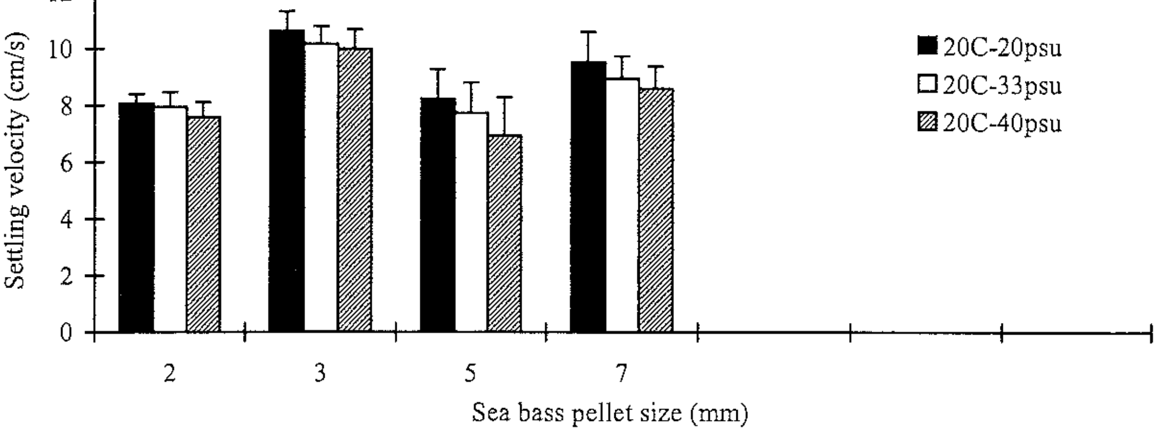

Fig. 2. Settling velocities of a range of size of sea bass feed pellets under a range of environmental conditions. Error bars represent 1 standard deviation.

velocities in water of 20 psu salinity were greater than those in 33 psu and 40 psu for any given pellet type, although differences were not always statistically significant. Under 20°C-33 psu condition, significant differences ($p < 0.001$) in the settling velocities of sea bream pellets were found in the order 4.5 mm > 3 mm > 5 mm > 1 mm (Fig. 1) whereas in sea bass pellets were 3 mm > 7 mm > 2 mm > 5 mm ($p < 0.001$; Fig. 2).

Within the same pellet type (size), there was no correlation between variation in pellet dimensions or nominal pellet densities (maximum length, diameter and weight, determined at room temperature) and settling velocity ($R^2 < 0.3$).

Nutrient Leaching Rate of Feed Pellets

The amount of nutrient leached from salmon diet pellets can be expressed as the differences in the total content of nitrogen or carbon within the pellets before and after immersion in sea water. From elemental composition analysis of pellet nitrogen and carbon over a time span up to 20 min, there were no significant differences ($p > 0.05$) in nutrient leaching between all six salmon diets (Figs. 3 and 4). However, there was a trend with nitrogen content in the smallest pellets (Ewos 2 mm) declining with immersion time (see Fig. 4). Although no statistical differences were found, the nitrogen leaching rate for Ewos 2 mm was estimated from 2.6 to 12.6% after immersion in sea water for 10-20 min.

Sedimentation Rate of Solid Wastes from Cage Farm

Carbon and nitrogen content of material collected in the sediment traps are shown in Table 2. The estimated nutrient loading with sedimentation rate together with the corresponding C/N ratios, are shown in Fig. 5. Carbon contents ranged from 17.4 to 23.5% DW. Nitrogen contents ranged from 1.9 to 2.5% DW. Average C/N ratios ranged from 7.7 to 9.4, the highest value (9.4) occurring at 10 m station in the first trial.

The temporal and spatial changes in sedimentation rates were between 15.4 and 31.7 g $DW \cdot m^{-2}d^{-1}$ in the first trial. Values in the second trial (38.5-65.5 g $DW \cdot m^{-2}d^{-1}$) were twice those of the first trial.

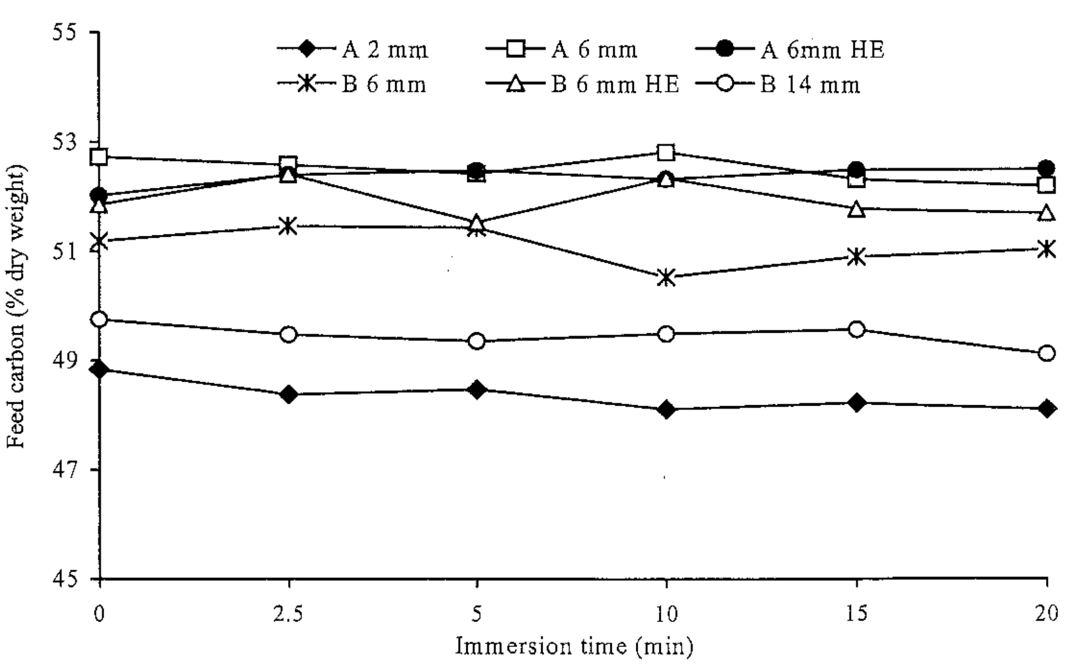

Fig. 3. Mean feed carbon content (% dry weight) of six Atlantic salmon diets (A-Ewos, B-Trouw) after immersion in sea water (10°C-33 psu).

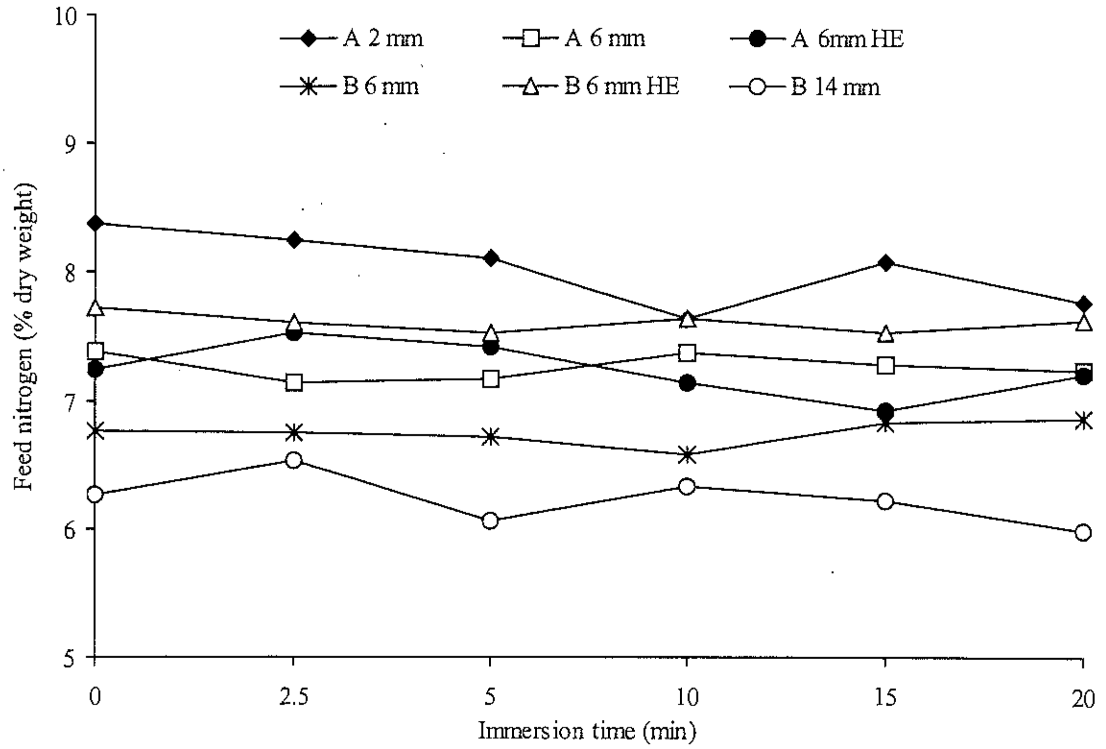

Fig. 4. Mean feed nitrogen content (% dry weight) of six Atlantic salmon diets (A-Ewos, B-Trouw) after immersion in sea water (10 °C-33 psu).

Table 2. Mean value (± S.D.) of sediment characteristics: general sedimentation rate (GSR; $g \cdot m^{-2} \cdot d^{-1}$), total carbon and nitrogen content ($mg \cdot g^{-1}$ dry weight) collected from sediment traps at three sampling stations (10, 20, 30 m from cages) on two sampling occasions (A: 3-6 Sept.1999; B: 6-13 Sept.1999). Figures in parenthesis are % dry weight values.

Sampling occasion and stations	Sediment characteristics		
	GSR	Total carbon	Total nitrogen
A			
10 m	31.7 ± 4.9	235.2 ± 12.5 (23.5)	25.0 ± 1.2 (2.5)
20 m	22.5 ± 0.6	174.0 ± 6.0 (17.4)	20.5 ± 1.9 (2.1)
30 m	15.4 ± 2.1	144.8 ± 12.4 (14.4)	18.7 ± 1.3 (1.9)
B			
10 m	65.5 ± 6.4	216.1 ± 10.0 (21.6)	25.0 ± 1.2 (2.5)
20 m	51.9 ± 2.5	195.1 ± 7.7 (19.5)	23.7 ± 1.0 (2.3)
30 m	38.5 ± 2.0	179.5 ± 6.0 (18.0)	22.2 ± 0.9 (2.2)

Discussion

The settling velocities of uneaten food are important for modeling of solid waste dispersion around cage farms. Settling velocities of extruded diets for sea bream diets ranged from 3.9 to 9.8 $cm \cdot s^{-1}$ and from 6.9 to 10.6 $cm \cdot s^{-1}$ for sea bass diets, broadly similar to those for salmonid diets. These comparisons exclude the steamed pellets (4.5 mm sea bream diets) that had the most rapid settling velocity (approximately 15 $cm \cdot s^{-1}$, Fig. 1) observed in the present study due to their greater density in the producing process. Moreover, there was no trend of increasing settling velocity with pellet size for sea bream and sea bass diets, which was found in Ewos salmon diets (see Chen *et al.* 1999b).

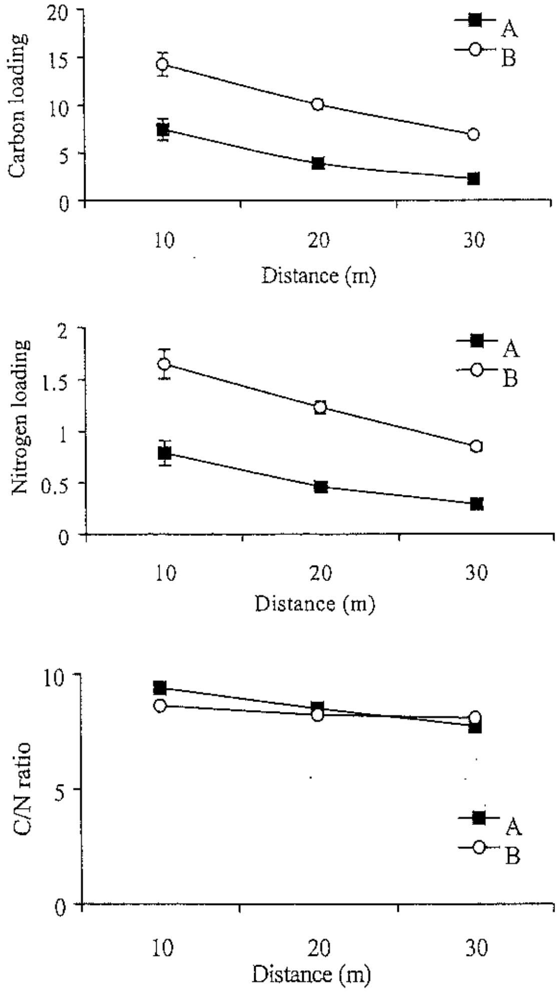

Fig. 5. Mean carbon and nitrogen loading (g C·m^{-2}·d^{-1}; g N·m^{-2}·d^{-1}) and corresponding C/N ratios at three sampling stations (10, 20, 30 m) on two sampling occasions (A: 3-6 Sept. 1999; B: 6-13 Sept. 1999), estimated from sediment trap data. Error bars represent 1 standard deviation.

The published data on settling velocities of aquaculture feeds is scanty. However, the settling velocities which are published for salmon diets (Gowen and Bradbury 1987; Findlay and Watling 1994; Elberizon and Kelly 1998; Chen *et al.* 1999b) were similar to sea bream and sea bass diets found here. In the present study, the use of large sample sizes (30 replicates per treatment) increased the statistical reliability of the settling velocity data (coefficients of variation ranged between 4-19 %, 6-18 % in sea bass and sea bream diets, respectively). Further, the experimental water column was much deeper than those used in other particle settlement studies (Robison and Bailey 1981; Findlay and Watling 1994), thereby reducing influences of drag by the tube walls and resistance exerted by the tube bottom.

Estimates were calculated of the time taken for the slowest (ProAqua 1 mm) and fastest (ProAqua 4.5 mm) settling sea bream pellets to fall through a 30 m water depth, typical of most fish farm sites, at 20°C and 33 psu. These were 738 s and 205 s, respectively.

Given the differences in settling times between feed pellet size shown by various authors, it might be expected that nutrient release is greater from smaller than from larger feed pellets. Any variation in nutrient release, however, is compounded by differences in surface area: volume ratios, smaller pellets leaching more nutrients in a given time than larger ones. The result of feed leaching trial in the present study do not confirm this as there were no significant differences in nutrient leaching of both carbon and nitrogen from all six salmon diets after immersion in sea water for 20 min. However, such pellets are highly water stable (Chen *et al.*, unpublished data). Although there was a trend for nitrogen content in smallest pellets, Ewos 2 mm, declining with the immersion time (see Fig. 3), no statistical differences were found. Hence, considering the time taken for the feed pellet to reach the seabed, the leaching rate of feed pellets was negligible during sedimentation. However, with regards to fecal pellets, another study (Chen *et al.*, submitted), shows that a rapid loss of fecal nutrients occurs 2.5 to 10 min after immersion in sea water. Total carbon and total nitrogen was found to leach by as much as 22% and 26%, respectively, after 5 min immersion.

A general relationship between sedimentation of material and distance from cages was apparent, i.e. more sedimenting material was associated with sampling sites closest to the cages. The dry weight of solid wastes was calculated from the total mass collected in the sediment traps. However, it should be noted that this may be an overestimate due to collection of planktonic material and small aquatic animals. The later posed no problem as they can be easily removed prior to weight determination.

In the absence of production data, it is difficult to compare the amount of food fed and the quantities of fecal material produced between the two consequent sampling trials. However, the amount of wastes produced by a fish farm depends on the total biomass and individual size of fish stocked and the feeding regime. Therefore, the second trial may have collected more sedimentation material than the first one due to different feeding regimes, between the trials, or natural factors such as weather or current speed and direction.

The composition of fish feces depends on the digestibility of the components in food. Data reported by Chen *et al.* (1999a) indicate that approximately 30 to 35% of the dry weight of feces is carbon, with nitrogen contributing about 3%. The carbon and nitrogen content of material collected in the sediment traps in the present study was lower than that of fecal material collected by dissection (Chen *et al.* 1999a) or leached fecal material which had been immersed for 2.5-10 min in sea water (Chen *et al.*, submitted). Since the traps were deployed for three or seven days, it is reasonable to assume that the lower nutrient content was due to more extensive nutrient leaching and organic decomposition.

Due to their faster settling velocities most food pellets would have fallen near to the cage, and possibly not have been collected by the traps. It was not possible, due to the nature of the equipment, to position these traps directly beneath the nets where more food would have been collected. Clearly, therefore, there are difficulties in directly quantifying the proportion of uneaten food and feces which is entering the environment

The carbon loadings found in the three stations contradict estimates from other findings in temperate areas (Hargrave 1994) but are similar to that reported for tropical areas (Angel *et al.* 1992). Hargrave (1994) suggested that the threshold for critical carbon loadings should not exceed assimilative capacity which he estimated to be around 1 g $C \cdot m^{-2} \cdot d^{-1}$ in marine cage farms in temperate areas. Therefore, much more work on this area of research is required.

Conclusion

While spatial distribution and sediment loading models for particulate wastes from marine fish cages have been under development for more than 10 years, the models still contain numerous assumptions that limit their usefulness. These include the use of very limited data for fish feed and fecal pellets sinking rates, which take no account of food manufacturer, type, size or the environmental conditions. The present study provides information on a range of pellet types for three of the most important European farmed fish species that may be readily incorporated into models. Such data, combined with validation of predictions through *in situ* field investigations will help improve the accuracy and usefulness of solid waste dispersal models.

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Long Term Evaluation of the Extruded Pellet Diets Containing Two Fishmeal Replacers for Growing Korean Rockfish (*Sebastes schlegeli*) in the Sea Cage Culture System

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Abstract

Three consecutive experiments were conducted in the sea cage culture system to compare three experimental extruded pellet (EP) diets with one raw fish moist pellet (RF) diet for growing Korean rockfish (*Sebastes schlegeli*). Three experimental EP diets of white fishmeal (WFM), soybean meal (SM) and fishmeal analogue (BAIFA-M) based diets were formulated on isonitrogenous and isocaloric basis of 50% crude protein (CP) and available energy of 16.7 kJ/g diet, and one RF moist pellet diet made of 80% frozen horse mackerel + 20% commercial binder meal. The major protein ingredients in three experimental EP diets are as follows: WFM diet, 100% WFM; SM diet, 70% WFM + 30% SM; BAIFA-M diet, 70% WFM + 30% BAIFA-M (% as the white fishmeal protein source in the diets).

Three different initial sized fish were used in the three consecutive experiments: Exp. I, 20.2 ± 3.6 g (mean ± SD); Exp. II, 57.6 ± 4.7g (mean ± SD); Exp. III, 96.3 ± 6.9g (mean ± SD). There were no significant differences in weight gain, feed efficiency, specific growth rate, hemoglobin, and hematocrit among the fish fed with all four diets. However, fish fed with RF diet had a lower survival rate than the fish fed with the other three EP diets for Experiments I, II and III.

These results indicate that SM and BAIFA-M could replace WFM up to 30% on the basis of CP for the long term feeding program of growing Korean rockfish in the cage culture system. These results also strongly suggest that the commercially well-accepted EP diets could be developed to replace RF moist pellet diet for the mass production of Korean rockfish without any adverse effects on growth performance.

Introduction

Aquaculture is one of the fastest growing agriculture industries throughout the world, and it is growing in response to various factors such as health concerns and limits on wild catch. Based on the trends in regional aquaculture growth over the past decade, world aquaculture production may reach 22 million tons by the end of the century, by the year 2000, one-quarter of the world's consumption of seafood (Bai *et al.* 1999). However, the success of aquaculture will most likely depend on the reduction of dependence of fish feed industry on fishmeal. Since feed cost is the major item of expense in intensive fish culture like any other livestock operation, feed cost management is vital to a successful fish farm operation.

Korean rockfish (*Sebastes schlegeli*) is an important commercial aquaculture fish species in Korea (Bai and Lee 1996). Actually this species has several desirable characteristics for aquaculture including high tolerance to both high and low water temperatures, ease in seedling production due to viviparous reproductive style, and tolerance to high stocking densities. Farming of this species has rapidly developed since 1987, and aquaculture production in 1997 reached 11,314 mt, which is the second largest in marine finfish aquaculture production followed by olive flounder, *Paralichthys olivaceus* (MOMAF 1998).

Moist pellet is one of the most common types of the marine finfish feeds in Korea. However, shortages of raw fish and water pollution from the use of moist pellet are significant constraints to expand the aquaculture industry. Although commercial extruded pellets (EP) have partly been introduced for marine finfish culture, EP diets are not well accepted by the fish farmers because of the lack in EP diets' qualities and palatabilities. Better EP diets and fishmeal analogue should be identified to substitute live fish and fishmeal in the commercial marine finfish feeds. Fishmeal, which has a good palatability and a high nutritional value in protein content and quality, has been used as the main protein source of fish feeds from the past. Since fishmeal is expensive and is one of the main sources of water pollution, nutritionists have anxiously been seeking for cheap and high-quality protein sources as fishmeal replacer during the past decades (Dabrowski and Hardy 1994). Soybean meal has been widely tested as a potential fishmeal replacer in diets for many fish species (Wee and Shu 1989; Reigh and Ellis 1992; Shimeno *et al.* 1993; Kaushik *et al.* 1995; Davies and Morris 1997; Refstie *et al.* 1997; Kang *et al.* 1999), and it has been extensively used in commercial diets. In recent years, our laboratory has been developing a commercial fishmeal analogue (BAIFA-M) made mainly by mixing different animal protein sources. This product has been tested in ingerlings (Kim and Bai 1997; 1999), but not yet in young Korean rockfish. Therefore, objectives of the present study were to evaluate BAIFA-M as a fishmeal replacer and to evaluate three EP and one RF diets for growing Korean rockfish reared in the sea cage culture system.

Materials and Methods

Experimental Design and Diets

The formulation and composition of the experimental diets are shown in Table 1. Three experimental EP diets of white fishmeal (WFM), soybean meal (SM) and fishmeal analogue (BAIFA-M) based diets were formulated on isonitrogenous and isocaloric basis of 50% crude protein (CP) and available energy (Dietary requirement, NRC, 1993, pp. 3-6) of 16.7 kJ/g diet, and one RF moist pellet diet made of 80% frozen horse mackerel + 20% commercial binder meal. The major protein ingredients in the three experimental EP diets are as follows: WFM diet, 100% WFM; SM diet, 70% WFM + 30% SM; BAIFA-M diet, 70% WFM + 30% BAIFA-M (% as the white fishmeal protein source in the diets). WFM, SM and BAIFA-M based EP diets were manufactured from the commercial feed company (Kum Sung Feed Co., LTD). For RF diet locally available frozen horse mackerel (80%) were mixed with 20% of commercial binder meal. The mixtures were pelleted by forcing them through a module, and then the pellets were stored at -20°C until use. The BAIFA-M was formulated by a specific ratio of mixing six animal protein sources such as blood meal, squid liver powder, meat and bone meal, leather meal, feather meal and poultry by-products.

Experimental Fish and Feeding Trial

Growing Korean rockfish *Sebastes schlegeli* were produced at a hatchery in Cheju Island and transferred to a cage culture site, in Tongyoung, Korea, by ship. During a 2-week conditioning period, fish were fed with commercial formulated diets (EP) to adjust to the experimental conditions in the cages (6 m x 6 m x 7 m per cage). Three feeding trials were conducted for three consecutive experiments. In the first 8-week experimental (Experiment I) period, three groups of 2000 fish averaging 20.2 ± 3.6 g (mean ± SD) were randomly assigned to diet treatment. At the beginning of the second 12-week (Experiment II) and the third 10-week (Experiment III) period, fish were redistributed in individual cages as groups of 1300 (57.6 ± 4.7 g) and 1000 (96.3 ± 6.9 g) fish, respectively. During the experimental periods, water temperature ranges were 18.3 ± 3.3°C in Experiment I, 12.6 ± 1.1°C in Experiment II, and 16.3 ± 1.4°C in Experiment III, respectively. Each of the four diets was fed on a dry-matter basis to fish in three randomly selected cages at a rate of 1.5-3.5% (to satiation) of total body weight per day. Fish were fed twice a day at 10:00 and 17:00 h during the three consecutive experimental periods. Fish in each cage were collectively weighed at the beginning and at the end of each experimental period.

Sample Collections and Analyses

At the end of each feeding trial, all fish were weighed and counted to calculate weight gain (WG), feeding efficiency (FE), specific growth rate (SGR), protein efficiency ratio (PER), hepatosomatic index (HSI) and condition factor (CF). Blood was obtained from the caudal vein of three fish randomly selected from each cage and hematocrits were determined by the microhematocrit method (Brown 1980). Hemoglobin was measured in the same three fish by the cyanmethemoglobin procedure using Drabkin's solution. Crude protein, ash and

Table 1. Composition and proximate analyses of four experimental diets (% of dry matter basis)[1].

Ingredients[3]	Experimental diets[2]			
	RF	WFM	SM	BAIFA-M
		1st (2nd & 3rd)	1st (2nd & 3rd)	1st (2nd & 3rd)
White fishmeal	-	41.18 (43.17)	34.38 (37.64)	28.46 (29.85)
Soybean meal	-	14.84 (14.45)	35.00 (36.00)	14.93 (14.95)
BAIFA-M	-	-	-	12.82 (12.82)
Wheat flour	-	21.90 (21.90)	16.43 (14.25)	22.61 (22.80)
Corn gluten meal	-	13.00 (13.00)	4.94 (4.95)	13.00 (13.00)
Poultry by-products	-	1.00 (1.00)	2.50 (2.50)	1.00 (1.00)
Feather meal		1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Fish oil	-	3.00 (3.00)	2.11 (2.11)	2.00 (2.00)
F-K.Mix 6 (SEA)	-	1.00 (0.40)	1.00 (0.40)	1.00 (0.40)
Fish-Minerals	-	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
M-CaP	-	0.50 (0.43)	0.50 (0.50)	0.53 (0.53)
Zeolite-120	-	0.43 (0.50)	0.50 (0.50)	0.50 (0.50)
Mexsil	-	0.10 (0.10)	0.10 (0.10)	0.10 (0.10)
Vitamin C-Fish	-	0.05 (0.05)	0.05 (0.05)	0.05 (0.05)
Commercial binder meal	20	-	-	-
Frozen horse mackerel	80	-	-	-
Proximate analysis				
1st experiment				
Moisture	59.0	4.2	4.4	5.6
Crude protein	60.3	49.4	49.6	49.3
Crude lipid	12.1	7.9	8.6	10.9
Crude ash	12.4	10.8	10.3	9.5
2nd & 3rd experiments				
Moisture	58.4	7.6	7.6	7.2
Crude protein	59.3	50.1	49.2	50.0
Crude lipid	12.1	7.9	8.9	11.1
Crude ash	12.5	11.0	10.8	9.7

[1] Ingredients information and formulation method are explained in Kim and Bai (1997).

[2] Protein source: RF, raw fish 100%; SM, soybean meal 30% + white fishmeal 70%; WFM, white fish meal 100%, and BAIFA-M, fish meal analogue 30% + white fishmeal 70% (BAIFA-M).

[3] Kumsung Feed Co., Pusan, Korea.

moisture of whole-body and the experimental diets were analyzed following the AOAC method (1995) while crude fat was determined by using the Soxtec system 1046 (Tecator AB, Sweden) after freeze-drying the sample.

Statistical Analysis

All data were analyzed by one-way ANOVA (Statistix 3.1, Analytical Software, St. Paul, MN, USA) to test for differences among treatments. When a significant treatment effect was observed, a Least Significant Difference (LSD) test was used to compare the means. Treatment effects were considered with the significant level at $P < 0.05$.

Results and Discussion

Growth and feed performance data of growing Korean rockfish for the three experimental feeding trials are summarized in Tables 2, 3, and 4. For the three experiments, I (20 g), II (57 g) and III (96 g), there were no significant differences in weight gain (WG), feed efficiency (FE), and specific growth rate (SGR) among the fish fed with raw fish (RF) moist pellet diet, and white fish meal (WFM), soybean meal (SM) and fish meal analogue (BAIFA-M) based three EP diets ($P > 0.05$). In Experiment I, the value of WG ranged from 176.9% to 178.6% and FE were 62.1% to 62.6%. These values are comparable to our previous results observed in Korean rockfish averaging 25.1g fed with the similar diet and feeding strategy (Kim and Bai 1999). In Experiments II and III, WG and FE were only 58.6-62.8% and 48.4-52.5% (with 57 g fish), and 40.8-46.6% and 38.8-44.6% (with 96 g fish), respectively. The low water temperature in natural environment or nutritional changes in the diets may have caused poor growth rate in Experiments II and III. SGR obtained in this study were lower than those reported by Kim and Bai (1997). Kim and Bai (1997) found that SGR of Korean rockfish averaging 2.8 g ranged from 1.29% to 1.50%. These results may indicate differences in digestibility and nutrient limitations of the dietary treatments (Meilahn *et al.* 1996). Protein efficiency ratio (PER) of fish fed SM, WFM and BAIFA-M based EP diets were not significantly different from other ($P > 0.05$). PER of fish fed with RF moist pellet diet was signifi-

Table 2. Results of Experiment I with 20 g Korean rockfish for 8 weeks[1].

	Diets				Pooled sem[2]
	RF	WFM	SM	BAIFA-M	
WG (%)[3]	178.6	177.4	176.7	176.9	0.81
SGR (%)[4]	0.64	0.63	0.63	0.63	0.002
FE (%)[5]	62.6	62.3	62.1	62.3	0.26
PER[6]	1.04^{b}	1.26^{a}	1.25^{a}	1.26^{a}	0.03
Survival (%)	88.6^{b}	98.3^{ab}	98.2^{ab}	98.5^{a}	0.40
HSI (%)[7]	2.88	3.21	2.76	2.77	0.11
Hb (g/dl)[8]	7.75	7.82	7.69	7.78	0.25
Hematocrit	30.3	30.5	30.1	29.8	0.68
CF[9]	1.73^{a}	1.73^{a}	1.64^{a}	1.42^{b}	0.05

[1] Values are means from triplicate groups of fish where the means in each row with different superscripts are significantly different ($P < 0.05$).

[2] Pooled sem = Pooled standard error of mean.

[3] Weight gain = (final weight - initial weight) x 100/initial weight.

[4] Specific growth rate = [(ln final weight - ln initial weight)/days] x 100.

[5] Feed efficiency = (increase in biomass of fish x 100)/feed intake.

[6] Protein efficiency ratio = weight gain/dietary protein intake.

[7] Hepatosomatic index = liver weight x 100/body weight.

[8] Hb = hemoglobin.

[9] Condition factor = (wet weight/total length^{3}) x 100.

cantly lower than those of fish fed with the other experimental EP diets ($P < 0.05$) in experiment I. However, PER of fish fed with RF moist pellet diet was significantly higher than those of fed with SM, WFM and BAIFA-M based EP diets in Experiments II and III ($P < 0.05$). Meilanh *et al.* (1996) reported a general decrease in PER corresponding to increases in Pro-Pak (commercial fishmeal analog) in the test diets; the differences were not significant. Their results combined with differences in pepsin digestibility values, may indicate differences in digestibility. Our results may suggest that the digestibility of different fish sizes in protein is different. Further evaluations of the digestibility of RF, SM, WFM and BAIFA-M in different sizes within the same

Table 3. Results of Experiment II with 57 g Korean rockfish for 12 weeks[1].

	Diets				Pooled sem[2]
	RF	WFM	SM	BAIFA-M	
WG (%)[3]	62.8	60.1	58.6	59.9	1.11
SGR (%)[4]	0.30	0.29	0.29	0.29	0.004
FE (%)[5]	52.5	50.4	48.4	49.6	0.91
PER[6]	0.89^{a}	0.85^{b}	0.82^{b}	0.84^{b}	0.02
Survival (%)	86.7^{b}	98.4^{a}	96.9^{a}	95.8^{a}	1.48
HSI (%)[7]	2.30^{c}	3.28^{ab}	2.72^{bc}	3.51^{a}	0.17
Hb (g/dl)[8]	7.87	7.79	7.95	7.92	0.26
Hematocrit	34.4	35.2	35.4	34.5	0.67
CF[9]	1.52^{b}	1.78^{a}	1.63^{ab}	1.90^{a}	0.05

[1] Values are means from triplicate groups of fish where the means in each row with different superscripts are significantly different ($P<0.05$).

[2] Pooled sem = pooled standard error of mean.

[3] Weight gain = (final weight - initial weight) x 100/initial weight.

[4] Specific growth rate = [(ln final weight - ln initial weight)/days] x 100.

[5] Feed efficiency = (increase in biomass of fish x 100)/feed intake.

[6] Protein efficiency ratio = weight gain/dietary protein intake.

[7] Hepatosomatic index = liver weight x 100/body weight.

[8] Hb = hemoglobin.

[9] Condition factor = (wet weight/total length^{3}) x 100.

Table 4. Results of Experiment III with 96 g Korean rockfish for 10 weeks[1].

	Diets				Pooled sem[2]
	RF	WFM	SM	BAIFA-M	
WG (%)[3]	46.6	42.2	40.8	41.2	1.32
SGR (%)[4]	0.20	0.20	0.19	0.20	0.004
FE (%)[5]	44.6	40.4	38.8	39.6	1.26
PER[6]	0.76^{a}	0.68^{b}	0.65^{b}	0.67^{b}	0.02
Survival (%)	95.1^{b}	97.5^{a}	97.4^{a}	98.7^{a}	0.44
HSI (%)[7]	2.54^{c}	4.34^{ab}	4.17^{bc}	3.73^{a}	0.24
Hb (g/dl)[8]	8.49	8.54	8.36	8.57	0.26
Hematocrit	38.5	38.6	38.4	38.2	0.94
CF[9]	1.79^{b}	1.91^{a}	1.85^{ab}	1.91^{a}	0.03

[1] Values are means from triplicate groups of fish where the means in each row with different superscripts are significantly different ($P < 0.05$).

[2] Pooled sem = Pooled standard error of mean.

[3] Weight gain = (final weight - initial weight) x 100/initial weight.

[4] Specific growth rate = [(ln final weight - ln initial weight)/days] x 100.

[5] Feed efficiency = (increase in biomass of fish x 100)/feed intake.

[6] Protein efficiency ratio = weight gain/dietary protein intake.

[7] Hepatosomatic index = liver weight x 100/body weight.

[8] Hb = hemoglobin.

[9] Condition factor = (wet weight/total length^{3}) x 100.

species are necessary in the future. Survival rate (SR) of fish fed with SM, WFM and BAIFA-M based EP diets were not significantly different from each other ($P > 0.05$). However, fish fed with RF moist pellet diet showed a significantly lower SR than that of fish fed with the BAIFA-M diet ($P < 0.05$) in Experiment I, but there is no significant difference observed in SR among fish fed with RF, SM and WFM based diets. In Experiments II and III, SR of fish fed with RF moist pellet diet is significantly lower than those of fish fed with SM, WFM and BAIFA-M based EP diets ($P < 0.05$). Based on the three consecutive experiments, the three experimental EP diets resulted in better SR than RF moist pellet diet. In order to get the better yield in Korean rockfish cage culture, it is necessary to use the formulated EP diets in the future.

Under our experimental conditions, SM and BAIFA-M could replace WFM up to 30% on the basis of CP for the long term feeding program of growing Korean rockfish in the cage culture system without any adverse effects on growth performance. Soybean meal is the most frequently studied dietary ingredient as a fishmeal replacer in many fish diets (Webster *et al.* 1992; Kaushik *et al.* 1995; Gomes *et al.* 1995; Kang *et al.* 1999). A combination of distillers grains with soluble and soybean meal can totally replace fishmeal in the diet without adverse effects on the growth and survival of catfish *Ictalurus punctatus* (Webster *et al.* 1992). Replacement of fishmeal by soy protein concentrate from 33 - 100% did not show differences in growth rates and nutrient utilization in 80 g rainbow trout for 12 weeks (Kaushik *et al.* 1995). Kang et al (1999) also reported that inclusion of 31% soybean meal did not affect growth and feed utilization in 26 g parrotfish for seven weeks. Our results also indicated that soybean meal could be used to replace 30% of WHM in Korean rockfish diets. BAIFA is a mixture of several animal protein sources, and it has been investigated in our laboratory in Korean rockfish (Kim and Bai 1997 and 1999) and common carp *Cyprinus carpio* (Park *et al.* 1999). It is reported that BAIFA-F, which is designed to be used in freshwater fish diets, can replace up to 60% of fish meal in common carp without any adverse effects, while BAIFA-M, which is designed to be used in marine fish diets, can replace up to 45% of fish meal in Korean rockfish fingerling (Kim and Bai 1997). In these three consecutive experiments, it also indicated that BAIFA-M could be used in Korean rockfish to replace fishmeal up to 30% in their diets without any adverse effects on growth performance.

In the biological measurements, hepatosomatic index (HSI) in Experiment I was not significantly different among all the dietary treatments ($P > 0.05$), and fish fed with RF moist pellet diet showed a significantly lower HSI than those fed with WFM and BAIFA-M based EP diets ($P < 0.05$) in Experiments II and III. HSI values (2.3-4.3) obtained in these experiments were similar to those (3.13-3.59) fish averaging 2.8 g (Kim and Bai 1997) and to those (2.07-2.69) fish averaging 25.1 g (Kim and Bai 1999) Korean rockfish. No significant difference was observed in hematocrit in the present experiments, which is approximately 30-38%. This result is similar to 35% among fish averaging 12.6 g (Bai *et al.* 1996); lower than 46-48% from fish averaging 2.8 g (Kim and Bai 1997) Korean rockfish. Hemoglobin ranged from 7.7 to 8.6 g/dl in our experiments. These values are also similar to 8.0-8.3 g/dl from 12.6 g (Bai *et al.* 1996) and 7.5-8.0 g/dl from 25.1 g (Kim and Bai 1999), but higher than those of 5.5-6.6 g/dl from 2.8 g (Kim and Bai 1997) size of Korean rockfish. When compared to the other species, the results of the present experiments were lower than those of 9-10g/dl from common carp data (Park *et al.* 1999), but higher than those of 3.6-5.5 g/dl from Japanese flounder *Paralichthys olivaceus* data (Kikuchi *et al.* 1994). Many researchers indicated that the changes could have been due to many different factors such as the essential nutrient contents in the diets, the environmental conditions and the fish species.

Whole-body proximate compositions at the end of the feeding trials are shown in Table 5. Crude protein (CP) of fish from SM, WFM, and BAIFA-M based EP diets were not significantly different in Experiments I and III ($P > 0.05$). Fish fed with WFM based EP diet showed significantly

Table 5. Results of Experiments I, II and III for whole body proximate analyses in Korean rockfish (% of dry matter basis)[1].

	Diets				Pooled sem[2]
	RF	WFM	SM	BAIFA-M	
Exp. I					
Moisture	65.6^{c}	69.5^{ab}	70.3^{a}	66.9^{bc}	0.76
Crude protein	53.0^{b}	59.0^{a}	60.2^{a}	58.2^{ab}	1.15
Crude fat	33.7^{a}	27.5^{b}	22.2^{c}	27.5^{b}	1.50
Ash	13.6^{b}	14.3^{ab}	17.0^{a}	12.6^{ab}	0.74
Exp. II					
Moisture	67.6^{b}	67.8^{ab}	70.5^{a}	67.4^{b}	0.53
Crude protein	52.1^{b}	53.6^{b}	58.7^{a}	55.1^{ab}	0.99
Crude fat	26.7^{a}	26.0^{a}	21.9^{b}	26.9^{a}	0.91
Ash	14.9^{ab}	17.4^{a}	16.9^{a}	13.4^{b}	0.60
Exp. III					
Moisture	66.5^{b}	67.9^{a}	68.6^{a}	68.5^{a}	0.29
Crude protein	50.9^{b}	53.3^{ab}	55.5^{a}	55.7^{a}	1.73
Crude fat	31.7^{a}	29.5^{ab}	27.5^{b}	28.6^{ab}	0.69
Ash	13.0^{a}	13.1^{a}	14.7^{a}	13.9^{a}	0.38

[1] Values are means from triplicate groups of fish where the means in each row with different superscripts are significantly different ($P < 0.05$).

[2] Pooled sem = Pooled standard error of mean.

lower CP compared with SM diet group ($P < 0.05$) but no significant differences existed among fish fed with RF, WFM and BAIFA-M diets ($P > 0.05$) in Experiment II. Fish fed with BAIFA-M based diet showed a significantly lower crude fat than those fish fed with RF moist pellet diet ($P < 0.05$) in Experiment I, but no significant differences was observed in crude fat among those fish fed with RF, WFM, and BAIFA-M diets in Experiments II and III. However fish fed with BAIFA-M based EP diet showed a significantly lower ash and moisture than those fish fed with the other three diets in Experiments II and III ($P < 0.05$). Nandeesha *et al.* (1995) reported that the proximate composition of the whole-body is affected by the environmental conditions, different genealogy, growth rate, feeding supply and diet formulations.

Therefore, these results indicate that BAIFA-M and SM could be used to replace WFM up to 30% on the basis of CP for the long term feeding program of growing Korean rockfish in the cage culture system without any adverse effects on growth performance. These results also strongly suggest that it is possible to use the extruded pellet diets containing WFM, SM and/or BAIFA-M to replace RF moist pellet diet in the mass production cage culture system for Korean rockfish.

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High Performance Grow-out Pelleted Diets for Cage Culture of Barramundi (Asian Sea Bass) *Lates calcarifer*

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Abstract

In Australia, barramundi (Asian sea bass) *Lates calcarifer* (Family Centropomidae) are reared to market weight on compounded dry-pelleted diets that traditionally contain high inclusions of fishmeal. Since 1993, the Australian Fisheries' Research and Development Corporation has supported a nationally coordinated research program to find more sustainable and renewable terrestrial protein alternatives to marine resources for the manufacture of aquafeeds. The research has focused on determining the suitability of terrestrial feed ingredients for barramundi by quantifying their digestibility and nutrient retention. In parallel, research has defined the requirements of the fish for critical, high cost nutrients – particularly crude protein (CP), essential fatty acids and energy. As a result of this research, highly effective barramundi grow-out diets containing little to no fishmeal have been developed and demonstrated under commercial cage-farming conditions to deliver equivalent or better fish growth and profits than traditional diets containing high inclusions of fishmeal. The potential of high-density diets (≥ 55% CP; ≥ 20% lipid) to further improve fish productivity and to minimise environmental impacts of the feed over that of standard diets (~45% CP; ~10% lipid) has given encouraging results under both laboratory and commercial cage culture conditions. Discount cash flow modelling has showed the internal rate of return on investment to increase from 8 to 23% by feeding the high density diet compared to the standard diet. This paper discusses the research carried out in Australia to develop cost-effective, low-polluting and high performance grow-out diets for cage-culture of barramundi.

Introduction

The farming of barramundi or Asian sea bass *Lates calcarifer* (Family Centropomidae) is an industry of growing importance in Australia. Because trash fish supplies are not abundant, barramundi are universally cage-reared and fed in Australia on compounded pelleted dry diets. The major economic impediments to intensive fish and shrimp farming in Australia as elsewhere in the world are the high cost of feeding and sensitivity to price received for the cultured animal (Chen *et al.* 1995; Paquotte *et al.* 1998; Shang *et al.* 1998). Detailed economic analyses of barramundi farming in Australia (Treadwell *et al.* 1991; Johnston 1997, 1998) also showed that farm profitability was very sensitive to changes in yield and price of marketed product while feed and labor comprised more than 50% of total operating costs. Reducing feed costs by better tailoring the dietary specifications to the nutrient requirements of the fish, providing these nutrients at least cost and adopting feeding practices that optimize productivity would greatly improve farm profitability.

The development of aquafeeds with a reduced content of fishery product is an urgent priority for all intensive aquaculture industries. Growth of the capture fisheries sector is very small (0.2% since 1996 and only 1.5% annually since 1984) and future yields are more likely to deteriorate than to improve (Tacon 1997, 1999; FAO 1999; Hardy 1999). Trash fish or fishmeal is the major protein source currently used in fish and shrimp feeds and comprises 50% or more by weight of the total feed (Lovell 1992; New 1996; Tacon 1997; Hardy 1999). Tacon (1999) estimated that 2.3 million tons (mt) of fishmeal is used annually for aquafeeds. In a typical year this constitutes about 35% of the world's annual production of fishmeal and almost 50% in 1998 when production fell to 4.75 mt because of the *El Niño* effect on the anchovy harvest. Clearly, the continued use of fishmeal at high inclusions in aquafeeds is not sustainable and diets based on more renewable terrestrial alternatives must be developed. Australia is particularly vulnerable to any world shortage of fishmeal as domestic production is just one tenth that of the amount imported (ABARE 1998). However, Australia has an abundant supply of terrestrial animal and plant protein meals, which have the potential to at least partly, if not fully replace the fishmeal presently used in compounded aquafeeds.

In 1993, the Australian Fisheries' Research and Development Corporation (FRDC) established a nationally-coordinated research program to develop improved and more cost-effective aquafeeds for four key farmed species: Atlantic salmon *Salmo salar*, black tiger prawn *Penaeus monodon*, silver perch *Bidyanus bidyanus* and barramundi (Allan 1997). All of these species in Australia are fed on pelleted dry aquafeeds containing high inclusions of fishmeal. The research program brought together 11 Australian aquaculture nutrition research groups to work collaboratively to find more sustainable and renewable terrestrial protein alternatives to marine resources for the manufacture of aquafeeds. The approach was to determine the apparent digestibility and assimilation of terrestrial protein meals as alternatives to fishmeal, define the requirements of the animals for key nutrients and demonstrate the cost-effectiveness of the developed diets under both laboratory and commercial cage farming conditions. This paper summarizes some of the research studies that have been carried out to develop high performance pelleted diets for on-growing of barramundi.

Apparent Digestibility of Feed Ingredients

Information on the apparent digestibility of alternative feed ingredients is critical for developing nutritionally-adequate and cost-effective aquaculture diets. However, the determination of apparent digestibility in aquatic animals is difficult. Complete recovery of feces as required for direct measurement of apparent digestibility is virtually impossible (Smith *et al.* 1980; De la Noue and Choubert 1986). For the indirect measurement of apparent digestibility using digestibility markers, obtaining a representative sample of voided feces, unaffected by leaching or urinary contamination, is not without considerable difficulty (Windel *et al.* 1978; Smith *et al.* 1980; Spyridakis *et al.* 1989; Brown 1991; Satoh *et al.* 1992). We examined hind gut dissection, manual fecal expression and various sedimentation techniques as alternative methods for fecal recovery and also compared chromium, titanium and ytterbium salts as alternative digestibility markers.

Total collection and sedimentation methods were unacceptable because of the rapid and quantitatively large amount of nitrogenous compounds lost from the feces into the surrounding water. As much as 53% of the dry matter (DM) and 62% of the total N of the feces were present in the liquid phase after a period of 24 h suspension in water. After 6 h suspension, proportionally more of the total N was associated with the suspended fraction than with the sediment (59.9% vs 29.7% of the original sample). The composition of the N in the supernatant and in the sediment was different; the sediment contained a high proportion of precipitable N (41.9% of original) compared to the supernatant (13.9% of original). This indicates that the N in the supernatant, as expected, is predominantly soluble. Collection of sedimented feces recovered after 3 h contact with water resulted in apparent digestibility estimates that were far higher ($p < 0.05$) than those derived using fecal samples recovered by dissection from the hind gut: DM, 69.6 vs 58.2%; crude protein (CP), 90.9 vs 80.3%; and gross energy (GE) 81.3 vs 72.5%, respectively.

The intestinal dissection procedure gave reliable digestibility estimates but the small fecal sample obtained and the high costs of labor and fish were serious disadvantages that militated against its use for routine determination of digestibility. Manual stripping of large barramundi (>300 g) also produced reliable digestibility estimates and this is advocated as being the best method of recovering feces for apparent digestibility measurement in barramundi. All three markers produced reliable digestibility estimates but ytterbium acetate was preferred because of its solubility (facilitated even dispersion in the diet), precise analytical measurement and absence of toxicity.

The chemical composition and determined apparent digestibility with barramundi of major protein sources available in Australia for aquafeed manufacture are detailed in Table 1. Protein and energy apparent digestibilities were high for all meals although the animal feed ingredients were slightly better digested than the plant meals except for wheat gluten, which was completely digestible. The digestibility of meat meal was variable and lower than for fishmeal and this was attributed to the meat meal's high ash content. These results demonstrate the similarity of barramundi to other carnivorous fish such as salmonids in being able to digest protein and energy from a wide variety of different terrestrial feeds (Hajen *et al.* 1993; Dong *et al.* 1993; Gomes *et al.* 1995; Gaylord and Gatlin 1996). This species similarity could be used by feed formulators to extrapolate data on the apparent digestibility of feed ingredients determined in one species with that of another where specific information is not available.

The cost-effectiveness of the alternative terrestrial protein meals in supplying digestible crude protein (DCP) and lysine (DLys) is detailed

Table 1. The chemical composition and apparent protein and energy digestibility coefficients determined with barramundi of major protein feed ingredients in Australia.

Feed ingredient	Composition (as fed basis)					Digestibility coefficients (%)[1]	
	Dry matter	Ash (%)	Fat (%)	Protein[2] (%)	Gross energy ($kJ \cdot g^{-1}$)	Protein	Energy
Fishmeal (Danish)	91.4	11.9	10.4	69.5	20.2	87.9± 0.98	83.3±1.27
Fishmeal (tuna)	93.3	28.3	10.4	52.9	16.1	92.3± 0.98	69.3±1.27
Poultry offal meal	92.3	16.4	13.4	60.7	19.8	78.8±3.5	76.7±5.6
Meat meal	93.8	31.8	10.3	54.5	16.4	53.9±3.9	58.2±6.5
Meat meal	95.5	23.1	13.9	58.1	18.0	63.5±3.4	66.5±3.4
Soybean meal (full fat)	91.0	4.8	16.7	40.8	19.7	84.8±3.8	75.9±7.8
Soybean meal (solv ext)	91.0	6.6	1.5	48.2	18.1	86.0±0.8	69.4±1.7
Canola meal	95.1	6.5	2.9	38.9	18.7	81.0±2.3	56.1±3.0
Lupin (dehulled)	89.5	2.4	7.9	39.4	17.1	98.1±1.3	61.5±1.8
Peanut meal	95.5	2.6	45.8	30.7	27.7	91.9±8.0	68.7±5.0
Wheat gluten meal	91.7	1.5	2.2	77.1	21.9	101.9±1.6	98.8±3.1

[1] Mean ± standard error. Data (Williams *et al.* 1998b) derived from feces collected either by hand stripping of the fish or intestinal dissection.

[2] N x 6.25.

in Table 2. Except for gluten, the plant protein meals were the cheapest sources of DCP and DLys and appreciably cheaper than fishmeal. Canola meal was the least expensive source of DCP and DLys but its unpalatability and poor acceptance by barramundi are particular problems if it is used at dietary inclusions above 10 to 15%. Meat meal was also much cheaper than fishmeal as a source of DCP and DLys.

Nutrient Assimilation from Alternative Feed Ingredients

The extent to which an animal utilizes absorbed nutrients, irrespective of their ingredient source, depends on how well all of the nutrients collectively satisfy the animal's immediate needs for maintenance, growth and/or reproduction. Theoretically, a diet containing all of the "essential" and "non-essential" nutrients in amounts ideally balanced to the immediate requirements of the animal will enable the nutrients to be utilized at the highest possible efficiency. Any departure from this ideal balance of nutrients would be expected to result in some lowering in the efficiency of nutrient utilisation (Cho *et al.* 1982; Knights 1985; Steffens 1989; Kaushik and Medale 1994). However, the effect of any such nutrient imbalance, or more specifically a relative deficiency of a nutrient, will vary according to the "essentiality" of the nutrient in question. Where metabolic processes allow the nutrient to be synthesized *de novo*, a dietary insufficiency of a particular nutrient may have little effect other than to elicit some reduction in overall nutrient utilization efficiency. Conversely, where the nutrient cannot be synthesized *de novo* or at a rate that sufficiently meets the animal's requirements, a dietary deficiency of such an "essential" nutrient will have more profound effects, varying in degree from slight growth retardation and inefficiency of nutrient utilization to death in the extreme.

The efficiency with which protein and energy was utilized by juvenile barramundi when fed diets of different protein source was investigated in growth experiments of 6 to 8 weeks duration. The net energy and protein accretion of the fish during these experiments were determined using conventional comparative slaughter procedures (Williams *et al.* 1995) and retention efficiency expressed as a function of dietary intake.

A summit dilution methodology adapted from that used by Fisher and Morris (1970) for determining the methionine requirement of laying hens was used to study protein and energy retention efficiencies when individual feed ingredients were serially substituted for a nutritionally-adequate summit diet. Twelve diets were fed in each experiment: the summit diet (Table 3)

Table 2. Cost of selected feed ingredients in Australia and costs[1] to supply digestible protein and lysine for barramundi.

Ingredient	Ingredient cost ($\$US \cdot t^{-1}$)	Dig. protein cost ($\$US \cdot kg^{-1}$)	Dig. lysine cost[2] ($\$US \cdot kg^{-1}$)
Fishmeal (Danish)	715	1.17	17.42
Fishmeal (tuna)	449	0.92	20.59
Poultry offal meal	357	0.75	17.79
Meat meal (52% CP)	218	0.74	11.19
Soybean meal (full fat)	280	0.81	16.90
Soybean meal (solvent)	252	0.61	11.82
Canola meal	150	0.47	5.12
Lupin meal (dehulled)	221	0.57	11.26
Peanut meal	176	0.62	15.78
Wheat gluten meal	1,105	1.43	83.71

[1] Ingredient cost based on Australian market prices ($AUD 1 = US$ 0.65) as of September 1999 (data from QDPI survey and provender millers).

[2] Lysine digestibility assumed to be the same as protein digestibility as found for shrimp and silver perch (Williams *et al.* 1998a)

and this diet serially diluted (other than for the vitamin and trace mineral premixes, which were held constant) with either an inert diluent (diatomaceous earth) at 10% increments up to 40% or with the test ingredient at 10% increments up to 70%. Feed ingredients examined were casein, Peruvian fishmeal, meat meal, solvent-extracted soybean meal and dehulled lupin. The daily food allowance was controlled by scale feeding (based on fish weight) to 75% of satiety to prevent fish from voluntarily increasing food intake as a means of compensating for a nutritional inadequacy of the diet.

Table 3. Formulation and proximate nutrient and energy composition of the summit diet used in the assimilation studies.

Attribute	Summit diet Formulation ($g \cdot kg^{-1}$; as fed)
Wheat (gelled)	240
Fishmeal (65% CP)	337
Squid meal (55% CP)[1]	48
Casein	95
Wheat gluten (82% CP)	145
Fish oil	95
Vitamin mix[2]	30
Mineral mix[2]	10
	Analysis (as fed basis)
Dry matter (%)	92.0
Ash (%)	7.3
Crude protein (%)	49.0
Dig. crude protein (%)	44.5
Crude fat (%)	14.8
Gross energy ($kJ \cdot g^{-1}$)	21.0
Dig. energy ($kJ \cdot g^{-1}$)	18.0

[1]Replaced with fishmeal when not available.
[2]Williams *et al.* (1998b).

In all experiments, dilution of the summit diet with the inert diatomaceous earth resulted in a linear decline in body N and energy accretion, indicating that the fish were responsive to dietary N and energy intake over the entire range of summit diet dilutions examined. Pooled across experiments, the efficiency with which N and energy of the summit diet was retained by barramundi was determined to be 37.8 and 50.6%, respectively. These values compare favorably with those reported for other carnivorous fish where estimates have ranged typically between 20 and 40% for N and 25 and 50% for energy (Brett and Groves 1979; Cho *et al.* 1976, 1982; Pfeffer 1982; Hidalgo and Alliot 1988; Arzel *et al.* 1995; Lanari *et al.* 1999).

Dilution of the summit diet with the respective test feed ingredient resulted in either a curvilinear or a linear change in nutrient retention efficiency. For N retention, the response was curvilinear for each ingredient with the asymptote value being similar to that of the summit diet, namely in the order of 34.5 to 41.7%. However, the extent to which the summit diet could be diluted before N retention efficiency was affected differed between the test ingredients. The effect of substitution rate on retention efficiency was greatest for soybean meal, casein and dehulled lupin and least for fishmeal and meat meal. Moreover, the rate of change in N retention efficiency with progressive test ingredient substitution was fastest for soybean meal, dehulled lupin and casein and slowest for meat meal and fishmeal (differences between fishmeal, meat meal and solvent soybean meal are illustrated in Fig. 1A).

For energy, a similar curvilinear response pattern was observed with each of the animal feed ingredients although the asymptote occurred at a lower substitution rate than for N with meat meal and fishmeal but at a higher rate for casein. A different pattern was seen in the case of both of the vegetable feed ingredients where retention efficiency declined linearly with increasing substitution of the summit diet (Fig. 1B). These differences between the test feed ingredients in retention efficiency response patterns clearly indicate the superiority of the animal protein over that of the vegetable protein. In terms of fish weight gain and nutrient retention, the three animal protein meals – Peruvian fishmeal, casein and meat meal – were clearly superior as substitutes for the summit diet than the dehulled lupin or soybean meals which were of similar nutritive value.

In terms of nutritional value, the most striking differences between animal and vegetable protein meals are the generally lower protein content and inferior essential amino acid profile of the latter. The essential amino acid composition of vegetable protein is characterised by its low content of sulphur amino acids (methionine and cystine), lysine and threonine and its comparatively high content of arginine. At first sight, these essential amino acid differences between the feed ingredients would appear to explain the observed poor retention efficiencies of the soybean and lupin meals. However, calculation of the retention efficiency of each of the essential amino acids showed these to progressively decline as the plant protein meals were increasingly substituted for the summit diet. This is clear evidence that protein deposition in the fish was not being constrained by dietary amino acid supply. Rather, the lower nutritive value of the soybean and lupin meals was undoubtably due to their lower DE content and/or an apparent greater energy inefficiency due to excess DCP having to be catabolised for metabolic energy (Cho *et al.* 1982; Knights 1985; Morales *et al.* 1994).

These studies have shown that terrestrial animal protein meals such as meat meal have considerable potential as alternatives to fishmeal in diets for barramundi. Diets containing high inclusions of meat meal (up to 70% of the diet) were well accepted by the fish and if used in nutritionally balanced diets should be able to replace most if not all of the fishmeal. Plant protein meals on the other hand were not as well accepted by barramundi at high inclusion rates (above about 40% for most meals) and energy

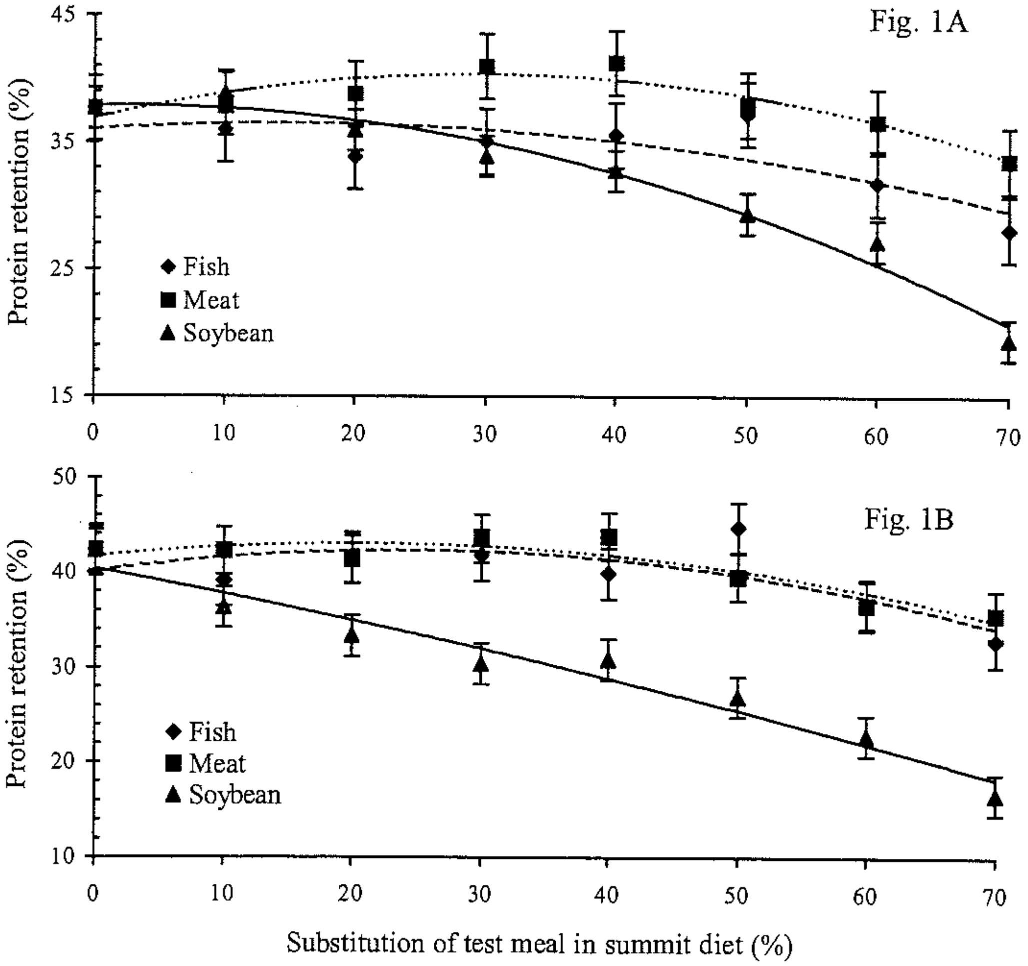

Fig. 1. Effect of serial substitution of a summit diet either by Peruvian fishmeal (Fish), meat and bone meal (Meat); or solvent extracted soybean meal (Soybean) on protein (Fig 1A) and energy (Fig 1B) retention in barramundi. Data standardized across experiments by equating fish performance on the summit diet.

digestibility was low, except for wheat gluten where it was fully available. The protein digestibility of plant protein meals was as high if not higher than animal protein meals. While plant protein meals are unlikely to be successful as complete replacements of fishmeal, they could be used as cost-effective partial replacements.

Nutrient Requirements

The nutrient requirements of barramundi have not been well defined but studies over the last decade have considerably advanced our knowledge on protein, lipid and vitamin requirements (see Boonyaratpalin 1997). These studies indicated that diets containing 40 to 50% CP (based on fishmeal) and 6 to 18% lipid were optimal for the growth of juvenile barramundi with fry requiring slightly higher concentrations of protein than grow-out fish. In a 3 x 3 factorial comparison of CP (35, 42.5 and 50%) and GE (lipid levels of 5, 10 and 15%), Catacutan and Coloso (1995) found a diet containing 50% CP and 15% lipid (a CP to GE ratio of 30 $mg{\cdot}kJ^{-1}$) supported the best barramundi growth. However, the diet containing 42.5% CP and 10% lipid (CP:GE of 31 $mg{\cdot}kJ^{-1}$) resulted in comparable fish growth and better protein efficiency and apparent protein retention. Fish fed the 35% CP diets showed very poor growth. Based on these results, they recommended a dietary specification of 42.5% CP and 10% lipid – a CP to GE ratio of ~31 $mg{\cdot}kJ^{-1}$.

Protein and Protein to Energy Requirements

We have carried out several laboratory tank experiments and on-farm net-cage studies to further define the dietary protein and dietary protein to energy requirements of juvenile barramundi. The production and nutrient retention responses of barramundi to dietary protein were measured in a laboratory experiment when the fish were fed with semi-purified dry pelleted diets in which the CP content was varied serially from 30 to 55% (27 to 52% DCP). The protein was a constant blend of fishmeal, casein, gluten and crystalline amino acids that was formulated to mimic the amino acid composition of barramundi protein. It was included in the diet at the expense of wheat starch with concomitant adjustment of diatomaceous earth and fish oil to maintain constancy of dietary energy (GE, 18.8 $kJ{\cdot}g^{-1}$; DE, ~15.5 $kJ{\cdot}g^{-1}$). The six diets were fed twice daily to apparent satiety to 720 fish (24 tanks each of 800 L stocked with 30 fish of 76 g initial weight) in a five week comparative slaughter growth assay.

As the DCP content of the diet increased, voluntary daily food intake (DFI) progressively declined while food conversion (FCR) similarly improved such that growth rate increased to an asymptote at about 41 to 42% DCP; 44 to 45% CP (Fig. 2). Interestingly, body accretion of N continued to increase curvilinearly with increasing DCP intake but the efficiency of N retention remained constant at 0.37 until an intake of 1.25 $g{\cdot}d^{-1}$ was attained whereupon efficiency steadily declined to reach 0.33 at an intake of 1.4 $g{\cdot}d^{-1}$. This result suggests that for the type of formulations used in the experiment, diets with DCP concentrations lower than about 42% were protein-limiting while those with higher protein concentrations were energy-limiting. The absolute retention of dietary energy also declined at the same point which confirms that the change between protein dependency and energy dependency occurred at about 42% DCP. The DCP:DE ratio at this break point was 26.7 $mg{\cdot}kJ^{-1}$ or in terms of CP:GE, equal to 24.5 $mg{\cdot}kJ^{-1}$. This agrees closely with the CP:GE value of 25.8 $mg{\cdot}kJ^{-1}$ reported by Tubongbanua (1987) but much lower than the estimate made by Catacutan and Coloso (1995) of ~31 $mg{\cdot}kJ^{-1}$. The lower value we found may be due to the reference protein having a more optimal ("ideal") amino acid profile than the protein used in the other cited studies. Further work is being done to confirm this result and to define requirements for essential amino acids.

The experiment failed to adequately define the dietary protein specification that would maximise productivity of barramundi. Nor was it possible to accurately define an optimal dietary protein to energy ratio. The data indicated that a diet containing 42% DCP and 15.5 kJ·g^{-1} DE enabled optimal FCR and N accretion of the fish, suggesting an optimal DCP:DE ratio of 24.5 mg·kJ^{-1}. However, these fish were fed twice daily to apparent satiety and DFI was observed to decline markedly with increasing protein content of the diet. Further, N and energy retention data demonstrated that energy and not protein was limiting the growth rate of the fish. It is speculated that the observed decline in DFI with increasing dietary protein content was not due to protein *per se* but probably the result of increasing unpalatability of the diet due to the higher inclusions of casein and diatomaceous earth. Other work has shown that casein, while highly digestible, is disliked by barramundi and that diatomaceous earth can similarly limit appetite because of its bulk and water absorption.

Two further experiments were carried out to examine the interactive effects of dietary protein and lipid/energy in barramundi held under controlled (28°C and 12:12 photoperiod) laboratory conditions. In the first 48 tank experiment, 12 diets were formulated in which four protein levels – 38, 42.5, 47.3 and 52% CP (34, 38.2, 42.5 and 46.7% DCP, respectively) were factorially arranged on three rates of oil addition – 4.0, 10 and 16% (14.5, 16.3 and 18.0 kJ·g^{-1} DE, respectively). In the second 48 tank experiment, 12 diets were formulated in which the oil inclusion rate was increased from 9 to 14.5 and 20% (DE correspondingly increased from 16 to 18 and 20 kJ·g^{-1}) and combined with four protein levels: serially incremented for each oil addition between 50 and 65% CP (44.5 and 58% DCP), 47.5 and 61% CP (42.5 and 54.5% DCP) and 44 and 60% CP (39 and 53.5% DCP), respectively. In both experiments, changes in dietary protein concentration and oil addition were achieved by serial alteration of casein (for protein) and a 3:1 blend of fish oil and soybean oil (for oil) at the expense of gelled starch and diatomaceous earth. These diets were fed once daily to satiety to fish with initial weights of 230 and 80 g for either eight or six weeks, respectively.

FCR and daily growth rate improved markedly as both the protein and the oil content of the diet increased, showing a clear protein sparing effect of oil addition (Figs. 3 and 4). In the experiment with the plate-size fish, there was no suggestion of an asymptotic response having been achieved at the highest dietary protein and energy concentrations examined, *viz* 46.7% DCP (52% CP) and 18 kJ·g^{-1} DE (Fig. 3). In the fingerling experiment where higher dietary protein

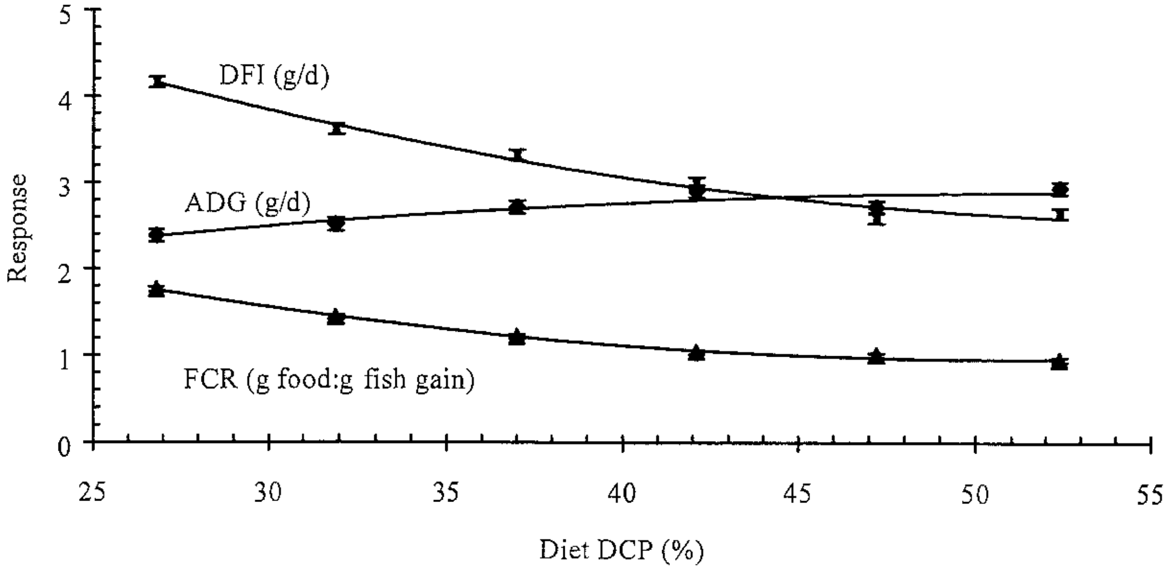

Fig. 2. Daily food intake (DFI), average daily gain (ADG) and food conversion (FCR) responses of fish to diets serially incremented in digestible protein (DCP) at constant energy.

and energy concentrations were investigated, the FCR and growth rate responses to dietary protein were similarly linear for the highest oil addition diet but were curvilinear for each of the two lower oil additions. For these latter two oil addition diets, the asymptote for FCR was achieved at a DCP concentration of 59.3% (66.0% CP) for the 9% oil addition diet and at 53.6% (59.7% CP) for the 14.5% oil addition diet. Corresponding asymptotic values for daily growth rate were 55.2% DCP (61.5% CP) and 53.7% DCP (59.8% CP), respectively. These results indicate that the growth of both small and large barramundi can be markedly improved by the feeding of nutrient-dense diets. Although the protein requirement of barramundi can be spared to some extent by increasing the dietary fat/energy content, the results clearly indicate the need for dietary protein specifications to be held to at least 50% DCP and 20 kJ·g^{-1} DE if the potential growth of barramundi is not to be unduly restricted.

Essential fatty acid (EFA) requirements

There are marked interspecies differences between fishes in the dietary essentiality of n-3 and n-6 fatty acids, even between closely related fish. For example, for optimal survival and growth, chum salmon (*Oncorhynchus keta*) required 1% of both 18:2n-6 and 18:3n-3 in the diet (Takeuchi *et al.* 1979), coho salmon (*O. kisutch*) required 1 to 2.5% of 18:3n-3 but more than 1% of 18:2n-6 was detrimental (Yu and Sinnhuber 1979) and rainbow *trout* (*Salmo gairdneri*) required 0.8 to 1.6% of 18:3n-3 but with no demonstrated requirement for n-6 fatty acids (Castell *et al.* 1972a, b; Watanabe *et al.* 1974). In addition to the essentiality for individual EFAs, there is mounting

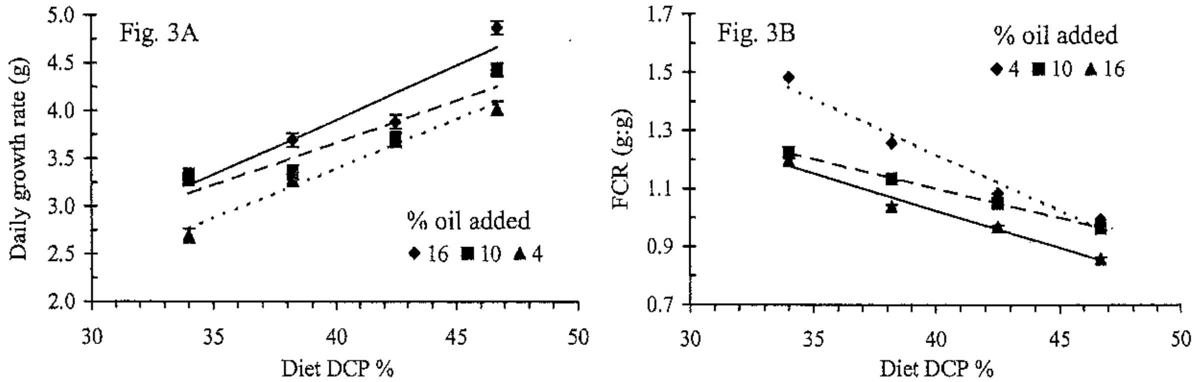

Fig. 3. Growth rate (Fig. 3A) and food conversion ratio (FCR) (Fig. 3B) of plate-size barramundi (initially 230 g, grown to about 475 g) fed with diets varying in digestible crude protein (DCP) and oil content.

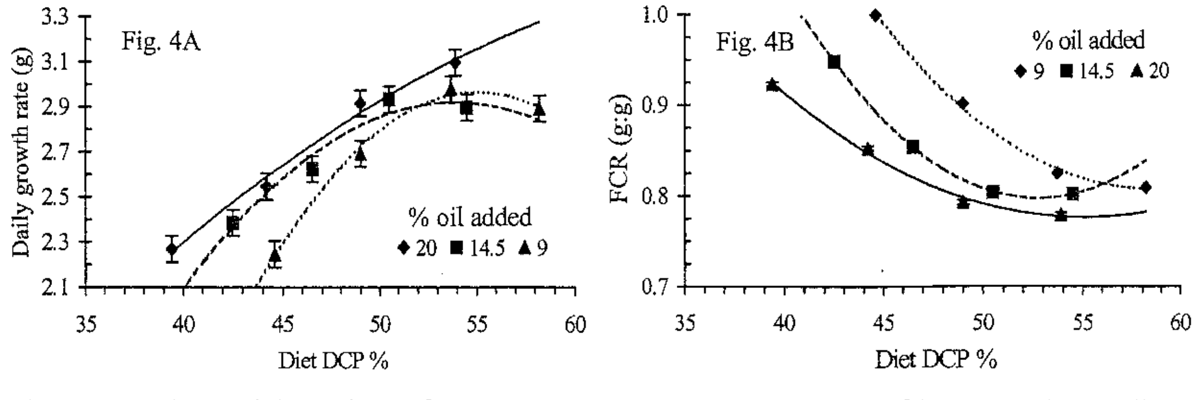

Fig. 4. Growth rate (Fig. 4A) and food conversion ratio (FCR) (Fig. 4B) of barramundi fingerlings (initially 80 g, grown to about 200 g) fed with diets varying in digestible crude protein (DCP) and oil content.

Table 4. Production and sensory analysis responses[1] of caged barramundi fed with diets varying in digestible protein to energy (DCP:DE).

Attribute		Diets and characteristics			± sem
	Dig. protein (%)	32.3	32.1	37.0	
	DCP:DE (mg·kJ^{-1})	23.2	19.5	26.3	
Survival (%)		97.8	96.7	95.6	1.37
Daily growth rate (g)		1.5	1.6	1.6	0.18
Food conversion (g feed: g fish gain)		1.77	1.67	1.62	0.191
Sensory analysis (overall liking)[2]		61.0	56.9	62.2	1.62

[1]Differences between diets not significant (P>0.05).

[2]Score out of 100 for overall liking of the fish.

evidence (see Sargent *et al.* 1999) that dietary requirements are affected by both the amount and type of other fatty acids contained in the diet. The balance between the individual EFAs and particularly the ratio of n-3 to n-6 fatty acids may be as important in determining the animal's requirements as the actual amount of each EFA present in the diet.

We examined the effect dietary n-3 to n-6 fatty acid ratio had on the productivity of barramundi when the fish were held at water temperatures of either 20 or 29°C. Six diets were formulated by incrementally varying the proportions of soybean oil and fish oil in the diet while holding the total amount of oil constant at 12%. The analysed contents of the diets (% air dry) for total n-3 fatty acids, n-6 fatty acids and total eicosapentaenoic acid (20:5n-3; EPA) plus docosahexaenoic acid (22:6n-3; DHA) varied serially from 3.0 to 1.56, 1.34 to 2.68 and 2.09 to 0.51, respectively; the n-3 to n-6 ratio varied from 2.24:1 to 0.58:1, respectively. Six hundred barramundi of mean initial weight of 176 g were equally stocked into 24 tanks (each of 800 L) with half being held at either 20 or 29°C. The fish were fed twice daily to apparent satiety for either 4 (those at 29°C) or 6 (those at 20°C) weeks.

FCR improved curvilinearly with increasing n-3:n-6 ratio with the response being more marked with fish at the highest water temperature. However, the asymptote response was similar irrespective of water temperature, occurring at a dietary n-3:n-6 ratio of ~1.7:1 (Fig. 5A) and an EPA + DHA content of ~1.8% (Fig 5B). At low water temperature, growth rate of the fish was predictably poor and was unaffected by the EFA content of the diet; in contrast, fish at high water temperature responded linearly with increasing dietary n-3:n-6 ratio (Fig. 5C) and EPA + DHA content (Fig. 5D). An unexpected result was observed for fish at high water temperature where DFI decreased curvilinearly with increasing n-3:n-6 ratio. The increased food intake on the diets containing the lowest n-3 fatty acid content could be interpreted as an attempt by the fish to increase intake of critical n-3 fatty acids. This is plausible since food conversion also showed a marked deterioration for diets containing the lowest n-3 fatty acid content. The lack of response to dietary fatty acid content by fish held at low water temperature was probably due to the reduced growth and thus, a minimal requirement for n-3 fatty acids.

In reviewing the essential fatty acid requirements of marine fishes, Tucker (1992) concluded that a dietary EPA + DHA concentration of 2.0% was a reasonable specification for the young of most species but this could be reduced to 1.4% for older fish. He stressed the essentiality of DHA and advocated that it comprise at least half of the n-3 fatty acid content of the diet. Boonyaratpalin (1989) recommended that the total n-3 fatty acid content of the diet for juvenile Asian sea bass should be 1.0 to 1.5%. Our data demonstrate that DFI and FCR are responsive to the dietary balance of n-3 to n-6 fatty acid and in turn, affect growth rate and nutrient retention. A n-3 to n-6 ratio of about 1.5-1.7:1 is suggested as being optimal for juvenile barramundi but more work is needed to unravel the complexity between absolute requirement for individual EFAs and the interactive effects between the balance of individual EFAs.

Commercial Trialing of Zero-fishmeal Grow-out Diets for Barramundi

Following laboratory tank studies, two 10-week on-farm experiments (F1 and F2) were carried out to compare the growth performance and taste characteristics of juvenile barramundi fed with one of four diets, a high fishmeal (control) diet, two experimental diets where most or all of the fishmeal was replaced by meat meal and a commercial barramundi diet (Table 5). Both experiments were carried out using caged fish (400 per 2 m^2 cage) in an aerated freshwater pond in accordance with a 4 x 4 randomised design. The experimental fish were managed as for the other fish on the farm, being fed to satiety once daily except on the weekend when fish were fed only on one of the days. At the conclusion of each experiment, trained taste panellists sampled fish from each cage for sensory evaluation.

In Experiment F1, diets comprising high inclusions of meat meal (contributing approximately 55% of the dietary protein) enabled barramundi to be farm-reared as successfully as those fed on either the high fishmeal control diet or the commercial diet (Table 6). However, the meat meal diets used in Experiment F1 did contain a small amount of fishmeal (contributing 15% of the dietary protein), which was included to ensure good palatability and ready acceptance of the diets by the barramundi. Exclusion of fishmeal from the experimental meat meal based diets fed in Experiment F2 had no deleterious effect on barramundi productivity with growth rate of the fish being equal to, or superior to both the high fishmeal control diet and the commercial barramundi diet (Table 6). Use of a low-ash, 60% protein meat meal conferred no nutritional advantage over that of a conventional 52% protein meat meal when each was included to provide similar protein contributions in diets

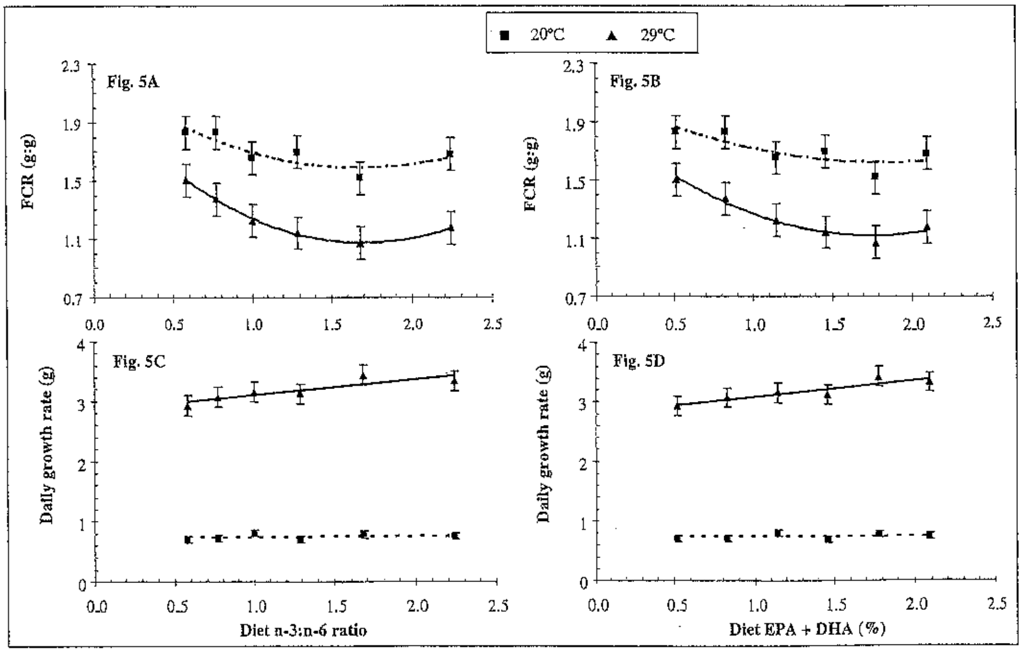

Fig. 5. FCR and growth rate responses of barramundi held at either 20 or 29°C and fed with diets varying serially in essential fatty acid content. Productivity responses expressed relative to either ratio of total n-3 to n-6 fatty acids (Fig. 5A and 5C) or total of eicosapentaenoic acid (C20:5n-3; EPA) and docosahexaenoic acid (C22:6n-3; DHA) (Fig. 5B and 5D).

formulated to be isoenergetic and isonitrogenous. In both of the on-farm experiments, the ingredient cost of diets formulated with the 52% protein meat meal was appreciably less than that for all other diets. Moreover, the productivity cost of the diet (expressed as food cost per unit weight increase of fish) containing 52% protein meat meal was from 73 to 84% lower than for diets containing predominantly fishmeal. In Experiment F2, increasing the estimated DE content of the diet from 15.0 to 16.2 kJ·g^{-1} (with a concomitant increase in protein content to maintain a constant protein to energy ratio) caused an almost 10% increase in its ingredient cost. However, this increased ingredient cost was offset by improved fish performance such that the productivity cost of the two meat meal diets was similar.

Trained taste panels were used to assess the flesh of farm-reared fish from each of the diets fed in Experiments F1 and F2. Differences in sensory scores between the diets were few and confined to Experiment F1 where fish fed with meat meal based diets had higher scores for "fishy" and "sweet" flavors and "firm" texture than those fed the high fishmeal control diet. Importantly, there was only an occasional low score of strong and undesirable taints such as "muddy", "weedy" or "metallic" which might otherwise mask more subtle differences in taste of the flesh. The strong liking by taste panellists for fish fed the high meat meal content diets indicates that fishmeal can be completely replaced in the diet of barramundi without reducing consumer acceptance (Table 6). However, particular attention was taken in the present work to ensure that all experimental diets were supplemented with sufficient fish oil to satisfy the fish's dietary requirement for highly unsaturated fatty acids.

Table 5. Formulation and critical nutrient composition of the diets fed to barramundi in two on-farm cage experiments (F1 and F2) investigating low fishmeal diets.

Attribute	Diet label and experiment						
	Control	Diet 1	Diet 2	Diet 3	Diet 4	Commercial[1] #1	Commercial[1] #2
Experiment	F1; F2	F1	F1	F2	F2	F1	F2
	Formulation (% as used)						
Wheat meal (gelled)	30.4	18.1	29.9	16.1	10.4		
Fishmeal (Chile)	35.0	10.0	10.0	0	0		
Meat meal (52% CP)	0	45.0	0	50.0	50.0		
Meat meal (60% CP)	10.0	0	40.0	10.0	10.0		
Blood meal (ring-dry)	0	0	0	0	0		
Soybean meal (full fat)	16.0	16.0	5.0	7.0	9.0		
Soybean meal (so ext)	0	0	5.0	15.0	10.0		
Wheat gluten	5.0	5.0	5.0	0	0		
Fish oil	2.5	4.0	3.3	5.0	8.5[3]		
Vit. & min. premixes	1.1	1.9	1.8	1.9	2.1		
	Composition (air-dry basis)						
Crude protein (%)	43.8	43.0	43.0	42.5	47.8	54.3	50.1
Digestible crude protein (%)	37.0	32.4	31.9	31.5	36.6	?	?
Digestible energy (kJ·g^{-1})[2]	15.0	15.0	15.2	15.0	16.2	15.0	15.0
Crude fat (%)	9.4	12.7	12.6	15.3	12.8	6.9	9.6
Ash (%)	9.5	14.9	9.5	14.6	14.1	9.3	7.6

[1] Two batches of extruded commercial grow-out barramundi diets. The composition of the commercial diets is not available.

[2] Estimated digestible energy (DE) values based on derived digestibility of similar feed ingredients. Values for the commercial diets are those stated by the manufacturer.

[3] Comprised 6.0% fish oil and 2.5% beef tallow.

Economics of Feeding Barramundi on High Nutrient Specification Diets

The pooled data (Fig. 6) of three experiments comparing the productivity of barramundi fed either a standard commercial (45% CP; 10% fat; 15 kJ·g^{-1} DE) or an improved high nutrient (55% CP; 20% fat; 19 kJ·g^{-1} DE) diet were used to estimate the profitability of feeding the alternative diets during grow-out. Economic data for barramundi farming in Queensland were collected through personal interviews to determine farm establishment and operational costs (Johnston 1997). Discounted cash flow analysis was used to determine the annual cost of production and the likely profitability of farming based on a developed 50 ton per annum production model farm (Johnston 1997, 1998). At the time the economic analysis was carried out in 1998, the cost to extruder-manufacture the standard and improved diets was stated by commercial aquafeed manufacturers to be US$ 657 and 910 per ton, respectively. It was assumed that the per kg sale price of the fish would be independent of the size of the fish over the range of expected weights and that fish moralities (40% from

Table 6. Production, dressing-out percentage, food cost per unit gain and overall sensory liking responses of barramundi in two on-farm cage experiments (F1 and F2) investigating low fishmeal diets.

Attribute	Diet label and experiment[1]									
Experiment	F1					F2				
	Control	Diet 1	Diet 2	Com. #1	± sem	Control	Diet 3	Diet 4	Com. #2	± sem
Start weight (g)	275.0^{A}	276.8^{A}	284.8^{A}	282.5^{A}	6.72	224.4^{X}	213.7^{X}	232.3^{X}	225.2^{X}	9.42
End weight (g)	440.6^{A}	439.5^{A}	459.1^{A}	485.8^{A}	21.17	420.8^{Y}	418.1^{Y}	449.4^{X}	416.8^{Y}	8.55
Weekly food issued (g)	25.0^{A}	24.0^{A}	25.4^{A}	25.9^{A}	1.25	25.3^{Z}	30.3^{X}	30.3^{X}	27.6^{Y}	0.34
Weekly gain (g)	18.1^{A}	17.6^{A}	17.9^{A}	21.2^{A}	1.75	20.8^{Y}	21.4^{XY}	23.2^{X}	20.3^{Y}	0.60
Food conversion (g:g)	1.44^{A}	1.43^{A}	1.47^{A}	1.25^{A}	0.070	1.22^{X}	1.44^{Y}	1.31^{XY}	1.37^{Y}	0.041
Fish recovered (%)	97.6^{A}	96.6^{A}	96.8^{A}	98.3^{A}	0.85	98.7^{X}	97.5^{X}	97.8^{X}	98.8^{X}	1.69
Dressing-out (%)	89.6^{A}	89.3^{A}	89.8^{A}	89.7^{A}	0.24	89.8^{X}	88.6^{X}	88.7^{X}	89.4^{X}	0.30
Food cost ($US/kg gain)	0.83^{B}	0.60^{A}	1.07^{C}	^{AB}	0.039	0.70^{Y}	0.58^{X}	0.57^{X}	^{Y}	0.025
Overall liking[2]	58.4^{A}	62.1^{A}	62.8^{A}	59.3^{A}	1.23	60.0^{X}	61.2^{X}	64.3^{X}	63.5^{X}	1.65

[1] See Table 5. Economic data for the commercial diets (Com #1 and Com #2) is not available.

[2] Score out of 100 for overall liking of the fish.

$^{A,B,C;\ X,Y,Z}$ Within experiment and trait, means without a common superscript letter differ ($P<0.05$).

Table 7. Production and economic data (US$) and predicted profitability for a model 50 ton per annum barramundi farm in which fish during grow-out are fed either a standard (45% CP; 10% fat; 15 kJ·g^{-1}) or an improved (55% CP; 20% fat; 19 kJ·g^{-1}) extruder pelleted diet.

Attribute	Standard diet	Improved diet
Production data		
Number of fish harvested ('000)	94	94
Harvest weight (g)	530	730
Feed used (tons)	79.7	81.2
Farm FCR	1.6:1	1.2:1
Economic data		
Invested capital ($'000)	512	512
Gross sales at $6.82·kg^{-1} ($'000)	333	469
Feed cost ($·ton^{-1})	657	910
Total feed cost ($'000)	53	74
Other operational costs ($'000)	240	278
Per annum farm profit ($'000)	40	117
Internal rate of return on investment (%)	8.0	22.8

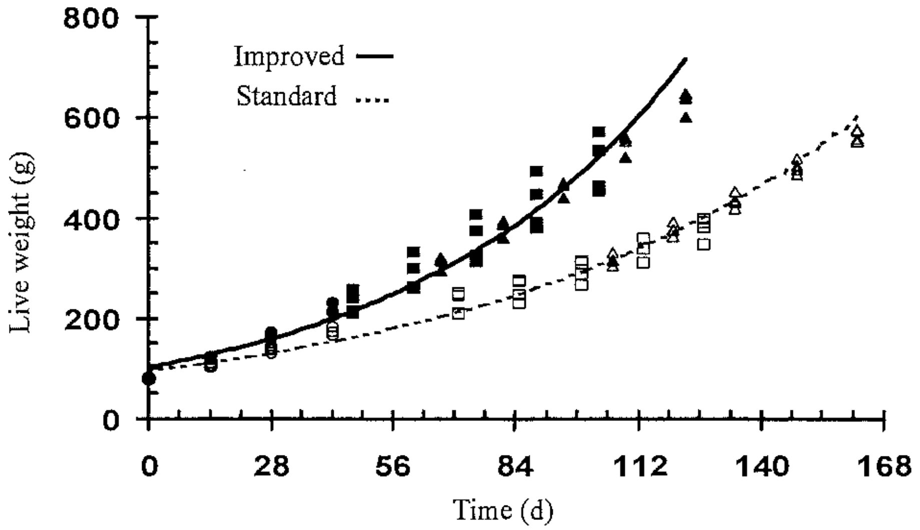

Fig. 6. Pooled data of three barramundi experiments comparing the growth efficacy of standard and improved diets.

stocking as 20 mm fingerlings) would be similar irrespective of the diet fed. A summary of the relevant production and economic data and the predicted farm profitability for farms using either the standard or improved diet is detailed in Table 7.

The economic analysis showed that feeding the improved diet was expected to increase farm profit by almost threefold over that of the standard diet; the internal rate of return on investment increasing from 8.0 to 22.8%. Better food conversion and faster growth rate of the fish on the improved diet more than adequately overcame the almost 40% higher cost of the improved diet. Feed manufacturers have subsequently commissioned on-farm studies to compare high nutrient specification diets against their standard grow-out diets for barramundi on-growing. These studies validated the laboratory findings and the barramundi industry in Australia is now almost universally using high nutrient diets for commercial on-growing of barramundi.

Conclusions

Research has conclusively shown that barramundi are able to efficiently digest and assimilate the nutrients from a wide range of terrestrial and plant protein feed ingredients. Terrestrial animal protein meals such as meat and blood meals are well accepted by barramundi and can be used in nutritionally balanced formulations as partial or complete replacements of the fishmeal. Plant protein meals, although not as well accepted by barramundi as meat and blood meals, are potential inexpensive partial substitutes for fishmeal. Data derived on the apparent digestibility of terrestrial feed ingredients can now be used to formulate diets on a digestible nutrient basis. Although further research is needed to better define the nutrient requirements of barramundi, our studies have shown that high nutrient diets containing 55% CP (~50% DCP) and 20 to 25% fat (~20 kJ·g^{-1} DE) not only support high rates of fish productivity but also result in higher farm profitability than what is achieved using standard 45% CP and 10% fat diets.

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Global Prospects for Cage Aquaculture of Marine Finfish: Input Costs, Market Value and Comparative Advantage

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Abstract

Cage aquaculture of marine finfish is a rapidly growing industry worldwide. While the most impressive rates of growth have been for cold water diadromous fish (mainly Atlantic salmon) there has also been strong growth in the production of warm water species, especially European and Asian sea bream and sea bass, and to a lesser degree groupers, snappers, and other tropical and subtropical species. The main driving forces behind the expansion are the difference between farm-gate price and input costs, as well as the availability of knowledge, skills and investment capital.

This paper examines the future trends in terms of market value on the one hand, and the input costs on the other. In particular, it examines the availability and costs of seed, trash fish, fishmeal and fish oil. Given the inevitable increase in competition, the issue of comparative advantage is addressed – i.e. where and under what circumstances cage culture of finfish is most profitable, and how this profitability can be maintained.

In practice, the higher growth rates (shorter cropping cycles) and lower labor costs in less developed countries are more than balanced at the present time by the higher labor productivity and access to premium and volume markets in more developed countries. In the long term however, as productivity rises and local markets and infrastructure strengthen, less developed tropical and subtropical countries are likely to develop a comparative advantage in the production of established species and internationally traded medium value marine finfish products.

Four product-marketing strategies are identified for the sector, which are more or less suited to different kinds of producers in different countries. Developing countries (especially those not subject to frequent typhoon) such as Indonesia and Thailand are well placed to produce large volumes of medium value finfish such as sea bass for local and international markets. Countries or regions with strong aquaculture skills and high levels of technical development (such as Taiwan) are best placed to produce medium volumes, and a wide variety of high value exotic species for local and international markets. In the medium and long term, small scale producers throughout the region will probably only be able to compete in local niche markets, if they can become effectively organized, and possibly "integrated" through producer organization or contract farming systems. The fourth major market – the international market for low-medium value chilled and frozen fillets – is probably not suited to supply from the marine cages, since competition from freshwater and brackishwater pond culture of easy to grow species such as tilapia is likely to be intense.

Introduction

Cage aquaculture of marine finfish is a rapidly growing industry worldwide. While the most impressive rates of growth have been for cold water diadromous fish (mainly Atlantic salmon), there has also been strong growth in the production of warm water species, especially European and Asian sea bream and sea bass, and to a lesser degree groupers, snappers and other tropical and subtropical species.

Although other factors (such as government intervention) have played a role, the main driving force for this expansion has been the profitability of the industry. This in turn has depended on:

- input costs
- market price
- the technical characteristics of the species (production parameters)
- the efficiency of production (technology and management)
- the suitability of the production location and site (comparative advantage).

This paper examines recent and likely future trends in these factors, and implications for the scale, location and profitability of the industry.

Production Trends

Marine and brackishwater cage culture has expanded rapidly over the last 20 years. In the 10 years between 1988 and 1997 aquaculture production of marine and brackishwater finfish grew at an annual rate of more than 10%, much of which was produced in cages. Production in 1997 stood at almost two million tons, valued at just under US$8billion (FAO statistics). While the most impressive rates of growth have been for cold water diadromous fish (mainly Atlantic salmon), there has also been strong growth in the production of warm water species, especially European and Asian sea bream and sea bass, and to a lesser degree groupers, snappers, and other tropical and subtropical species (Fig. 1). There have also been significant developments in China (mainland) with a rapid increase in the production of a range of marine finfish including sea bass, sea bream, yellow fin and grouper in both ponds and cages. There is also a substantial and relatively stable production of well established species such as yellowtail (*Seriola*) in Japan. Significant production of warm water marine finfish species is confined to Asian and Mediterranean countries. A large part of this production takes place in cages.

Table 1 provides an overall summary of price, production trends and producer nations for major aquaculture species groups over the ten-year period (1988-1997). The variation is striking, and highlights the importance of under-

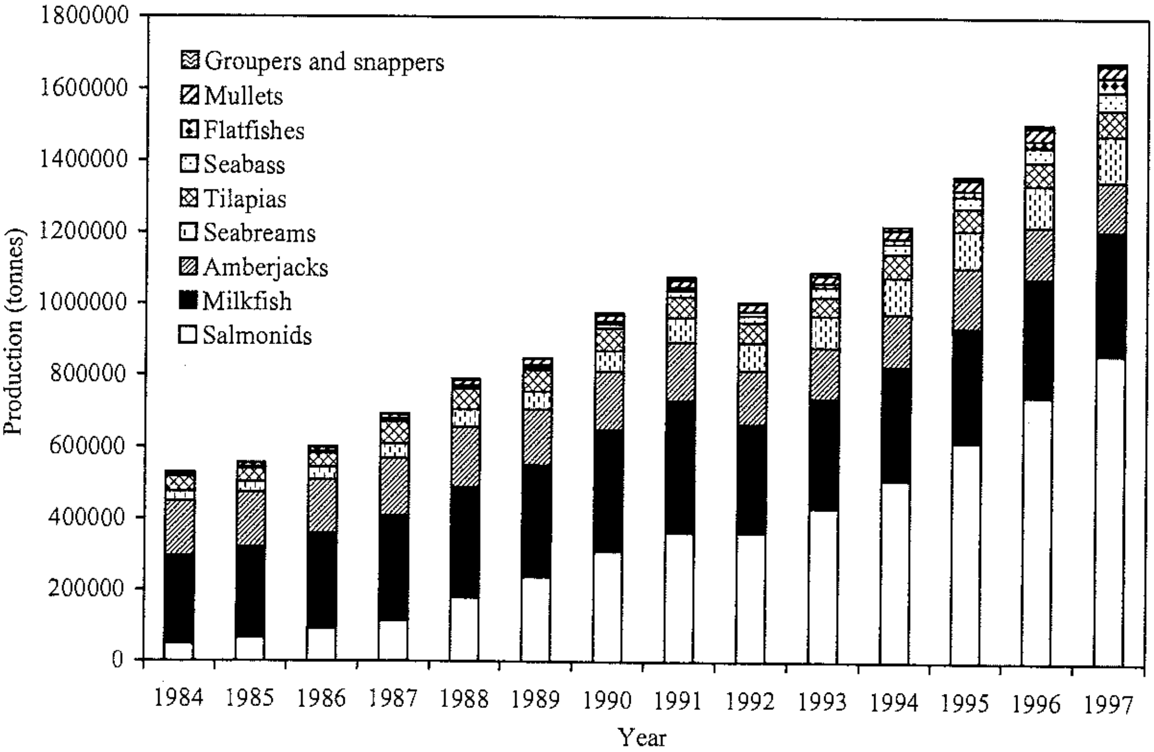

Fig. 1. Culture of tropical marine and brackishwater finfish – by major species group (Data FAO Fishstat).

standing both the nature of the market for particular species and products, and the stage in the product cycle.

Markets and Prices

Farm gate value for marine and brackishwater finfish varies from less than $ 2/kg (milkfish; some mullets; tilapia) to $ 20+ for some grouper species. For several species prices rose rapidly in the late 80's in response mainly to the booming economies of SE Asia, peaked in the early 90's, and have since declined slightly, although there is significant variation between species.

Table 1. Production and price trends for selected marine finfish.

Species	World production (mt)	Average unit value (US$/kg)	% change in average unit value in major producing country, 88-97	Average annual growth value (%) in production	Main producing countries[1]
Atlantic salmon	640,000	3.3	-52	19.1	Norway, Chile, UK, Canada, USA, Ireland, Faeroe Islands, Australia
Yellowtail or Japanese Amberjack (*Seriola quinqueradiata*)	138,536	8.6	+38	-1.3	Japan, Korean Republic
Japanese Seabream (*Pagrus major*)	81,426	7.7	-27	7.2	Japan, Taiwan, Korea, China
European (Gilthead) Seabream, *Sparus auratus*	40,779	7.0	-59	41.5	Greece, Turkey, Spain, Italy, Egypt, France, Malta, Portugal, Israel, Morocco, Tunisia, Slovenia, Croatia
Asian Sea bass, (Barramundi), *Lates calcarifer*	27,180	7.4	-45	37.2	Greece, Italy, Egypt, France, Malta, Morocco, Tunisia, Spain, Portugal, Israel, Cyprus, Slovenia, Algeria
European Sea bass, *Dicentrarchus labrax*	16,094	4.7	+67	12.8	Indonesia, Thailand, Malaysia, Taiwan, Australia, Singapore, China, Hong Kong
Other sea bass	6,694	9.0	-25	65.1	Turkey, Croatia
Flounder or Bastard halibut, *Paralychthys olivaceus*	34,857	14.7	+73	30.0	Korean Republic, Japan
Grouper, *Epinephelus* spp.	5,901	☆	+111	10.8* 19.5**	Taiwan, Hong Kong, Thailand, Malaysia, Philippines, Singapore, UAE, Tunisia, Korean Republic
Snappers	1,954	5.4***	+17	33***	Malaysia, Hong Kong, Taiwan
Turbot	3,001	9.0		44.5	Spain, France, Portugal, Netherlands, Germany, Malta, Ireland

[1] In descending order of importance (1997); excludes production < 1,000 mt.

☆ Includes groupers nei (9.7), Greasy grouper (10.6), Areolate grouper (15.3), Groupers and sea basses nei (20.2), etc.

* Greasy grouper; **Areolate grouper; ***Mangrove red, Russel's.

Global average export prices over a 10-year period for selected finfish products are shown in Figs 2 (fresh chilled) and 3 (frozen). Atlantic cod, taken as a "baseline" for high quality marine finfish has shown limited price movement, typically around US$ 2/kg. Atlantic salmon has shown a steady decline in price from more than US$ 7/kg in 1988 to less than $ 4/kg in 1997. This price drop is directly related to a dramatic increase in cage farm production (see Fig. 4). Sea bream prices showed strong but erratic increases in the late 80's and early 90's, followed by a steady decline in recent years, again related mainly to rapid increase in cage farm production in S Europe. Sea bass has shown a similar price trend, but much less extreme, with only a modest decline in recent years. Overall, there has been a significant convergence in the price of farmed species since the late 80's and early 90's, reflecting the international nature of the market, and an essentially similar market niche, with prices for fresh chilled product typically in the range of US$ 4-6/kg.

A similar trend is apparent in the case of frozen products, although sea breams, valued mainly as a high quality fresh product, are relatively less valuable in frozen form.

The relationship between farm gate value and production is explored further for the different species and countries.

Atlantic salmon (Fig. 4) is now primarily an export product and the pattern of price and

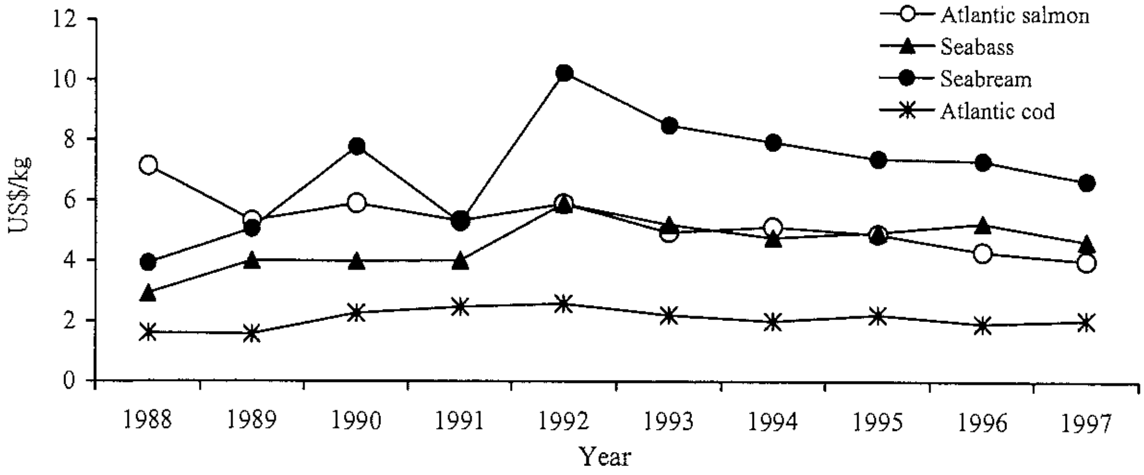

Fig. 2. Fresh or chilled finfish: export price trends for selected products (FAO data).

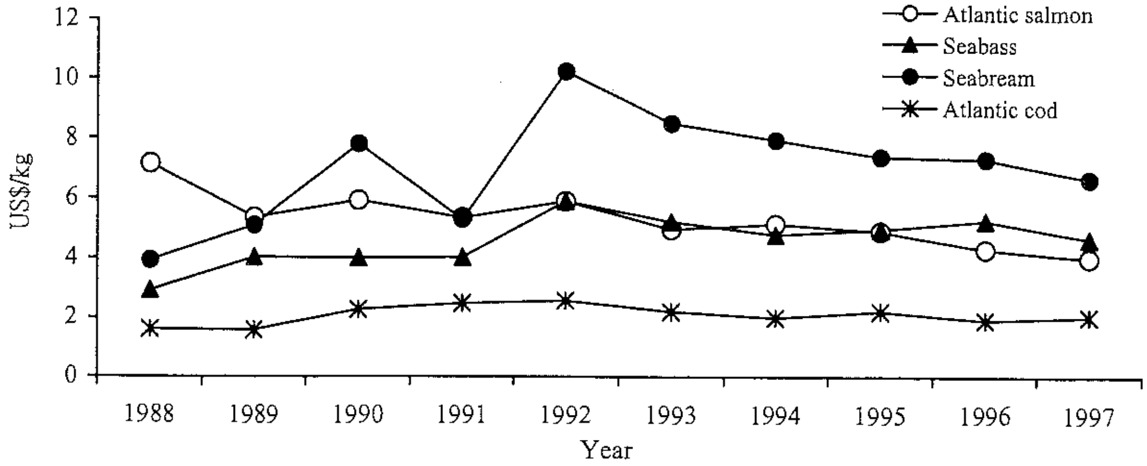

Fig. 3. Frozen whole finfish: export price trends for selected products (FAO data).

production is similar for all producing countries. There has been a rapid increase in production, associated with a steady decline in price. A similar pattern can be found in the case of European sea bream. Sea bass (Figs. 5 and 6), however, shows significantly different patterns in different countries, reflecting the limited development of the export market. In Taiwan, price has fallen significantly in recent years, related to domestic market saturation and limited export development. Thailand on the other hand has experienced an overall increase in farm gate value, related to increased domestic market demand during the early '90s. Greece, with significant export of European sea bass, has also experienced a decline in unit value, but the export price has nonetheless been significantly higher than that for its cousin in Thailand and Taiwan (Fig. 7). This figure shows that there has been a steady convergence of export price from the different countries as the export market becomes more global in nature.

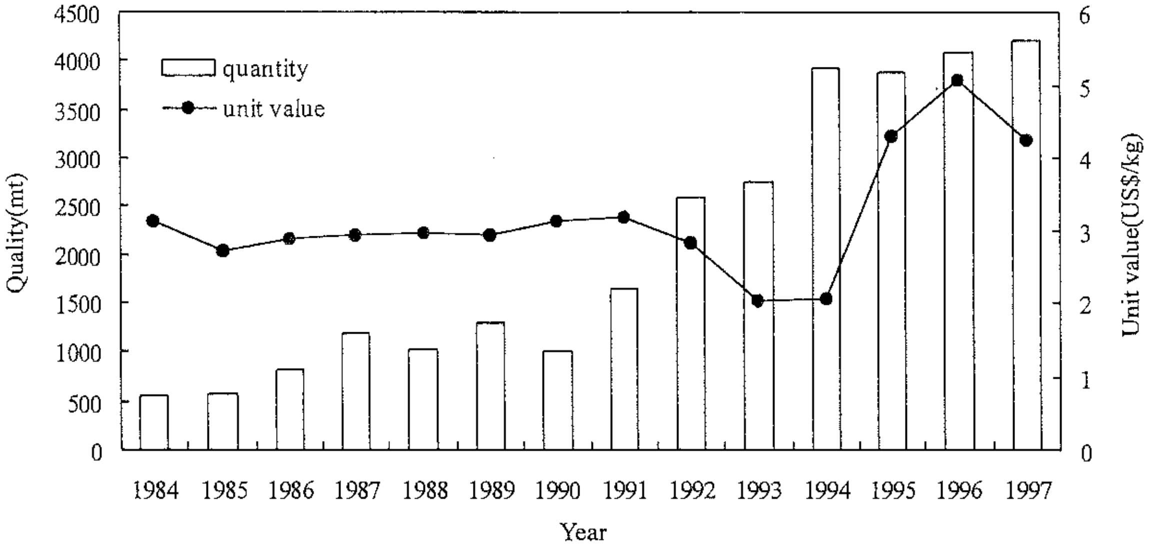

Fig. 4. Production and farm gate value of Atlantic salmon (FAO data).

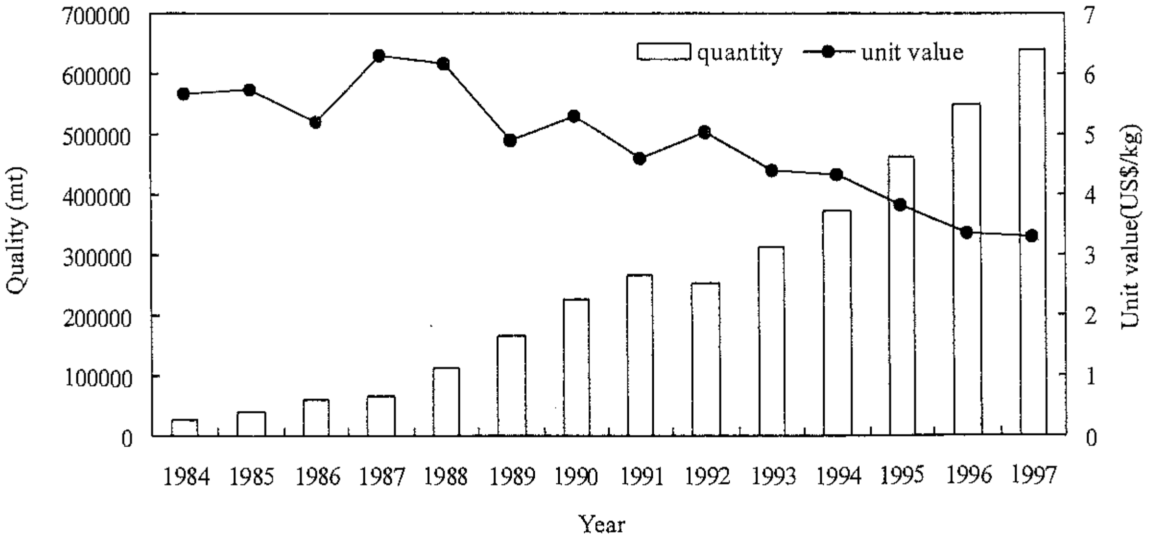

Fig.5. Seabass (*Lates calcarifer*) production and unit value in Taiwan (FAO data).

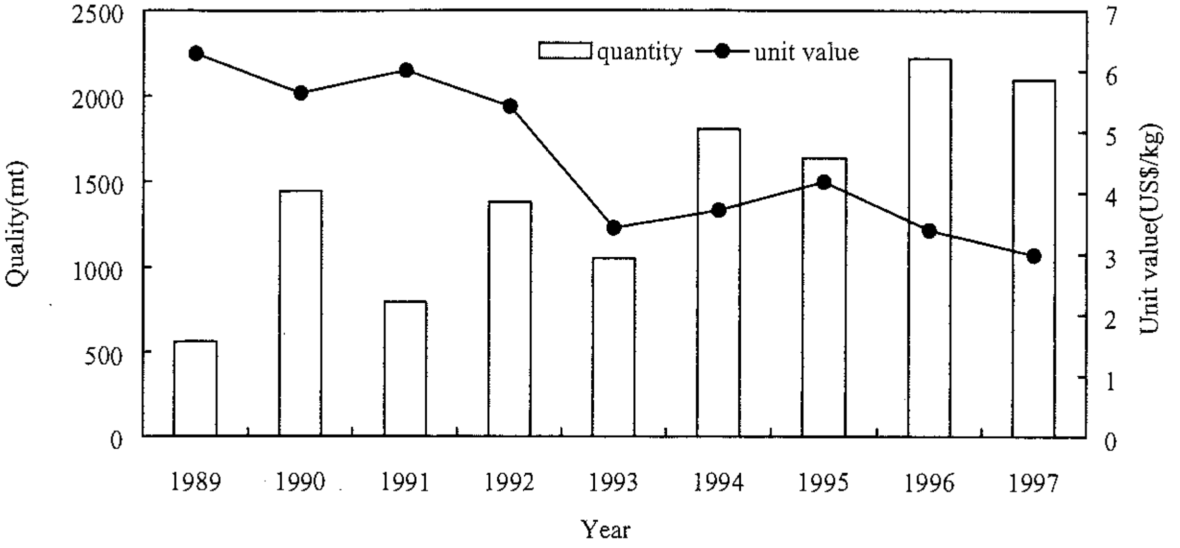

Fig. 6. Seabass (*Lates calcarifer*) production and unit value in Thailand (FAO data).

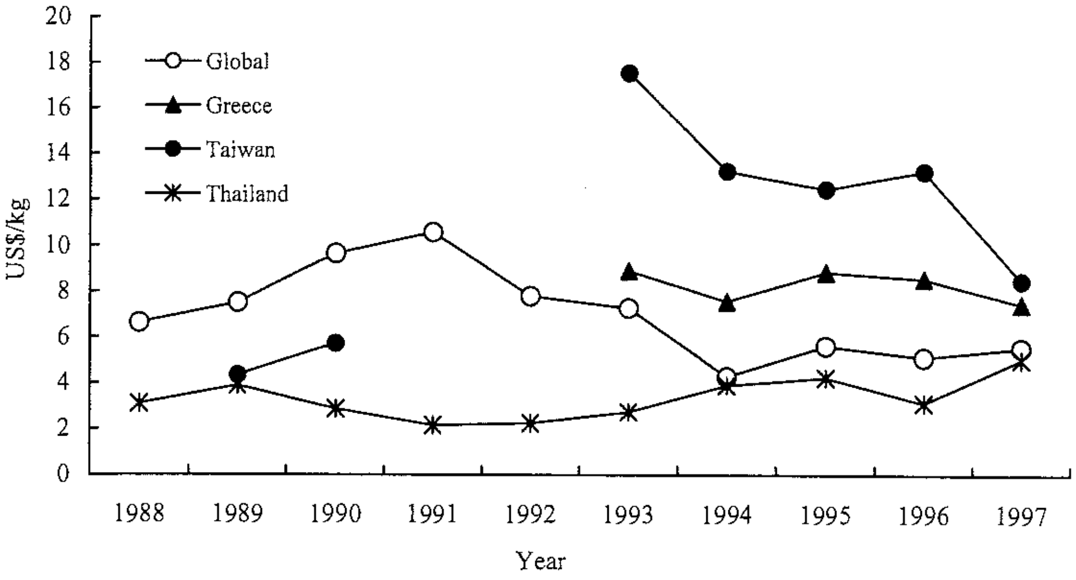

Fig. 7. Export price trends for frozen seabass from selected countries (data FAO).

Driving Forces and Constraints

The rapid increase in production is related to strong market demand, and in some cases technical advances. Strong market demand is due mainly to:

- population growth and increased income
- the worldwide popularity of seafood as a healthy food, and as a luxury food
- cheaper and easier international trade, transport and communications
- declining wild catches of high value marine fish species.

The recent decline in the Asian economies, in Japan in particular, has had a significant impact on prices, especially luxury species. There is even speculation that the nature of the Japanese market has changed fundamentally in recent years. The very rapid increase in production of some species (notably Atlantic salmon, sea bass and sea bream) has also exerted a steady downward pressure on price, but this has been met in

Europe with significant gains in efficiency, allowing the industry to continue its growth.

In some cases increased production has been greatly facilitated by the development of hatchery technology (e.g. European and Asian sea bass and sea bream). This has generally been initiated by government research institutes, but with the private sector playing a significant role in all cases. In Japan, Taiwan and Korea there now exists high levels of skill in the production of a wide range of marine finfish species.

Yellowtail production may have been partly constrained by limitations on wild seed supply, although markets have also probably been limiting. Production of groupers, which has been generally low and erratic (especially so if individual species are considered), is undoubtedly constrained by a shortage of high quality yet reasonably priced seed.

Good sites for marine cage culture are not common, although there are a limited number of excellent sites in S Thailand; Central and N Vietnam; the NW coast of Sumatra (e.g. Sibolga); Sulawesi; some parts of Sabah, Malaysia, and one or two atolls in the Maldives. Although sites appear to be limiting in many parts of Asia, it should be remembered that countries such as Scotland produce around 100,000 mt of salmon from relatively few sheltered sea lochs. Larger and better cages, better cage arrangement, suitable mesh nets, and lower pollution feeds are all required to overcome these site limitations.

The incidences of typhoons, lack of shelter, and shallow, sometimes muddy, coastal water of variable salinity, are significant constraints to near-shore marine cage culture in some tropical countries. In some cases, they will preclude development altogether; in others they will make it more expensive.

The lack of high quality pelleted feed is probably a significant constraint to increased production and efficiency, including labor productivity, in many areas. Given the expertise in the region in the production of shrimp and livestock feeds, this is surprising.

Lack of capital is a problem for many farmers in SE Asia. Start up grants was a significant feature of the European industry, and this has not been available in most Asian countries. Aid projects now tend to focus rather exclusively on immediate poverty alleviation needs, rather than on the stimulation of potentially successful industries. However, it is notable that capital costs per unit production in more efficient production systems are not high. Start up costs for small producers may be reduced either through the development and mass marketing of more efficient small-medium scale cage systems, and/or through better organization, resulting in economies of scale in purchasing equipment and inputs.

Lack of effective marketing, in particular the very low levels of export marketing, is also a major constraint. These again are closely related to scale and/or organization of enterprise. Given the price differentials between European and Asian farmed sea bass (for example) there is a clear opportunity, but this will require effective marketing coupled with a steady supply of high quality products.

Access to good information and new technology is also probably a constraint in many areas.

However, the basic driving forces for expansion are likely to continue, and many of the constraints are likely to diminish. Seed production for several new species is likely to be commercialized. High quality pelleted feeds will become more widely available. Improved technology, such as stronger offshore cages, is likely to reduce the significance of site constraints. The quality of information and access to it is increasing rapidly throughout the world.

Cage culture of marine finfish is therefore likely to continue its expansion, but with increasing competition in the case of major species, and constrained mainly by local circumstances.

Market Opportunities and Outlook

Live Finfish

There is a high value market for live marine finfish, mainly in Hong Kong, although much is re-exported to mainland China (Pawiro 1998). Although prices are very high for some species, this market has a limited potential for aquaculture development in most countries for two main reasons:

- The size of the market is small. Imports of live marine finfish to Hong Kong (the major regional trader) in 1998 were approximately 19,000 mt, of which around 7,000 mt was high value reef fish, more than 80% of which was classed as "other grouper" with an average import value of US$ 6.8/kg (Piwari 1999).
- Live fish cost a great deal to transport, and mortality is sometimes high. This translates to a high differential between farm gate and import value, especially for producers distant from markets.

Although the size of this market is likely to increase as economic growth re-establishes itself in the Asian region, production is likely to remain a relatively specialist activity suitable for farmers close to the market. Furthermore, grouper seed is either not available or costly in many parts of the region, and there is no immediate prospect of change.

Fresh Chilled and Frozen Marine Finfish

Prices of high quality marine finfish are converging to an export price for fresh chilled or frozen product of around $ 4-6/kg, corresponding to a farm gate price of $3-5/kg. It seems likely that as production of sea bass and sea bream continues to rise, prices will decline to levels similar to those for salmon ($3-4/kg), which has excellent yield and market characteristics. To enter this market therefore, production costs will need to be low.

Frozen Fillets

The frozen fillet market is likely to continue to expand, but there will be strong competition from lower value marine capture fish, and also freshwater/brackishwater pond farmed species such as tilapias and catfish, which are likely to be cheaper to produce than marine finfish grown in cages. However, off flavors are a significant problem in pond grown fish, and this may lead to a market premium for cage farmed fish, cage "finished" fish, or tilapia grown in brackishwater. This is already motivating Thai farmers to grow tilapia in cages to take advantage of a significant price premium associated with better condition and lack of off flavours (Menasveta, 2000).

Input Costs and Sustainability

Feed

Feed costs comprise between 30 and 60% of production costs for marine finfish in cages, with higher proportion in more developed and productive systems.

There has been much discussion about the sustainability of an industry which depends so heavily on the use of other marine fish, and on the effect that increased demand from aquaculture will have on the price of fishmeal.

The price of fishmeal has varied between 300 and US$ 600/mt in recent years, with record high prices in 1997 and 1998, followed by a significant fall in early 1999. There is no immediate prospect of significantly increased prices. This is because there is significant substitutability between fishmeal and high quality oil seed and plant meals (see for example Caro Ros 1998; Pike 1988; Tacon 1988; Anon. 1998, 1999).

Aquaculture feeds account for about 25% of fishmeal consumption, mainly of the high quality "special" meals. The balance is used mainly in the broiler, pig, and cattle feed markets. When fishmeal prices rise, animal feed companies reduce their use of fishmeal, and increase the proportion of soya and other vegetable meals. With careful formulation and a range of additives, the fishmeal content of aquaculture feeds can also be reduced (see for example Williams *et al.*, this symposium). Prices are therefore unlikely to rise significantly in the medium term, with production rates steady or increasing slightly, and prices constrained by competition with vegetable meals. Since most forms of aquaculture are more demanding than livestock rearing in terms of feed quality, it is anticipated that aquaculture will use a greater share of fishmeal production, especially of the high quality meals and oils. Significant price increase, or supply problems appear unlikely in the medium term.

Prices of the other components of formulated fish feeds (vegetable meals, binders, etc) may decline in the short term, and are unlikely to increase significantly in the medium term.

"Trash fish" is commonly used for cage culture throughout Asia. This is derived from a wide variety of coastal and offshore fisheries. Costs are typically US$ 0.20-0.35/kg. The status of most of the fisheries which supply this feed is poorly understood, but there are signs that the cost is increasing in some regions, with aquaculture competing for supplies with the fish sauce industry, pig raising and other activities. It is likely that many farmers will shift to formulated feeds as high quality products become available at reasonable prices.

Seed

Seed supply to aquaculture is highly variable according to species. Seed production for salmonids is technically relatively simple and very well established. Seed production for sea bass and sea bream, though well established in Europe and Asia, is more technically demanding, with small larvae, and a requirement for live zooplankton feed (usually rotifers and *Artemia*, which in turn depend on production of microalgae for food).

Artificial production of seed for other species, such as yellowtail (*Seriola*), groupers and some reef fish is difficult, requiring very small zooplankton (e.g. super small rotifers, oyster larvae etc). In addition, there are problems of behavior, cannibalism, and susceptibility to physical damage at metamorphosis, especially in the case of groupers. Although Taiwan has been reasonably successful in producing seed for these species, the costs are high, and survival/production rates are erratic, even among experienced producers. However, there is significant experience in the production of an increasing range of marine finfish species in Japan, Taiwan, mainland China, and Korea.

Prices for hatchery and wild caught seed are extremely variable (Table 2), but as technology improves and the industry matures, prices for small sized seed are likely to decline significantly, and seed costs will become a relatively small part of the overall growout costs.

Table 2. Indicative costs of selected finfish seed.

Species/Country	Cost (US$/pc)
Salmon smolt (Europe, 1999)	1.6
Sea bass fry (15-day) (Thailand, 1999)	0.003-0.01
Grouper fry (40-day) (Thailand, hatchery model estimate)	0.3-0.6
Grouper fry (wild, 3-4 cm) (South Thailand)	0.2
Grouper fry (3 cm) (Taiwan, recent years; highly variable according to supply/demand)	0.5-3.0

Grow-out Characteristics of Different Species

Feed Costs

Feed costs for cage aquaculture are high relative to terrestrial livestock production (Table 3).

Feed costs for salmonids have been substantially reduced through improvements in feed formulation; corresponding reductions in food conversion rate (to as little as 1), and further improvements are also likely.

Much work has also been done on the development of improved feeds for European sea

Table 3. Feed costs for selected farm products.

Product	Feed costs (US$/kg product*)
Broiler chickens	0.42
Pigs	0.75
Beef cattle	0.83
Salmon	1.19

*After Forster, 1999.

bass and sea bream. Although there have been reductions in recent years, feed conversion rates for these species (especially sea bream) remain significantly higher than those for salmonids. Less is known (or rather published) about optimal formulations for Asian sea bass and sea bream, and suitable reasonably priced high quality pelleted feeds are hard to obtain in many parts of the region. Most producers prefer to rely on trash fish, whose quality is more "transparent" and performance is more predictable. These are, however, less convenient and ultimately more costly (Table 4), and may be associated with disease spread. Work in Australia (see Williams *et al.*, 2000) shows that low food conversion rates for sea bass using dry pellets are achievable, even in the absence of fishmeal.

It is commonly assumed that salmon and other marine carnivores such as sea bass and groupers will be more demanding in terms of feed formulation than the mainly omnivorous and herbivorous species sucb as tilapias, milkfish and siganids. This does appear to be true, although experiences suggest that these herbivorous fish still grow better on high protein diets with a significant fishmeal component. Clearly there will be a trade off between cost and quality, but it is probable that some species will be significantly cheaper to feed than others.

Table 4. Technical characteristics of different marine finfish species or species groups with cage culture potential.

Species/group	Feed	Seed supply	Water quality requirement	Behaviour and stocking density	Growth rate
Atlantic salmon	Dry pellet; highly specified formulation; Marine carnivore. Low FCR with high feed cost	Hatchery; simple technology	Water quality; high salinity (growout)	Adapts well to high density	Egg to market (2-3 kg) in 2+ year
Sea bream	Dry pellet; Moist pellet; Marine carnivore. Higher FCR than salmon?	Hatchery; moderate technology	High quality; high salinity	Adapts well to high density	Egg to market (400 g) in 1 year
European sea bass	Dry pellet; Marine carnivore. Higher FCR than salmon?	Hatchery	Tolerant of variable salinity	Adapts well to high density	Egg to 500 g in 1 year
Asian sea bass	Trash fish; formulated pellets; good FCR possible	Hatchery and wild	Tolerant of variable salinity and medium water quality	Adapts well to high density	Egg to 500 g in 1 year
Yellowtail (*Seriola* spp.)	Trash fish and pellets (marine carnivore)	Wild seed; hatchery technology not commercial	High quality; high salinity	Adapts well to high density	Egg to 1 kg in 1 year; 6 kg in 2 years
Flatfish (bastard halibut; turbot)	Trash fish and pellets	Hatchery	High quality; high salinity	Stocking density limited by behaviour?	Egg to 800 g in 1 year
Groupers and snappers	Trash fish and pellets (marine carnivore)	Wild seed and hatchery seed (Taiwan); Hatchery production difficult and expensive	Coral groupers: high salinity; high quality. Estuarine groupers: medium/high quality; medium high salinity	Aggressive and territorial; dislike bright sunshine; prefer refuge	Egg to 800 g in 1 year

Maximum Stocking Density for Fast and Healthy Growth

Good information on maximum stocking density, or the trade off between stocking density and growth and health, is not available for many tropical species. This is partly related to the difficulty of establishing general figures, given the range of compounding factors, such as cage size, feeding rates, water quality and exchange, and different management traditions or attitudes to risk. In some cases stocking density is constrained simply due to lack of capital.

However, it is likely that aggressive territorial species such as groupers will require lower stocking densities and/or the presence of various forms of shelter or refuge. The better performance of groupers in ponds with refuges compared with cages in Nha Trang in Vietnam (Trai and Hambrey 1988) may be related to this requirement.

The characteristics of selected marine finfish suitable for cage culture are summarized in Table 4.

Water Quality Requirements

Almost all species require high and stable water quality for maximum health and growth. Nonetheless, some species are significantly more tolerant of poor water quality than others, and this may confer a substantial advantage in areas where water quality occasionally declines.

- Salmonids and some flatfish species have a very high water quality requirement, but this is generally not limiting in those temperate regions where they are currently produced.
- Sea bream has a high water quality requirement, and this may be a limiting factor in many sheltered tropical and subtropical locations, which periodically experience poor water quality conditions.
- Sea bass is reasonably tolerant of wide ranges in salinity and relatively poor water quality.
- Some groupers require very high water quality and stable high salinity; others (estuarine groupers) are more tolerant of varied salinity and poor water quality.

Growth Rate

Growth rates generally reflect preferred temperatures, with tropical species usually faster growing than subtropical and temperate species

There are many other species that have been tested or tried on a limited scale. Of particular interest from a technical-economic point of view are the siganids (herbivorous grazers) mainly in the Philippines, and "black kingfish" or Cobia (*Rachycentron canadum*), a fast growing marine carnivore, which has been grown in Taiwan and Vietnam in recent years. Both of these appear to adapt well to cage culture conditions. Cobia is also relatively simple to spawn and rear in hatchery conditions.

Productivity and Product Quality

The above analysis brings up some significant questions. In particular, why is it that production of Atlantic salmon in N Europe, and sea bass and sea bream in southern Europe continues to expand despite falling prices, while production of sea bass and sea bream in tropical and subtropical Asia shows limited growth despite higher farm gate prices, more rapid growth, lower labor costs, and good access to markets? Furthermore, how can there remain such a big difference between the value of Asian sea bass and European sea bass?

There are several possible answers:

- Salmon, sea bass and sea bream were supported and encouraged by national governments and tbe EU in less developed parts of Europe during the early development phase.
- Sea cage farming in Europe and America has adapted to falling prices through significantly improved productivity. This has required rationalisation of the industry leaving relatively few highly efficient producers.
- The structure of the industry in Asia, and in particular the lack of involvement of large companies in significant research and investment resources, may have constrained productivity improvements.
- The Asian industry has focused on low volume/high value domestic markets rather than

high volume, and slightly lower value, export markets.

- Traders and consumers can be both conservative and discriminating, and differences in flesh quality between (for example) Asian sea bass and European sea bass may be sufficient to maintain price differentials.

Basic input costs and productivity for selected aquaculture production systems are shown in Table 5. The last column provides some figures from the US broiler industry for comparative purposes. Despite the faster growth rates in Asia, and the far lower unit labor costs, actual labor costs per kg of production are actually lower in Europe, where labor productivity (kg production per unit labor) is a magnitude higher. Feed costs are also slightly higher in Asia, reflecting the less efficient use of trash fish as opposed to scientifically formulated pellets. Perhaps more surprisingly and of particular interest in development terms, investment costs (per unit production) are also lower in Europe, reflecting very high capital productivity.

It is clear that if the cage aquaculture industry in Asia is to grow as rapidly as it has in Europe in recent years, and compete in international markets, it will need to rationalise, with larger and/or better organized farms using more efficient cages, better feeds, and yielding far higher labor productivity. It will also need to market its products more aggressively in export markets.

Comparative Advantage

In practice, South and Southeast Asia, and in particular Thailand, have several significant comparative advantages in terms of cage culture production of marine finfish:

- tropical climate allowing for rapid growth rate and production cycles of less than 1 year
- well established hatchery production of (e.g.) sea bass in Thailand supplying low cost seed, and potential for hatchery production of a wider range of marine finfish species
- low labor costs and significant skills and experience in aquaculture production
- good location relative to east Asian markets coupled with rising domestic consumption
- strong seafood processing sector
- many suitable sites (in the region as a whole).

Other countries, such as Vietnam, China (including Hong Kong and Taiwan), and Korea have ready access to small but high value markets for live marine finfish, and despite lower temperatures, are probably best situated to supply these. Australia has rather few (relative to its size) sheltered areas for marine cage culture, and

Table 5. Input productivity for different cage culture operations and locations.

Quantity (mt)	Atlantic salmon (Europe)[1]	Sea bass (Thailand)[2]	Grouper (Vietnam)[3]	Chicken (US)[4]
Time to market (yrs)	2+	1	1	0.15
Labor (MD/mt)	5	40	600	
Labor (US$/mt)	405	500	600	
Food (kg/mt)	1,200	6,500	5,900	
Food (US$/mt)	1,300	1,600	1,800	430
Investment ($/mt/yr)	<100	160	1,000	
Seed ($/mt)	600	500	1,000	
Total production cost (US$/kg)	2.4	2.5-3.1	4.4+	<0.65
Farm gate value	3.3 (1997)	4.3 (1997)	5-10	0.65

[1] Based on medium scale Scottish fish farm 1999.

[2] AARM (TCU) AIT (unpublished field data).

[3] Trial 1997.

[4] Forster 1999.

higher labor costs, but with strong R&D support, and a range of climatic conditions suited to different species.

Development Strategies

There is significant potential for the further expansion of marine finfish culture in Asia. South and Southeast Asia have significant comparative advantages for the production of marine fish in sea cages. In particular, it has a wide range of species, high temperature and rapid growth; and in some areas plenty of skilled labor, and a strong tradition of aquaculture. There are clear market opportunities related to price differentials of high quality marine finfish in Asia, America and Europe.

The major practical constraints, such as high quality reasonably priced feed and seed, and improved technology, are likely to be overcome for many species in the coming decade. The more subtle developmental and institutional constraints such as low productivity (probably related to inadequate investment), the scale and organization of production, and ineffective marketing, are likely to become more important. These constraints will be of greater or lesser importance depending upon the nature of the target market.

There are four main markets that might be accessible to cage farmers of marine finfish:

1. high value live marine finfish (low volume; high value; mainly Asian)
2. local niche markets (low volume; medium-high value)
3. internationally traded chilled and frozen marine finfish, such as sea bass and sea bream (high volume; medium value)
4. international marine finfish fillet market (high volume; low value).

Production of high value live marine finfish has only limited potential for expansion, and high transport costs imply that only farms located close to markets (mainly Hong Kong) are likely to be successful. However, the size of this market can be increased if a much wider range of species can be produced. Countries with strong aquaculture skills and high levels of technical development (such as Taiwan) are best placed to develop these systems.

Production of fish for local niche markets is already a significant business in some SE Asian countries, and may be particularly suited to small-scale producers with intimate knowledge of local markets. The success of this approach will depend on local species and technologies.

Production of large volumes of medium value marine finfish for world markets in fresh and frozen finfish offers the greatest potential overall for marine cage aquaculture, and in particular for the tropical countries of Southeast Asia, which have significant comparative advantage in terms of growth rates and labor costs. However, in order to compete in this market, significant productivity and quality gains will be required. Investments by large companies, or vertical integration by companies contracting small and medium scale producers (as has taken place in the broiler industry in the US and to some extent in the salmon industry), may be required to achieve this shift, and at the same gain access to markets.

Marine cage culture is probably least well suited to the mass production of relatively low value fish for the fillet or block market, since production of species such as tilapia in ponds or cages (if feed costs can be kept down), alongside traditional capture fisheries, are likely to be significantly cheaper in the long run.

In terms of regional development and poverty alleviation, an important question is whether small-scale producers have any comparative advantage in terms of supplying the four markets discussed above. Small-scale producers are only likely to be able to compete in markets 2 and 3 (niche markets, and medium value internationally traded fresh or frozen finfish). In the case of the former they will achieve comparative advantage only through a deeper knowledge of specific small and lucrative markets. In the case of the latter, they will only be competitive if significant quality and productivity gains can be achieved. This implies greatly improved farmer organization, and/or the development of cooperatives or contract farming systems to achieve the necessary economies of scale and market access. Significant improvements in on-farm technology and management will also be required.

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Socioeconomic Aspects of Cage Aquaculture in Taiwan

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Abstract

Sustainable development of marine finfish cage aquaculture calls for comprehensive planning. Investments in offshore cage aquaculture must take into account socioeconomic, environmental and biotechnological considerations. This paper deals with the socioeconomic aspects of cage aquaculture in Taiwan. The socioeconomic problems facing farmers are high production costs, marketing factors, externality, user conflicts, and lack of infrastructures. Feed is the most important cost item. Cost structure varies with technology, species, and size. The fish farmers need to increase farm size (cages) to reduce production costs. The production of large size fish, which is especially for sashimi product, should target both the domestic and the Japanese markets. Despite the fact that cage aquaculture is a promising opportunity for expansion, it poses a high risk. Some well engineered cages have also been lost to storm conditions. Cages have also been vulnerable to poaching and vandalism. Marine fish farming can have significant environmental impacts and cause deterioration of coastal water quality. Therefore, some environmental and supporting regulations on cage aquaculture are needed to prevent marine pollution and to provide adequate safeguards to private investments.

Introduction

Aquaculture is one of the major fisheries in Taiwan, since aquacultural production constituted 37.2% of the total values of fisheries production in the last decade. Several factors contributed to the successful development of this industry, including the development of advanced culture technology and the ingenuity of fish farmers. However, the rapid expansion of land-based aquaculture and over-pumping of groundwater for fish ponds have resulted in adverse effects on the environment such as land subsidence and water pollution. Environmental degradation, diseases, and poor culture practices caused the collapse of shrimp culture industry in 1988. In 1995, government authorities decided not to encourage land-based fish farming anymore. At the same time, the authorities shifted aquaculture policy toward offshore cage culture.

The development of offshore cage farming industry in Taiwan has heen slow. Currently, the most important species for cage aquaculture is cohia, which has a great potential as an export product to Japan. The preliminary success of cobia culture has led to a significant interest of fish farmers to enter the industry. However, sustainable development of cage aquaculture for cobia and other species calls for careful planning. In view of the development potential and planning requirement, a socioeconomic analysis is needed to document the industry's structure and possible constraints for further expansion. This paper examines certain socioeconomic aspects of cage aquaculture in Taiwan. The initial section describes the social aspects of offshore cage culture, including the potential social benefits, user conflicts and environmental issues. The second section deals with the economic aspects of cage aquaculture. It focuses on the economic characteristics of fish farms, total capital investment, production costs, marketing channels and the market for cultured finfish in Taiwan.

Social Aspects of Cage Aquaculture

Supply of High-value Seafood and Employment Opportunities

One of the major social benefits of cage aquaculture is that it produces high-value fish products for human consumption. Cage aquaculture species is predominately high-value species such as cobia, yellowtail, red drum, red sea bream, red snapper and yellow sea bream. These marine fish can provide the essential nutrients to human diets in terms of animal proteins, essential amino acids, some vitamins and minerals. In 1992, about 21 metric tons of marine fish were provided by the cage aquaculture industry in Taiwan (Table 1). By 1998, the total production had increased to 2,763 metric tons and the total value of production was NT$ 522,498,000. Cage aquaculture is an activity that generates many direct and indirect jobs and therefore provides a high social benefit to the rural areas. Sea farming is a complex activity, which requires numerous complementary activities such as construction, engineering, and manufacturing. Thus, employment opportunities are created in cage farms as well as in associated activities such as hatcheries, processing plants, feed mills, ice plants, cold storage plants, companies supplying equipment, drugs, and chemicals, exporting companies, etc. At the farm level, employment opportunities are created at both the management and worker levels.

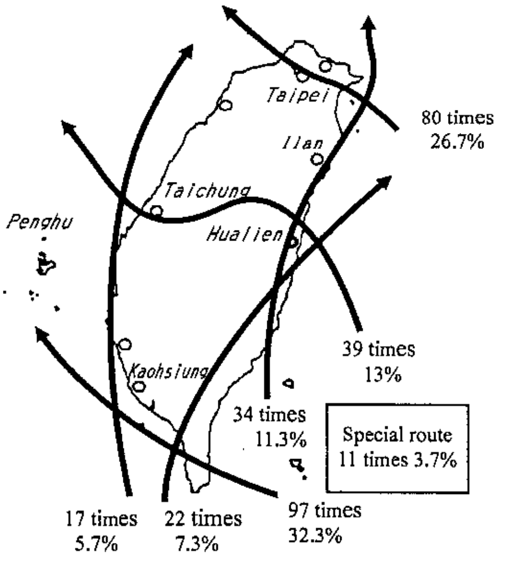
Table 1. Production, value and area of cage aquaculture in Taiwan.

Year	Production (mt)	Production value (NT$1000)	Area (m²)
1989	21	3,218	15,936
1990	103	13,726	13,050
1991	86	11,541	89,936
1992	130	29,327	116,436
1993	138	31,529	184,436
1994	150	36,278	180,500
1995	357	94,128	513,000
1996	678	147,500	533,728
1997	837	186,074	390,525
1998	2,763	522,498	1,072,986

Source: Taiwan's Fisheries Yearbook.

Lack of Suitable Culture Sites

Suitable sites for marine cage culture in Taiwan are limited unless a typhoon-proof cage technology is available. Every year about three to four typhoons land somewhere in Taiwan during a 3-month period from July to September. Typhoon paths are plotted in Fig. 1. Most typhoons occur in the east coast. The development of cage culture has been hampered in the east and northeast coast. The sea in the Penghu islands is protected against most typhoons. This is the reason why most of the sea cage farming activities take place in the Penghu islands.



Source: Twu *et al.*, 1986

Fig. 1. Approach routes of typhoons (1897-1983).

The coastline of Taiwan is found to be very uniform with only few indentations. Thus, only a few protected areas in the north and northwest and at the west coast of the most southern part of the island can be found. But apart from the main island, the Penghu islands offer protected sites and provide one of the best areas for cage farming. It is estimated that the Penghu islands have

1,942 cages for fish farming (Fig. 2). Some 380 cages are situated in Pingtung, which is located at the east coast of the most southern tip of Taiwan. About 190 cages are installed in the Ryukyu Island.

User Conflicts

Since cages occupy space, this can disrupt access and make navigation difficult. The impacts of cage aquaculture on the marine environment can bring about conflict among other users such as commercial fishermen and recreational anglers. Due to the licensing systems of cage aquaculture in Taiwan, real conflicts between commercial fishermen and cage farmers may be minimized. Under the exclusion-based fishery rights, an applicant of cage aquaculture has to be a member of the local fishermen's association (Table 2). Under the zone-based fishery rights, the local government officers shall consult the local fishermen's association or village when they approve an application for offshore fish farming. The local fishermen are often given preference in employment in cage aquaculture companies to minimize conflicts.

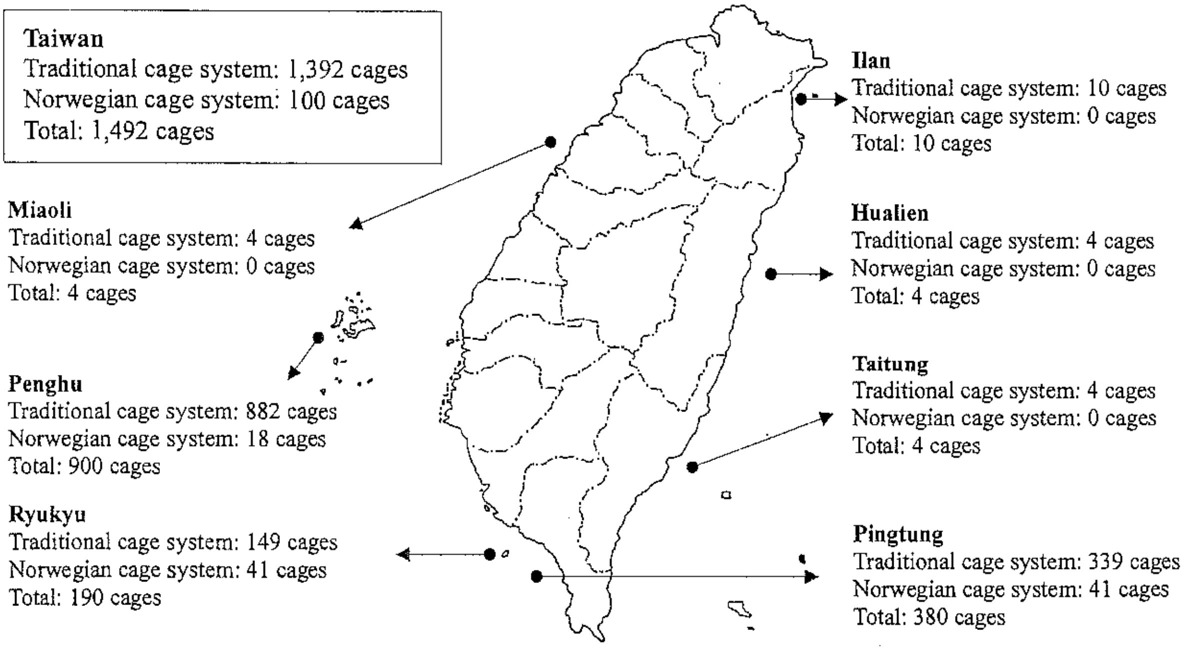


Fig. 2. Number of floating cages in Taiwan by location and system.

Table 2. Licensing systems of cage aquaculture in Taiwan.

Item	Licensing system under zone-based fishery rights	Licensing system under exclusion-based fishery rights
Applicable county	Penghu	Pingtung, Ryukyu, Tainan, Kaohsiung, etc.
License/monitoring authority	Local government	Fishermen's association
Applicant's qualification	Self-employer, partnership, company, cooperation, public agencies, fishermen's association or cooperatives	Members of fishermen's association or cooperatives
Area restriction per applicant	Individual < 3 ha Organization < 10 ha	< 1,000 ha
Lease period	5 years	10 years
Disadvantage	Diseconomies of scale	Too political

Environment and Security Problems

The number of cages in Taiwan has increased and because of overfeeding and fish waste, culture sites can be polluted. Overfeeding is not only a waste of resources, it also leads to water quality problems. The use of trash fish to feed fish can also contaminate the culture ground. Escape of farmed species is another area of environmental concern. Cultured fish that escape from captivity may interbreed with wild stocks, altering genetic composition and compromising wild population. Security is another problem for cage fish farmers as cages are situated in bodies of water that are publicly owned and are thus highly vulnerable to poaching and vandalism. Cages are also more vulnerable to typhoons or storm damage than ponds in aquaculture.

The legal framework of cage aquaculture is shown in Fig. 3. Under the basic law, license systems for cage aquaculture are implemented, but currently Taiwan lacks environmental and supporting laws. Laws on the prevention of marine aquaculture pollution and accidents are needed and should include important regulations concerning requirements of environmental impact assessments, restrictions on drug and chemical uses, and standards for feed composition and management practices. To facilitate the development of cage aquaculture, legislation on supporting activities relating to infrastructures, transportation vessels, and research are also needed.

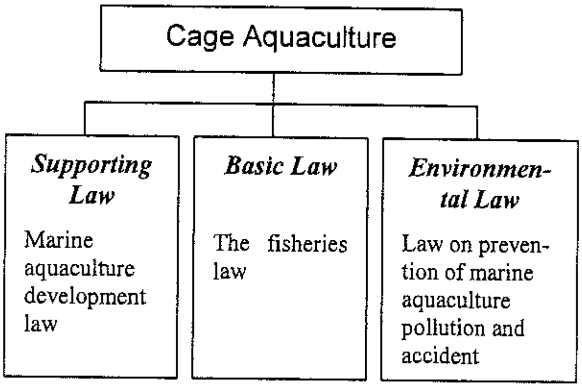


Fig. 3. Legislations on marine pollution prevention and cage aquaculture development.

Economic Aspects of Cage Aquaculture

Economic Characteristics of Cage Culture Farms

The socioeconomic characteristics of cage aquaculture farms by species are shown in Table 3.

Table 3. Socioeconomic characteristics of cage aquaculture farms by species, 1998.

Item	Cobia	Grouper	Red drum	Yellowtail	Red sea bream
Sample size (farms)	4	8	6	4	4
No. of cages	25.95	21.50	5.67	32.25	50.00
Areas (m^3)	10,252	4,933	4,960	17,360	19,500
Stocking density (fish/m^3)	9.82	8.33	7.15	7.76	9.19
Mortality rate (%)	41.25	36.25	45.83	37.50	42.50
Production per farm (kg)	23,375	9,225	3,350	121,250	16,875
Production per m^3 (kg)	3.17	3.83	1.39	15.11	3.47
Long-term workers (person)	2.37	3.50	2.67	4.50	2.25
Short-term workers (person)	3.75	3.67	4.00	5.25	6.50
Household size (person)	5.13	4.63	4.33	3.75	4.50
Experience of manager (yrs)	7.63	5.88	4.17	7.00	11.25

In general, cage culture in Taiwan is made up of relatively small-scale operations. On the average, the cobia farms have 26 cages, totaling 10,352 m^3 while the red sea bream farms have 50 cages. The stocking density of the cages for all species cultured is rather uniform, averaging eight fingerlings/m^3. The mortality rate varies with species, but is generally around 42%. The average production per farm of the five types of farmers varies considerably. Total volume harvested per farm is higher for yellowtail farms than other farms.

At present, Taiwan's cage farming industry is still a labor-intensive operation; considering the fact that the major operational tasks of feeding and harvesting are done manually. Family members provide majority of the tasks in small farms. Since most of the cage managers have been engaged in aquaculture activities for 4 to 11 years, this implies that many of the cage operators are no longer new in the business.

The total investment in cage culture varies depending upon the number of cages and the type of materials used in the construction of cages. Table 4 shows the average capital investment in cage aquaculture by species. Red sea bream farms has a total capital investment of NT$ 8,655,417. The largest investment is on the net cage, which represents more than 70% of the total capital investment. Boat and motor are also major investment items.

Production Costs of Cage Aquaculture

Table 5 presents the cost structure of cage culture by species. Transportation and marketing costs are not included. Feed is the most important cost item for cage aquaculture in Taiwan. Feed cost accounts for an average of 50% of the production costs. As such, profit is highly sensitive to feed cost. Currently, fish farmers use trash fish or formulated diets to feed fish. The protein contents of the formulated diets are as high as 40%, which could be decreased to reduce feed costs. The conversion rates are also important for feed costs. Thus, improving feeding practices and management are essential in cage aquaculture. Labor is another important cost item. Labor cost can be controlled by the fish farmers to reduce their costs of production. To reduce its labor costs, the cage industry must automate production operations.

Total production cost per kg is higher for culture species in Taiwan than salmon produced in Norway since the Norwegian aquaculture industry produces salmon in large culture units of cages to reduce production costs. It is therefore recommended that fish farmers in Taiwan consider increasing the size of their small production units to a more efficient scale. As the size of production system increases, production costs per kg are reduced; since fixed costs can be spread over larger production levels.

Table 4. Investments per farm of cage aquaculture by species in Taiwan, 1998.

Item	Cobia	Grouper	Red drum	Yellowtail	Red sea bream
Sample size (farms)	8	8	6	4	4
Cages* (NT$/farm)	2,056,250	2,431,250	2,276,667	4,137,500	6,112,500
Boat and motor (NT$/farm)	350,000	607,500	793,333	194,000	825,000
Electricity generator (NT$/farm)	117,500	32,500	8,333	45,000	0
Feed preparation					
Equipment (NT$/farm)	88,125	163,750	36,667	112,500	240,000
Freezer (NT$/farm)	221,429	193,750	41,667	87,500	250,000
Work and storage shed** (NT$/farm)	125,000	531,250	0	175,000	966,667
Miscellaneous (NT$/farm)	34,750	126,750	209,166	25,000	261,250
Total investments (NT$/farm)	2,993,054	4,086,750	3,365,833	4,776,500	8,655,417

* Including: net, rope, buoy, anchoring, etc. ** Including: feed storage, office, etc.

Table 5. Production costs (NT$ per kg live weight) of cage aquaculture by species.

Item	Cobia	Grouper	Red drum	Yellowtail	Red sea bream	Red Snapper	Yellow sea bream
Seed stock costs	5.56	20.23	19.70	31.44	13.90	10.21	8.02
Feed	48.92	55.68	43.32	51.24	41.65	39.67	57.51
Labor	9.39	22.27	13.07	15.81	22.21	11.77	21.62
Depreciation	3.45	9.50	6.27	5.73	9.72	4.98	7.33
Interest	2.27	6.07	3.47	3.54	6.01	3.14	4.62
Miscellaneous costs	3.30	5.65	3.58	3.73	5.77	3.16	6.04
Total costs/kg	72.89	119.40	89.41	111.49	99.26	72.93	105.14

Source: Wang and Huang (1998).

Methods of Achieving Economic Production

The production system of marine cage aquaculture was introduced in Southern Taiwan in the 1970's and expanded significantly in the last few years. However, the production system of cage culture of marine finfish has not been improved. Under the system, the young of the species are produced in hatcheries and then stocked in cages in the offshore where they grow to the market size. The production system of cage culture of marine finfish can be categorized in a number of production stages (Fig. 4). The first stage is the hatchery spawning, egg and fry production. The second stage involves growth of fry to phase I fingerlings. The third stage is the growth of phase I fingerlings to phase II fingerlings. The last stage is the grow-out of phase II fingerlings to market size fish. Cage fish farmers can specialize in one of the four stages of production system or may integrate a combination of these stages. The division of labor in the production system will reduce risks since some stages can be operated on shore instead of offshore in the ocean and improve economic efficiency.

The success of a production system in floating cage culture depends primarily, if not exclusively on its profitability. The profitability of cage aquaculture can be improved if (1) the production per unit water area can be increased and (2) the cost of production can be reduced.

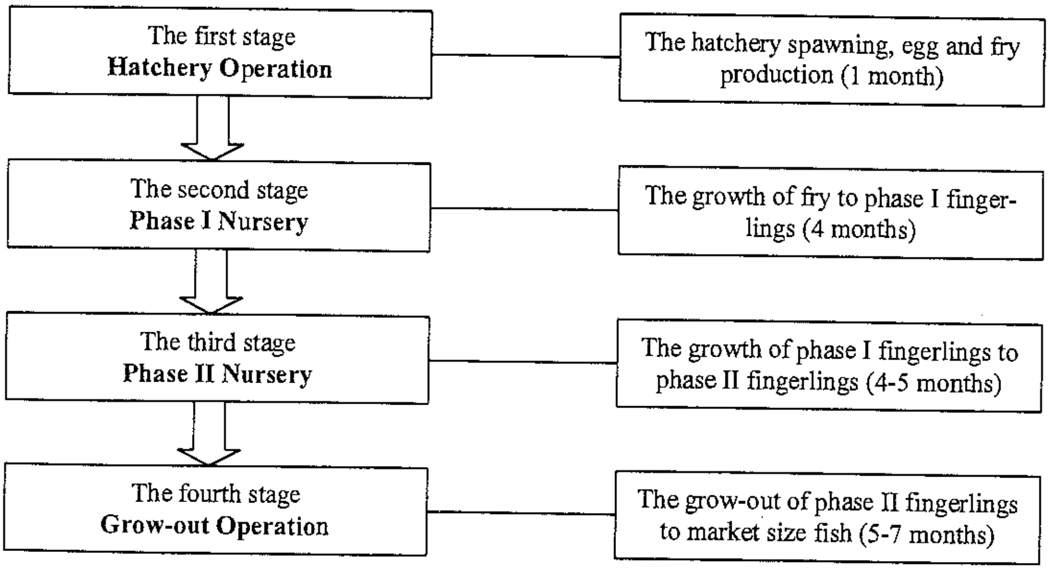


Fig. 4. Production systems of cage aquaculture.

These can be achieved by choosing the suitable production system, providing a suitable culture site with good water quality; providing optimum stocking density and feeding frequency; using quality feeds and fingerlings; preventing disease and ensuring efficient treatment; and proper maintenance of cage as well as good farm management (Fig. 5).

Marketing channels are very short for cultured fish (Fig. 6). There are two major marketing channels of cage cultured fish : (1) Producer → Restaurants → Consumers and (2) Producer → Export markets → Consumers. Thus, growers concentrate on two markets: domestic and export outlets. The domestic market outlets are the traditional ones such as restaurants and fish markets. The major export markets are Japan and Hong Kong. The cage cultured fish in Taiwan can be categorized into three products: (1) the 600 g plate-size fish, which is sold live and used for steamed fish, (2) the 2-3 kg size fish, which is used for sashimi, and (3) the 8-10 kg size fish, which is used for sashimi and delivered "fresh on ice". Since the cage cultured fish are sold live or fresh on ice in Taiwan, improvements in post-harvest technologies are needed to ensure product quality.

To further expand the markets and improve marketing efficiency, producers must employ some marketing strategies for their marine products. The marketing strategies suggested are as follows:

1. Select live fish, fillet products and sashimi market segments for expansion.
2. Establish brand names for cage aquaculture products.
3. Position cobia against salmon in sashimi markets.

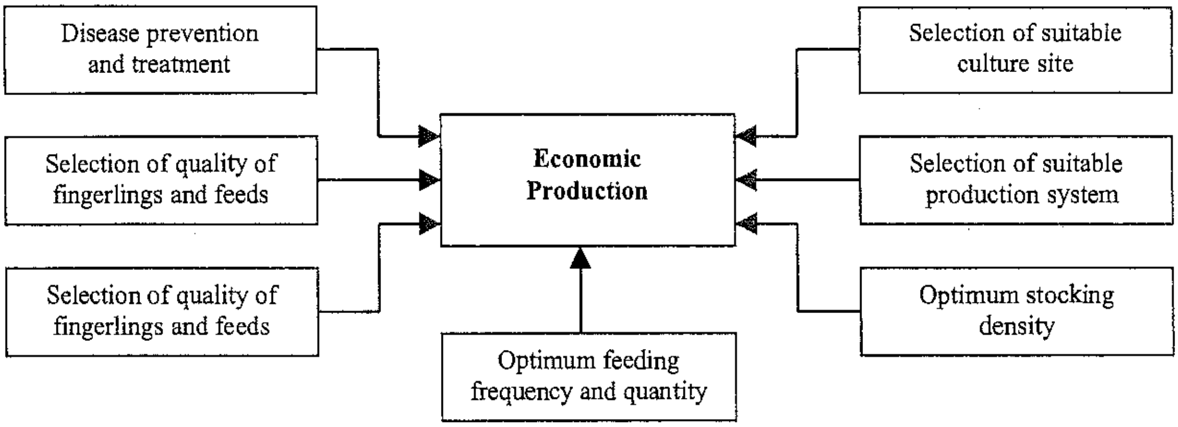


Fig. 5. Methods of achieving economic production in cage aquaculture.

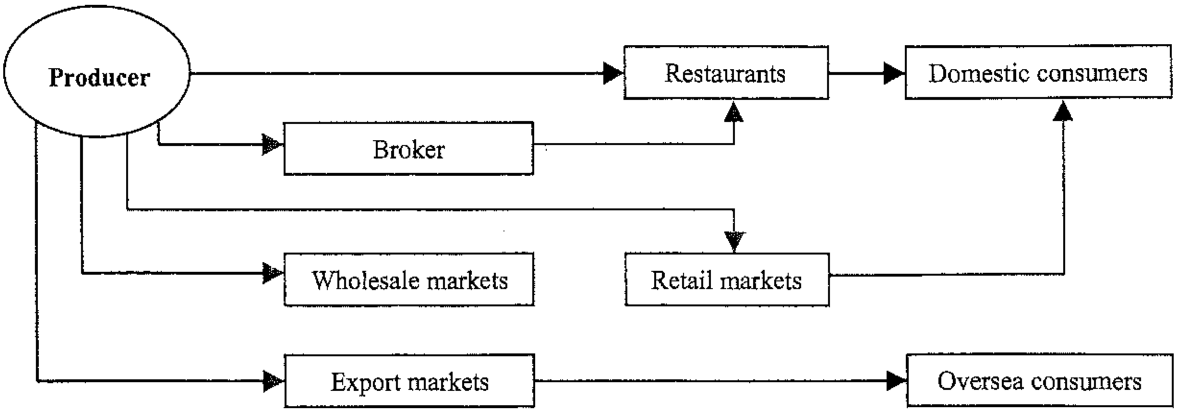


Fig. 6. Marketing channels for aquatic products from cage aquaculture in Taiwan.

4. Diversify marketing channels and market outlets.
5. Implement producer's cooperative marketing programs through Taiwan's Offshore Aquaculture Association.
6. Use affordable price strategy instead of high-price strategy.
7. Conduct effective advertising and promotion programs to increase consumers' demands.
8. Create a quality and quantity assurance system for cultured fishes.

Domestic and Export Markets for Cage Cultured Fish

The domestic market for marine fish has expanded substantially since the Taiwanese are very fond of seafood and their per capita disposable income has increased in recent years. Cage farmers market about 50% of their harvests in domestic markets. The farm gate prices of cage cultured fish are shown in Table 6.

Table 6. Price of major cage cultured fish species in Penghu, Taiwan, 1999.

Month	Cobia* (NT$/kg)	Red sea bream** (NT$/kg)	Grouper** (NT$/kg)
January	120-130	175-185	300-400
February	130-140	175-185	300-400
March	130-140	175-185	300-400
April	145-155	170-180	300-400
May	150-160	170-180	300-400
June	180-190	180-190	300-400
July	180-190	180-190	300-400
August	220-230	210-215	300-400
September	220-230	210-215	300-400
October	220-230	210-215	300-400

* live weight = 7-8 kg/fish; ** live weight = 1 kg/fish.
Source: Fishermen's Association of Penghu (unpublished).

Cobia has a drastic price increase resulting from an effective promotion program. Grouper and sea bream command high prices. Domestic markets for expensive finfish are limited, but once supplies exceed demands, prices will drop and affect the cage farmers' profits.

Taiwan's imports of farmed salmon have increased significantly over the past five years. The imports of salmon totaled about 20,117 tons in 1997 (Table 7).

Table 7. Taiwan's import of salmon, 1997.

Country origin	Import (mt)	%
Norway	11,386	56.6
Canada	3,963	19.7
Chile	1,609	8.0
Japan	1,288	6.4
U.K.	865	4.3
Others	1,006	5.0
Total import	20,117	100.0

Source: Council of Agriculture, Taiwan.

The Norwegian aquaculture industry supplied 56.6% of the total imports of salmon. Cobia is the substitute species for salmon in sashimi markets and commands a higher price than salmon. Thus, cobia has a great market potential in Taiwan.

Cobia is one of cage cultured fish exported to Japan. It commands good acceptance by Japanese consumers. Cobia must be able to compete in the Japanese market that demands high quality and competitively priced products. This includes good color, texture and meat quality. Once its reputation for quality is established in the Japanese market, exports of Taiwanese cobia can increase rapidly.

The market for farmed salmon is very large. Salmon is consumed in many countries throughout the world. The largest markets for salmon are in Japan, U.S. and Europe. In Japan, per capita levels of salmon consumption are higher than in other countries. In recent years, imports of farmed salmon particularly from Norway have been increasing. Thus, the production of farm salmon from Norway, Chile, U.K. and Canada has increased significantly in recent years. If industrial fish farming for cobia can be developed in Taiwan, the lower production cost and the price will make it possible to compete with salmon in the export markets.

Hong Kong and Singapore have had strong market demands for high-value marine finfish since the 1970's (Wong 1995). These countries have a strong preference for seafood and have also shown rapid economic growth. In Hong

Kong, grouper is in high demand for Chinese-style cooking which requires fresh-killed fish. It was estimated that total imports of live grouper was 6,555 metric tons in 1998 (Table 8). The major suppliers of live grouper to Hong Kong were Thailand, Indonesia and the Philippines. Thailand is the biggest supplier but the fish mostly consist of low priced grouper. Groupers are the high priced finfish in Taiwan with a production from aquaculture well over 2,529 metric tons in 1997 (Table 9). Taiwan's exports of farmed grouper to Hong Kong is increasing. Thus, Hong Kong is considered as an important export market for Taiwanese cage aquaculture industry in the future.

Conclusions

There is great potential for cage aquaculture development in Taiwan. The industry is still centered in the South and Penghu islands, where yields are relatively low. The high cost of production is a critical problem for the industry. Since feed is the leading cost on most farms, development of a better formulated and cost-effective feed is necessary. The average farm size (i.e. number of cages) should also be increased to reduce average production costs. The productivity is very low compared to salmon farms in Norway. Cages are also vulnerable to typhoon and storm damages. Technological advances may help resolve some current problems. Some potential market developments are promising. The major export markets for cage cultured products (Japan and Hong Kong) are increasing their imports. To further expand the market, producers must establish a quality and quantity assurance system. For the large size fish, which is for sashimi, producers should target both the Japanese and the domestic markets. Besides market development, disease prevention, use of dry pelleted feed and economies of farm size are needed for the success of industrial fish farming in Taiwan. In addition, some environmental and supporting regulations on cage aquaculture are also needed to prevent marine pollution and to facilitate private investment in sea-based fish farming.

Table 8. Major suppliers of grouper to Hong Kong, 1998.

Origin	Import (mt)	Average price (HK$/kg)
Thailand	3,650	48
Indonesia	1,341	85
Philippines	483	77
Malaysia	394	69
Australia	306	80
Vietnam	102	85
Others	279	66
Total	6,555	62

Source: Hong Kong Agriculture and Fisheries Department, 1998.

Table 9. Grouper production and trade in Taiwan, 1995-1997.

Item	1995	1996	1997
Domestic production from aquaculture (mt)	2,104	1,882	2,529
Export (mt)	67	229	249
Import (mt)	20	9.3	17.5

Source: Taiwan Fisheries Yearbook.

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Diseases of Cage Cultured Fish in Marine and Brackishwater

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Abstract

As most cage culture are intensive, fish are found to be susceptible to disease infections, particularly under unfavorable environmental conditions that cause fish stress. Diseases commonly found in cage cultured fish are caused by bacteria, viruses and parasites. Among bacterial diseases, vibriosis and *Aeromonas columnaris* are probably the most commonly encountered in marine fish cultured in cages. Vibriosis occurs widely among grouper, sea bass and snapper in the Southeast Asian region; while Pasteurellosis and streptococcosis are the most serious infectious diseases in Japan. Among viral diseases, Lymphocystis, RSIV, VNN are reported to infect many cultured marine fish causing high mortality, particularly in juveniles and young adults. Among parasitic diseases, cryptocaryonosis caused by *Cryptocaryon irritans*, shows low host specificity and is commonly found among caged grouper, snapper and sea bass fingerlings. Capsalid monogeneans have been reported to cause heavy mortality in a wide range of hosts in cultured marine fishes in Japan and Southeast Asia. They include six species of *Benedenia,* three species of *Neobenedenia* and two species of *Megalocotyloides.* Cases of parasitic crustaceans are seldom found in cultured marine fish. However, caligids, argulids, irgasilids and isopods were reported to cause severe injury and sometimes mortality among cultured fish.

There are few effective therapies for these diseases. In Japan, vaccination was reported to be successful in controlling RSIV. Antibiotics have been used to treat some bacterial diseases. Dipterex is effective in treating yellowtail infected by *Caligus elongatus,* while freshwater water dip was effective for *Caligus* sp. in cultured groupers and snappers in Malaysia.

Introduction

Fish have been successfully cultured in net cages in the tropical regions. This system is practiced intensively. Intensive culture system, either in ponds or in cages, has always lead to epizootic disease problems. In the marine environment, where environmental parameters fluctuate widely, fish become more susceptible to diseases. When any diseases occur in cages, they are almost impossible to be controlled and treated.

Among the diseases found to cause severe damage to fish cultured in marine cages, bacterial diseases appear to be most significant, causing the most severe loss to this system. Advances in fish disease research in Asia are mostly in Japan, Taiwan and Korea. In Southeast Asia attention to disease problems are gradually increasing.

The technologies for culture of marine fish in cages are much more advanced and well developed in East Asia than Southeast and West Asia. As far as diseases are concerned, this also implies that the identifications, treatment and control of diseases are much more documented and studied in East Asia than at other Asian countries. Nevertheless, the diseases mentioned in this paper are found in marine fish species cultured in East and Southeast Asia. In these Asian countries, many of the species cultured are similar, with marketable fish from Southeast Asia being sent to East Asia for consumption and fish fries from East Asia to Southeast Asia for culture in marine cages.

Bacterial Diseases

Vibriosis

Among the bacterial diseases in fish cultured in marine and brackishwater cages, vibriosis appears to be the most significant one. In Southeast Asia (SEA), grouper (Fig. 1), sea bass (Fig. 2) and snapper have always been reported as affected by vibriosis. Severe mortality is often the outcome of this disease.

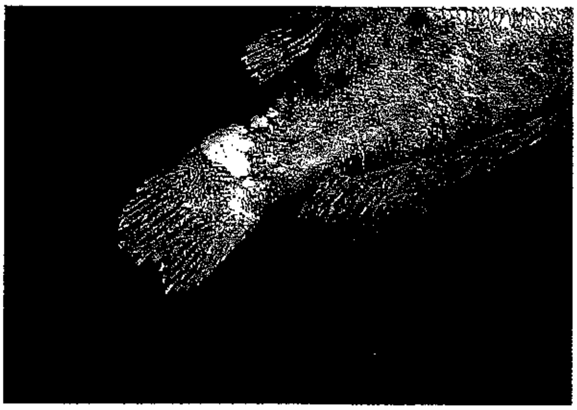

Fig. 1. Vibriosis in grouper, typical symptom of hemorrhage at the tail.

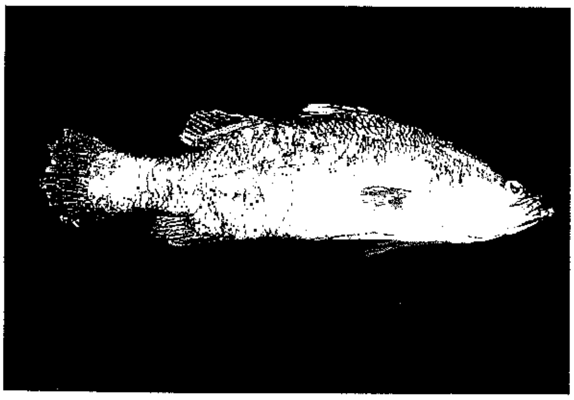

Fig. 2. Vibriosis in sea bass.

This occurs more frequently during periods of wide and long lasting fluctuation of salinity, increased organic load, stress brought about by poor transportation and much handling during transportation, net changing, and grading of fish. The period following initial stocking is particularly critical. Oftentimes, more than one species of Vibrio are isolated from the diseased fish. In Southeast Asia, *V. parahaemolyticus* and *V. alginolyticus* are the main species involved (Wong and Leong 1986, 1990). In East and West Asia, the most common isolates are *V. ordalii*, *V. echithyoenteric*, *V. trachuri*, *V. damsela* and *V. anguillarum*. Vibrio causes hemorrhages and red boil on the body surface. Hemorrhages are initially small, gradually enlarging and becoming deep lesions. Darkening of the body may be observed. Internal pathology occurs as the disease progresses with congestion and hemorrhage of the liver, enlargement and liquefaction of spleen, liver and kidney. Vibrio also causes gastroenteritis but this is less common.

Columnaris Disease

Also called the tail rot syndrome (Fig. 3), this disease was observed in all major fish cultured in cages (Ruangpan 1985; Ruangpan *et al.* 1987; Leong *et al.* 1992). Sea bass seems to be more susceptible to this disease. Since 1988, epizootic of columnaris disease was observed whenever the sea bass fingerling was introduced for culture in net cages throughout SEA (Perngmark 1992; Leong 1994). In East Asia, a large variety of marine fish (snapper, grouper, yellowtail, red sea bream, Japanese flounder, grey mullet etc.) cultured in cages are also effected by this disease (Arthur and Ogawa 1996; Lavilla-Pitogo *et al.* 1996; Sako 1996). The bacterium involved as etiological agent of this disease is *Flexibacter maritimus* in Japan (Wakabayashi *et al.* 1986), and the species of flexibacter involved in the tail-rot disease in sea bass is still to be ascertained. The histological study of this disease indicated that the pathogen infection occurred in the damaged tissue, particularly in the damaged caudal fin where the bacteria enter and multiply in the epidermis and dermis (Perngmark 1992).

The flexibacter bacterium has also been found in sea bass affected by scale-drop disease. The bacterium is found multiplying under the epidermis, particularly along the collagen fibre and do not enter the muscle, but does secrete proteolytic enzymes in breaking up the muscle cells (Leong and Wang 1993).

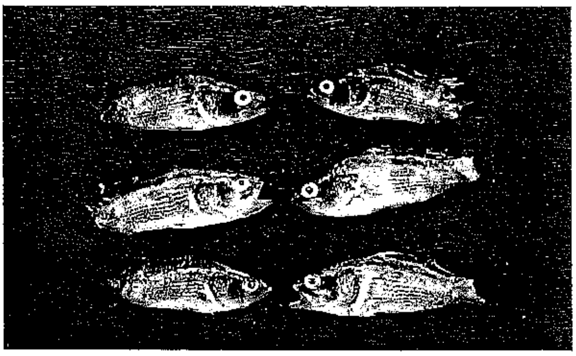

Fig. 3. Tail rot disease in sea bass caused by flexibacter bacteria.

Edwardsiellosis

This is an infectious systemic bacterial disease caused by *Edwardsiella tarda.* This disease has been reported from a large variety of marine cage cultured fish: crimson sea bream, *Evynnis japonicus* (Kusuda *et al.* 1977), yellowtail, *Seriola quingueradiata*, red sea bream, *Chrysophrys major* (Yasunaga *et al.* 1982), Japanese flounder *Paralichthys olivaceus* (Nakatsugawa 1983). Hemorrhagic ulcers on the opercula and body surface characterize this disease. Grayish white spots are scattered in the spleen and kidney (Kusuda *et al.* 1977). Fish swims in a whirling motion.

Salati (1988) reported that the most effective drug is oxolinic acid followed by trimethoprim, oxytetracycline, furazolidone and piromidic acid. However, it is necessary that sensitivity tests to the antibiotic must be obtained before using it.

Pasteurellosis

This is one of the most important infectious diseases in cultured yellowtail in Japan. It was reported to cause the loss of about 2063 tons in 1992 (Sako 1996). Black sea bream, horse mackerel, and Japanese flounder in Japan and Korea have been seriously affected by this disease (Kusuda and Salati 1993; Park and Sohu 1996; Sako 1996).

The etiological agent is *Pasteurella piscicida*. This bacterium is affected by water temperature and the disease tends to occur when the water temperature is about 20-25°C. It is a septicemia disease with no external signs. A large number of white spots are found mainly in the spleen and kidney and to a lesser extent in the liver. Infected fish rapidly loses vigor, sinks to the bottom of the cage and dies.

Streptococcosis

This disease has caused serious loss in cultured fish in Japan in 1992; 5,954 tons of yellowtail, 63 tons of horse mackerel and 208 tons of Japanese flounder (Sako 1996). In Southeast Asia, grouper and rabbit fish are also affected by this disease (Leong 1994).

Streptococcus spp. are etiological agents of this disease. Exopthalmia, haemorrhages, abdominal distension and erratic swimming are the common symptoms. Darkening and sometime ulceration of body surface may be observed.

In SEA, grouper cultured in net cages after four to six weeks or are reaching approximately 200 gm often die overnight without any apparent symptoms of disease except that the body that darkens. This lethal condition is referred to as "sleepy-grouper syndrome" (Fig. 4). In Singapore and Indonesia, they were reported to be caused by a virus (Chua *et al.* 1994; Arthur and Ogawa 1996). In Malaysia, they were found in a high number and large variety of monogeneans as well as gastroenteritis vibriosis (Leong and Wong 1993).

Control and Treatment

Control and treatment of these bacterial diseases are emphasized on good animal husbandry and adequate nutrition. Chemicals and antibiotics have often been applied but the success rate is limited. Reduction of stocking density helps to reduce mortality in affected sea bass. Sulfa drugs at 50-200 mg/kg of fish weight per day for 10-20 days gave good results when administered during the initial stage of the disease (Sano and Fukuda 1987). Early recognition of the external symptoms of the bacterial diseases and immediate treatment for all fish, infected and non-infected, in the same cage are extremely important in achieving high recovery rate. Treatment of vibriosis in grouper has been most effective through intraperitoneal injection at a dosage usually ranging between 0.1-0.2 ml per fish according to the weight of the fish.

Medicated feed with any antibiotic in Southeast Asia has usually been found to be unsatisfactory. In Japan, erythromycin, spiramycin and jasamycin were reported to be the most effective antibiotics in controlling streptococcosis (Kashiwagi *et al.* 1977; Shiomitsu *et al.* 1980; Kusuda and Onizaki 1985; Kusuda and Takemaru 1987; Takemaru and Kusuda 1988, 1990). Leong *et al.* (1997) reported that grouper vaccinated against vibriosis did not show any sign of sleepy-grouper syndrome. The vaccinated grouper were healthier and grew faster.

Fig. 4. Sleepy grouper disease.

Viral Diseases

Lymphocystis

This disease (Fig. 5) is characterized by tumor-like masses of tissue on the body surface. It is a highly contagious infection caused by a cytoplasmic DNA iridovirus. In East Asia, outbreaks of this disease have been reported for sea bass (Miyazaki and Egusa 1972; Park and Sohu 1996), yellowtail (Matsusato 1975) Japanese flounder (Tanaka *et al.* 1984; Park and Sohu 1996) red sea bream (Chen 1996; Muroga 1997) and rockfish (Chun 1998). In Southeast Asia, lymphocystis is mainly found infecting sea bass and to a lesser extent the grouper as well (Limsuwan *et al.* 1983; Chao 1984; Leong 1994). Matsuoka (1995) reported the incidence of this disease as having increased since the early nineties, particularly in Japanese flounder. Muroga (1997) reported that this disease has been a major viral disease of maricultured fish in Japan.

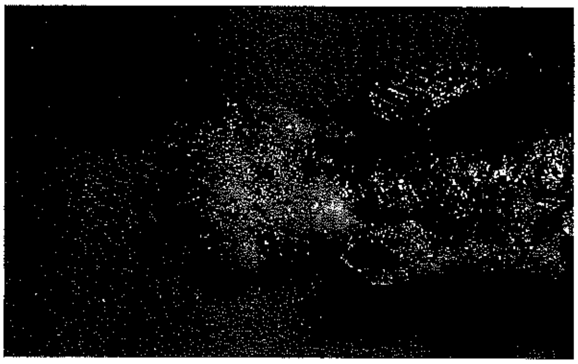

Fig. 5. Lymphocystis disease in sea bass.

Red Sea Bream Iridovirus

This disease is not limited to red sea bream but affecting many other species (Matsuoka *et al.* 1996; Nakajima 1997). A similar disease was reported in cultured grouper in Thailand (Danayadol *et al.* 1997). The affected fish become lethargic, exhibit severe anemia, petechiae in gills, hypertrophic spleen and enlarged basophilic splenic cells. In these enlarged cells, the iridovirus is present in a crystalline array (Inouye *et al.* 1992).

Viral Nervous Necrosis (VNN)

VNN is a significant disease causing high mortality in marine cage cultured fish. It was first reported in Japanese parrotfish and later in a 1985-87 disease outbreak (Yoshikoshi and Inouye 1990) in more than 10 species of fish in Japan (Mori *et al.* 1992; Muroga 1995; Nakai *et* *al.* 1995). Similar diseases have been reported in Asian sea bass (Glazebrook *et al.* 1990; Comps *et al.* 1994), and grouper (Danayadol *et al.* 1993, 1995; Chua *et al.* 1995; Tanaka *et al.* 1998). This disease is characterized by loss of appetite, lethargy, dark body coloration, erratic movement, loss of balance and hyperexcitability in response to noise and light. Mortality often occurs within one week from the onset of the first symptom. Extensive spongiosis is typically observed in the retina, brain and central nervous system (Glazebrook *et al.* 1990; Yoshikoshi and Inouye 1990; Danayadol *et al.* 1995; Boonyaratpalin *et al.* 1996; Nguyen 1996).

No effective chemical agents have been reported to control viral diseases. At present, virus can be detected by enzyme-linked immunosorbent assay (ELISA) and a polymerase chain reaction (Arimoto *et al.*, 1992; Mushiake *et al.* 1992, 1994). PCR was used to detect the presence of virus in spawners. The use of PCR-negative spawner can effectively prevent the vertical transmission of viral diseases.

Parasitic Diseases

Parasitic diseases of marine cage cultured fish are found as ecto parasites and endoparasites. Some of them are bost specific. Myxosporeans are endoparasites in visceral cavities such as gall bladder, swim bladder, urinary tract, blood, and muscle. *Sphaerospora epinephili* was found in the urinary system of adult groupers from SEA (Supamattaya *et al.* 1990, 1993). Fish infected with this parasite exhibited highly vacuolated epithelial renal tubules.

Several species of external parasites have been reported in marine cage cultured fish. *Cryptocaryon irritans,* a holotrich ciliate are commonly found on affected grouper, snapper and sea bass fingerlings. Fish have sbown high susceptibility at the early stage of cage culture (Chong and Chao 1986; Leong 1994). In heavy infestation by this parasite, pinhead size whitish blisters are observed scattered all over the skin. Fish produce increased mucus on the gills and body surface and may frequently swim to the surface gasping for oxygen.

At least three genera of capsalid monogeneans are found in marine cage cultured fish. They are found on the skin, under the scales and on the gills (Fig. 6), but diplectanid and dactylogyrid are found only on the gills. These parasites feed on the epithelial cells and mucus. Active feeding on mucus and epithelial cells leads to hemorrhages, inflammation and mucus hyperproduction (Paperna 1991; Egusa 1992). Monogeneans, attaching around the eyes damage the cornea and cause blindness (Egusa 1992; Ogawa *et al.* 1995; Colorni 1998). Heavy mortality has been reported in flounder and black rockfish with an intensity of 900-1500 worms/fish (Ogawa *et al.* 1995).

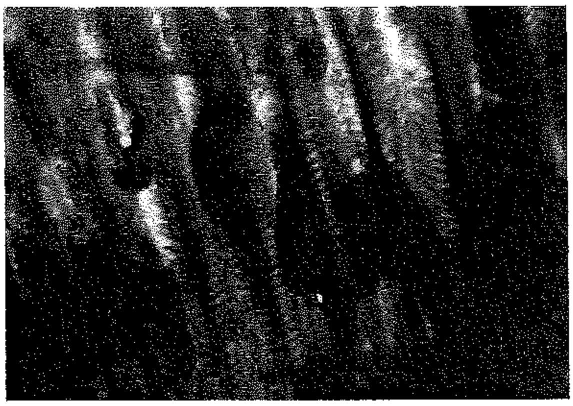

Fig. 6. Monogeneans on the gill of grouper.

In 1992, heavy mortality due to sleepy grouper syndrome in cultured grouper (*E. coioides*) occurred in SEA. Heavy infestation of *Benedenia* spp. and *Neobenedenia* sp. as well as gastroenterititis was found in the affected fish (Leong and Wong 1993).

It is very difficult to control this parasite in a caged environment. However, a freshwater dip for about five minutes is sufficient to dislodge the parasite from the host.

Parasitic crustaceans reported from marine cage cultured fish are relatively few. Only heavy infestation can cause severe damage. There were reports of *Caligus* causing serious injuries in marine cage cultured fish in Japan (Fujita *et al.* 1969), Philippines (Lavina 1977) and Malaysia (Leong and Wong 1988). Ruangpan (1988) reported the mortality of juvenile sea bass caused by isopod *Aega* sp.

Fujita *et al.* (1969) successfully treated yellowtail infested with *Caligus elongatus* by 50-second immersions in 100 ppm solution of Dipterex. Freshwater dipping proved to be effective for *Caligus* sp. in cultured grouper and snapper. However, they may be reinfected after being transferred back to tbe cage.

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Entry Points and Low Risk Strategies Appropriate for the Resource-poor to Participate in Cage Aquaculture: Experiences from the CARE-CAGES Project, Bangladesh

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Abstract

Cage aquaculture has a limited and ultimately unsuccessful history in Bangladesh. It is postulated that a major reason for this is the failure to properly address the resources and limitations in terms of inputs (cages, seed and feed) of potential cage operators. Cages were often over-designed for their purpose, costly and made of materials often not locally available. The large cages used also required large amounts of seed and feed, which were not within the resources of poorer farmers. The CARE-CAGES (Cage Aquaculture for Greater Economic Security) project has largely overcome these constraints to the entry of poorer groups with the provision of small low cost cages, which require less inputs (feed and seed). The principal advantage of cages for the poor groups is that no land/water body ownership is required. Provided water body access is available, poor, landless groups can operate cage aquaculture. Traditional cage culture (production of table fish), however, still requires a relatively long period of time from stocking to harvesting, which is difficult for rural poor farmers, targeted by development projects such as CAGES to cope with. These farmers suffered difficulty in obtaining, and are unwilling to take on credit in such a high-risk activity as cage culture. In 1998, farmers in the CAGES suffered complete losses in approximately 13% of all cages placed in the water, with no fish obtained – this is a high-risk activity. There are, however, entry points that are more suited to the resource profile of poorer groups. In the experience of the CARE-CAGES project in Bangladesh, we showed how nursing, overwintering and/or fattening of various species could offer entry points, and lower the risks for the resource-poor groups to profitably participate in cage culture as one of their livelihood strategies.

Introduction

Unlike many other Asian countries, Bangladesh has a limited history in cage culture as a fish production system. The only "traditional" use of "cages" is the holding of fish in small bamboo boxes, in the Sylhet region. The first documented attempts on cage culture were in research institutes in the 1970s and 1980s. These were small-scale research projects conducted near the campuses of the institutes, and little attempt was made to involve rural farming or fishing households in cage culture (Haque 1978; Islam *et al.* 1988; Hossain *et al.* 1986; Haque *et al.* 1988). The first serious attempt to introduce cage culture to Bangladesh occurred during the 1980s in the 65,000 ha Kaptai Lake (Felix 1987); however, this and other attempts in Dhanmondi

Lake, Dhaka were unsuccessful. The failure of these projects, which attempted a technology transfer approach using large cages similar to other Asian countries, left a strong impression in the aquaculture and fisheries agencies that cage aquaculture was not technically feasible in Bangladesh.

In 1991 and 1992, the Department of Fisheries (DoF) and Overseas Development Agency (ODA, now DFID), supported the Northwest Fisheries Extension Project (NFEP) in conjunction with CARE in piloting cage culture in northwest Bangladesh. The cages used were small in size, and therefore more appropriate for the poor women groups targeted. Although initially successful, the project failed due to high levels of post-stocking mortalities.

NFEP has continued to pursue cage culture activities as one component of its aquaculture development programs through a combination of working with farmers and on-station trials. Much of this work has been documented in the NFEP papers 1-25 (NFEP papers).

CARE's CAGES (Cage Aquaculture for Greater Economic Security) project is the first aquaculture development project to focus exclusively on cage aquaculture systems. The project is currently targeting the resource-poor groups in six regions of Bangladesh (Barisal, Comilla, Dhaka, Jessore, Natore and Sylhet) to take up cage aquaculture as part of their livelihood strategy. In each region, several types of water body are used including rivers, canals (*Khals*), permanent oxbow lakes (*baors*), and semi-permanent standing water bodies (*beels* and *haors*). All water body types have shown success, though those prone to flash floods, and/or high turbidity are more risk prone.

A wide range of species is cultured by farmers depending on the resources (seed and feed) and the market opportunities (sell at market or to pond farmers). The principal species cultured by farmers in 1998 are shown in Table 1. The ratio of different species cultured is similar in 1999, although more pangas and prawn are being farmed due to their relatively high profitability in 1998.

The first three years of this DFID-funded project was concerned with introducing cage culture into a country with very limited previous experience in the system. Returns and profits have increased each year since project inception, and the project has built up cage culture technical "packages" that are generally successful within the Bangladesh context for our target groups. Our target groups are the resource poor, including landless rural people with the project placing particular emphasis on the participation and empowerment of the women. These groups are not involved in the traditional pond based aquaculture systems, as they do not own or have access to ponds. These groups can, however, take part in cage culture as it does not require ownership of a water body (pond), and cages can be set in many different water body types.

Table 1. Species farmed by cage farmers in the CARE-CAGES Project in 1998.

Common name	Latin name	Percentage of species in 1998
Tilapia	*Oreochromis* spp.	39
Silver barb	*Puntius gonionotus*	34
Grass carp	*Ctenopharyngodon idella*	10
Pangas	*Pangasius sutchi*	6
Silver carp	*Hypophthalmichthys molitrix*	2
Others		9

The project has been successful in opening up the possibility of cage culture to many poorer groups with low cost cages (Kabir and Ziaul, in press). The small cages require limited numbers of fry for stocking, and the use of less expensive, locally available feeds has been encouraged. Although the project began testing a large number of different species, experience showed that only a relatively few are suitable for successful low input, cage culture. These grow-out systems are, however, still not suitable for very poor groups due to risks, relatively high start-up costs and cash-flow difficulties.

The experiences of the CAGES project showed that there are three niches that may be more appropriate uses of cages for the resource-poor groups than traditional grow-out systems. The first is the nursing of various species of cultivated fish, which the farmer can sell to on-growers (both cage farmers and the larger numbers of pond and prawn *gher* farmers). The second is a specialist type of nursing where fry are overwintered in hapas, with fingerlings being sold early the following season to grow-out farmers when a premium price can be obtained. This system can be operated by cage farmers in the cages they already posses, and is therefore an additional source of income to the cage farmer, allowing more than a year round production from cages. And finally, use of cages as holding or fattening units. This niche may be best exploited by fishers enabling a premium price to be obtained for their fish due to a larger sized product (price of many species increase substantially with size) and giving them the ability to sell fish when market prices are high, for example during festivals. Each production system will be compared and contrasted to grow-out production in terms of risks, costs, and cash flow to farmers.

Production Strategy 1: Nursing

There is an opportunity for cage farmers in Bangladesh to operate small-scale nursery operations in fine-mesh cages or "hapas" as there are in general many fry available from the numerous hatcheries, but there is a shortage of fingerlings.

Risks

These systems involve many harvests during one season (typically from March to November) hence the risk of "all the eggs in one basket" is avoided which is in contrast to grow-out systems, where most farmers can only produce one crop of fish per season. If during production there is complete loss of fish (which occurred in 13% of the cages in 1998), then nursery operators can restock, producing several other crops in that year, and still make profit. A similar loss to a grow-out farmer, especially towards the end of the production cycle will result in complete loss of investment. Nursery cage operators have reduced risk of losses through the use of multiple, short-term production cycles. Table 2 shows a breakdown of the losses suffered by the cage operators in 1998.

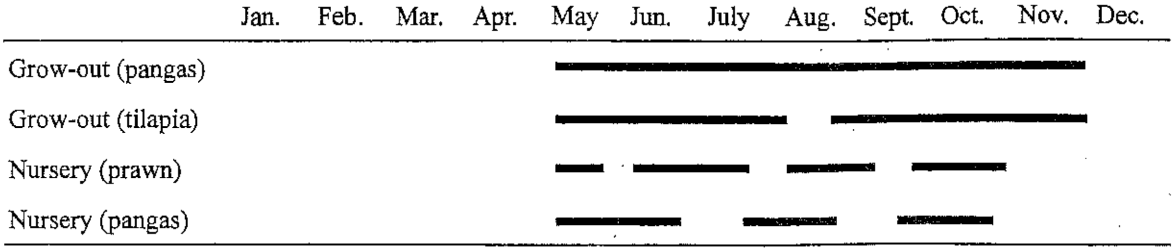
For most of the categories shown in Table 2, a reduced culture cycle will reduce risks, as explained above. However, an increasing problem for farmers as cage culture becomes more successful is the increasing amount of poaching being carried out. The nursing of fry to fingerlings should reduce the threat of poaching, as thieves are less likely to steal small fingerlings than large sized table fish. Nursing systems are therefore likely to be less prone to poaching, which reduces further the over all risk of the activity.

Table 3 shows graphically the difference in

Table 2. Number of cages (from a total of 1,046) that suffered a complete loss of fish in 1998.

Fish escapees	Poaching/theft	Stocking moralities	Culture moralities	Net cutting (sabotage)	Others
85	22	11	7	4	4

Table 3. Comparison of typical grow-out and nursery rearing cycles in cages.



the number of production cycles between grow-out and nursery systems, and also how different species have different amounts of time for grow-out and nursery operations.

Start-up Costs

A constraint to the entry of poorer groups into cage culture is the initial start-up costs required. Poor groups are often unable to afford the initial capital investment to start cage culture activities. A comparison of the start-up costs of typical grow-out and nursery cages are shown in Table 4.

As shown in Table 4, nursery systems are considerably less expensive than grow-out cages. Cage costs are less because fine-mesh netting is considerably less expensive (US$13-19/cage) than traditional cage netting material (US$19-26/ cage) in Bangladesh. Feed costs are also much reduced per cycle for most species although a higher fish meal diet is generally applied which costs more per kg. The substantially reduced quantity means that overall feed costs are less in nursing compared with grow-out systems. Seed costs are slightly higher in nursery systems, reflecting the greatly increased number of fry used. It should be noted that this number can be varied according to the farmers' ability to afford seed, and that these are not fixed costs. Individually the small fry used in nursery systems are considerably less expensive than the larger fry required for successful grow-out. The increasing price of fry with size is shown in Table 5 for pangas and tilapia in the Dhaka region. Further details on fry price are provided in the following section.

Cash-flow

As shown in Table 3, nursery systems produce several crops, hence income during the season, the first sales of fingerlings is achieved between 20 and 30 days, with all nursed fry being sold within 30-40 days depending on species. This is in contrast to grow-out systems where there is a considerable time lag between initial investment in cage, seed and feed, and any income. This time lag may be a considerable problem to resource poor farmers, who cannot afford to wait for such a long time for returns. Many poorer groups rely on loans to start cage culture operations. Interest on these loans in rural Bangladesh is typically around 20% per year. Hence in nursing, the entire loan of around $15 can be repaid within 40 days of taking it out, meaning a considerable saving to the farmer.

Table 4. Cost in Taka (US$) of typical grow-out compared to nursery systems.

	Grow-out	Nursery
Cage	450-500 ($9-10)	200-250 ($4-5)
Seed	200-300 ($4-6)	300-500 ($6-10)
Feed (through cycle)	300-500 ($6-10)	150-200 ($3-4)
Total	950-1,300 ($19-26)	690-950 ($13-19)

Table 5. Price of fry compared to fingerlings in Dhaka region in August.

	Size (cm)	Cost per fry/ fingerlings (Tk.)
Pangas fry	2.5	0.7
Pangas fingerlings	10	7-10
Tilapia fry	1-2	0.15-0.2
Tilapia fingerlings	5	0.5-0.7

Data obtained form CAGES profects, Dhaka Regional Technical Officer.

Production Strategy 2: Overwintering of Fry

There is an opportunity for rural poor cage farmers to fulfill a niche market in supplying premium quality large sized fingerlings, early in the year for both cage farmers, and especially the very large demand for such fingerlings from pond farmers. The perception of farmers is that overwintered fingerlings are "hardier" and grow faster than same season fingerlings, and when given the choice will prefer to buy these overwintered fry. Table 6 demonstrates this showing the difference in survival and growth of three replicated cages of same season fingerlings compared with three replicated cages of over wintered fingerlings, all of which had the same initial mean weight.

Table 6. Comparison of growth and survival of overwintered and same-season fingerlings.

Same season fingerlings		Overwintered fingerlings	
Survival (%)	Mean weight (g)	Survival (%)	Mean weight (g)
66	90	89	170
63	100	85	180
58	98	86	186

Risks

It has been noted that risks were related to length of time in the water, as until fish are harvested there is a risk of complete loss. The longer period of overwintering the fry of approximately three months means overwintering poses a higher risk than nursing during the normal production cycle although the reduced risk of flash floods and subsequent high water turbidity at this time of year (early December-end of February) may reduce the chance of failure. As with traditional nursing, risks related to poaching are lowered as fish are not large in size. This is due to the more limited market for stolen fingerlings (grow-out farmers), compared to larger fish, which can be sold in the market directly for consumption.

The point is that risks are low because little additional income is required and the farmer is utilizing his/ her asset (cage) at a time of the year when it would normally not be in use. Overwintering of fry is best seen as an additional income for cage operators, providing more year round income to the household with limited costs.

Start-up Costs

Start-up costs for overwintering of fry are in most cases limited to the purchasing of fry, with some on-going repairs to the cage and netting, and a minimal amount of relatively low cost feed.

This superior quality and low availability means there is a vast difference in price (Table 7) between small fry available late in the season (November/December), which have a limited market, and large, overwintered fry early in the year (February/March). This price difference is what the overwintering fry farmer is attempting to capitalize on.

Apart from fry, other costs relate to feed and cage repairs. Both of these costs are however minimal, especially the latter, which should only include routine repairs. Feeding of overwintered fry is also a low cost operation. Fish should be fed on maintenance diets, to minimize stress (fish appetite may be reduced or disappear in winter water temperatures), water quality degradation and cost. The aim is not to obtain good fish growth, but to allow conditions in which the largest number of healthy fingerlings can be produced to be sold early next season.

Table 7. Price difference (from CAGES staff experience) in Dhaka district between the end of season fry and overwintered fingerlings.

	November/December		February/March	
	Size (g)	Cost (Tk.)	Size (g)	Cost (Tk.)
Pangas	5	1-1.5	15	5-8
Tilapia	3	0.2-0.3	10	5-8
Grass carp	5-7	0.5-0.6	15-20	2-3

Cash Flow

As discussed earlier, overwintering provides more year round supply of cash from the cage. In addition, the timing of fry purchasing is at a time of year when farmers should have sold their grow-out or nursery fish, and in a position of credit.

Production Strategy 3: Fattening of Fish/Prawn Species

The integration of cage aquaculture with fishing communities appears as a lucrative option for fishers. Fisher communities are at an advantage over other cage operators for several reasons including:

- Fisher groups have access to trash fish, which can be used to feed caged fish species without cash out goings;
- Fisher groups tend to live near water bodies hence poaching and theft, which is a major problem in the CAGES project will be minimized; and
- Fisher groups are among the poorest rural groups and as CAGES is a DFID-funded project, these people are our target groups.

Fisher groups have attempted to culture many different local species including several high value piscivorous species. However, to date none of these attempts have been successful. The main reason for the failure is the underfeeding of these piscivorous fish. It is a myth to say that there is such a thing as "trash fish" in Bangladesh as there is a market for all the fish caught. Hence, fishers are reluctant to feed these piscivorous fish with adequate quantities of caught fish to allow reasonable growth. As a result, the caged fish show poor growth and the enterprise is rarely profitable.

However, there has been considerable success among fisher groups when the cage was used as a fattening enclosure, this being stocked and partially harvested in a continuous manner. This system is an extension of the *Dhoar* system practiced in Sylhet region by fisher groups (Talukder 1998). In traditional fisher groups, fish are placed into these cages, and once a reasonable amount has been collected, fish buyers come to the village and buy all the fish held. No feed is given to the fish and fish are held for a maximum of three weeks.

There is an opportunity for fisher communities to use cages as a short term holding/fattening system to increase the size of fish caught therefore they increase the market price, as well as hold their catch until a favorable market price is available – for example during a festival.

Risks

Risks in this system are minimal, as there is a continuous cycle of fish being added (newly caught) and removed (sold to market).

Costs

Costs of this system are minimal and relate only to the cage and feed, as the "seed" component of the cage system consists of the fishers' catch. Feed costs are usually related only to the time for collecting snails and mussels, as fisher groups rarely buy feedstuff. Clearly there is a hidden cost, which is only minimal as most feed collection is done by children (Is this right?). Capital outlay costs are therefore related only to the cage.

Fishers in Jessore use this system to fatten and hold a number of species in polyculture, though *Macrobrachium* spp. dominates. The fishers trap prawns in bamboo traps. If the prawns are of suitable size, then they are usually sold immediately. If, however, they are undersized for a premium price, they are placed in fixed cages and fattened until they attain the required size. Table 8 shows the increasing price of prawn with size. The premium price obtained for large prawns means the system is highly profitable.

The cages enable the farmers to gain control over market price, with the option not to sell the prawns immediately if the market price is lower than usual. Prawns and other fish can thus be held in cages until premium prices are available such as during festivals.

With little investment, the fisher community can integrate a holding/fattening cage as part of their fishing activities, substantially increasing

Table 8. Increasing market price for prawns with size, based on the experiences of CAGES staff.

Size of prawn (g)	Market price of fishers (US$/kg)
25-40	3-4
40-80	4-6
80-100	6-9

their control over their potential markets and with it increasing their income.

Summary

Over the last four years, the CARE-CAGES project has developed technology packages that provide profit to many farmers most of the time, and it is estimated that over 80 % of the beneficiaries will make a net profit in 1999. As discussed in this paper, other production systems could be used as alternatives (nursing, holding/ fattening) or incorporated (over wintering fry) to traditional grow-out of fish in cages. The project is currently planning the cautious expansion of these production strategies, based on our experience to date. Participation of the resource-poor in cage culture may be encouraged through these alternative production strategies, which may be the more appropriate systems considering the resource profile of rural poor groups, as well as the fact that these are offering entry points and reduced risks to poorer beneficiaries.

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Integrated Cage Culture in Ponds: Concepts, Practice and Perspectives

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Abstract

The integrated cage culture in ponds refers to the system in which high valued species are stocked in cages suspended in ponds while filter-feeding species are stocked in open water outside the cages. While the caged fish are fed with high protein diets, the open-pond fish are solely dependent on the natural foods generated from cage wastes.

The following advantages make the integrated cage culture in ponds attractive and promising:

(1) Wastes derived from high protein diets of caged fish are reused as a valuable nutrient source to generate natural foods for open pond fish.
(2) Nutrients in wastes derived from cages are recovered thus reducing nutrients contained in effluents, which are usually released directly or indirectly to the surrounding environment, causing accelerated eutrophication in those waters.
(3) It is used in polyculture ponds to confine costly high protein diets to caged high valued species to achieve higher economic returns.
(4) It is used in subtropical or temperate regions, where tropical fish species cannot overwinter, to make full use of growing seasons and make management such as fish harvest easy and convenient.
(5) This system makes it possible to fatten large fingerlings with high protein diets in cages and nurse fry with natural foods derived from cage wastes in open water in a single pond, which could allow small-scale farmers with one pond to maximize fish production and profitability.

The integrated cage culture in ponds has been practiced in caged catfish-open pond tilapia and caged large tilapia-open pond small tilapia. Encouraging results have been achieved from the said trials.

Introduction

Cage culture has long been practiced in Southeast Asia (Ling 1977) since its introduction in the Yangtze River delta in China some 750 years ago (Hu 1994). The modern cage culture with high stocking density and artificial feed becomes increasingly popular because of its high production and economic returns. Many versions of modern cage culture have been developed for intensive culture of commercially important species in various parts of the world (Coche 1978; Beveridge 1996). Most cage culture is situated in open water environment such as rivers, reservoirs, lakes, and the sea.

As caged fish are generally fed with high protein diets, wastes derived from feed are either directly or indirectly released to the surrounding environment, causing accelerated eutrophication in those water (Beveridge 1984; Ackefors 1986; Lin 1990). The waste substances produced by cage culture in open water systems are discharged so diffusely as to preclude practical methods of treatment (Seim *et al.* 1997). Thus, the wastes from cage culture have been a major concern as a source of pollution to natural waters.

In contrast, animal manure has long been used to grow fish in integrated farming, and chemical fertilizers as pond input to stimulate the growth of planktonic organisms as foods for herbivorous or omnivorous fish in ponds (Pillay 1990; Edwards 1991). The wastes from intensive fish culture are potential fertilizer that can be reused to generate natural foods for filter-feeding fish species (Lin *et al.* 1997). Based on the concepts and practices of cage culture and integrated farming of fish and livestock, an integrated cage culture in ponds has been developed to maximize fish production from a given input resource and to mitigate environmental impact of intensive aquaculture (Lin *et al.* 1989).

Integrated Cage Culture in Ponds

The integrated cage culture in ponds is a system in which high-valued fish species is fed with artificial diets in cages suspended in ponds, where filter-feeding fish is stocked to utilize natural foods derived from cage wastes (Fig. 1). A number of experiments has been conducted using combinations of catfish-tilapia (Lin *et al.* 1989; Lin 1990; Ye 1991; Lin and Diana 1995) and tilapia-tilapia (Jiang 1993; Yi *et al.* 1996; Yi 1997) at the Asian Institute of Technology, Thailand during the past decade.

Catfish-tilapia Integrated Cage Culture in Ponds

Hybrid catfish (*Clarias macrocephalus* x *C. gariepinus*) and Nile tilapia (*Oreochromis niloticus*) are commonly cultured freshwater fish in Thailand with an annual production of 44,100 and 76,100 metric tons, respectively (DOF 1997). The major production system for tilapia is semi-intensive with inorganic or organic fertilizer inputs. Hybrid catfish are intensively monocultured at extremely high density (30-100 fish·m^{-2}) and commonly fed with chicken offal, trash fish or pelleted feed in earthen ponds, giving the production of 12.5-100 metric tons.

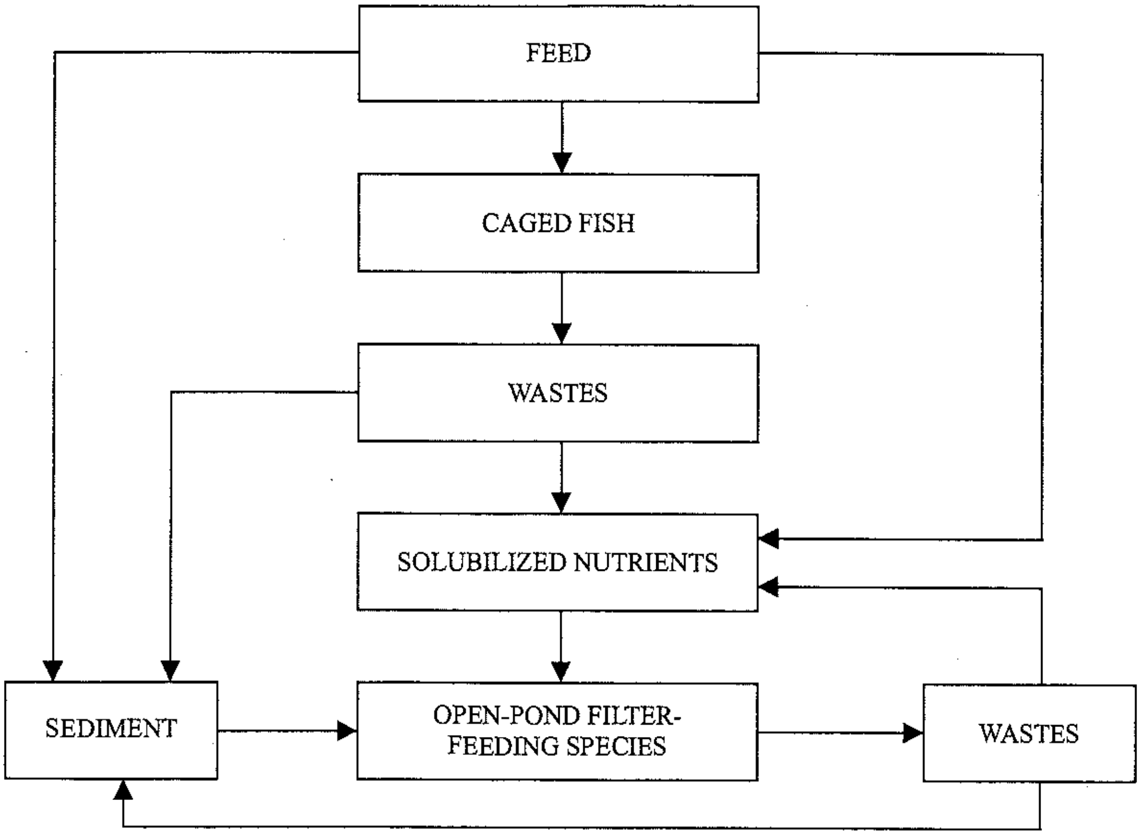

Fig. 1. A diagram of the general scheme for the cage-cum-pond integrated culture system.

Wastes as uneaten feed and metabolic products in the hybrid catfish ponds often result in excessive phyto- and zooplankton blooms. Although the hybrid catfish can tolerate low dissolved oxygen due to their ability to breathe air, water quality does appear to influence their growth and survival (Diana *et al.* 1988). To maintain favorable water quality, the pond water with rich nutrients and organic matter is periodically exchanged with new source water, causing pollution in natural waters (Lin and Diana 1995).

To reuse the hybrid catfish wastes, a preliminary experiment was conducted in two 250-m^2 earthen ponds each with two 3.2-m^3 cages suspended 20 cm off the pond bottom near the center of each pond (Table 1) (Lin *et al.* 1989; Lin 1990). Catfish fingerlings of 3-7 g size were stocked in two cages in each pond at densities of 125 and 250 fish·m^{-3}, with a total of 400 and 800 fish·cage^{-1}, respectively, while tilapia of 11-12 g size were stocked at 1 fish·m^{-3}. The final total production of hybrid catfish ranged from 33.7 to 83.0 kg·cage^{-1} with an individual weight of 111-137 g and daily weight gain of 0.6-0.9 g·fish^{-1} in the 148-day grow-out period. The open-pond tilapia production was outstanding, with total harvests of 62.8-80.3 kg·pond^{-1}, mean individual weight of 367-408 g, and average daily weight gains of 2.4-2.7 g·fish^{-1}. The extrapolated tilapia production was approximately 8,000 kg·ha^{-1}·year^{-1}, which surpasses either that of both conventional integrated fish-livestock system (AIT 1986) and a system optimally fertilized with chicken manure (Diana *et al.* 1988). The nutrients in the wastes fertilized the ponds at a rate of 2.59 kg N and 0.59 kg P ha·day^{-1}, giving a N:P ration of 4.33. Open-pond tilapia recovered 15.35% N and 20.55% P contained in the wastes produced by caged catfish.

Lin and Diana (1995) conducted a follow up experiment for three months to determine the productivity and practical stocking ratio of hybrid catfish and tilapia (Table 2). This experiment was conducted in six 250-m^2 earthen ponds with one and two 3.2-m^3 cages suspended 20 cm off the pond bottom in low and high density treatments, respectively. Catfish fingerlings of 13-17 g size were stocked at a density of 275 fish·m^{-3}, with a total of 880 and 1760 fish·pond^{-1} in low and high density treatments, respectively,

Table 1. Summary of growth performance of caged catfish and open-pond tilapia in a catfish-tilapia integrated cage culture in ponds for 148 days (Lin *et al.* 1989; Lin 1990).

	Pond A			Pond B		
Performance Measures	Catfish		Tilapia	Catfish		Tilapia
	Cage 1	Cage 2		Cage 1	Cage 2	
Water volume (m^3)	3.2	3.2	220	3.2	3.2	220
Stocking						
Density (fish/m^3)	125	250	1	125	250	1
Total no. (fish)	400	800	220	400	800	220
Total wt. (kg)	1.2	4.8	2.6	1.2	5.6	2.4
Mean wt. (g/fish)	3	6	12	3	7	11
Harvest						
Survival (%)	92	80	90	67	54	78
Mean wt (g/fish)	100	130	408	127	96	367
Net yield (t/ha/year)	3.5	7.7	7.7	3.2	3.8	6.0
Gross yield (t/ha/year)	3.7	8.2	7.9	3.3	4.1	6.2
FCR	1.5	2.7	-	3.4	3.0	-
Waste loading rates (kg/ha/d)	2.51 N & 0.57 P			2.68 N & 0.62 P		
Nutrient recovery rates (%)	17.75% N & 24.02% P			12.94% N & 17.08% P		

while tilapia of 6-7 g size were stocked at 2 fish·m^{-3}, giving the catfish and tilapia stocking ratios of 2:1 and 4:1, respectively. The two catfish:tilapia stocking ratios did not significantly affect catfish growth with a mean weight gain of 2.16 g·fish^{-1}·day^{-1}, but resulted in significant differences in tilapia growth with mean weight gains of 1.41 g·fish^{-1}·day^{-1} in the low density treatment and 2.38 g·fish^{-1}·day^{-1} in the high density treatment. In terms of pond area, the extrapolated total production of hybrid catfish ranged from 30 to 50 metric tons·ha^{-1}·year^{-1}, which is comparable to that in traditional pond systems, while the extrapolated total production of tilapia ranged from 8 to 11 metric tons·ha^{-1}·year^{-1}, which surpasses that in ponds fertilized with conventional chicken manure (Green 1992) or chemical fertilizers (Diana *et al.* 1991). In this experiment, the nutrients in the wastes fertilized the ponds at rates of 3.71 kg N and 1.10 kg P·ha^{-1}·day^{-1} in the low density treatment, and 8.06 kg N and 2.20 kg P·ha^{-1}·day^{-1}. Tilapia recovered 12.75% N and 14.27% P contained in cage wastes in the low density treatment, and 7.42% N and 8.27% P in the high density treatment. The reduced nutrient recovery rates in the high density treatment are probably due to the resultant lower survival rate caused by worse water quality. Additional aeration may be a good way to increase the nutrient recovery rates by open-pond tilapia. To reduce the nutrient loading in pond effluents, open-pond tilapia culture could be extended for some periods after harvesting caged bybrid catfish.

Ye (1991) used four catfish:tilapia ratios (2.5:1, 5:1, 10:1 and 15:1) to study the nutrient budgets and determine tbe appropriate stocking ratios in the catfish-tilapia integrated culture in a 3-month experiment (Table 3). Hybrid catfish fingerlings (22-23 g size) were stocked at 25, 50, 100, and 150 fish in 1-m^3 cages each suspended in a 5-m^3 outdoor static concrete tank with10 tilapia fingerlings (7-9 g size). Tilapia died after three and four weeks in the 15:1 and 10:1 treatments, respectively. The results in the remaining two treatments showed that to produce 1 kg of live catfish generated 48.0-60.0 g N and 10.0-12.5 g P as metabolic wastes; approximately 30-

Table 2. Summary of growth performance of Nile tilapia and walking catfish for 122 days (Lin and Diana 1995).

Performance Measures	Treatment A		Treatment B	
	Caged catfish	Open-pond tilapia	Caged catfish	Open-pond tilapia
Water volume (m^3)	3.2	220	3.2	220
Cage number/pond	1		2	
Stocking				
Density (fish/m^3)	275	2	275	2
Total no. (fish)	880	440	1,760	440
Total wt. (kg)	12.6	3.1	26.4	3.0
Mean wt. (g/fish)	14.3	7.0	15.0	6.7
Harvest				
Survival (%)	95.8	90.5	87.5	69.8
Mean wt (g/fish)	273.8	179.2	270.2	297.2
Net yield (t/ha/year)	26.1	8.1	46.9	10.3
Gross yield (t/ha/year)	27.6	8.5	50.0	10.6
FCR	1.94	-	2.24	-
Waste loading rates (kg/ha/d)	3.71 N & 1.01 P		8.06 N & 2.20 P	
Nutrient recovery rates (%)	12.75% N & 14.27% P		7.42% N & 8.27% P	

Table 3. Summary of nutrient budget in a catfish-tilapia integrated cage culture in ponds for 90 days (Ye 1991).

Nutrients	Nitrogen (%)		Phosphorus (%)	
	2.5 catfish to 1 tilapia	5 catfish to 1 tilapia	2.5 catfish to 1 tilapia	5 catfish to 1 tilapia
Feed	100.00	100.00	100.00	100.00
Nutrient gain				
Catfish	35.44	29.92	43.85	36.89
Tilapia	13.41	4.05	17.28	4.94
Total	48.85	33.97	61.13	41.83
Nutrient lost				
Sediment	23.38	34.87	31.04	51.09
Water	11.94	6.86	4.92	4.09
Other	15.84	24.30	2.90	2.99
Total	51.16	66.03	38.86	58.17
Nutrient recovery rates by tilapia	20.77	5.78	30.77	7.83

35% N and 37-44% P input from the feed were incorporated into catfish; 4-13% N and 5-17% P were incorporated into tilapia; 7-12% N and 4-5% P remained in pond water; 23-35% N and 31-51% P were accumulated in pond sediment; 16-24% N and 3% P were unaccounted for. Among the nutrients contained in the wastes, tilapia recovered 6-21% N and 8-31% P. Ye (1991) then concluded that 2.5:1 is the most appropriate catfish-tilapia ratio in this cage-cum-tank integrated culture system.

Tilapia-tilapia Integrated Cage Culture in Ponds

Nile tilapia are commonly grown in semi-intensive ponds based on fertilizers or on integrated systems with livestock (Boyd 1976; Edwards 1986, 1991; Diana *et al.* 1991). However, size at harvest under such systems usually averages 200-300 g in five months (Diana *et al.* 1991), and it may take as long as five more months to rear the fish to 500 g under semi-intensive culture (Diana *et al.* 1994). In some countries such as Thailand, Nile tilapia fetch a much higher price at a size greater than 500 g than those smaller than 300 g size. Therefore, there is a trend to culture Nile tilapia to big size in intensive culture system. Moreover, Diana *et al.* (1996) indicated that supplemental feeding of Nile tilapia starting at 100-150 g size is probably the most effective way to produce large size tilapia. Therefore, the cage-cum-pond integrated culture system could be used to fatten large size tilapia in cages in ponds and to nurse small size tilapia in open ponds by utilizing natural foods derived from the cage wastes.

Jiang (1993) used the same experimental systems as Ye (1991) to determine the appropriate stocking ratio of caged large tilapia and small tilapia at large in tanks (Table 4). Large tilapia (220-248 g size) were stocked in cages at 3, 5, 10, 15, 20 and 25 fish in 1-m^3 cages, while small tilapia (18-20 g size) were stocked at 15 $fish{\cdot}tank^{-1}$ (3 $fish{\cdot}m^{-3}$). Growth performance indicated that the 10:15 ratio was optimal.

To develop a tilapia-tilapia cage-cum-pond integrated rotation system, a series of experiments was conducted in fifteen 330-m^3 earthen ponds with 4-m^3 cages suspended 20 cm off the pond bottom. In a 3-month grow-out cycle, the large-size tilapia were fattened in cages to marketable size and small size tilapia nursed in ponds to restock the cages (Yang *et al.* 1996; Yang 1997). In the first experiment, the optimal stocking density of caged tilapia was determined as 50 $fish{\cdot}m^{-3}$ with a total of 200 caged $fish{\cdot}pond^{-1}$. Results of the second experiment indicated that the appropriate number of cages per pond was 2 $cages{\cdot}pond^{-1}$. To make this system rotate every three months, the third experiment was conducted to determine the optimal density of open-pond tilapia. The results showed that the optimal stocking density of open-pond tilapia was 1.4 fish·m^{-3}, and also indicated that the carrying capacity and growth performance of caged tilapia could be enhanced by lowering the stocking density of open-pond tilapia. The fourth experiment was conducted to compare the growth performance of both caged and open-pond tilapia between the integrated cage culture and the traditional mixing-size pond culture. The results revealed that the growth performance of both caged and open-pond tilapia was significantly better in the integrated cage culture than in the traditional mixing-size pond culture.

The results of the final experiment in the series are summarized in Table 5. Large size tilapia (124 g) were stocked at 50 fish·m^{-3} in two 4-m^3 cages suspended in 330-m^3 earthen ponds with a surface area of 313-393 m^2 and water depth of 1-1.2 m, while small size tilapia (16 g) were stocked at 1.4 fish·m^{-3}. The final production of caged tilapia was 91.9 kg·cage^{-1} with an individual weight of 465 g and daily weight gain of 4.06 g·fish^{-1} in the 86-day experimental period. The final mean weight of open-pond tilapia production was 124 g with mean daily weight gain of 1.35 g·fish^{-1}·day^{-1}. The extrapolated tilapia production was approximately 6.7 mt·ha^{-1}·year^{-1}. The nutrients incorporated in caged tilapia accounted for 36.41% N and 45.47% P of the total nutrient inputs. The nutrients in the wastes fertilized the ponds at a rate of 1.75 kg N and 0.37 kg P ha·day^{-1}, giving a N:P ratio of 4.73. Open-pond tilapia recovered 20.52% N and 27.98% P contained in the wastes produced by caged tilapia.

To optimize integrated cage-cum-pond rota-

Table 4. Summary of growth performance of both caged and open-pond Nile tilapia in a tilapia-tilapia integrated cage culture for 86 days (Jiang 1993).

Performance Measures	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
Stocking					
Caged tilapia					
Total number (fish/tank)	3	5	10	15	20
Total wt. (kg/tank)	0.742	1.137	2.341	3.304	4.579
Mean wt. (g/fish)	247.5	227.4	234.1	220.3	228.9
Open-pond tilapia					
Total number (fish/tank)	15	15	15	15	15
Total wt. (kg/tank)	0.289	0.270	0.279	0.278	0.275
Mean wt. (g/fish)	19.3	18.0	18.6	18.5	18.3
Harvest					
Caged tilapia					
Survival (%)	100	100	100	95.5	75.0
Net fish yield (kg/tank)	0.722	0.949	0.969	0.590	-0.799
Gross fish yield (kg/tank)	1.464	2.087	3.309	3.894	3.780
Mean wt. (g/fish)	488.0	417.3	330.9	271.8	252.3
Feed conversion ratio	2.39	2.41	2.64	4.47	-
Open-pond tilapia					
Survival (%)	100	100	100	100	77.8
Net fish yield (kg/tank)	0.766	0.837	0.940	0.962	0.664
Gross fish yield (kg/tank)	1.055	1.107	1.219	1.240	0.938
Mean wt. (g/fish)	70.3	73.8	81.3	82.7	80.5
Extrapolated total yield (t/ha/year)	12.9	15.5	16.6	13.5	-1.2
Nutrient recovery rate by open-pond tilapia (%)	29.3%N 26.4%P	24.1%N 21.7%P	23.7%N 21.4%P	21.3%N 19.4%P	-

tion culture system, large-size tilapia (approximately 140 g) can be fattened to more than 500 g in two cages in a pond with a surface area of 300-400 m^2, while small-size tilapia (approximately 20 g) can be nursed to around 140 g size in open-ponds by utilizing cage wastes and then can be removed every three months to restock the cages.

Table 5. Summary of growth performance and nutrient efficiency of both caged catfish and open-pond tilapia in a tilapia-tilapia integrated cage culture in ponds for 86 days (Yang 1997).

Performance Measures	Caged tilapia	Open-pond tilapia
Water volume (m^3)	4	330
Stocking		
Density (fish/m^3)	50	1.4
Total no. (fish)	400	462
Total wt. (kg)	49.4	7.2
Mean wt. (g/fish)	124	16
Harvest		
Survival (%)	98.8	92.0
Mean wt (g/fish)	456	124
Net yield (t/ha/year)	18.2	6.2
Gross yield (t/ha/year)	24.9	7.1
FCR	1.22	-
Waste loading rates (kg/ha/d)	1.75N & 0.37P	
Nutrient recovery rates (%)	20.52%N & 27.98%P	

Discussion

The cage-cum-pond integrated culture reuses wastes derived from high protein diets of caged fish as a valuable nutrient source to generate natural foods for open pond fish. The system can recycle nutrients from feeding wastes to natural foods for filter-feeding species and maintain desirable water quality, thus to enhance nutrient utilization efficiency in closed ponds. As the wastes of conventional intensive cage culture pollute natural waters, the cage-cum-pond integrated culture recovers nutrients from wastes derived from cages, thus reduces nutrients contained in effluents and mitigates eutrophication in receiving waters.

The cage-cum-pond integrated culture also provides economic advantages as it confines costly artificial diets to feed caged high-valued species only. In comparison, in mixed polyculture of those species with different feeding habits in open ponds, low-valued species compete the feed provided to the target high-valued species, resulting in economic inefficiency. In the cage-cum-pond integrated culture, the filter-feeding species are raised with natural foods in open ponds where the cost of fertilizers can be saved.

The cage-cum-pond integrated culture is also relevant to culture warm water fish in subtropical or temperate regions, where overwintering of these fish is a problem. The cage-cum-pond integrated culture can make full use of growing seasons and facilitate convenient fish harvest at the end of the growing season, without needing to drain the ponds. The warm water fish cultured in ponds are ofren small in size, which fetch lower prices. The cage-cum-pond integrated culture system can produce larger, better priced fish and achieve higher growth performance in caged fish and other fish in open ponds.

These experiments illustrated the principle and practicality of the cage-cum-pond integrated culture system, which may make small-scale pond culture more sustainable.

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Problems and Issues of Nile Tilapia Cage Farming in Taal Lake, Philippines

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Abstract

An assessment of the different problems and issues of cage farming Nile tilapia, *Oreochromis niloticus,* in Taal Lake was conducted. Selected but important water quality parameters were identified and monitored. Ammonia was found to be extremely high while dissolved oxygen was very low. Observed parameters were indications of high nitrogen loading in the cage site. Some identified problems that cause the pollution of Taal Lake were high stocking density, high feeding rates, chessboard-type positioning and congestion of fish cages, floating dead fish from mass mortality abounding in the area, and scattered waste materials. These various conditions are considered stressors that predispose the fish to chronic diseases. Instances of fish kill were also observed under acute conditions. High mortality was commonly observed during summer when there is no wind to circulate the water. Prolonged or sudden rush of wind during summer has been suspected to overturn the lake bringing up to surface noxious and anoxic water to where the cages are positioned.

Reduction in the stocking density, single-line positioning of cages, installation of improvised aerator during problem situations leading to disease outbreaks and high fish mortality, waste disposal management, and continuous monitoring of limnological parameters were some recommendations made to improve the condition of the lake. Reduction in the stocking density and single line positioning of cages will distribute wastes thinly from cages and allow circulation of water. Government role to mitigate the problems is also emphasized.

Introduction

The Philippines has an estimated 430,000 ha of freshwater communal areas for fishing that include bodies of water such as lakes, rivers, dams and reservoirs. Such freshwater bodies can be considered as sites for Nile tilapia, *Oreochromis niloticus,* rearing in enclosures including cages and to some degree, pens.

The Laguna Lake Development Authority, a government agency, had a fishpen pilot project in Laguna de Bay particularly in Looc, Cardona in 1973 that first tried cage aquaculture inside the said enclosure. Cage culture of Nile tilapia started to flourish starting in 1977 as a commercial enterprise in the lake. Expansion was noted since then in various coastal towns of the lake. Culture of Nile tilapia in enclosures is now a major source of income of fishfarmers in Laguna de Bay and other lakes and reservoirs in the country. To name a few these are Sampaloc Lake in Laguna, Lake Sebu in Southern Mindanao, Taal Lake in Batangas, Magat Dam in Isabela and Pantabangan Dam in Nueva Ecija.

Taal Lake is the third largest lake in the Philippines, which is located in Batangas, Luzon between 120°55’ to 121°05’ E and 13°55’ to 14°05’ N. The lake has a total surface area of 24,356 hectares and average depth of 60.1 meters. Its length and width are 24-30 km and 14-19 km respectively. Resting on Volcano Island is a Crater Lake, which is believed to be the most treacherous among the 21 active volcanoes in the Philippines (PHIVOLCS 1991). Various activities and emissions from the volcano can affect the lake’s physico-chemical parameters, which may be detrimental to the fish. Volume of ejecta from the 1965 eruption was 40 million cubic meters (Santos and Listanco 1980). This could have possibly affected the chemistry of the lake, even long after eruption.

Nile tilapia cage culture has become a lucrative business in the government-identified coastal towns of Taal Lake in the past two decades. Cage culture in the lake has its own zone. Even nonresidents have been allowed to venture into cage aquaculture. In 1997, it has been estimated that there were 3,140 units of fish cages (100 m^2 each) covering an area of 46.4 hectares or about 0.19% of the surface of the lake and that the estimated production of cage culture operation is 63.4 $kg \cdot m^{-2} \cdot yr^{-1}$ (Alcanices 1997).

In general, aquaculture in Taal Lake has followed a countrywide trend with the use of a more intensive method of culture and modern technology that involved higher stocking density and large input of feeds.

The increasing environmental pollution of the lake and frequent occurrence of fishkill, lately in the second quarter and early third quarter of 1998, has alarmed the residents and fishfarmers of the municipalities of Agoncillo, San Nicolas and Laurel, Batangas. Cage culture which was considered as a sustainable means of livelihood is now viewed as a potential polluter of Taal Lake.

This paper presents some of the salient physico-chemical features of the Taal Lake important to cage culture of Nile tilapia. Bacteriological examination results of diseased Nile tilapia in cages are mentioned. Environmental impacts of cage culture that led to the pollution, fishkill and continuous degradation of the lake are also discussed. Socioeconomic and political issues as well as essential management measures to solve the problems in Taal Lake are also presented.

Methodology

Visits in Laurel and Agoncillo cage sites in Taal Lake were done by the team from the Freshwater Aquaculture Center, Central Luzon State University (CLSU). Visits were held during the summer of 1997, 1998 and 1999 to conduct water quality monitoring, parasitology and microbiology and investigate possible causes of the frequent occurrence of fishkill in the cages of Nile tilapia. Aquaculture practices and prevailing environmental conditions were likewise noted.

In situ water analysis inside and outside cages was done. Temperature and dissolved oxygen were measured using a YSI Dissolved Oxygen meter. Water transparency was determined using a modified Secchi disk and water pH by a digital pH meter. Water samples for ammonia analysis were collected at the surface and at 4-meters depth of the water column. Each sample was fixed with 1 ml of 10% formalin solution for analysis at CLSU laboratory. Although ammonia and nitrate were measured on-field using a portable Hach Kit, analysis of ammonia in the laboratory was likewise conducted.

The results of the analysis, observations and possible recommendations were presented on August 21, 1998 during a consultation-seminar conducted in the municipality of Agoncillo, Batangas to a group of fishfarmers, operators and representatives from LGU's.

Problems and Issues

Location of Cages

Aquaculture zone, particularly cage farming sites, in Taal Lake covers the shallow littoral areas sheltered from monsoon winds extending from the coast of Barangay Aya, Talisay to Barangay Berinayan, Laurel, including the coast of Tanauan Bay down to Barangay Manalaw, Agoncillo (Presidential Commission on Tagaytay-Taal 1993). The zone also includes a narrow strip (not more than 50 m. wide) of littoral water along the mainland coast inside the fish sanctuary as an aquatic zone exclusively for tilapia hatcheries.

The location of cage farming has a serious implication in the success of an intensive aquaculture since being sheltered from the wind means circulation/aeration of the water to produce the much needed oxygen and diffusion of harmful byproducts of aquaculture are not facilitated.

Selected Water Quality Parameters

Some water quality parameters which have impact on tilapia cage culture are temperature, transparency, pH, dissolved oxygen, and ammonia. Each of these parameters is discussed below.

Temperature

Temperature is an important parameter in limnological studies, since it affects the distribution of organisms, density of water and solubility of gases and minerals (Boyd 1990). Temperature in Lake Taal began to increase starting in 1989 (Zafaralla 1995) to 31.1-34.2°C as monitored by the CLSU team. The temperature pattern generally indicated warming of Taal Lake during particular times of the year and intensified by the fact that the lake lies on a caldera with various volcanic cones. Several hot springs are known to flow into the lake.

The sudden increase in temperature between the years 1997-1998 could be attributed to strong El Niño conditions in December, 1997 as reported by the National Oceanic Atmospheric Administration and intense heat of the sun penetrating the surface of the water column. The absence of strong winds during the El Niño phenomenon and summer months to circulate the water in the lake was reported. Water replenishment due to rains in the lake was also nil during these months. The combined high temperature and lack of wind aeration during the summer months are considered fish stressors.

Transparency

Water transparency decreased with the highest mean reading of 4.5 m in 1989 (Zafaralla and Santos 1992) to 1.75 m in 1998 done by the CLSU team. The trend showed eutrophication of the lake mainly due to plankton growth and probably enhanced by particulate organic matters from uneaten feeds, fish feces, and decaying fish. Floating dead fish inside and outside the cages were a common sight and daily fish mortality was a regular occurrence during disease outbreaks. The coastal community of numerous households could also have contributed to eutrophication since the sewerage system flows into the lake. Human activities in the shore normally cause resuspension of particulate matters.

The decreasing trend in water transparency indicates increasing turbidity level in Taal Lake. Without vigorous or continuous wind mixing, the atmospheric CO_2 easily diffuses through the water surface for plankton growth. The observed turbidity level of 1.75 in 1998 indicates eutrophication of the lake. This could only mean that more organisms are present in the lake that compete for space, oxygen and other resources. The carrying capacity of the lake for cage culture purposes is henceforth reduced.

Hydrogen ion concentration (pH)

The pH of the lake water was alkaline ranging from 8.5 to 9 (Tabirara *et al.* 1983; Delmelle and Bernard, undated). The CLSU team obtained pH readings of 8.7-9.2 in 1998, which conform to the pH measurement by the said authors. Santos and Listanco (1980) reported that alkali basalt group constituted samples of lavas from the Taal volcano. This could have a certain degree of influence on the high pH readings in the lake if they form part of the deposits at the bottom. The earthquake in 1990 might have caused the decrease in pH due to disturbance of decomposing organic matter at the bottom of the lake (Zafaralla 1995) or due to increased emission of sulfurous gases. General observation, however, indicated that the water of Taal Lake is basic. This pH characteristic of the lake could also be attributed to its early connection with the sea (Hargrove 1991).

Tabirara *et al.* (1983) suggested that the pH increase could be attributed to the emission of ammonia during intense volcanic activity that neutralized the sulfuric acid. During CLSU's first visit in 1998, the ammonia readings were 0.021-0.209 ppm. However, during the second visit in 1998 the reading was 3.0 ppm at the height of fish kill in cages. Ammonia was assumed to be byproducts of metabolism and floating and decaying dead bodies of cage cultured fish. High pH and ammonia concentrations of the lake waters are indicative that the cage cultured fish is subjected to stressful environment, including high stocking density.

Dissolved oxygen

The lowest DO reading was observed in 1989 (Zafaralla and Santos 1992) and 1997 (Alcanices 1997). Increasing number of fish cage structures in chessboard positioning was noted in 1991. This hindered the flow of water and minimized the circulation of dissolved oxygen. More fish were cultured hence more fish were competing for the available oxygen.

The positioning of cage structures in chessboard type limited the removal of toxic waste metabolites from the vicinity of the site. More wastes were decomposed by the microbes, which increased the biological oxygen demand (BOD) and further competing for available dissolved oxygen.

The fishkill in August 1998 could have been predisposed by low dissolved oxygen concentration, measured at 2 ppm by the CLSU team, and high ammonia concentration. Water temperature of 34.2°C was measured at the time of the visit. The El Niño phenomenon appeared to extend warm months without strong winds that would circulate and aerate the water in the lake regularly. High temperature can reduce saturation of oxygen and increase the metabolic activity of organisms including fish stocks. High biological oxygen demand to decompose more wastes is expected.

Ammonia (NH_3)

Zafaralla (1995) mentioned that ammonia constitutes one of the compounds that can be detected from volcanic regions. Taal Lake is a caldera with about 40 cones and craters according to PHIVOLCS (1991), the presence of high ammonia in specific areas particularly during seismic activities and threats of volcanic eruption are possible. This could be justified by the observed ammonia level of 0.9 ppm in 1990 (Zafaralla 1995). However ammonia is also a byproduct of metabolism excreted by aquatic organisms.

The CLSU team got ammonia readings from 0.021-0.209 ppm on its first visit in 1998. However, a high concentration of total ammonia at 3.0 ppm at the height of the latest fishkill in 1998 was observed by the CLSU team during its second visit in 1998 and could be attributed to the effect of fish cage operation, heightened by high stocking density and presence of congested cages. More cages and fish stocked in cages means more ammonia is excreted as a byproduct of metabolism. Excessive feed inputs, accumulation of organic wastes and decomposing dead fish scattered in cage sites aggravated the already deteriorating condition in the cage sites.

Impact of High Stocking Density

A fishfarmer normally operates at least one unit fish cage to a maximum of 20 fish cages in Taal Lake. However, big-time cage operators can have more than 50 cages each. Every fishfarmer uses the same kind and size of fish cage measuring 10x10 m^2. Majority of the fishfarmers stocked from 25,000 tilapia fingerlings to as much as 50,000 fingerlings per cage. Total estimated amount of feeds used ranged from 200 bags (5,000 kg) to 400 bags (10,000 kg) per cage depending on stocking density. The Genetically Improved Farmed Tilapia (GIFT) foundation hatchery operators, however, advise their fingerling buyers to stock the cages to a maximum of only 14,000 fish per cage. This is laudable and along the direction of sustainable aquaculture in Taal Lake. Reduction of cages by single line positioning is still advised to prevent congestion.

Lake overturning, the surfacing up of anoxic bottom water, is one major factor that led to mass mortality of cultured fish in cages in Taal Lake. The chessboard positioning of cages, high stocking density and insignificant wind action could have aggravated this phenomenon. Whenever there is a strong wind coming from the coastal area and traversing the cage site, overturning of the lake bottom water is possible. It is a fact that bottom water especially that which is directly below the cage site is anoxic and toxic due to the decomposition of layers of settled wastes from the overlying cage operation. These wastes are composed of uneaten feeds, fecal matters, and other organic debris that settled at the bottom of the lake.

Preceding conditions are likely to increase turbidity level and further limit the production of oxygen by photosynthesis, which will eventually decrease dissolved oxygen level in the water. The increased biological oxygen demand (BOD) by bacteria during their metabolic activity in decomposing organic matters will further decrease dissolved oxygen level. This condition increased the stress level of fish, impaired their growth and predisposed the fish to disease and ultimately to mortality. Under extreme conditions, stress in fish could directly result in mortality. Fish kill is further magnified due to combined factors of overcrowding and poor environmental conditions. This could also be a probable cause of the fish kill in August 1998 in some cage areas due to sudden occurrence of continuous strong wind that brought up the anoxic bottom water to cage site.

When the weather is very calm and there is no wind to induce circulation and aeration of water, stratification normally occurs. This is true in deep lakes. Only the upper layer of the water body is provided with dissolved oxygen due to photosynthesis. This is the photic zone where enough sunlight penetrates for photosynthesis. At lower concentration of oxygen the fish stay at the surface gasping for air. The deeper portion is depleted with dissolved oxygen. Boyd (1990) mentioned that the driving force causing net transfer of oxygen between air and water is the difference between oxygen tension. This means that transfer of oxygen could take place when the water is under saturated with oxygen while the atmosphere is supersaturated with oxygen. When oxygen deficit or oxygen surplus is great, the rate of net transfer is slow because the surface film of water quickly reaches equilibrium and further net transfer requires that oxygen diffuse from the film to greater body of water. Diffusion of oxygen is very slow when there is no water movement but is quicker when there is water movement facilitated by wind action. Oxygen therefore in the cage has its major source from photosynthesis only during calm weather but low oxygen concentration is worsened by more fish competing for oxygen in a cage. It is also expected that more organisms are present in a eutrophic lake also competing for oxygen. Very alarming is the report that as early as 10:00 in the evening, fish are already seen at the surface gasping for air.

Another source of concern is the high level of ammonia monitored during fish kill. Ammonia in the water can hardly escape to the environment due to lack of water disturbance that should enable the gas to diffuse out through the surface film.

Positioning of Cages

The chessboard type positioning of cages is currently the practice in Taal Lake (Fig. 1). The cages are arranged in a manner that they are congested in a particular site. Schmittou (1993) noted that circulation of oxygen is better in smaller cages than in larger ones. Diffusion of oxygen from without into the entire volume of water inside the cage is a function of the area of the cage (hence the total volume of water inside the cage). The smaller is the area the quicker will be the supply and saturation (due to diffusion) of oxygen from without to within the cage. Oxygen produced through photosynthesis inside the cage is definitely not enough especially when the cage is overstocked. This is one of the reasons why adopting the chessboard type positioning of cages in Taal Lake is discouraged. Water circulation is limited and the diffusion of oxygen into the water is hindered. Although Taal Lake is a large body of water, cage areas are greatly affected. Prolonged exposure of fish to low dissolved oxygen levels causes stress to the fish. Chronic disease may develop which eventually results in fish mortality.

The use of single-line positioning is therefore recommended (Fig. 2). The module may contain four to five 10x10 m^2 cages in single line and placed strategically in the lake where both sides will normally receive oxygen through wind action or turbulence. Another set may be installed but at a distance agreed upon by stakeholders or after thorough evaluation by scientists. This positioning will avoid dissolved oxygen depletion and congestion will therefore be controlled. The fish will have free access to oxygen. Waste accumulating at the bottom of the lake will become thinner and its toxic effect will be dissipated.

Diseases

Marketable tilapia in Taal Lake cages showed disease signs such as eye opacity, exophthalmia, ulcerations, fin rot, erratic swimming and discoloration similar to the signs described by Yambot (1998, 1996) in Nile tilapia.

Stewart (1997) mentioned that pollutants can produce conditions which cause discomfort in fish, changed behavior and reduced growth, resulting in reduced appetite and resistance to diseases, gill damage and increased moralities. Stressed fish are susceptible to microbial and parasitic infections because their immune system has been weakened.

Alitropus sp., an isopod, has been observed infesting Nile tilapia in cages. They have been monitored seeking shelters in folds of sacks of sand, which serve as sinkers to cages. The presence of different sizes of said isopods in the folds suggests that the shelter also served as a breeding ground. Hence instead of sacks of sand, it was recommended that concrete blocks with

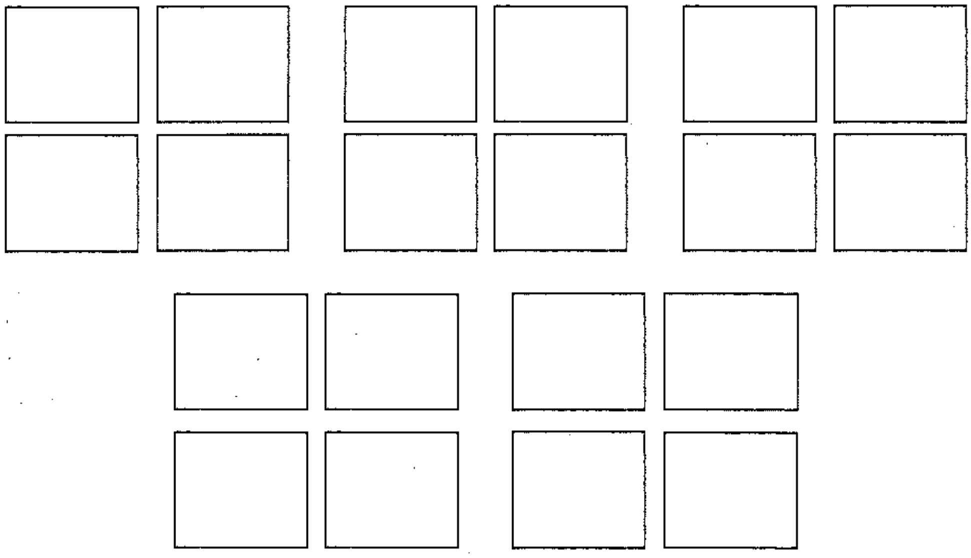

Fig. 1. Chess board type positioning of cages in Taal Lake hinders water circulation thus oxygenation is poor.

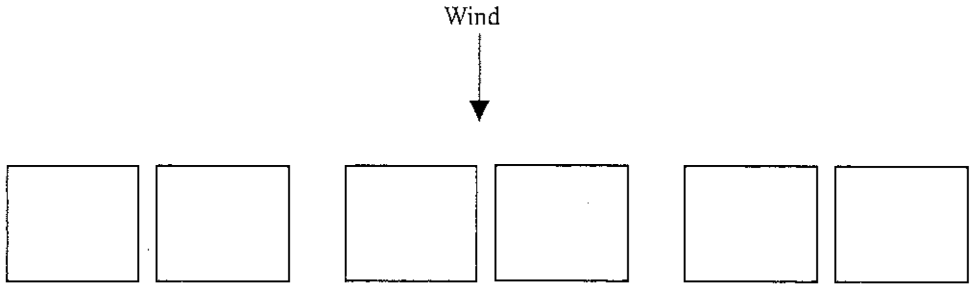

Fig. 2. Single line positioning of cages allows water circulation where wind is blowing perpendicularly.

smooth surface could be used as weights.

Consistent isolation of *Aeromonas hydrophila* from various tissues of diseased Nile tilapia collected from aquaria, tanks and cages during disease outbreaks in the Philippines from 1994-1996 shows a recurring septicemia (Yambot 1998). However, the isolates obtained from the sampled Nile tilapia in 1997 from the cages were gram positive, slow-growing and catalase negative. Primary and other tests conducted appeared to describe the characteristics similar to *Streptococcus* sp. Only bigger fish were observed to have been affected by the outbreak and manifested disease signs such as erratic swimming, hemorrhages, exophthalmia and eye opacity.

The isolates in 1999 were motile, gram negative, fast growing and fermentative. They were positive in tests for oxidase, catalase, arginine, aesculin, Voges-Proskauer, indole, Simmons' citrate and methyl red. Tests for ornithine and lysine decarboxylase were negative. The response of the isolates to the different tests appears to conform to the characteristics of *Aeromonas hydrophila*, which is an opportunistic pathogen of stressed fish. Disease signs such as hemorrhages, discoloration, eye opacity and exophthalmia were observed in Nile tilapia regardless of size. No *Streptococcus*-like isolates were obtained during this year.

A eutrophic lake is productive yet it indicates high organic load in the system favorable to the growth of microbial organisms and dense presence of competitors. Heavy growth of plankton shades the layer below making the photosynthetic zone shallower. In addition, the decomposers of the accumulated layers of organic nutrients on cage site bottom compete for oxygen resulting in high biological oxygen demand and significantly reducing the available dissolved oxygen required by fish. The eutrophic environment becomes more stressful to the fish, hence it becomes susceptible to the attack of bacterial pathogens (Tonguthai and Chinabut 1997; Inglis *et al.* 1993). So, the fish in a eutrophic lake may die not as a direct effect of pollution but rather due to disease organisms in the polluted water or to toxic substances present in a polluted water (Botkin and Keller 1998).

Phosphorus Loading Through Feeds

Phosphorus that enters into the aquatic environment may come from various sources such as (a) sewage that contains phosphorus-rich detergents, human wastes and animal wastes and (b) agricultural run-off containing fertilizers (Freedman 1995). Watershed sloping towards the lake favors the run-off of agricultural contaminants whereas communities living in the coastal areas of the lake contribute sewage.

In Taal Lake, the use of artificial diet, specifically commercial feeds in cage aquaculture, is one of the basic but primary sources of pollution leading to its eutrophication. This includes phosphorus, which is considered as a limiting factor in the growth and proliferation of plankton in the aquatic environment. In addition to phosphorus, eutrophication of a lake is also caused by inputs of nitrate (Mason 1996; Moss 1988).

Phosphorus availability stimulates high primary production and is considered as the most widely accepted theory for the cause of eutrophication of freshwaters (Freedman 1995). Its presence can easily enhance recurring plankton bloom, its eventual die-off, and dissolved oxygen depletion.

Beveridge (1987) estimated that 1,000 kg of feeds for tilapia may contain a total amount of 13 kg (1.3%) phosphorus. He further stated that 1,000 kg of tilapia have 3.4 kg (0.34%) of phosphorus. Nile tilapia culture in Taal Lake has an average feed conversion ratio (FCR) of 1:1.5, that is, for every 1.5 kg of feeds given to fish, 1 kg of the amount is converted into fish flesh. This FCR value is acceptable to and targeted by the farmers. To estimate the amount of phosphorus lost to the environment, the following computation is shown:

(1,500 kg feeds x 1.3% P in feeds) – (1,000 kg fish x 0.34% P in fish) = 16.1 kg P

Based on this computation, an amount of 16.1 kg phosphorus for every 1,500 kg of feeds given to fish is lost to the environment and made available to boost eutrophication of the lake. The scenario becomes more appreciable if we consider that a cage could utilize about 200 bags (5,000 kg) to 400 bags (10,000 kg) of commercial feeds in one rearing cycle and there are more than 3,000 cages in the designated zone supposedly protected from the wind therefore with less water circulation particularly during summer. Phosphorus is made available in the site through the fecal matters, urine and uneaten feeds enhancing the growth of plankton and other organisms. More likely, dissolved phosphorus in the form of phosphate in urine is readily available to enhance primary productivity (Alcanices 1997). Floating dead fish are also observed during mass moralities and contribute to the availability of phosphorus in the aquatic environment.

Ammonia Pollution

It is also significant to discuss the contribution of ammonia in the pollution of Taal Lake. As stocking density increases, feed input and ammonia excretion also increase. The use of artificial diet is one of the basic sources of nitrogen loading in the aquaculture system. The artificial diet, which has a considerable amount of protein for fish growth contains a certain fraction of nitrogen, added to the environment. It is estimated that nitrogen loading in aquaculture ranged from 75-221 kg/ton fish. As aquaculture expands from semi-intensive to intensive (high stocking density), 7-31 times more nitrogen load (Edwards 1993) will be generated.

While it is the aim of aquaculture to provide sufficient and balanced feed diet necessary for fish growth, not all of the feed given to the fish are converted to fish flesh. Portions of the diet are uneaten, some are converted to fecal matters, and some are excreted to the gills and dissolved into the receiving water. These losses loaded into the environment are primary contributors to nitrogen pollution in Taal Lake. Nitrogen pollution may occur in several ways. These may be due to overfeeding of fish or feeding of fish at a time when they are not feeding, feeding unstable and highly soluble diets, and providing a diet of poor absorption and nitrogen retention efficiency (Handy and Poxton 1993).

Kibria *et al.* (1998) summarized the percentages of nitrogen retention and nitrogen losses in fish fed artificial diet. Specifically for tilapia, 23.44% is retained and assimilated into the body tissues of the fish, 42.2% is dissolved into the environment through gill excretion, 14.4% as fecal matters and 20.0% is uneaten (Beveridge and Phillips 1993). These percentages were based on one ton (1,000 kg) tilapia production. From the analysis, 3% is N content of tilapia, 8% is N content of feed, 4% N is fecal content (based on approximately 360 g of feces produced per kg food ingested) and feed conversion ratio of 1.6:1 (Beveridge and Phillips 1993).

Feed components, which were not converted into fish flesh, are excreted as organic waste in the form of fecal matter. Bacterial decomposition of this waste will increase biological oxygen demand and generate ammonia nitrogen.

A mathematical computation based on Beveridge and Phillips (1993) to determine the minimum and maximum nitrogen retention and losses per day in tilapia fed artificial diet at different stocking densities in the fish cage of Taal Lake is presented in Table 1.

It is indicated in Table 1 that as stocking density increases, there is a corresponding increase in nitrogen loss in the form of uneaten feeds from 5-15 kg/day to 10-30 kg/day. The implication is that, fishfarmers in Taal Lake are not only imparting pollution to the lake but are also imposing additional capital input on feeds.

Beveridge (1984) indicated that the proportion of uneaten food in cages is considerably greater than those from tanks or ponds. This is probably due to higher feeding rates and high stocking density employed resulting to higher feed loss. The use of floating feeds in a feeding ring appears more advantageous than the sinking feeds.

Gill excretion of ammonia by fish is a major source of ammonia in aquaculture system (Tucker and Boyd 1985). It constitutes the dissolved nitrogen in the environment, which is 42.2% in the case of tilapia. Boyd (1990) noted that the amount of ammonia excreted by fish can be determined from the net protein utilization (protein gain by fish – protein in feed) and the percentage protein in feed, which is as follows:

Ammonia-Nitrogen (g/kg feed)
= (1.0 – NPU)(protein/6.25)(1000)

where:
NPU = net protein utilization
Protein = decimal fraction of protein to nitrogen
6.25 = average rate of protein to nitrogen

The value of NPU for high quality diet is about 0.4. Thus, for a feed with crude protein of 28%, the ammonia-nitrogen excreted would be:

Ammonia-Nitrogen excreted
= (1.0 – 0.4)(0.28/6.25)(1000)
= 26.9 g N/kg feed

Based on the computed ammonia-nitrogen excretion of 26.9 g N/kg feed and assuming that there is no water exchange in the cage culture system,. the minimum and maximum amount of ammonia-nitrogen excreted per day and its concentration in water is presented in Table 2.

Socioeconomic and Political Concerns

On January 22, 1996, former President Fidel V. Ramos issued Executive Order No. 296 ordering the dismantling and relocation of fish cages and fish structures along the Pansipit River and Taal Lake not later than 30 days upon promulgation of the order. However, in view of the clamor of the local fishfarmers to allow the fish to be harvested first, and the need to delineate permanent fish cage zones, the deadline was requested to be extended to 120 days.

The Task Force on Taal Lake Management that was created under EO 296 is composed of the Executive Director of the Presidential Commission of Tagaytay-Taal (PCTT) created by EO

Table 1. Minimum and maximum nitrogen retention and nitrogen losses per day in Nile tilapia (10-30 g/fish) fed with artificial diets at different stocking densities.

Nitrogen retention/Losses	Proportion of feeds (kg)			
	25,000 fish/cage		50,000 fish/cage	
	25 kg feeds per day (min)	75 kg feeds per day (max)	50 kg feeds per day (min)	150 kg feeds per day (max)
Retained (23.44%)	5.86	17.58	11.72	35.16
Dissolved (42.2%)	10.55	31.65	21.10	63.30
Fecal (14.4%)	3.60	10.80	7.20	21.60
Uneaten (20%)	5.00	15.00	10.00	30.00

Table 2. Minimum and maximum amount of ammonia-nitrogen excreted per day and its concentration in water (assuming the cage is a close system).

Stocking density (no. fish·cage^{-1})	Feeding rate (kg·cage^{-1}day^{-1})	Amount of NH_3-N excreted (g N feeding^{-1}·cage^{-1}·day^{-1})*	Amount of NH_3-N concentration (mg water·day^{-1})**
25,000	25 (min)	672.5	1.68
	75 (max)	2,017.5	5.04
50,000	50 (min)	1,345.0	3.36
	150 (max)	4,035.0	10.08

*Ammonia-nitrogen excreted over the total volume of the water (10 m x 10 m x 4 m).
**Assuming there is no water exchange from within to without.

845 and the governor of Batangas as co-chairs, with the regional directors of DENR, DILG, DA-Region IV, the PNP and mayors of concerned municipalities as members. The main functions of the task force is to dismantle fish cages, fishpens and other aquaculture structures in the lake and to prepare a zoning plan for the lake to enhance the lake's fish culture industry. The plan allows the construction of fish cages and pens in about 10% of the total lake area of 32,435 hectares.

Pursuant to Republic Act # 7586 proclaiming national potential areas, Taal Volcano Island was declared as a fish reserve area in line with the declaration of the Island as a National Park by virtue of Republic Act # 7623.

In cooperation with the Cooperative Development Authority by PCTT, some of the fish cage structures are presently run by locally-based fishermen cooperatives. However, some socioeconomic problems are encountered between owner-operators and LGU's and among fishfarmers themselves e.g. issuance of permits, number of allowable fish cage for every member of the cooperative and noncompliance of fishfarmers on the policies imposed by the concerned agencies assigned in the development of the lake.

Reduction in cages will mean economic displacement since there is no alternative source of livelihood offered by the government for those cage farmers depending on cage culture. Political will to implement regulation is also wanting considering the series of dialogues and information drive conducted by the CLSU team in several barangays whose cages are at stake in the lake. In spite of knowing the effects of congested cages and overcrowded condition on the survival of the cage cultured fish and the industry in general, there is no apparent action on the part of the government to implement measures to mitigate the problems brought about by incorrect cage farming practices. On the cage farmers' side, Hardin's classical Tragedy of Common (1968) seems to be a reality in the lake since no one would like to reduce his stocks and cages, get out first, or sacrifice his interest in cage farming in any way to attain sustainable aquaculture in the lake.

Continuous education for a sustainable cage farming and ultimately to prevent further eutrophication (or pollution) of the lake and demise of cage culture in the lake should be done through the concerted efforts of all stakeholders.

Recommendations

Based on the above mentioned findings and observations, the following are hereby recommended:

1. Organization of an inter-agency group to monitor and analyze the limnological characteristics of the lake and emissions of Taal volcano. The physico-chemical parameters of the water are vital to the survival of fish in cages and behavior of other chemical parameters.
2. Reduction of the number of cages and stocking density per cage. Cages are so congested and stocks per cage are very high hence pollution due to fish wastes and excess feeds is inevitable. Reduction will minimize the environmental stressors encountered by the fish and will improve their growth and survival.
3. Provide correct amount of feeds through regular sampling of fish and computation of the amount based on fish body weight. Excess feeds given to fish are pollutants to the environment and most often a product of disregard of existing feeding technology.
4. Single-line positioning of cages. This will allow better circulation of the water and dissipation of wastes into the environment.
5. Installation of aeration system for emergency purposes to provide oxygen. This may be a generator-powered compressor to aerate the water or a centrifugal pump to bring up, circulate and expose the water to aeration.
6. Proper disposal of dead fish. Floating dead fish should be collected and buried onshore to eliminate further infection of surviving fish and pollution of the water.

In addition, strict enforcement of fishery quarantine rules and transplant regulation before introduction of any species into the lake to prevent introduction of diseases should be observed. Pollution control measures along coastal areas should also be implemented. Domestic and industrial wastes could further pollute the already deteriorating lake water. Occurrence and frequent outbreaks of diseases are signs of stressful environmental condition.

With the existing condition of the lake, additional area for cage culture, which means addition of more cages, fish stocks and wastes, will further deteriorate the lake. Reduction, not addition, should be considered in an overburdened body of water.

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An Overview of Freshwater Cage Culture in Thailand

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Abstract

Despite its long history and a large number of rivers and reservoirs in Thailand, cage culture contributed only 0.3% of 200,000 tons in total fish production from freshwater aquaculture. Over the last decade, tbe peak of annual fish production from freshwater cages reached 2,700 tons in 1991 and declined since to a minimum of 600 tons in 1995. Although cage culture takes place in various habitats such as river, reservoirs, irrigation canals and large ponds, its predominant habitats are in flowing waters. Among a dozen of cultured species, red snakehead (*Channa micropeltes*), catfish (*Pangasius* spp.), marble goby (*Oxyeleotris marmoratus*) and tilapia (*Oreochromis* spp.) topped the list. The production of those species fluctuated drastically resulting mainly from deteriorating water quality, competing for trash fish feed, changing market value, and shifting culture practices. However, disease and fingerling supply caused the reduction and limitation in culture of the most valued marble goby. Recently, the cage culture of tilapia has gained great popularity in certain parts of the country. Cage culture has been a small-scale, artisanal operation with little research and technical innovation. Further development of cage cultures in freshwater lies on ecologically sound multiple uses of reservoirs and flowing waters. In addition, integration of intensive cage culture with semi-intensive species in ponds should also be promoted.

Introduction

Thailand is endowed with a large variety of indigenous fish species in its natural inland freshwaters including rivers, floodplains, swamps, canals and rice fields (Smith 1945). Those waters provided abundant fish supplies to human consumption in most parts of the country in the past. However, in recent years, the fish catch from natural stocks, although increasing in total landing has been in short supply because of the ever-increasing consumer demand. To make up for the shortfall of fishery products, aquaculture has been playing a major role, especially the semi-intensive pond culture. While fish production from ponds provides the general public with relatively low-cost commodity, certain high-valued fish species are found more suitable to be raised in cages in natural waters. As cage culture is an on-water operation it requires little land and thus suitable for landless people who live adjacent to canals, rivers and reservoirs. Most cage culture practiced in Thailand is artisanal, based on local available materials for cage construction and indigenous fish species for stocking. However, cage culture of freshwater fish in Thailand has vacillated markedly over the past two decades and the trend for future development remains uncertain.

Fish Production Statistics

The total annual fishery production in Thailand has increased steadily during the last two decades from 1.8 million tons in 1980 to nearly 4 million tons at present (DOF 1997). As a coastal country bordering the Gulf of Thailand and Andaman Sea, marine fish catch accounted for approximately 80% of the total fishery products, the remaining 20% came from freshwater catch and aquaculture (DOF 1997). The freshwater aquaculture has steadily increased from

89,000 tons in 1986 to almost 200,000 tons in 1995, predominantly consisting of eight species (Table 1).

Fish production from cage culture has contributed insignificant and erratic quantity with annual production ranging from 600 to 6,700 tons from 1986-1995 (Table 2). Among a dozen cultured species (Table 2), the production has been dominated by catfish (*Pangasius* spp.), marble goby (*Oxyeleotris mamoratus*) and red snakehead (*Ophiocephalus micropeltes*) (Fig. 1). However, with the recent increase in popularity of tilapia culture in cages, production has reached record high.

Environmental Conditions for Cage Culture

The aquatic environment of inland waters can be broadly categorized into open flowing waters (lotic), such as rivers, streams and canals, and closed standing system (lentic), e.g., lakes, reservoirs and ponds. All those waters are potential habitats for cage culture of various fishes around the world (Beveridge 1996). In Thailand, few natural lakes exist and most surface water bodies are rivers, canals and reservoirs (Fig. 2, Vongvisessomjai 1998). As many of those water bodies are distributed in the north, northeast and

Table 1. Production of freshwater species from aquaculture in 1995.

	Production (ton)	%
Tilapias	76,100	38.8
Common carp	3,600	1.8
Silver barb	27,400	14.0
Snake skin gourami	16,700	8.5
Walking catfish	44,100	22.5
Snakehead	5,800	3.0
Pangasius catfish	7,300	3.7
Giant freshwater prawn	7,800	4.0
Other	7,200	3.7
Total	196,000	100.0

Table 2. Total freshwater fish production from aquaculture and from cage culture, 1986-1995.

Year	Freshwater (ton)	Cage culture (ton)
1986	89,300	1,702
1987	89,800	936
1988	102,100	1,774
1989	91,700	1,797
1990	103,800	6,748
1991	122,700	2,696
1992	142,100	1,138
1993	161,600	787
1994	170,400	839
1995	196,000	613

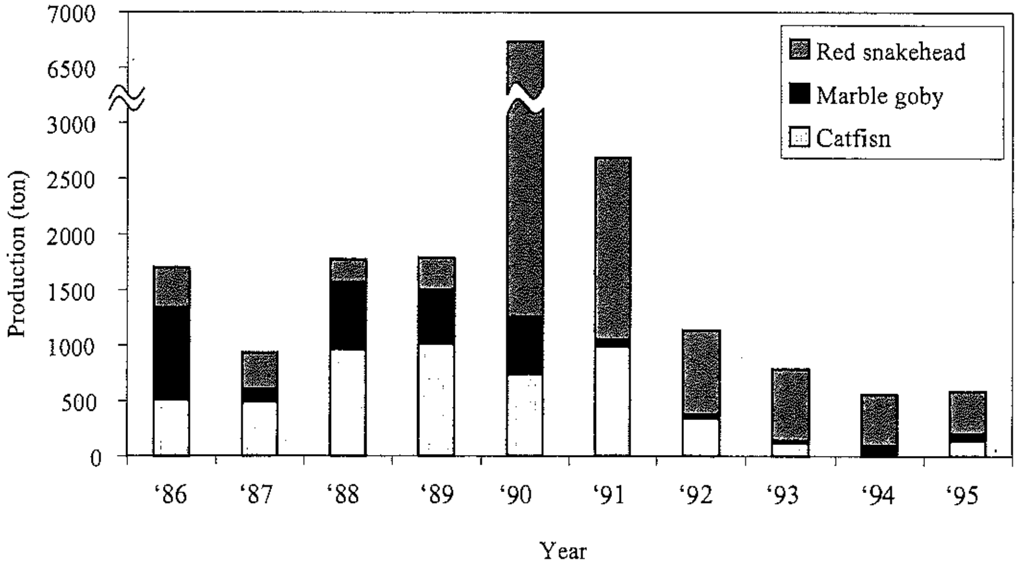

Fig. 1. Production of major freshwater species from cage culture in Thailand during 1986-1995.

central parts of the country with distinctive rainy and dry annual cycles, their hydrological regime and water quality are extremely variable.

In a riverine environment, high turbidity, low dissolved oxygen and toxic contaminants are the major water quality problems for cage culture. Floods and strong currents resulting from heavy rainfalls often prevent cage access and destroy cages. During the rainy season most river water is not only turbid with silt and clay from erosion and runoffs, but also occasionally contaminated with toxic substances from agricultural, domestic and industrial washouts. Water quality is particularly poor, often detrimental to fish, at the beginning of the rainy season and near the end of the dry season with low water flow. In several instances, the waste effluents from sugar and paper mills caused mass fish kill down stream from the waste discharges, causing conflicts between the industries and fishing communities, including cage farmers.

The lacustrine waters in Thailand are predominantly reservoirs and dams constructed for irrigation and hydropower generation. There are 18 major reservoirs with an approximated total surface area of 2,250 km^2 (Chookajorn 1992). Other than capture fisheries from natural stocks, those waters have not been widely used for aquaculture, except for a few cages in isolated instances. Legal and logistic restrictions, as well as low economical incentives are perhaps the major reasons that deter the development of cage fish culture in those waters.

Materials and Construction of Cages

Based on the nature of construction materials, two basic types of cage exist – traditional and modern types. The traditional, old timer's cages were constructed with wooden planks or woven bamboo strips, and floated by bamboo tubes (Table 3). Normally, wooden cages are larger than 10 m^3 and serve longer than 10 years. Aside from being able to sustain strong water currents they also serve as deterrent to poaching. Bamboo cages are smaller (5 m^3) with shorter life span (3 years), but initial investment is considerably less than the wooden cages. Both wooden and bamboo cages suffer from low rate of water exchange and poor water quality as materials are tightly spaced with small mesh openings.

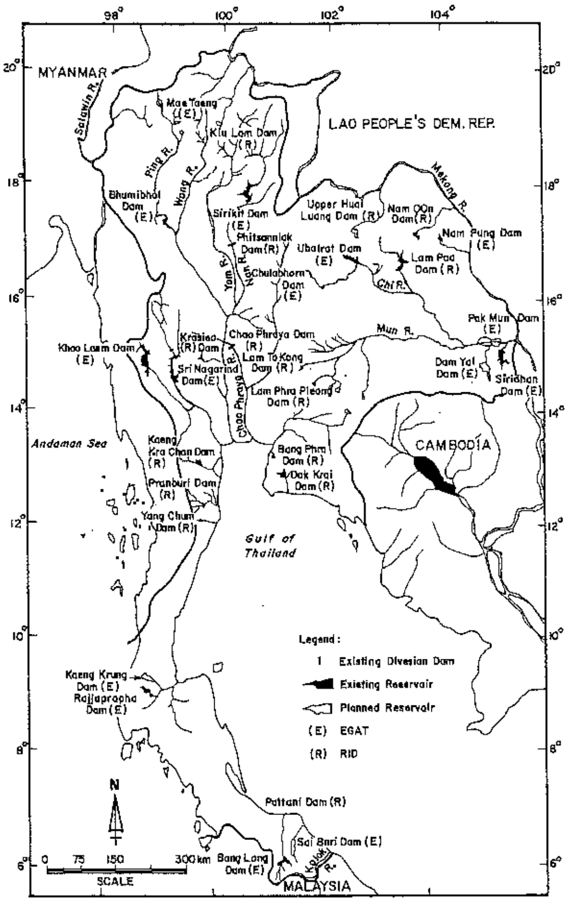

Fig. 2. Map of Thailand showing major surface water resources including rivers and reservoirs.

The modern cages are constructed using multi-filament nylon nets with metal or PVC frames, and floated by used oil barrels, plastic drums, or styrofoam blocks. The common cage size is 20-30 m^2 of surface dimension with a depth of 2-2.5 m. Mesh size is 1 cm for nursing cages and 3-4 cm for grow-out. To prevent fish escape from accidental damage the cages are normally constructed in double netting layers. While the set up may require greater initial investment, its neatness and streamline provide greater convenience for daily operation and routine maintenance on one hand and enhance water exchange rate on the other. On the average, those synthetic materials last approximately for five years. Cage fouling that plagues marine cages appears to be a minor problem in freshwater.

Comparisons Among Major Species Cultured in Cages

Among the few species of cage cultured fish in Thailand, red snakehead, marble goby and stripe catfish are the most commonly raised and profitable (Table 4). The marble goby, in particular, has been most sought after for its high quality flesh and ability to stay alive for an extended period of time under moist condition. It fetches high market price (> $\$10 \cdot kg^{-1}$) domestically as well as abroad. Despite its wide distribution in riverine and lacustrine habitats throughout the Southeast Asia, it has invariably been cultured predominantly in cages in flowing water. The cage culture in Thailand started some 30 years ago and peaked in the early 1980s with an annual production of 600 tons. Due to the serious disease outbreak caused by *Aeromonas hydrophila* during the mid-1980s, production plummeted since and has hardly recovered to this day for no apparent reasons. Although the fry have been successfully produced in hatcheries (Tavarutmaneegul and Lin 1988), juveniles caught from the wild are exclusively used for cage stocking. Little research effort has been made for the existing problems, including slow growth from fry to juvenile stage, peculiar feeding behavior and environmentally related high mortality rate.

The second lucrative species for cage culture is stripe catfish with a net profit of \$0.5-1 kg^{-1} and it can be cultured at extremely high density at 40-90 $kg \cdot m^{-2}$ in one-year cycle. Owing to its air breathing ability, it can live in poor water quality and low quality diet, e.g., chicken offal and restaurant wastes. Pond culture is more common than cage culture. Few problems, other than occasional slow market, are encountered for cage culture of this fish. Red snakehead culture has been in existence in small areas in Nakhon

Table 3. Comparison of major features of cage culture for important species in Thailand.

Species	Habitat	Cage type	Dimension (m^3)	Stocking density ($fish \cdot m^{-2}$)	Seed source	Feed	Production ($kg \cdot m^{-2} \cdot crop^{-1}$)
Snakehead	River	Wood	20-40	200-500	Wild	Trash fish	100-350
Marble goby	River	Wood Bamboo	10-20	30-180	Wild	Trash fish moist pellets	20-60
Catfish	River	Wood Bamboo	20-100	50-400	Wild Hatchery	Pellet Waste	40-90
Giant gouramy	River Reservoir	Wood Net	30-100	40-60	Hatchery	Pellet Plant	25-50
Tilapia	River Pond	Net	30-50	30-100	Hatchery	Pellets	15-40

Table 4. Partial costs and income for cage culture of major fish species (values are in US$)

Species	Seed (per 100 fish)	Feed (per kg)	Fish price (per kg)	Operation cost (per kg)	Net profit (per kg)
Snakehead	2.7-4	0.1-0.2	0.7-1.1	0.3-0.8	0.14-0.36
Marble goby	7-30	0.1-0.2	4-10	1.5-3	2-5
Catfish	8-20	0.5	1.7-2.2	0.7-1.4	0.5-1
Giant gouramy	0.83	0.14	0.8-1	?	?
Tilapia	4-5.5	0.5	1-1.1	0.7-0.9	0.1-0.5

Swan, where natural fry are readily available from a large swamp. Fish are fed mostly on moist pellets made of small marine fish.

Production of cage cultured tilapias has steadily increased from a few bundred in 1996 to 2,500 tons in 1998, and a greater production is expected in 1999. The general features of tilapia modern culture are shown in Table 5. The fish are cultured in nylon net cages of 3 x 3 x 2.5 m and fed with commercial pelleted diet. The fish are stocked at 30-100 fingerlings·m^{-2} with a production level of 10-40 kg·m^{-2} for three to four months. With a relatively low profit margin ($0.1-0.5 kg^{-1}), the risk of tilapia culture in cages is high, especially from high mortality caused by poor water quality. For red tilapia, the main problem appears to be limited domestic market.

Constraints and Opportunity

The production and development of cage culture of freshwater fish in Thailand are markedly lower than its neighboring countries in the Southeast Asian region, particularly Indonesia, Philippines, and Vietnam. The major constraints for the development of freshwater cage culture in Thailand are largely due to limited domestic market and relatively high costs compared to pond reared fish. The traditional major freshwater species produced for domestic consumption in Thailand are walking catfish, silver barb, snakeskin gouramy, and tilapia. These species have been produced semi-intensively in ponds at considerably lower costs for producers and market price for consumers, as compared to cage reared products depending on costly artificial diets. The other constraint is that poor water quality prevails in most flowing waterways, such as rivers and irrigation canals, where cages are located.

Despite the recent marked increase in tilapia cage culture, the opportunity for further development of freshwater cage culture in Thailand depends on ecologically sound multiple uses of reservoirs and flowing waters. However, fish production from cage culture, tilapias or other species, is likely to be extremely limited in the future without exporting markets.

Table 5. Some typical features of tilapia cultured in cages.

Cage size	3m x 3m x 2.5m
Stocking size (g)	50
Stocking rate (no. fish·cage^{-1})	1,000
Growout period (day)	120
Survival (%)	85
Harvest size (g)	600
Production (kg·cage^{-1})	510
Cost (US$·cage^{-1}·crop^{-1})	482
Cage (US$·cage^{-1}·crop^{-1})	30
Seed (US$·cage^{-1}·crop^{-1})	55
Feed (US$·cage^{-1}·crop^{-1})	397
Gross income (US$·cage^{-1}·crop^{-1})	536
Net income (US$·cage^{-1}·crop^{-1})	54

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Current Status and Sustainability of Cage Culture in Reservoirs: A Case Study in China

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Abstract

Cage culture has become a significant contributor to fish production in China during the past two decades, particularly due to the rapid expansion in the use of reservoirs. For example, in Ziyang prefecture of Sichuan province, the culture area and fish yields increased from 0.13 ba and 60 tons in 1984 to 20.9 ba and 16,412 tons in 1998, respectively. The productivity and total catch in the open water of reservoirs also increased from 150 $kg \cdot ba^{-1} \cdot year^{-1}$ and 1,133 tons in 1984 to 3,009 $kg \cdot ha^{-1} \cdot year^{-1}$ and 22,700 tons in 1998, respectively. The cultured species in cages include common carp, grass carp, silver carp, bighead carp, crucian carp, deep crucian carp, prussian carp, largemouth catfish, *Leiocassis* sp., channel catfish, Wuchang bream, Mandarin fish, soft-shelled turtle, Nile tilapia and pig frog.

However, due to high production and economic returns, farmers and some government staff set up excessive number of cages in reservoirs. Cage area has reached 1-3% of the total surface area of reservoirs. As most caged fish are fed with pelleted diets, rapid eutrophication occurred in many reservoirs, causing occasional massive mortality of fish in cages and even in open-water in recent years due to deteriorated water quality. This has restricted further development of reservoir fisheries, and hampered multi-uses of reservoirs.

To achieve sustainable cage culture in reservoirs, the following measures should be considered: (1) establish and enforce regulations for reservoir fisheries; (2) set up water quality monitoring systems; (3) determine reservoir carrying capacity for cage culture based on fish production and ratio of cage area to open-water area; (4) optimize the stocking ratios between filter-feeding fish and fed-fish in cage culture, and species composition and density of fish stocked in open water; (5) encourage and promote production and use of environmentally friendly feed such as floating pellets; (6) improve cage design and layout, and to collect cage wastes; (7) use mechanical method to oxygenate bottoms and mix reservoir water. The purposes of all these measures are to reduce nutrient loading, recycle nutrients and improve nutrient utilization efficiency, minimize pollution, and thus achieve sustainable development of reservoir fisheries.

Introduction

Cage culture originated in the Yangtze River delta in China some 750 years ago (Hu 1994) and has long been practiced in Southeast Asia (Ling 1977). Many versions of modern cage culture have been developed for intensive culture of commercially important species in various parts of the world (Coche 1978; Beveridge 1984).

In China, the water area of reservoirs suitable for fish culture is about 2.66 million hectares. However, the Chinese ancient practice of cage culture remained largely unaltered until about 20 years ago (Hu 1994). Cage culture has been developed rapidly in China, since the introduction of modern cage culture techniques from foreign countries in the 1970's (Chen 1979; Hu and Lu 1980; Dai 1978). Cage culture has become a significant contributor to aquaculture production in China during the past two decades, particularly from rapid expansion in the use of reservoirs. During the 1980's, the water area for reservoir fisheries reached 1.37 million hectares with a total production of 0.2 million tons. By 1998, the water area for reservoir fisheries accounted for 80% of the total reservoir water area suitable for fish culture, giving a total production of about 1.3 million tons, which accounted for 9.8% of the total national production of freshwater aquaculture of about 13.2 million tons (Chinese Fisheries Association, pers. comm.). This paper presents a case of cage culture in reservoirs in Ziyang prefecture, Sichuan province of China, and its associated problems.

Current Status of Cage Culture in Ziyang Prefecture

Ziyang is one of the smallest prefectures in the southwestern inland province of Sichuan. However, Ziyang produced 12% of the total provincial fish production in 10% of the total provincial fish-culturing area; 28% of the total provincial reservoir fish production in 14% of the total provincial reservoir water area; and 43% of total provincial cage fish production in 31% of the total provincial cage area in 1998 (Sichuan Fisheries Association, pers. comm.; Table 1). Reservoir fishery has rapidly developed in Sichuan province, particularly in Ziyang since 1984. Aside from the traditional pond culture, reservoir fishery is becoming a major contributor to fish production, primarily in three ways. The first is capture fishery with stocked species, the second is enrichment of small reservoirs with chemical fertilizers and stocked with hatchery-reared fish species, and the third is cage culture.

Fish production from reservoirs accounted for 51% of the total fish production, while cage culture accounted for 72% of the reservoir fish production in Ziyang in 1998 (Table 1). The average productivity in cages was 78.5 kg·m^{-2}·year^{-1}. For example, the Sancha Reservoir in Ziyang, which is one of the biggest reservoirs in Sichuan province, has about 1,533 ha of effective water area for fish culture; and the total cage area occupied 17.5 ha (about 7,000 cages of 25 m^2 size), accounting for 1.14% of the total open water area, in 1996. The area for cage culture of filter-feeding species, silver carp (*Hypophthalmichtys molitrix*) and bighead carp (*Aristichthys nobilis*), was 2.5 ha. Fish production from cage culture was 11,300 tons with an average productivity of 64.8 kg·m^{-2}·year^{-1}. The highest productivity reached 180.3 kg·m^{-2}·year^{-1}.

The major species for cage culture in Ziyang prefecture are silver carp, bighead carp, common

Table 1. Status of total aquaculture, reservoir aquaculture and reservoir cage culture in Ziyang prefecture, Sichuan province of China, in 1998.

Type	Items	Sichuan	Ziyang	
Total aquaculture	Culture area (ha)	153,389	15,229	(9.9%)
	Production (tons)	388,455	44,371	(11.5%)
	Productivity (tons·ha^{-1}·year^{-1})	2.53	2.94	
Reservoir fisheries	Culture area (ha)	54,741	7,559	(13.8%)
	Production (tons)	81,471	22,747	(27.9%)
	% of total aquaculture	21	51.3	
	Productivity (tons·ha^{-1}·year^{-1})	1.49	3.01	
Reservoir cage culture	Culture area (ha)	67	21	(31.2%)
	Production (tons)	38,277	16,412	(42.9%)
	% of reservoir fisheries	47	72.2	
	Productivity (tons·ha^{-1}·year^{-1})	571.5	785.2	

Note: The numbers in parentheses are percentages of culture area and production of Ziyang prefecture in the totals of Sichuan province.

carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), crucian carp (*Carassius auratus*), deep crucian carp (*Carassius auratus cuvieri*), prussian carp (*Carassius auratus gibelio*), largemouth catfish (*Silutus merdionalis*), *Leiocassis longirostris*, channel catfish (*Ictalurus punctatus*), brown bullhead (*Ictalurus nebulosus*), Wuchang bream (*Megalobrama amblysephala*), mandarin fish (*Siniperca chuatsi*), soft-shelled turtle (*Trionys sinensis*), Nile tilapia (*Oreochromis niloticus*), and pig frog (*Rana grylio*).

Major Problems of Cage Culture in Reservoirs in Ziyang

Excessive Development

Due to high production and economic returns from cage culture, the development of cage culture in reservoirs was out of control in Ziyang prefecture during the early and middle 1990s. The cages were set up not only by farmers but also by some government staff to an area of 1-3% of total open water area, which exceeded the apparent carrying capacity of reservoirs. The Sancha Reservoir is a typical example.

Deteriorated Water Quality and Eutrophication

Problems associated to intensive cage culture are release of wastes such as uneaten feed and feces, stimulation of primary production, and deterioration of water quality in reservoirs. Recently, massive fish mortality occurred occasionally in both cages and open water. In 1996, the depletion of dissolved oxygen in the Sancha Reservoir killed about 200 tons of fish in cages and huge amounts of silver and bighead carps in open water. In the winter season (November to January), mass mortality occurred due to deoxygenation and toxicity of hydrogen sulphide caused by an overturn of the reservoir water. Similar events also occurred in summer (July and August) probably triggered by hot weather and low water volume.

Water quality of the Sancha Reservoir showed that the yearly average vertical temperature differential between surface and bottom was 4.2℃ from October 1995 to September 1996. Water color was yellowish during high water level, and changed gradually to light green during low water level. The pH ranges changed from 6.7-7.7 in 1983 to 7.0-9.3 in 1995/1996. Dissolved oxygen concentration in surface water was highest in April and August, and lowest in December with a minimum value of 0.38 $mg{\cdot}L^{-1}$. The bottom water became almost anoxic from June to August, compared to its saturated state (7.2 $mg{\cdot}L^{-1}$) in 1983. Chemical oxygen demand (COD) was above 10 $mg{\cdot}L^{-1}$ from June to August compared to 4.5 $mg{\cdot}L^{-1}$ in 1983, and gross primary productivity was about 5.62 g $O_2{\cdot}m^{-2}{\cdot}day^{-1}$. Both COD and gross primary productivity reached the levels of well fertilized ponds. Although the unionized ammonia concentration was not high, the inorganic nitrogen contents exceeded 0.3 $mg{\cdot}L^{-1}$. Relatively low inorganic phosphorus concentration might have limited further increase in primary productivity. Hydrogen sulphide was always detected in the water where dissolved oxygen concentration was below 2 $mg{\cdot}L^{-1}$. The concentration of hydrogen sulphide was highest in December, and lesser from June to August.

Changes in plankton and nekton community structure were observed. The planktonic species diversity decreased with increasing standing crop of small size, nondigestible and even toxic species. Resultant increase in zooplankton standing crop was also apparent in the reservoirs (Table 2). The zooplankton standing crop in all reservoirs, except the Baohuating Reservoir, exceeded the minimum value (3 $mg{\cdot}L^{-1}$) of eutrophic reservoirs (Li 1994).

Poor Feed Property

One of the major problems resulting from cage culture is the poor quality of pelleted feed with low binding property, which disintegrated easily contributing to a proportion of uneaten waste and nutrients released directly to open water. The poor property of pelleted feed also made high feed conversion ratios (e.g. 1.5-1.8

Table 2. The concentrations of zooplankton in reservoirs in Ziyang prefecture in 1994.

Reservoirs	Shufangba	Motanhe	Bajiaomiao	Baohuating	Fanlong
Species distribution (individual/L)					
Protozoa	6	5	6	3	3
Rotifera	4	7	9	7	9
Cladocera	3	3	7	5	4
Copepoda	2	2	2	1	2
Total zooplankton concentration(mg·L)	10.75	5.75	19.40	1.49	8.05
Trophic levels	Extremely eutrophic	Highly eutrophic	Extremely eutrophic	Mesotrophic	Highly eutrophic

for cage culture of common carp), resulting in high production costs.

Inappropriate Design and Management of Cages

In general, a larger cage lowers the construction cost compared to similar volume consisting of several small cages. But the low surface to volume ratio of larger cage reduces water exchange rate, resulting in lower fish production performance and less economical efficiency (Schmittou 1993; Li 1994). To save construction cost, the common cage sizes in Ziyang ranged from 25 to 49 m^2. Large cage sizes with high stocking rates caused much poorer water exchange, resulting in low dissolved oxygen, which may cause fish mortality in cages, especially in calm and host weather.

Positioning of cages relative to each other is also important to water quality in cages (Schmittou 1993). Hypernutrification is often apparent in freshwater cage sites where water currents are low and sluggish dilution is limited (Beveridge 1996). Thus relocation of cages is often necessary, especially when cages are stocked at very high density and heavily fed. In Ziyang, the cages were usually laid out in an undesirable "H" shape, and were not moved unless severe dissolved oxygen depletion happened. Large amounts of uneaten feed and fish feces accumulate at the bottom of the reservoir below the cages, causing anaerobic conditions that often produce toxic substances such as lactate, ammonia, methane and hydrogen sulphide (Boyd and Bowman 1997). During winter (November to January), the full overturn of reservoir often caused severe dissolved oxygen depletion and deteriorated water quality that leads to mass fish mortality.

Conflicts with Reservoir Fisheries

To increase the production of open-water fish, some small reservoirs were fertilized with inorganic nitrogen (N) and phosphorus (P) fertilizers with N:P ratio of 2:1. This practice enhances high fish yield up to 6 tons·ha^{-1}·year^{-1} in the reservoirs stocked with filter-feeding fish as major species. However, excessive nutrient loading from fertilization reduces the euphotic zone, and destabilizes water quality, which might cause disasters to cage culture in such reservoirs. This practice also caused wastes of nutrients, and increased total costs for both open-water fishery and cage culture.

Inappropriate Stocking Patterns of Open-water Fish

The practice of fish stocking in reservoirs often disregards the ratio of species with various feeding habits. The unbalanced stocking ratio between phytoplankton feeder (silver carp) and zooplankton feeder (bighead carp) does not make full use of the plankton in reservoirs and large amounts of unutilized dead plankton settled in sediments and further deteriorated water quality. The only bottom feeder species stocked in reservoirs is common carp, because the difficulty in catching most bottom feeder species has not been solved completely, and also low dissolved oxygen in hypolimnion deterred detrital feeders from the bottom.

Strategies for Sustainable Reservoir Cage Culture

The above problems associated to cage culture have restricted further development of reservoir fisheries. Cage culture has even been banned completely in some reservoirs. However, the appropriate way to solve such problems is to develop more sustainable technologies to safeguard water quality for fish production and other water uses in reservoirs. Cage culture and open-water fishery in reservoirs are interdependent (Fig.1). To achieve the sustainable development of reservoir cage culture, the following aspects should be taken into account.

1. Establish and enforce regulations for reservoir fisheries. The cage culture and open-water fishery in reservoirs must be regulated to prevent excessive development and environmental pollution.
2. Set up water quality monitoring systems. Important water quality parameters must be measured at regular intervals and more frequently during warm periods to alert farmers of dangerous water quality conditions.
3. Determine reservoir carrying capacity for cage culture based on fish production and ratio of cage area to open-water area. Carrying capacity varies greatly with many factors, including fish species and their life stages cultured, quality and quantity of feed, and biological, chemical and physical characteristics of the water environment (Schmittou 1993). Based on previous work on the carrying capacity of feeding cages in reservoirs

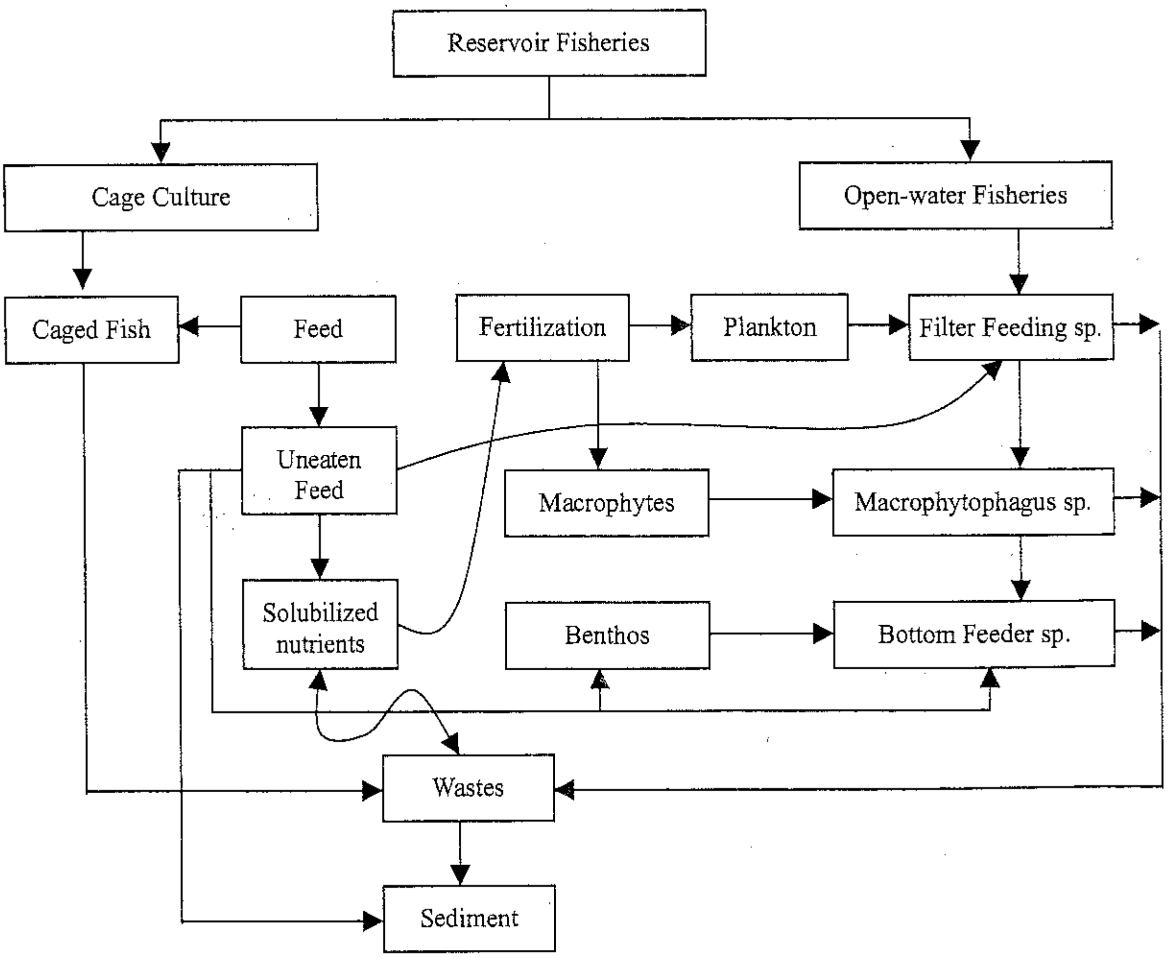

Fig. 1. A diagram of major flow of nutrients in reservoir fisheries.

(Li *et al.* 1989; Hu 1994) and the characteristics of reservoirs in Ziyang, it bas been suggested to limit the ratio of cage area to open-water area to 0.1% with cage production of 135 kg·m^{-2}·year^{-1} for the Sancha Reservoir (Sichuan Fisheries Association, pers. comm.). Thus, the total production from feeding cages in the Sancha Reservoir will be limited to around 2,100 tons, compared with 11,300 tons in 1996. Accordingly, feed inputs and waste loading will be largely reduced. To minimize the economic impacts on farmers by the proposed fish reduction, it has been recommended to adjust cultured species in feeding cages by replacing low-valued species with high-valued species.

4. Optimize the stocking ratios between filter feeding fish and fed fish in cage culture, and species composition and density of fish stocked in open water.
5. Encourage and promote tbe production and use of environmentally friendly and nutritionally complete diets such as floating pelleted feed through regulation of feed use to increase feeding efficiency and reduce feed and nutrient loss, thus, preventing pollution in open waters.
6. Improve cage design and layout. Low volume cages of 1-4 m^3 size should be adopted by more farmers. Cage positioning should be changed from "H" shape to the single line and two to four meters apart for maximum water exchange. Cages are better placed near shore because water in this area is not too deep and uneaten feed from cages can be better used by filter feeding and bottom feeder species. Moreover, because bottoms of this area are usually in the euphotic zone, accumulated wastes on the bottoms can be better decomposed and used by plankton and macrophytes. Moving cages from places to places is a good way to avoid deteriorated water quality in cage sites due to accumulated wastes. For cages placed in the deep water area, the installation of solid waste collection bags below cages is necessary to prevent accumulated wastes on the anoxic bottoms. The collected wastes could be pumped to a waste collection boat regularly, diluted and spread to the shallower area near shore.
7. Use a mechanical method to reduce risks from the wastes accumulated on reservoir bottoms. An airflow mixer bas been designed to oxygenate and stir bottoms, and mix water on the cage sites after relocating cages regularly. The airflow mixer makes water mix vertically to break down the thermal stratification, accelerate microbial decomposition of wastes under aerobic conditions, reduce toxic substances produced under anaerobic conditions, and eliminate mass fish mortality due to upwelling of anoxic water containing the toxic substances from hypolimnion to the surface. After using the airflow mixer, certain amounts of lime are applied to neutralize acids, accelerate nutrient release from silt, and sediment solids caused by the airflow mixer.

These measures can help cage culture and open-water fishery in reservoirs develop sustainably in terms of technical, social, economic and environmental aspects.

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Illuminated-cage Nursery of the Asian Sea Bass, *Lates calcarifer* Bloch, (Centropomidae): Effects of Initial Body Size and Stocking Density

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Abstract

This study was conducted to determine the appropriate initial body size and the corresponding stocking density of sea bass, *Lates calcarifer*, during nursery rearing in illuminated cages. Hatchery-produced sea bass fry of different initial sizes of 7.2 (day 15), 13.2 (day 22), and 15.2 mm (day 29) were stocked at densities between 300 and 1,500 m^{-3} in decreasing order with fish size. Nylon net cages (1x1x1 m) set in a protected sea cove area were individually lit at 300 lux using incandescent bulb placed at 1 m above water surface. Artificial lights attract wild zooplankton that served as prey to young sea bass. After 42 days of culture 22-day old sea bass fry with 13.2 mm TL initial size and stocked at 400 m^{-3} showed the highest growth (35.3 mm TL, 535.7 mg BW) and survival rates (64.4%). At a stocking density of 800 m^{-3}, tbe survival rate was the second highest at 43%. Although day 15-fry at 7.2 mm TL initial size showed bigber specific growth rates (11 % day^{-1}) and size at harvest (29-31 mm TL, 346.2-374.4 mg BW), survival rates (11-15 %) were lower than the day 22- and 29-fry (30-64%). Calanoid copepods of the genus *Calanus, Paracalanus* and *Acartia* dominated the diet (81-90%) of sea bass at different size groups. Percentage number of shooters ranged from 0.5-1.4% of total stocks and were not significantly different among treatments. The present results indicate that sea bass should spend 21 days in the hatchery prior to nursery rearing in illuminated sea cages. Sea cages are inexpensive and more cost-effective than ordinary cage or earthen pond for sea bass fingerling production.

Introduction

Successful rearing of fish fry in illuminated cages was first demonstrated for freshwater species *Coregonus lavaretus* in a deep freshwater lake (Brylinski *et al.* 1979; Mamcarz and Szczerbowski 1984). Cages were illuminated to attract wild zooplankton that served as food and eliminate the use of supplemental feeds for rearing juvenile fish (Rosch and Eckmann 1986; Champigneulle and Rojas-Beltran 1990). Illuminated cage nursery was considered as an alternative to the traditional pond or ordinary floating cage installed in ponds for marine fish fingerling production (Fermin *et al.* 1996; Fermin and Seronay 1997). This rearing technique provides some practical significance in terms of higher growth rates, increased stocking density and a nonpolluting fish nursery technique. The Asian sea bass, *Lates calcarifer*, is a well sought-after food fish in Southeast Asia. Although hatchery production has been successful (Duray and Juario 1988; Parazo *et al.* 1991; Rimmer and Rutledge 1991; Barlow and Rimmer 1993), production of fingerlings for grow-out culture is still low which limits marketable-size production. Hence, alternative nursery culture techniques should be developed to increase the supply of fingerlings.

The present study aimed to determine the optimal body size at stocking and the corresponding stocking density of sea bass fry for rearing in illuminated nursery cages. It also aimed to investigate the feeding performance of sea bass of different body sizes on light-attracted zooplankton in artificially lit nursery sea cages.

Materials and Methods

A 3x3-factorial experiment involving three fish sizes (Factor A) and three stocking densities (Factor B) for each size group was conducted at a protected cove near the SEAFDEC Igang Marine Research Station, Nueva Valencia, Guimaras. A single batch of hatchery-reared sea bass fry was transported to the nursery site on days-15, -22 and -29 after hatching thus, representing the three size groups with mean total length of 7.2, 13.2 and 15.2 mm, respectively. Stocking densities were 500, 1000 and 1500 for day-15 group, 400, 800 and 1200 for day-22 group and 300, 600 and 900 for day-29 group.

Each cage (1x1x1 m) was illuminated using a 100-watt white incandescent bulb installed at 1 m above the water surface between 1800 and 0600 h. Mean illumination level was measured at 300 lux using a digital light meter (Minolta, Japan).

Zooplankton density inside the cage was determined by regular samplings at 5-day intervals using a Kemmerer vertical water sampler (2.1-l capacity). Three samplings were done per cage. Samples were pooled, passed through a 150 μm mesh plankton net and fixed in 5% buffered formalin solution until analysis.

Ten fish samples were taken per cage and measured for total length and body weight at weekly intervals. Fish were then fixed in 10% formalin solution until size measurement and gut content analysis. "Shooters" or cannibals which had a 33% size difference from the rest of the stocks (Parazo *et al.* 1991) were removed without replacement to minimize cannibalism-induced moralities.

Cages were replaced with clean ones after each sampling. Used cages were brushed to remove silt and algae that clogged the meshes, and dried under the sun.

During the course of the experiments, water temperatures ranged from 28-32°C, salinities varied from 33-35 ppt, and dissolved oxygen levels (4.5-7.2 ppm) were within acceptable limits for fish culture.

Fish data were analyzed by two-way analysis of variance (ANOVA) using the SAS statistical package (SAS Institute Incorporated, 1991). Data on zooplankton abundance were normalized by log+1 transformation prior to one-way ANOVA. Significant differences among treatment means were compared by Duncan's multiple range test at 5% probability level.

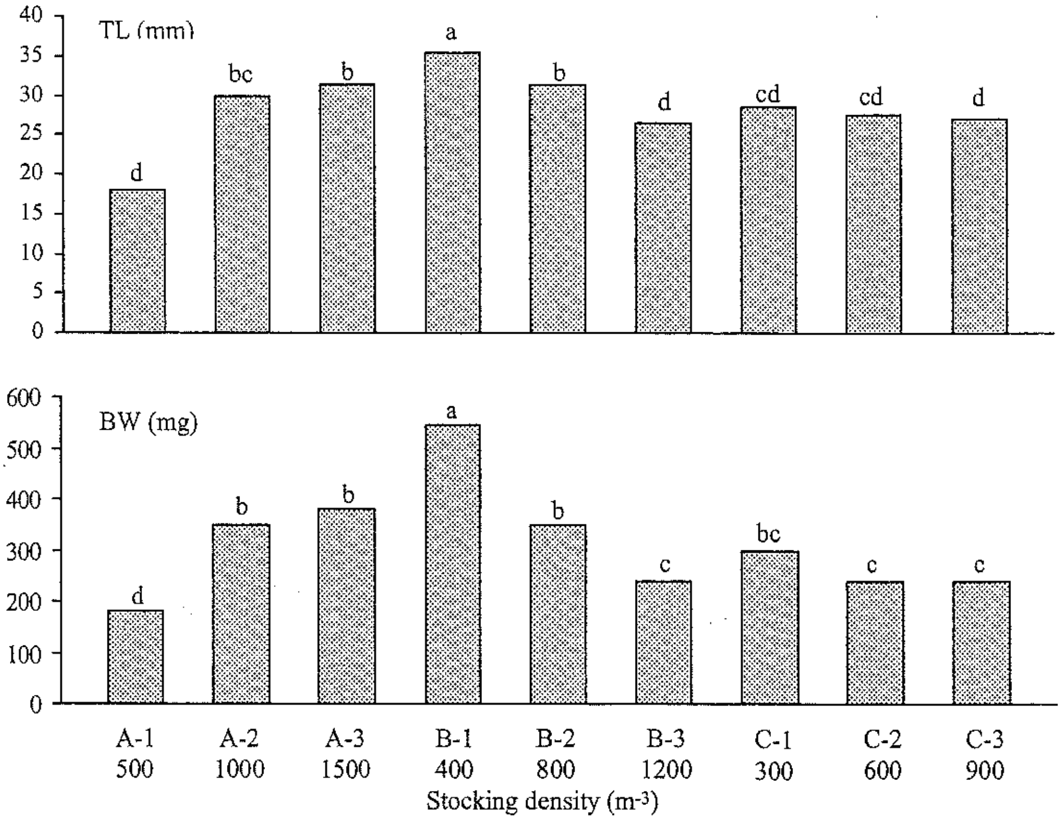
Results

Growth and Survival

Twenty-two-day old sea bass fry with initial size of 13.2 mm TL and stocked at 400 m^{-3} showed the highest growth rate with final body size of 35.3 mm TL and 535.8 mg BW ($P < 0.05$, Fig. 1). This was followed closely by fish of the same age and size but stocked at a higher stocking density of 800 m^{-3}, having a final length and weight of 31 mm and 344 mg, respectively. Similar growth rates (30 and 31 mm TL, 346 and 374 mg BW) were exhibited by 15-day old fry (initial size of 7.2 mm TL) and stocked at 1,000 and 1,5000 m^{-3} respectively. Significantly lower growth rates (range: 27-28.3 mm TL and 232-294 mg BW) were exhibited by 29-day old fry stocked at three densities and the 22-day old fry stocked at 1200 m^{-3} ($P < 0.05$).

Specific growth rates (SGR, range: 10.6-15.8% day^{-1}) were significantly highest among day-15 sea bass at all stocking densities tested ($P < 0.05$, Fig. 2). SGRs of day-22 fry ranging from 5.9-8.3 % day^{-1} decreased with an increase in stocking density. Day-29 sea bass at three stocking densities showed similar SGRs ranging from 5.6-6.3 % day^{-1} which were significantly lower than the rest of the treatments.

Survival rate (64.4%) was significantly highest in day 22 sea bass stocked at 400 m^{-3} (Fig. 2). This was followed by fish at the size group stocked at 800 and 1,200 m^{-3} with 43 and 34% survival rates, respectively, and day 29 fish stocked at all three densities tested (range: 29-35%). The lowest survival rates were shown by day 15 fish at all three densities tested (0-15%).



Legend: A= day 15 (7.2 mm); B= day 22 (13.2 mm); C= day 29 (15.2 mm).

Fig. 1. Final length and wet body weight of sea bass reared at varying initial sizes in illuminated floating nursery sea cages.

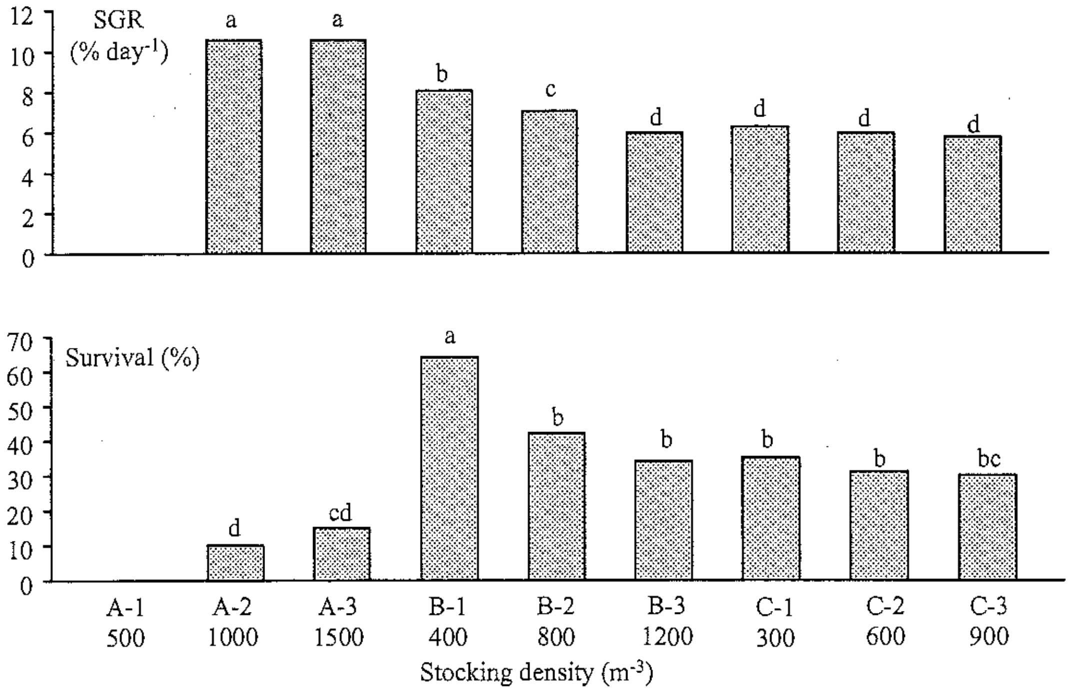
Zooplankton Abundance and Fish Feeding

The ranges and means of light-attracted zooplankton inside the cages are presented in Table 1. Zooplankton density increased with illumination period with the highest density of 193 individuals l^{-1} obtained at 0500h. Among the major zooplankton groups, copepods comprised the highest population at all sampling periods ranging from 80-85%. Calanoids and Cyclopoids densities increased with illumination time as compared with Harpacticoids densities that did not vary with time.

The percentage composition of various food items in the stomach of sea bass at different size classes was presented in Table 2. Calanoid copepods dominated the diet (67-90%) of sea bass at all size classes. Smaller-size sea bass (7.2 mm) ingested more Anomurans and Brachyurans (11 and 22%, respectively) compared with bigger-size fish. Feeding incidence (96-100%) determined five days after stocking did not vary significantly among the different size groups.

Discussion

The optimum size of hatchery-reared sea bass fry for stocking in illuminated floating nursery sea cages was 13 mm with a stocking density of 400 m^{-2}. At this size, fish must have spent 21 days in the hatchery and fed on *Brachionus* and *Artemia* for a minimum duration of 12 and 10 days, respectively (Parazo *et al.* 1991) prior to stocking in the nursery cages. Sea bass grew to fingerling size of 35 mm TL and 536 mg BW within 42 days with a survival of 64.4%, the highest among the different treatments. Doubling the stocking density at 800 m^{-3} has lowered the survival rate to 42%. Results of an earlier study showed that sea bass fry with an initial size of 19 mm TL and stocked at 600 m^{-3} in illuminated nursery cages gave the highest growth (8.5% day^{-1}) and survival (50%) rates only when given supplementary feeding of minced fish flesh during daytime (Fermin *et al.* 1996). Fish stocked at 600 m^{-3} and fed only on light-attracted zooplankton had lower growth and survival rates.



Legend: A= 15 day old; B= 22 day old; C= 29 day old.

Fig. 2. Specific growth rate and percent survival of sea bass, *Lates calcarifer* fry stocked at age/size in illuminated floating nursery sea cages. Bars sharing the same letters are not significantly different at 5% level of significance.

Table 1. Ranges and means of light-attracted zooplankton in floating nursery cages stocked with seabass, *L. calcarifer* fry at different initial sizes at stocking. Zooplankton abundance (number per liter) were observed at 1800, 2200 and 0500 h every after 5 days (n= 84). Cages were illuminated at 300 lux near the water surface.

Taxonomic Group	Sampling time (h)					
	1800		2200		0500	
	Range	Mean	Range	Mean	Range	Mean
Brachyurans	0.06-1.20	0.38	0.09-15.44	2.27	0.08-50.33	11.69
Anomurans/Pagurids	0.08-0.11	0.03	0.07-3.89	0.55	0.07-5.33	0.09
Copepods:						
Calanoids	0.67-9.67	4.86	1.53-51.11	18.99	1.33-95.75	21.03
Cyclopoids	2.20-74.25	15.60	2.13-226.58	32.40	6.11-527.75	112.99
Harpacticoids	1.17-4.83	2.56	0.20-3.89	1.85	0.67-4.13	2.24
Nauplii	9.17-44.60	27.98	2.93-39.33	16.66	2.00-70.93	27.69
Hyperiids	0.07-1.53	0.43	0.07-7.00	0.34	0.11-2.20	0.42
Pteropods	2.17-25.13	11.86	0.87-43.80	13.05	1.20-49.55	16.80
Total zooplankton l^{-1}		64		86		193

Table 2. Percentage composition by number of various food items in the stomach of sea bass, *L. calcarifer*, fry reared in illuminated floating nursery cages.

Taxonomic Group	Size class (mean total length, mm)		
	7.2	13.2	15.2
Anomurans	10.59	7.42	3.29
Brachyurans	22.07	2.80	7.82
Copepods	67.25	89.69	88.86
Hyperiids	0.01	0.00	0.00
Pteropods	0.07	0.10	0.02
No. of fish examined	45	45	45
No. of fish with food in the gut	43	45	43
% Feeding incidence	96	100	96

Younger sea bass stocked with an initial body size of 7 mm grew quite fast similar to 22-day old fry. However, survival rate was the lowest. Fish stocked at 500 m^{-3} did not survive beyond 21 days of rearing. The low survival rate of smaller-size fry could be attributed to poor feeding efficiency on light attracted zooplankton which comprised mostly of copepods (81-85%). In the hatchery, 15-day sea bass have just begun feeding on *Artemia* (Parazo *et al.* 1991). According to Mamcarz (1988), the effects of available food resources were at its strongest during the period of larval growth. Furthermore, once the larvae switched to food taken up from the water column, not only size differentiation due to competition among individuals ensued but also growth retardation of some of them.

The high percentage of copepods in the diet of sea bass reared in illuminated cages was in agreement with the observation that young sea bass have an ontogenetic progression of prey from microcrustacea to macrocrustacea (Patnaik and Jena 1976; Davis 1985; Barlow *et al.* 1993). In the smaller-size group (day-22), fish fed more of the Anomurans and Brachyurans and less of the copepods, which was the reverse for bigger juveniles. Conway *et al* (1993) stated that there were several factors that fish larvae would be subjected to in nature, which included changes in the individual condition of the larvae, differences in nutritional quality within and between food species, and food digestibility. Furthermore, if large proportions of food species are poorly digestible, fish larvae could suffer loss in condition causing death through starvation or increased vulnerability to predation.

Conclusion

It is concluded that the optimal size of hatchery-reared sea bass fry for nursery rearing in illuminated floating net cages is 15 mm or at least 21-day old. Using younger juveniles for stocking resulted to poor survival. Sea cages are inexpensive and can be utilized as isolated or small nursery farms. The present study confirms earlier results that illuminated-cage nursery is a better alternative to earthen ponds or ordinary cages and is a cost-effective method of sea bass fingerling production.

Acknowledgments

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An Asia-Pacific Regional Cooperative Network for Grouper Aquaculture Research

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Abstract

Groupers (Family Serranidae, Sub-family Epinephelinae) are fishes of high economic importance throughout their range, and there is considerable interest in the development of grouper aquaculture worldwide. However, the development of sustainable grouper aquaculture is currently constrained by low fingerling availability due to limited hatchery production and the reliance on dwindling supplies of trash fish for grow-out. Several initiatives are being developed in the Asia-Pacific region to overcome these problems. The Australian Centre for International Agricultural Researcb (ACIAR) is supporting research studies to develop improved hatchery and grow-out technology for grouper aquaculture, the Network of Aquaculture Centres in Asia-Pacific (NACA) has developed a world wide web site dedicated to the reporting and discussion of grouper aquaculture (http://naca.fisheries.go.th/grouper/) and the Asia-Pacific Economic Cooperation (APEC) is sponsoring an Asia-Pacific grouper network to facilitate improved collaboration and coordination of grouper aquaculture research within the region. These activities and their interlinkages are outlined in this paper.

Introduction

Aquaculture of high value finfish species such as groupers (Family Serranidae, Sub-family Epinephelinae) is an industry of increasing importance throughout the Asia-Pacific region. The development of large markets for live reef fish, particularly in Hong Kong and southern China, has increased pressure on wild stock resources. In many areas, the demand for live reef fish and the profitability of this trade, has encouraged overfishing and the use of destructive fishing practices such as cyanide poisoning. Such practices not only kill nontargeted species but also result in considerable habitat destruction (Johannes and Riepen 1995; McManus *et al.* 1997; Barber and Pratt 1998).

The development of aquaculture technology for high value groupers would not only support an economically beneficial aquaculture sector in the region but would also assist in reducing pressure on wild stocks. Currently, the major bottlenecks to increased aquaculture production of groupers are the generally poor and highly variable survival of the larvae in hatchery culture and the dwindling supply and increasing cost of fishery product that is presently the mainstay for growing fingerlings to market weight. As a first step towards a more sustainable live reef fish industry, the Network of Aquaculture Centres in Asia-Pacific (NACA) convened a regional workshop on "Sustainable Aquaculture and Coral Reef Fisheries" at Sabah, Malaysia in 1996 (Cabanban and Phillips 1999). The objectives of the workshop were threefold: (1) to assess the status of breeding and grow-out technology of coral reef fishes; (2) to identify the resource management issues in coral reef fisheries, especially in relation to the live fish trade and aquaculture of coral reef fishes; and (3) to develop strategies for alleviating the impacts of exploitation of coral reef fishes for aquaculture and the live fish trade. The recommendations arising from this workshop relating to grouper aquaculture and the initiatives that have been, or are being implemented in response to these recommendations, are outlined in this paper.

The Sabah Workshop on Coral Reef Fish

The workshop was held at Tuaran, Sabah, Malaysia from 5th to 7th December 1996. More than 100 participants attended the workshop, with all Asia-Pacific countries having a significant interest in the trade or aquaculture production of coral reef fishes being well represented. Twenty two invited papers were delivered which gave an overview of the status of aquaculture production, live fish trade and resource management of groupers and other candidate coral reef fish in the Asia-Pacific (Cabanban and Phillips 1999). Working group discussions were held to debate and make recommendations on three aspects: (1) Technical aquaculture issues; (2) Environmental interactions and resource management; and (3) Coastal management, socio-economics and trade.

The major constraints to the successful aquaculture of groupers were identified as the generally poor survival of fish during larval rearing and the unreliable production (or availability from the wild) of fingerlings for on growing to market size. Attendant with these issues was the concern that supplies of trash fish presently being used as the predominant source of food for on growing of groupers were dwindling and therefore becoming more expensive. Reliance on such fishery supplies for grow-out would become a major bottleneck to industry development upon successful large-scale hatchery production of fry.

There was unanimous opinion that further research was necessary to develop reliable larviculture techniques for grouper species. Research priorities were to better understand the digestive physiology and nutritional requirements of the larvae, to determine the acceptability and nutritional suitability of alternative live feeds, and to develop improved larval rearing systems. The importance of broodstock condition as a factor influencing the quality and vitality of the larvae was also recognized. However, the difficulty in carrying out statistically valid experimentations because of the logistics of broodstock holding was seen as a severe impediment restricting research being done on this aspect.

There was also general agreement that pellet diets were preferable to trash fish for grouper grow-out both to spare usage in the face of decreasing supplies and to lessen the pollution and waste that result from feeding of trash fish. The development of cost effective and palatable pelleted feeds with a reduced reliance on fishery product was viewed as a high priority with research being necessary to define the nutritional requirements of the fish and the nutritive value of terrestrial alternatives to fish meal. The early detection and treatment of fish disease were seen to be issues of increasing importance as grouper aquaculture becomes more intensively managed. A particular need was an improved viral disease diagnostic capacity in the Asia-Pacific region.

Specific recommendations during the workshop to speed up progress in developing reliable and sustainable grouper aquaculture technology were:

(1) Research coordination at national and international levels needs to be strengthened to fill in the gaps in knowledge in need-based areas.

(2) Improve the system of exchange and dissemination of information. It was generally agreed that NACA was in the best position to undertake this role, subject to funding constraints.
(3) Similar workshops should be held in the future to allow follow up and examination of progress achieved.

NACA Grouper Web Page

A major recommendation of the Sabah regional workshop was the improvement in the exchange and dissemination of information and research coordination at national, regional and international levels on grouper reef fish aquaculture. A specific recommendation was the development of a world wide web grouper site. This was launched in June 1997 by NACA in partnership with the Asian Institute of Technology, Thailand and the Centre for Tropical Ecosystems Research, Denmark (http://naca.fisheries.go.th/grouper/). The Australian Centre for International Agricultural Research (ACIAR) and the Fisheries Working Group of the Asia-Pacific Economic Cooperation (APEC) are supporting the further development of the site, as well as additional information collation and distribution initiatives.

Current research topics and publications relevant to grouper aquaculture and the management of coral reef fisheries are available online. A bibliography of coral reef fish publications since 1990 is maintained and updated in a searchable database. A database providing the contact details of more than 100 researchers and industry personnel can be searched according to organisation type and interest grouping (eg breeding and larviculture, fish disease, economics, policy and legislation, etc). The site also supports a forum for grouper aquaculture discussion where all subscribers can contribute and participate in a free and open exchange of ideas on grouper aquaculture; no fee is charged to subscribe to the discussion forum. A calendar of forthcoming events, training courses and other available services, news items and links to other relevant sites are maintained on the site.

ACIAR Grouper Aquaculture Project

In response to the other two recommendations from the Sabah regional workshop, ACIAR is supporting a research project to develop improved hatchery and grow-out technology for grouper aquaculture in the Asia-Pacific region.

Activities

The project has three major components:

(1) Larval rearing of groupers. The objective of this component is to improve the growth and survival of groupers during the hatchery phase. The research will concentrate on developing better understanding of the capacity of grouper larvae to digest various live prey organisms, and the nutritional composition that must be provided by live prey. This information will be used to assess the suitability of different live prey organisms at different stages of the larval rearing process, and to develop improved nutritional profiles for live prey organisms. Direct enhancement of larval nutrition using artificial diets will also be examined. These results will be integrated with other studies on environmental factors affecting grouper larvae to develop an improved methodology for larval rearing of groupers.
(2) Diet development for on growing of groupers. The objective of this component is to develop compounded feeds for grouper grow-out that have low environmental impact, have a low content of fishery product and are as cost-effective for the on-growing of grouper as the alternative of using trash fish. This will be tackled in a structured way such as acquiring nutritional information on feeds available for diet manufacture, characterising the requirements of groupers for key nutrients and demonstrating the cost effectiveness of the compounded feeds under simulated commercial farming conditions.
(3) Support for the grouper aquaculture research and development program. In this component, the objective is to add value to the existing

grouper aquaculture R&D efforts in the Asia-Pacific region by improving communication and promoting collaborative research between regional laboratories and agencies. NACA will facilitate communication among grouper aquaculture researchers by pursuing reports of research findings from participating institutions, as well as by compiling and publishing this information in regional aquaculture magazines, and on the NACA grouper web site.

Participants

The participating agencies and an outline of their activities in the ACIAR project are as follows.

(1) Queensland Department of Primary Industries (QDPI), Northern Fisheries Centre, Cairns, Queensland, Australia. QDPI is responsible for the overall project management and will carry out larviculture research with flowery cod/tiger grouper *Epinephelus fuscoguttatus*, barramundi cod/mouse grouper *Cromileptes altivelis* and gold-spot cod/greasy grouper *E. coioides*. Larviculture research will focus on the nutritional composition of live feeds, the ontogeny of the digestive tract, the qualitative and quantitative measurement of digestive enzyme capacities and the development of improved culture systems.

(2) Commonwealth Scientific and Industrial Research Organisation (CSIRO), Marine Research Laboratory, Cleveland, Queensland, Australia. CSIRO will be responsible for the management and coordination of the grow-out diet development component of the project. Research activities will concentrate on determining the nutritional requirements of the fish, particularly protein to energy ratio and in developing pelleted dry grow-out diets based on high inclusions of terrestrial protein meals.

(3) Southeast Asian Fisheries Development Centre (SEAFDEC), Tigbauan, Iloilo, Philippines. SEAFDEC will investigate aspects of the larviculture and grow-out of estuary cod *E. coioides*. Key larviculture research aspects will be to understand the influence environmental factors have on embryonic development, hatching and survival of early larval stages, to determine the fatty acid requirements of tbe larvae and to study the ontogeny of the digestive system of the larvae. The grow-out research will focus on determining the apparent digestibility of dry feed ingredients and in applying current research knowledge on nutritional requirements to develop practical diets for juvenile grouper grow-out.

(4) Research Station for Coastal Fisheries (RSCF), Gondol, Bali, Indonesia. RSCF will be involved in larviculture research with *C. altivelis* and camouflage grouper *E. polyphekadion*. The nutritional composition of live feeds, the suitability of both live and artificial feeds for larval rearing and the development of improved systems for intensive larval rearing will be the key research activities.

(5) Research Institute for Coastal Fisheries (RICF), Maros, Sulawesi, Indonesia. The apparent digestibility of locally available feeds and the development and economic evaluation of practical diets for grouper grow-out will be the prime research activities of RICF. In addition, the results of laboratory tank studies on the nutritional requirements of groupers will be validated for net-cage culture conditions.

(6) Blue Water Barramundi, Mourilyan, Queensland, Australia. This commercial hatchery will provide larvae and fingerlings of gold-spot cod, *E. coioides* for larval rearing and grow-out experiments in Australia.

(7) NACA, Bangkok, Thailand. NACA will facilitate improved communication and coordination of collaborative grouper aquaculture research within the Asia-Pacific region. This will be addressed through the interactive NACA grouper web site, the dissemination of newsletters and the convening of workshops, which serve as forums for the exchange of information on issues relevant to grouper aquaculture research.

All of these agencies are already involved in the different aspects of grouper aquaculture pertinent to the ACIAR project. The ACIAR project will "value-add" the participating agencies' existing research efforts by providing opportunities for enhanced collaborative research that target the identified constraints to sustainable grouper aquaculture. Direct benefits of the ACIAR project will be improved grouper hatchery technology, allowing hatchery production of fingerlings for grow-out, and the development of cost-effective compounded grouper grow-out diets that are not heavily reliant on fishery product.

Asia-Pacific Grouper Network

Improving collaboration and coordination of grouper aquaculture research within the Asia-Pacific region was identified at the Sabah regional workshop and in the ACIAR grouper project as a priority for advancing grouper aquaculture. The NACA grouper web page was established as a first step towards this goal. To start on this initiative, NACA and ACIAR convened a Grouper Aquaculture Research Workshop in Bangkok, Thailand from 7th to 8th April 1998 (Rimmer *et al.* 1998) to maintain the momentum for coordinated grouper aquaculture R&D. The objectives of the workshop were to (1) identify constraints to the development of successful grouper production technology; (2) identify research in progress in the Asia-Pacific region; and (3) establish a network of grouper aquaculture researchers in the Asia-Pacific region with the end in view of fostering cooperative research and facilitating information exchange.

It was clarified during the workshop that a large research effort is being mounted in the Asia-Pacific region to develop improved grouper aquaculture technology. There was agreement among the participants that more rapid progress could take place if duplication of research effort was reduced and if a wider collaborative approach to research was undertaken. In addition to documenting priorities for grouper aquaculture research (similar to that identified at the Sabah regional workshop), the workshop made two recommendations for better coordination of grouper aquaculture R&D efforts in the Asia-Pacific:

(1) There is a need to establish coordinated grouper research in the Asia-Pacific region, which would be facilitated through:

- establishment of a research program comprising the institutional or collaborative projects to address the key issues identified at the workshop–to be facilitated by NACA in cooperation with the other institutes
- the agreements made by the institutions to participate in a regional coordinated research program on grouper aquaculture technology development
- additional training opportunities, for example through staff exchanges and short-term attachments at participating institutions.

(2) There is also a need for an improved exchange and dissemination of grouper research findings, which would be facilitated by:

- providing institutional support to researchers to attend grouper aquaculture sessions at regional conferences and workshops
- focussing technical workshops on aspects of grouper aquaculture such as breeding and larviculture, grow-out diet development, and fish health issues
- reporting of research findings in regional aquaculture magazines (eg. Asian Aquaculture and Aquaculture Asia) and journals, and on the NACA grouper web site.

Consideration was also given as to how these recommendations could be implemented. It was suggested that an Asia-Pacific Grouper Network (APGN) be established to facilitate coordination of grouper aquaculture effort in the region and that this would be best achieved as a NACA initiative. In cooperation with the other institutes, NACA would establish a cooperative grouper aquaculture R&D program based on the Bangkok workshop recommendations. This grouper aquaculture R&D program would then formally be communicated to all participating institutions seeking their support and commitment to the initiative. Such commitment would hopefully enable institutional funds available for grouper aquaculture research to be directed towards more collaborative and coordinated grouper research and that additional research funding would be sought by the APGN from international agencies such as APEC.

APEC Fisheries Working Group

The Fisheries Working Group was established by APEC in 1991 to: (1) promote the conservation and sustainable use of fisheries resources; (2) promote sustainable development of aquaculture and habitat preservation; (3) seek solutions to common fisheries resource management problems and aquaculture disease control; (4) enhance food safety and quality of fish and fisheries products; and (5) promote sector-specific work relating to trade and investment liberalization and facilitation.

In 1998, the Fisheries Working Group approved funding to NACA for a three-year project to establish a framework or model for future collaboration and cooperation on grouper aquaculture issues among the major agencies within the Asia-Pacific region. A primary aim of the regional research network is to develop the capacity to establish a sustainable grouper aquaculture industry that will benefit all collaborating economies. This would provide an alternative source of income/employment to people currently engaged in dangerous and illegal fishing practices and thereby protect endangered reefs and reef fish from the pressures of destructive fishing practices. The planned activities include:

(1) Year 1 – APEC/NACA workshop to coordinate research in Asia-Pacific. The workshop will establish a work program and set research priorities for grouper culture across the region. This process will start on existing NACA and APEC initiatives directed at solving problems associated with grouper aquaculture and ameliorating the effects of unsustainable fishing practices.

(2) Years 1-3 – APEC-funded technical staff exchanges. An essential component to the success of the research network would be the APEC funded staff exchanges among participating economies. These technical staff exchanges are designed to facilitate efficient transfer of research results and technology, and encourage further collaboration on R&D between APEC/NACA economies.

(3) Year 3 – Final workshop to review progress of research and to define future research requirements.

Two other grouper projects were approved in 1999. The first is a one-year project to develop strategies for research in grouper viral diseases and to investigate options for future funding from additional sources to undertake an international collaborative research effort on grouper viruses and their impacts. The lead agency for this project is the Thailand Department of Fisheries. The second project is to produce a farmer-friendly manual on grouper health and husbandry. The lead agency for this project is SEAFDEC, and the manual will be translated into various languages by the participating institutions for the benefit of the local farmers.

Coordination of Grouper Aquaculture R&D in Asia-Pacific

Since the December 1996 Sabah workshop on coral reef fish, there has been sustained momentum to develop mechanisms to improve the coordination of grouper aquaculture R&D efforts in the Asia-Pacific region. Key initiatives have been the development of a NACA grouper web site for information exchange, the establishment of an ACIAR collaborative project to develop improved hatchery and grow-out technology for grouper aquaculture and APEC's recognition of the role grouper aquaculture can have in ameliorating the effects of unsustainable fishery practices such as cyanide poisoning and explosives. These initiatives are closely interlinked (Fig. 1) and will assist in the development of a strong Asia-Pacific alliances for collaborative grouper aquaculture R&D. For these initiatives to succeed in achieving more rapid advancement of grouper aquaculture technology in the region, researchers will need to genuinely participate in collaborative research and to influence their institutions' participation by being strong advocates for the regionally-coordinated grouper

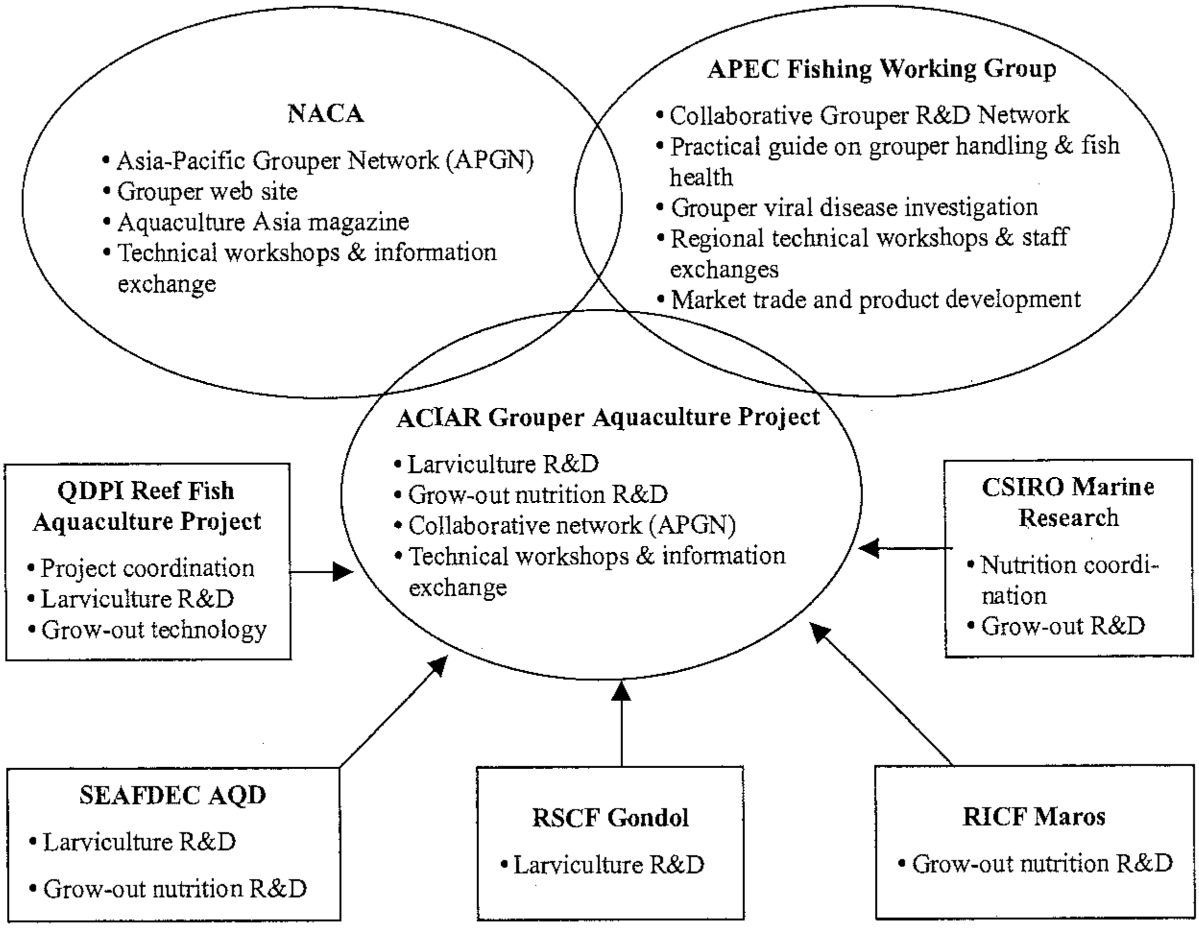

Fig. 1. Grouper aquaculture R&D collaborative linkages in the Asia-Pacific region.

aquaculture R&D network. Anyone who is interested in grouper aquaculture and would like further information about these initiatives should register their interest on the NACA grouper web site (http://naca.fisheries.go.th/grouper/).

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Post-harvest Technology of Farmed Fish

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Abstract

The development of Atlantic salmon farming in Norway has been very rapid, from a few tons 15-20 years ago to about 400,000 tons in 1999. This is an impressive growth and today's production volume is also considerable compared to aquaculture in Asia. The rapid volume increase have been possible due to the efficiency and advanced technology used in all stages from feed production, fry production, and cage farming to post harvest processing, distribution, and marketing.

One of the first technological hurdles to overcome was to increase and shorten the time for fry production. Due to low temperatures in the rivers in Norway, normal growth time before the fish could be transferred to seawater was three to four years. With the introduction of energy systems and heat pumps, optimum temperatures from egg to smolt reduced the on-growing time to about one year.

In the early years of salmon farming, post harvest was adopted from small-scale traditional fishing. To increase quality and shelf life for the high value product and rapidly increasing volumes, technology developments for handling and processing were started. Traditional icing in boxes is labor-intensive and results in slow chilling, water drainage, etc. Effective handling and chilling techniques with the use of refrigerated seawater or brine have been developed and today, chilling of live fish is also introduced.

Today's slaughter and processing plants have a capacity of 80-100 tons a day. This is obtained by using rational technical solutions for every processing step in the plant. Care is also taken to reduce heavy work. Effective cleaning/washing routines are introduced and all materials are chosen to meet high hygienic standard.

This paper presents techniques, processes, and technology, which are important to optimize quality and increase shelf life of fish products from the fish farm to the consumer.

Introduction

The tremendous growth rate of salmon farming in Norway is usually observed from a biological point of view. Certainly, the research and development in this area has been impressive and the work of pioneers is almost unbelievable. What is lesser focused on is how profitable the production has been. The value of the products is in the market, not in the cages. A similar challenge as the on-growing has been to export more than 90 % of the production to consumers all over the world, with competitive quality and cost in a market where food is abundant.

The development in handling, processing and distribution and marketing has been impressive. This has required basic knowledge of world fish market, marketing and market development. The brand name "Superior Norwegian Salmon" and a high eating quality of the products have been parts of marketing. To achieve this, knowledge of quality and efficient processing, packing systems, distribution chains, etc., has been developed parallel with the production growth.

Fishing and fish processing have been traditions in Norway for a long time now. A very long coast towards one of the richest fishing grounds in the world has made it possible to live in our cold land. This abundance of fish, besides providing food to our population, has for hundreds of years also given income through export of fish to warmer countries.

The export of fish and fish products was up to the last part of 1800 based on dry, salted, and salted-dried fish. Although the effect of chilling on storage life and use of "natural" ice and snow has been known for hundreds of years, the developments in refrigeration made a shift in preservation. Since the beginning of 1950, the main part of our fish export is based on chilling and freezing. Expertise in handling, processing, distribution etc. was important for the growth of salmon export.

Quality

Quality is generally defined as "product as expected by the buyer", and for fish, this in practice means almost like newly slaughtered fish. To judge the quality with objective measurements of chemical and physical parameters is a complex task. Intensive research has given a good knowledge of the changes in the fish due to chemical and biochemical processes "post mortem" (after death). These complex changes in the tissue, fat and other components, growth of bacteria, and physical processes will reduce the nutritional, hygienic, sensoric, and technological quality. However, no single measurement of one or a few of these factors will describe the change of the total quality as defined by buyers. In addition, most of these measurements are time consuming and require equipment and expertise.

For the practical purpose in fish trade, the changes in appearance (skin, eyes, gills, etc.) and sensory quality (smell, task, color etc.) are the most important and also such information exists for many species, especially cod. The changes in total quality score with time are today usually regarded as a straight-line plot dependent on time for storage at a constant temperature, although smaller differences from this are found in some investigations.

Shelf life is defined as the time elapsed before the quality score falls below a certain limit. It is important to know that this limit depends on the market and may vary due to use and preparation/processing. Some countries like Norway have, therefore, defined a quality limit for fish by describing acceptable organoleptic qualities like smell, consistency, color, taste, etc. The quality of "Superior Norwegian Salmon" from the early stages of farming has been very important for market acceptance.

It is well known that newly caught/ slaughtered fish depends on biological variations, (age, sex, spawning etc.) and feeding. In farming, feeding is important for taste and intrinsic factors and also for shelf life. Starving the fish before slaughter will empty the stomach and reduce the enzyme activity, bacterial amount, and biochemical activity.

Handling of Fish

In fishery and farming, we know that handling, transport, and the slaughter process affect quality. Stress results in physiological changes and loss of energy reserve in the muscle, early onset of death stiffness (rigor mortis), and reduced shelf life. Rough handling of live and also newly slaughtered fish may give mechanical wounds and bruise, blood spots, gaping in the fillet, etc. Little and careful handling will, therefore, be especially important for yield and labor in filleting and processing. Special care must be taken in handling of in rigor fish, due to danger for mechanical damage of the fish flesh.

Chilling

For animal products, which no longer have the natural protection of living products, the shelf life of fresh products at ambient temperatures is short. We also find large variations in storage life at a given temperature between products like animal meat and fish. Due to the lower temperatures in water, the micro-organisms in the fish are adapted to this and benefit less from chilling. For fish, there also are great variations between species as experienced in some of the most important fishes in Norway.

The variation between the fat pelagic fish like herring and mackerel and lean fishes like cod is interesting to notice. Atlantic salmon also shows a remarkable high storage life compared to pelagic fat fish. However, the most important observation is the sharp decline in storage life with increasing temperatures close to freezing point.

Little data on the shelf life of warm water fish is found in literature. However, some data indicate increased effect of chilling as long as the number of pshycrofile bacteria is low. Increased knowledge of quality changes of actual farmed fish at actual distribution temperatures is needed. In addition, "brand name" quality limits for marketing should be given and accepted by the market.

Altbough temperature is the most important factor, variations in material, handling, packing, etc. also influence storage life. It is therefore common to give a variation zone of expected shelf life, depending on the Product – Process and Packing (PPP) factors. One should also be aware of the fact that additional preservation like use of CO_2 (MAP) has little effect on the total quality loss of fish, only on bacterial count.

Freezing

Where longer storage is necessary, like for ensuring supply between seasons or due to time demanding transportation and distribution, or simply to have a better marketing method as prepacked products in supermarkets, freezing is used. Since no microorganisms are active below -8°C to -12°C, many governments accept temperatures up to -12°C for short periods. Generally a maximum temperature of -18°C (0°F) is required, and some people seem to believe this to be a magic number. However, all investigations on storage life show great variation with products, processing, packing (PPP-factors), and SIK.

One of the most investigated quality factors of shelf life is freezing rate. Detailed studies of this have shown differences in the structure of ice in cells dependent on how quickly crystallisation occurs. Research and practical experience has, however, shown that with reasonable freezing rates used in processing plants, subjective quality is similar to the fast frozen items for most products. On the other hand, modern freezing equipment is expensive, and short freezing time is important to increase the capacity of the freezer. Besides, this will often ensure low weight loss in freezing.

Surveys of the cold chain in many countries have shown a wide variation in storage temperatures. The reasons for this vary, but by tradition, age of plant and company policy is important. Increased capital cost and energy consumption with lowering of temperature must be taken into consideration, but most new plants in industrialised countries are today designed for storage at -28/-30°C. This clearly shows that the cost of refrigerated storage at these temperatures is regarded as low compared to its advantages such as better quality and/or longer storage periods. For high value products where very high quality is demanded, even lower temperatures is used. For tuna and other valuable fish, temperatures of -50°C to -60°C are used in many plants in Japan. Experiments with fat fish like herring, mackerel and salmon in Norway indicate that the effect of lowering the temperature decline at -40/-45°C, a temperature easily obtained with today's refrigeration technology, is desirable.

Freezing is the long-term preservation method, which gives the most fresh-like quality after correct thawing. The given storage life data is valid only when the fish is frozen immediately after slaughter. The main market problem is the quality evaluation of a frozen product, which is more or less impossible without thawing. However, a main problem is some producers use low grade/poor quality fish, which disappoint customers and may easily destroy the reputation of brand names.

Harvest and Processing

Harvest and processing include a number of different processes and operations. How the operations are carried out depends on factors like type and volume of fish, available labor and cost, available technology, and effect on the quality of operation. Today, market requirement for ethical handling and slaughter of fish, sustainable production, and especially quality, health and food safety must be taken into consideration.

The development of technology for harvest and processing of salmon has been tremendous these last 10-15 years to be able to follow up the farming volume. In the early stages of farming, fish was mainly slaughtered at the farms at irregular intervals using simple equipment and under poor working conditions. Almost all operations were manual including containers, tables, etc., used for storage and processing. Typical capacity was four to eight tons per day, and ice chilling in boxes were used. Refrigerated rooms and ice plant or access to ice were the main requirements.

Today, almost all operations in typical plants in Norway have mechanical equipment and capacities of 50-80 tons a day. Besides capacity, the equipment used should take care of quality requirements, be easy to operate and easy to clean and maintain. Quality management and control systems are used to ensure total quality, safe food and production efficiency. It is important to stress that planning, construction, and management of plants require knowledge from different fields of technology, and the focus here will be on the most important operations and equipment.

Handling and Transport

The centralization of slaughter and processing plant requires the transfer of fish from cages to a well boat, transport to a plant, transfer to an intermediate storage and into the plant. For the transfer landing nets, covered canvas was used in the early days. This requires crowding of the fish in the cage, and catching in the net aside from causing stress to the fish, is laborious and has low capacity. Today, special vacuum pumps are mainly used. The only part that may cause damage to the fish is the valves, but with the correct design this is a minor problem. These pumps may be used for the transfer of live fish and also for slaughtered fish in water.

Construction of well boats, and especially designs of the tanks are important. Correct water flow, oxygenation of the water, and control of water quality must be assured. Some of the new vessels are also equipped with chilling systems to lower the water and fish temperatures during transport.

Slaughtering and Gutting

The slaughtering process is important for the quality of the fish. In Norway, as in most countries, this is done by cutting the gills or artery and bleeding in air or water. To handle the fish during this operation, calming of the fish is necessary, which is usually done in water saturated with CO_2. Both the anesthetization and bleeding in water cause high stress, and other methods are looked for. In freshwater, electric fields are used, but saltwater requires special systems, which are under development. Experiments with chilling of live salmon have shown that besides efficient chilling, the fish at temperatures of 1 to 2°C can be handled.

Gutting is still done manually in a two step operation. The first is by opening the belly and removing the guts by cutting the gullet and veins and then removing the whole entrails. The second operation is cleaning using a vacuum suction system and washing. A lot of work has been laid down in workplace design and layout, tools, and equipment. In a well-designed gutting/ washing arrangement for salmon net working time is down to some seconds. Also gutting machines for salmon, which removes the gut whole without damaging the belly, are constructed and under testing. The main advantage is the elimination of the heavy work and some reduction in labor.

Chilling

The single most important factor for shelf life of fish is the product temperature. Chilling or lowering the product temperature requires transport of heat from the product surface. In addition, heat has to be transported from inner parts to the surface to be removed. The driving force in heat flow is the temperature gradient or temperature differences and result in temperature distribution for a thin and a thick product. Increasing thickness of fish and fish layer will increase temperature differences from the surface to the center of the fish and greatly increase chilling time.

In addition to temperature differences in the product, the temperature difference between the surface and chilling media depends on heat transfer rate. Theoretical calculations of chilling or freezing processes are mathematically difficult and will also depend on input data that has to be assumed. However, both calculations, physical understanding, and measurements of temperatures show a large decrease in chilling rate with time. This is also obvious since the driving force, the temperature difference, reduce drying chilling.

Traditionally icing was the most common method for chilling of fish, and the reasons for this are:

- Ability to store large refrigeration capacity pro volume as latent heat.
- Temperature of wet ice is 0°C and constant during melting.
- Efficient heat transfer in contact with fish.
- Melt water secure high humidity.
- Easy to transport (with correct technology).
- Cheap production and storage costs.

The efficiency, however, depends on the contact surface between ice and fish and the amount of ice. To reduce volume and weight in distribution, often too little ice is used. To increase chilling efficiency, it is now common to prechill the fish in ice/sea water (CSW) in containers or especially designed CSW or Refrigerated Sea Water (RSW).

Ice Production

As has been observed, use of ice is important for chilling and control of temperature in the plant, and especially in distribution. Due to easier handling and transport, "wet ice" is preferred (wet surface, less sticking than subcooled ice flakes). Many automatic plate ice machines are used where ice is frozen on vertical plates with evaporating refrigerant inside which gives rapid freezing. Harvesting of ice is cyclic by heating plates with bot gas and the crushed ice usually falls into a storage bin.

Due to efficient freezing, the energy consumption is low and the production requires no labor. Also automatic ice delivery from storage bins is used, and ice is distributed to the site where it is used. Dosage of ice into fish boxes is also automatic in boxing lines.

Also pumpable ice (flow ice) is taken into use in some plants. These are small ice particles usually in a thin brine. The advantage is easy distribution and use since the ice is pumpable, but is more expensive to produce and contains a fair amount of water, which lowers the refrigeration capacity pro kilo.

Freezing

The challenge in distribution of chilled products is the low storage life of most food. The consumer's preference for "fresh" high quality foods is therefore difficult to satisfy. As mentioned earlier, this actually has led to increase freezing of very fresh product for later thawing and processing/marketing. However, to achieve high quality "refreshed products", freezing – storage and especially thawing are extremely important.

Experiments and experiences show that freshness when frozen is one of the main factors for end quality. Freezing before rigor mortis is recommended. If not possible, a fast chilling and low temperatures within a short storage period is acceptable. In practice none or little effect of freezing time on practical quality is found for fishes as long as freezing is completed within 15-20 hours. Freezing time depends on product size and packing, freezing principle and temperature. The driving force for heat transfer is the temperature difference and freezer temperature of -35°C to -40°C For small products like pieces of fillets, burgers, etc., temperatures down to -50°C is used to reduce weight loss and increase the capacity of equipment. The products should not be removed from the freezer until frozen and storage temperature is reached.

Bulk Freezers

Freezing is removal of heat from the products, and discussions of freezers are discussions on use of the available heat transfer methods: conduction, convection and radiation. All principles are well known and the developments today are mainly in making the freezing methods more efficient and especially increasing capacity of equipment, reducing weight losses and automatization.

Air freezing is still the most common freezing method for aquaculture products, although from a heat transfer point of view, air is not very efficient. Due to low density and specific heat, large volumes must be circulated between products and evaporator. This requires fans and energy input into the freezers, which gives increased refrigeration requirement. Besides, chilling/freezing of product surface is relatively slow and results in evaporation losses. But since air does not harm the product and packing, it can be used for most products regardless of geometry and size, and is available everywhere. The most common air freezer is the tunnel type. The products should be stacked in a way that allows air to flow over the product surface to give effective heat transfer and the arrangement should provide uniform air distribution. Due to the heat load of product and fan air temperatures will increase through tunnel and dimensions; airflow rate and refrigeration system should ensure temperature.

Tunnels are typical general purpose freezers, and with correct arrangement used for all types of food from tuna fish, fish in boxes to fillets. However, small products and freezing on trays will give high labor cost and often also high weight loss. Batch freezing is most common, the tunnel is filled up during production and freezing starts. After completed freezing, the tunnel is emptied, defrosted, and ready for a new batch.

Filleting and Consumer Packing

Especially in industrialised areas where an increasing number of consumers will not spend time to prepare and cook food, the consumption of industrially prepared food is rapidly increasing. The products vary depending on market from fillets or pieces of fillets to prepared dishes ready for heating in microwave ovens. In general, the trend is against more ready to eat products both for restaurants and home cooking. For small volume products filleting, skinning, deboning, and cutting of fillets is done by hand. To increase efficiency and reduce labor and cost, production is based on machines and line production. The fillet is transported between the operations on belts and the number of operators is given by fillet machine capacity.

For freezing of fillets and prepared food in line production, continuous freezers are used. Different types are available, depending on the type of products and volume, space available in the plant and cost. For larger volumes spiral belt freezers are often used due to low space requirement. The product is loaded on the strait part of the belt, and large products may become deformed in the spiral part.

Storage and Distribution

Shelf life for fish is extremely dependent on temperatures as discussed earlier. Storage temperatures should, therefore, be lowered from the common 4-6°C often found in chillers today, to -1 to 0°C, even for iced fish. Measurement has shown that even with ice in the boxes some fish will have poor contact with the ice and temperatures close to room temperature are frequently found.

Frozen storage temperatures are important for taste, colors, consistency, weight loss, etc. Surveys of the cold chain in many countries have shown a wide variation in storage temperatures. The reason for this varies, but tradition, age of plant, and company policy is important. Increased capital cost and energy consumption for lower temperatures must be taken into consideration. However, most new plants in Northern Europe today are designed for storage at -28 to -30°C. This clearly shows that cost of refrigerated storage at these temperatures is considered low compared to advantages as better quality and/or longer storage life. For high value products where very high quality is demanded, even lower temperature is used. For tuna and other valuable fishes, temperatures of -50 to -70 °C are used in Japan. Measurements at our institute also show the advantages of low temperatures for storage of salmon. There is a quite large effect of reducing temperatures from -25°C often found today, to about -45°C.

Also, more theoretical studies within the area of water in foods have shown a change in ice crystal size to an amorphous of "glassy" state at around -40/-45°C. This will influence chemical reactions and thereby reduce quality losses. As a conclusion, temperatures of -45/-50°C should be considered for especially high quality products.

During chilling and freezing, heat is removed from the products and efficient heat transfer to chilling media is required. When the product has reached storage temperature, no more heat has to be transferred. This is a quite different situation where the product should be protected from transfer of heat. In principle, the storage arrangement, therefore, should be that cold air circulation removes the heat before reaching the product. Airflow over unpacked products should be avoided to reduce weight loss. The main problems seen are poor heat removal along walls and especially from doors. The doors should not be kept open unless for transport. For heavy transport, automatic doors should be used. Poor door use is one of the main problems in cold storage and besides high temperature it also gives problems with frost formation, defrosting of coolers, heat load, etc.

To avoid heating of cold products in distribution, equal storage requirements are needed. For distribution at sea and on land (railroad, trucks etc), refrigerated equipment is available and is usually used for main transport routes. Also for air cargo containers exist, but are not in common use due to weight and volume loss in the cargo hold. Knowledge on how to use the equipment is often lacking, especially in transfer between the different ways of distribution, mistakes with exposure to high temperature are seen.

Some general knowledge of the cold chains exist, particularly in Europe. However, the main focus is often on display cabinets and the end of the chain and less on transport and storage. An important part of market planning is to plan the distribution and logistic system. This should also be tested and be watched closely at the start and also regularly as a part of quality assurance. What can be expected may be learned for our salmon export where different research projects have been following distribution chains to the most important markets.

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ABSTRACTS OF POSERS

The Wake of Net Cage and Its Effects

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Abstract

A model experiment was used to study the flow velocity distribution of the wake and the deformation of cage shape and volume under the various sites of single and multiple net cages. It was expected to offer some fundamental and crucial information for the present cage aquaculture and also for future studies. The results obtained in the present experiment showed that:

When D/L was small, the wake distribution of the net cage revealed less flow velocity at the back of the cage side and faster at the central part of the cage side. When D/L was large, the flow velocity was least at the right back of the net cage, and the wake velocity of the cage sides was even faster than the upstream velocity.

The distribution on the external sides of net cages deployed in parallel and single net cages showed similar results. But the wake on the cage sides of the central two cages deployed in parallel had dilated and the flow passed the gaps between the two cages and its velocity was obviously higher than the velocity on the cage sides.

As the cage was deployed in series, the closer the cages, the larger the volume ratio. It is suggested that decreasing distance makes the mean velocity of the back cages become smaller and the volume of the back cages become dilated.

Under the various velocities, if a net cage was deployed right behind the two paralleled net cages with one width of cage distance between these cages, the volume ratio of the rear and the front cage was equal to one or less than one. The volume ratio became dilated when the cage distance was increased.

In conclusion, the deformation of the net cages could be decreased if a suitable deployment among the cages could be allocated. In addition, a net cage deployed right behind the gaps of the cages deployed in parallel could facilitate the flow exchange of the seawater.

A Practical Study of Design and Analysis for a Net Cage Structural System

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Abstract

Aquaculture not only exercises leadership in the aquatic production industry, but also obtains much valuable foreign exchange in Taiwan. Following the well-developed aquaculture, however, is the commensurate losses on natural resources such as stratum subsidence, soil salinization, and so on. In order to reduce the loss and to increase aquatic production, aquaculture using marine net cages seems to be a possible way.

Based on a model test, the objective of this study is to improve a net-fixed device of the traditional cage for resisting strong waves and currents that always cause fish death due to a serious destruction of the cage. A new stable cage design is proposed in the study under consideration of both tension reduction of the mooring cables and volume increase of the net shape.

Investigation of the Relationship Between the Attaching Materials in Sea Cages and Seawater Environmental Factors

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Abstract

Aquaculture in sea cages is one of the enthusiastic developments in Taiwan recently. However, many technical problems must be overcome. For example, a less toxic antifoulant that is suitable in the local marine environment must be developed. The main objective of this research is to understand the relationship between the attaching materials in sea cages and the seawater environmental factors. Results of this research can be utilized as a theoretical basis in developing novel antifoulants.

The field study was performed at a sea cage farm in Zhukeng of Pingdong County. Several simulated net frames were fixed five meters under the sea surface. After a certain period of time, we dislodged one of the frames, and the attaching materials of the net were monitored. Parameters monitored include marine fouling organisms and sludge. At the same time, we investigated the seawater environmental factors.

Results of this research have shown that attachable exoskeleton organisms, such as barnacles and corals, are the major contributors of attaching materials onto the net. The attaching activity was shown in a series of order as that of sludge attaching first, followed by algae, and then seedlings of barnacles or corals, and then the different organisms continue growing. The amount of algae and movable exoskeleton organisms (such as crabs) on the net depends on the seasons, but attachable exoskeleton organisms do not. The growth rates of attaching materials are mainly controlled by the concentrations of chlorophyll and silicate in the seawater. Salinity is found to inhibit the growth rate. Ammonia is the major nutrient source of algae, but is found toxic to the exoskeleton organisms. Nitrate, nitrite, and phosphate ions are the secondary nutrient sources for algae.

Studies on the Caligusiasis and Benedeniasis of Marine Cage Cultured Fish in Pingtung Area of Taiwan

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Abstract

The present study attempted to investigate and study the parasitic diseases (caligusiasis and benedeniasis) occurring in marine cage-cultured fish in Pingtung area of Taiwan. The major cage-cultured fish species included grouper (*Epinephelus* spp.), red sea bream (*Pagrus major*), cobia (*Rachycentron canadum*), and greater yellow tail (*Seriola dumerili*). There were differences in the prevalence of these two parasitic diseases in different seasons and fish species. For the caligusiasis, it was always found in grouper and seldom found in the other three species. The cases of caligusiasis were observed throughout the year especially in summer. The diseased fish became darker, secreted more mucous and showed hemorrhages on the body surface. Then these lesions would result in inflammation and ulcer by secondary bacterial infection. The cases of benedeniasis were major in great yellow tail and then in grouper. The infection occurred in the whole Pingtung area including Shauliuchyou starting March. The cases gradually decreased in July of the same year. The affected fish secreted more mucous in the skin and scoured the cage that resulted in hemorrhage on the body surface, the scales falling, secondary bacterial infection and inflammation. Heavily infected fish turned anemic and weak and finally died.

Comparison of Various Aspects of Marine Cage Farming Between Norway and Taiwan

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Abstract

There is only a few years difference when Norway and Taiwan started marine cage farming. At present, however, development is highly significantly different between the two countries. Norway has become the number one marine cage farming fish producer in the world.

There are a lot of reasons that relate to the difference, such as: species of fish, marine engineering technology, nutrition and feed, developed vaccines for the fish, genetic breeding, automation, laws and regulations relating to this field, fish processing technology, marketing, environmental protection, and basic researches on various aspects. Norway has established the propagation techniques on quite a few species of fishes and the main species that has been farmed in the marine cages is still the Atlantic salmon. Taiwan had concentrated on the development of pond farming until about three years ago. Since then, the government and aquaculturists have been paying more attention and effort on the development of offshore marine cage farming. There are a few species of fishes that have been farmed in marine cages including cobia, various groupers, amberjack, *Lutjanus* spp., permit fish, and red sea bream.

There are a few different types of cages being used in Norway: inshore wooden-frame cage, walkway stainless steel frame cage, high density PE circle cage, and Bridge-stone cage. In Taiwan, a few types of cages are also used and these are: inshore wooden-frame cage buoys suspended “soft cage”, small floats hanged submerged “soft cage”, and high density PE circle cage either floating or submersible. Taiwan has very few inner bays while Norway has many fjords, which are very adequate for the development of cage farming although both countries have typhoon and hurricane problems respectively in different seasons. Finally, the government of Norway has given the enterprises the so called “investment reduction” to encourage them to financially support research projects (including aquaculture research). This has significant impact on the development of marine cage farming in Norway.

The Cage Culture in Penghu

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Abstract

At present, forty-one cage culture systems are operated in Penghu. Their productions are approximately equal to 3,200 tons in 1998. The highest production of fish in cage culture is *Rachycentron canadum* (40%). *Pagrus major* (25%) is the second most important species. Over 70% of the fish in cage culture are distributed in Penghu areas except one species, *R. canadum.* The number of different fish species in cage culture fluctuates every year because of the fish price in the commercial markets. The fish feeds in cage culture include trash fish, dry feed, and moist feed. Seasonal variations of different feeds are present in cage culture. The four different designs of cage culture are fixed-flotation, semi-flexible, flexible, and semi-submersible. The future trends of cage culture systems will be operated in the commercial size. Typhoon is the potential threat in cage culture and this factor correlates with the cage designs, fish species, and fish body size. In conclusion, monsoons, typhoons, and commercial market sizes are three of the most important factors affecting cage culture in Penghu areas.

New Development in Sea Cage (Underbody)

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Abstract

Development in sea cage net design is probably one of the most important aquaculture advances nowadays. However, there are still many problems that need to be solved. How to develop a net sea cage suitable for Taiwan environment is the most vital issue.

Large, commercial scale aquaculture in Taiwan has nearly 20 years of history. Due to the environmental conditions and geographic location, research should focus on ways to confront heavy waves and to enhance safety and, therefore, to establish investors' confidence and improve aquaculture management and techniques. Technology nowadays should be advanced enough to provide new techniques in order to design a multi-functional cage for aquaculture and piscicapture purposes.

Hereinafter, a newly developed square net cage designed by our company will be introduced. The following topics will be elucidated: structure, rationale, operation, and comparison to the conventional net cage.

I. Underbody structure and design
II. New improvements
  1) Resistance to strong waves and storms
  2) Greater volume
  3) Special plug, making operation easier
  4) Easy to observe
  5) Funnel-shaped underbody allows easy collection of dead bodies and waste food
  6) Lower disease rate
III. Comparison to conventional net cage
  1) Easier to replace and disassemble
  2) Lower density
  3) Higher survival
  4) Better stability

Taiwan Offshore Aquaculture Association: Reasons to Organize and Future Perspectives

TAIWAN OFFSHORE AQUACULTURE ASSOCIATION

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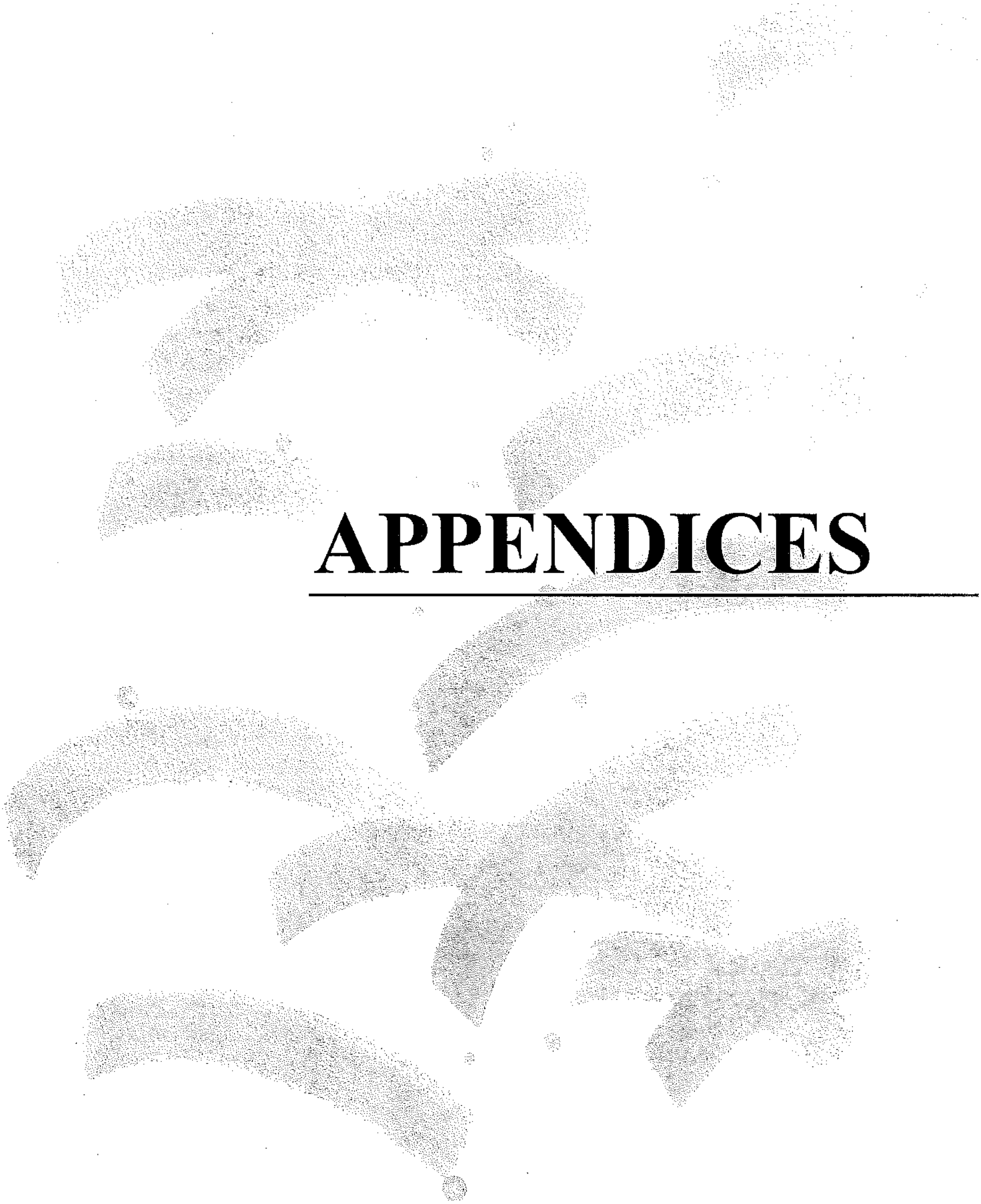
Abstract

The Taiwan Offshore Aquaculture Association was organized on August 13, 1999, with Lin Mao-Sheng as the first elected secretary general. The association has 65 individual members and 14 group members.

On August 13, 1999, the Tungkang Marine Laboratory, Taiwan Fisheries Research Institute, and Council of Agriculture opened a conference that established the association and held an "Offshore Aquaculture Products Sensory Evaluation" after the conference. Mr. Lin Mao-Sheng was elected as the first board chairman and many scholars and officers positively supported the conference. The Taiwan Offshore Aquaculture Association, approved by the Ministry of Interior, was formally registered on October 7, 1999.

The Taiwan Offshore Aquaculture Association enthusiastically pushes different kinds of projects, primarily assisting the government in managing the natural resources and in preserving the environment. For the aquaculture industry, the association builds related information, upgrades sales management, and reorganizes related aquacultural public services. Furthermore, the Taiwan Offshore Aquaculture Association also assists relevant businesses in (1) developing technical skills, (2) creating brands of products, (3) strengthening insurance systems, and (4) building offshore aquaculture-related businesses in order to achieve reasonable usage of natural resources, promote the quality of fishing products and to efficiently manage and internationalize the industry. The future perspectives of the Taiwan Offshore Aquaculture Association are to constantly evaluate the use of national offshore water resources and to continuously develop the economy of fishing villages.



APPENDICES

ORGANIZING COMMITTEE · · · · · ·

Chair: *I Chiu Liao,* Asian Fisheries Society

Vice Chairs:
C. Kwei Lin, Southeast Asian Chapter – World Aquaculture Society
Guang-Hsiung Kou, Taiwan Branch – Asian Fisheries Society
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SYMPOSIUM PROGRAMME

Tuesday, 2 November 1999

09:00 REGISTRATION

16:00 FREE TOUR
- To visit Chin Sheng Fishing Net Mfg. Co. Ltd.

18:30 GET TOGETHER PARTY
- Hosted by Chin Sheng Fishing Net Mfg. Co., Ltd.

Wednesday, 3 November 1999

08:30 WELCOME CEREMONIES
- Welcome address:
  I Chiu Liao, President, Asian Fisheries Society
  C. Kwei Lin, President, Southeast Asian Chapter, World Aquaculture Society

08:50 GROUP PHOTO

SESSION I

Moderators: M. Shariff and C.T. Chueh

KEYNOTE ADDRESS

09:00 The Norwegian regulation system and the history of the Norwegian salmon farming industry
- Knut A. Hjelt

COUNTRY PAPERS

09:40 Cage aquaculture in Australia: a developed country perspective with reference to integrated aquaculture development within inland waters
- Geoff J. Gooley*, Sena S. De Silva, P.W. Hone, Lachlan J. McKinnon and Brett A. Ingram

10:05 Status of cage aquaculture in India
- S.C. Pathak

10:30 COFFEE BREAK

Moderators: A.H. Arthington and L.S. Fang

11:00 Cage culture in Japan toward the new millennium
- Fumio Takashima and Takafumi Arimoto*

11:25 Cage aquaculture in Korea
- In-Bae Kim

11:50 Cage aquaculture in Malaysia: an overview
- Mohamed Shariff* and N. Gopinath

12:15 LUNCH BREAK

Moderators: O. Magnussen and Y.H. Chien

CONTRIBUTED PAPERS

13:30 Cage design in CARE-CAGES project, Bangladesh
- A.K.M.N. Kabir and S.M. Ziaul Huque*

13:50 Engineering risk analysis for submerged cage net system in Taiwan
- Chai-Cheng Huang

14:10 Offshore cage systems
- Egil Lien

14:30 Automation of feeding management in cage culture
- Bjørn Myrseth

14:50 Derived data for more effective modeling of solid wastes dispersion from sea cage farms
- Yrong-Song Chen*, Malcolm C.M. Beveridge and Trevor C. Telfer

15:10 Production of quality seed of tilapia by small scale farmers in their ponds using nylon net cages – a participatory on-farm research trial with farmers of northwest Bangladesh
- Benoy Kumar Barman*, David C. Little and Peter Edwards

15:30 COFFEE BREAK

Moderators: E. Flores and S.Y. Shiau

16:00 Long term evaluation of the extruded pellet diets containing two fishmeal replacers for growing Korean rockfish (*Sebastes schlegeli*) in the sea cage culture system
- Jae-Young Choi, Kang-Woong Kim, Sungchul C. Bai and Jae-Yoon Jo*

16:20 High performance grow-out pelleted diets for cage culture of barramundi (Asian sea bass), *Lates calcarifer*
- Kevin C. Williams*, C.G. Barlow, L. Rodgers, N. McMeniman and W. Johnston

16:40 Global prospects for cage aquaculture of marine finfish: input costs, market value and comparative advantage
- John Hambrey

17:00 Socioeconomic aspects of cage aquaculture in Taiwan
- David S. Liao

17:20 GENERAL DISCUSSION

18:00 END OF SESSION I

18:30 WELCOME RECEPTION
- Hosted by King Chou Fish Net Mfg. Co., Ltd.

Thursday, 4 November 1999

SESSION II
Moderators: I.-B. Kim and M.S. Su

KEYNOTE ADDRESS

08:30 The major problem of cage aquaculture in Asia relating to sea lice
- Ju-Shey Ho

COUNTRY PAPERS

09:10 Cage aquaculture in western Australia – current status and future plans
- Sagiv Kolkovski, Greg I. Jenkins, Chan L. Lee*

09:35 Recent developments in freshwater and marine cage aquaculture in the Philippines
- Clarissa L. Marte*, Philip Cruz and Efren Ed. C. Flores

10:00 Present status of fish cage culture in Thailand
- Piamsak Menasveta

10:25 COFFEE BREAK

Moderators: B.R. Smith and D.S. Liao

10:55 Potential of marine cage aquaculture in Taiwan: cobia culture
- Mao-Sen Su*, Yew-Hu Chien and I Chiu Liao

11:20 Status of cage mariculture in Vietnam
- Le Anh Tuan*, N.T. Nho and John Hambrey

CONTRIBUTED PAPERS

11:45 Diseases of cage cultured fish in marine and brackishwater
- Kamonporn Tonguthai* and T.S. Leong

12:05 LUNCH BREAK

Moderators: P. Menasveta and J.F. Huang

14:00 Entry points and low risk strategies appropriate for the resource poor to participate in cage aquaculture: experiences from the CARE-CAGES project, Bangladesh
- Ken I. McAndrew*, David C. Little and Malcolm C.M. Beveridge

14:20 Integrated cage culture in ponds: concepts, practice and perspectives
- Yi Yang* and C. Kwei Lin

14:40 Problems and issues of Nile tilapia cage farming in Taal Lake, Philippines
- Apolinario V. Yambot

15:00 An overview of freshwater cage culture in Thailand
- C. Kwei Lin* and Kamtorn Kaewpaitoon

15:20 COFFEE BREAK

Moderators: C. Lee and T.I. Chen

15:50 Current status and sustainability of cage culture in reservoirs: a case study in China
- Zongwen Wu, Jianwei Guo and Yi Yang*

16:10 Illuminated-cage nursery of the Asian sea bass, *Lates calcarifer* Bloch, (Centropomidae): effects of initial body size and stocking density
- Armando C. Fermin

16:30 An Asia-Pacific regional cooperative network for grouper aquaculture research
- M.A. Rimmer, Kevin C. Williams*, M.J. Phillips and H. Kongkeo

16:50 Post-harvest technology of farmed fish
- Ola M. Magnussen

17:10 GENERAL DISCUSSION

17:40 ACKNOWLEDGMENTS/ANNOUNCEMENTS
- Closing Speech:
  I Chiu Liao, President, Asian Fisheries Society
  C. Kwei Lin, President, Southeast Asian Chapter, World Aquaculture Society

18:30 FAREWELL DINNER
- Hosted by TML Friends' Club

Friday, 5 November 1999

POST-SYMPOSIUM FIELD TRIP

08:50 Flight from Kaoshiung to Makung

09:50 Visit cage culture sites

12:00 Lunch

14:00 Visit local cultural exhibition (for participants)
AFS council meeting at Penghu Aquarium of TFRI (for AFS council members)

18:00 Dinner

20:30 Stay in Bower Hotel

Saturday, 6 November 1999

POST-SYMPOSIUM FIELD TRIP

08:00 Visit Penghu Aquarium of TFRI

10:30 Visit Penghu Branch of TFRI

12:00 Lunch

14:00 Flight from Makung to Taipei or Kaohsiung

POSTER VIEWING *(During coffee break and lunch break of 3 and 4 November)*

The wake of net cage and its effects
- Dar-Yang Weng and Kuan-Yung Hsieh

A practical study of design and analysis for a net cage structural system
- K.C. Yu, S.S. Leu and Y.S. Chow

Investigation of the relationship between the attaching materials in sea cages and seawater environmental factors
- Chun-Lan Huang and Huo-Yuan Jeng

Studies on the caligusiasis and benedeniasis of marine cage cultured fish in Pingtung area of Taiwan
- Poh-Shing Chang and Yu-Chi Wang

Comparison of various aspects of marine cage farming between Norway and Taiwan
- Chi Yuan Liu

The cage culture in Penghu
- Ping-Sheng Ueng, Shyi-Liang Yu and Ching-Hsiewn Ou

New development in sea cage (underbody)
- Chin-Fu Lo

Taiwan Offshore Aquaculture Association: reasons to organize and future perspectives
- Taiwan Offshore Aquaculture Association

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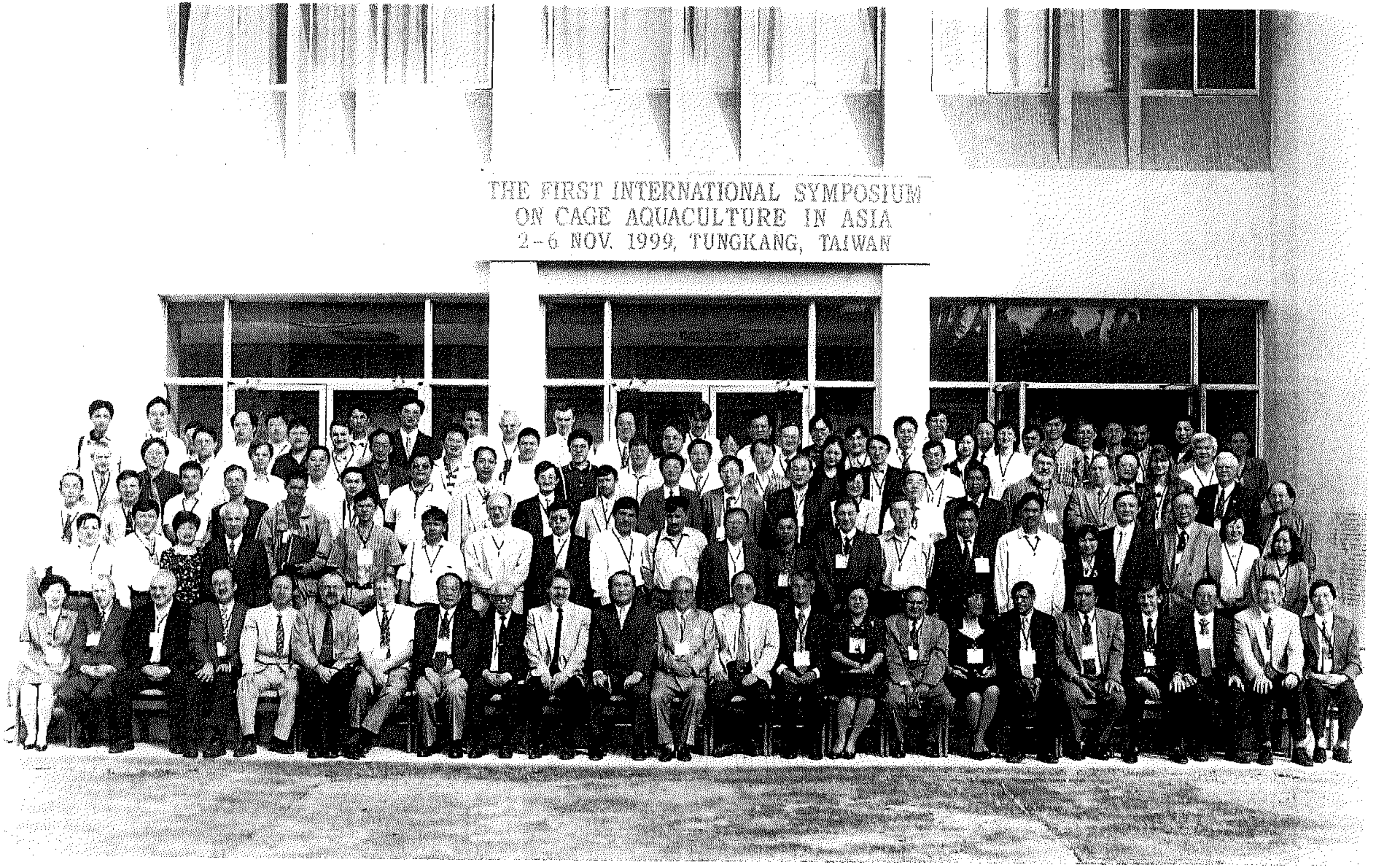

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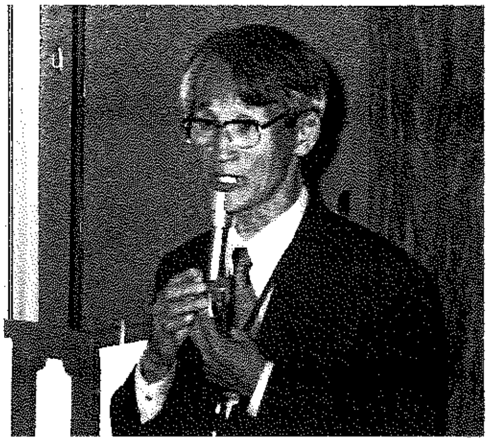

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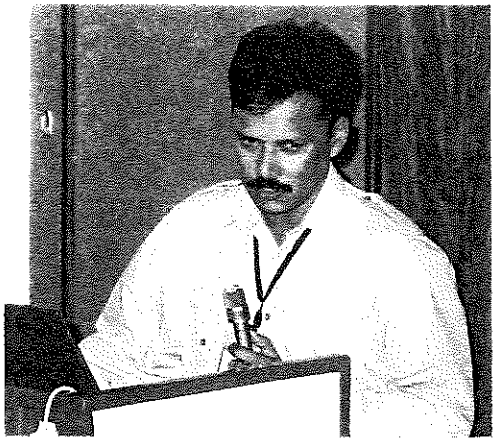

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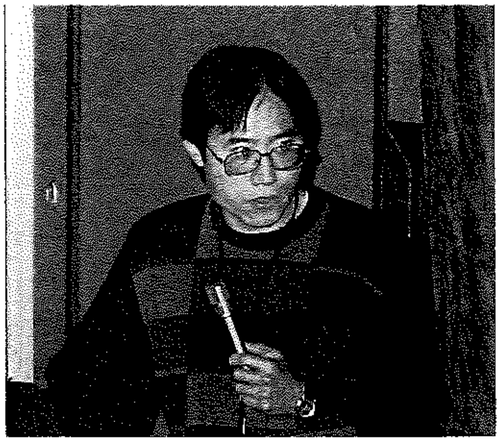

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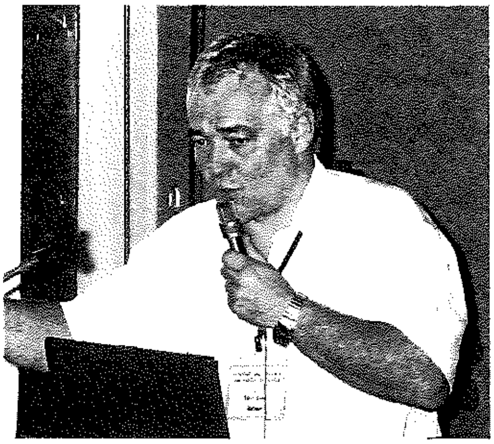

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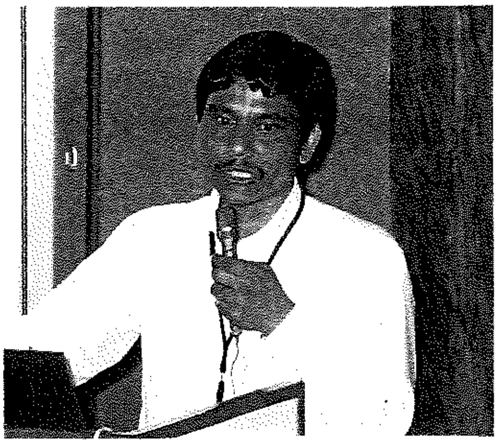

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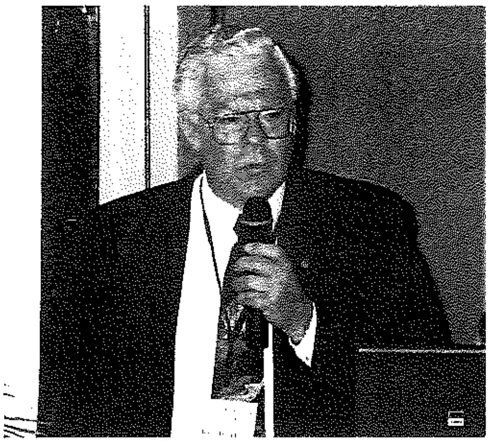

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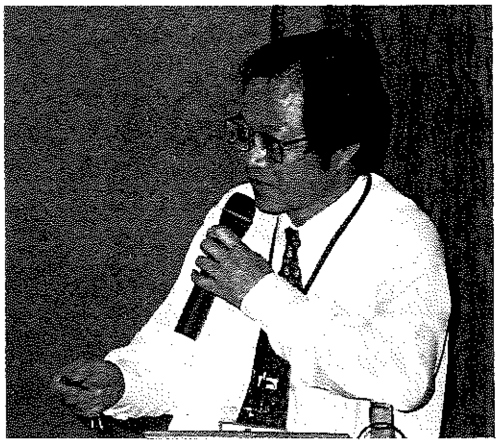

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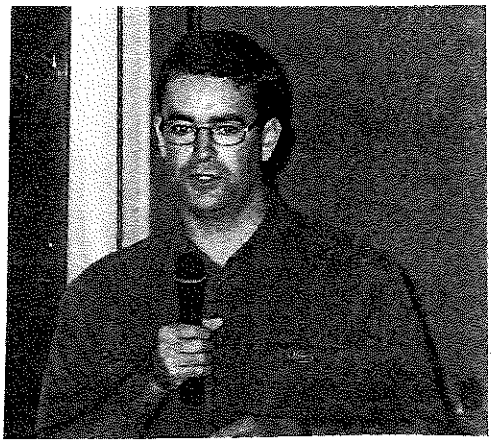

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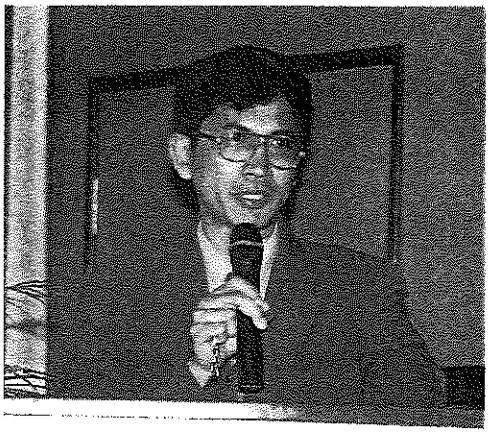

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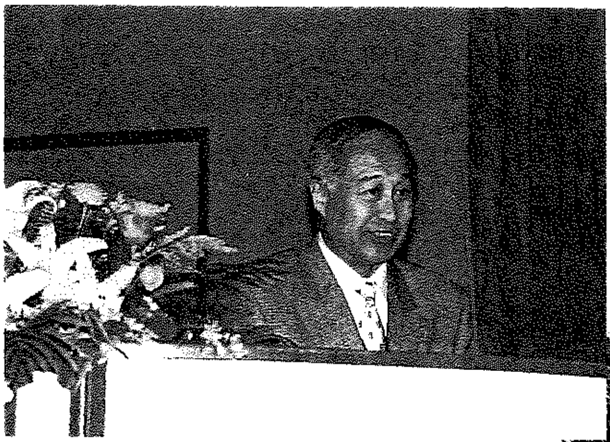
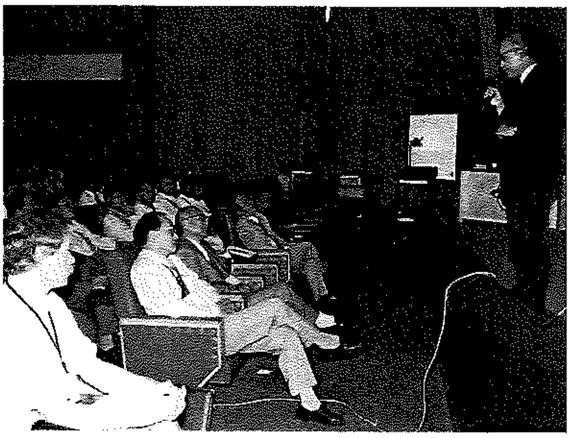
SYMPOSIUM ACTIVITIES



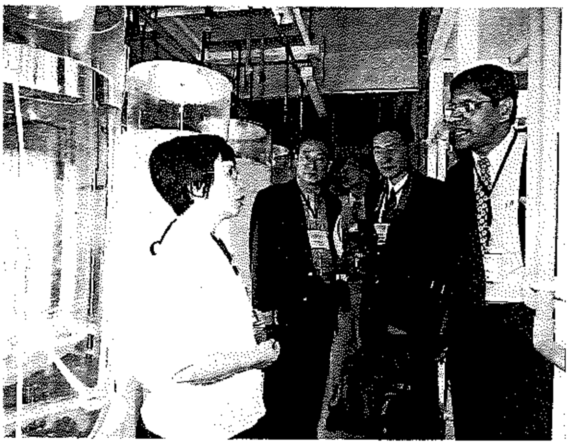
Dr. I Chiu Liao, Asian Fisheries Society President, delivering the welcome address

Dr. C.Kwei Lin, President of the Southeast Asian Chapter of the World Aquaculture Society, also delivering a welcome address



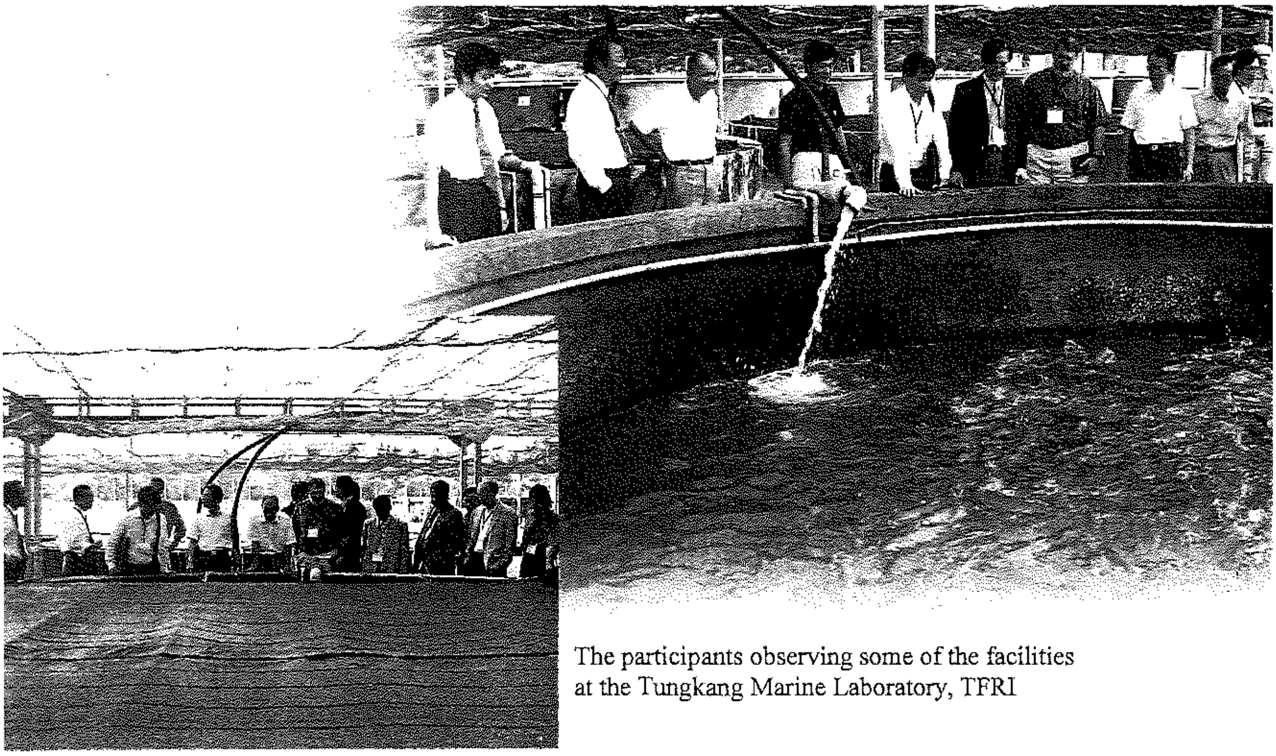
Prof. Ju-Shey Ho answering questions after his keynote address

Dr. Tzyy-Ing Chen (the only lady in the group) of TML showing the participants some of the posters at the Tungkang Marine Laboratory, TFRI

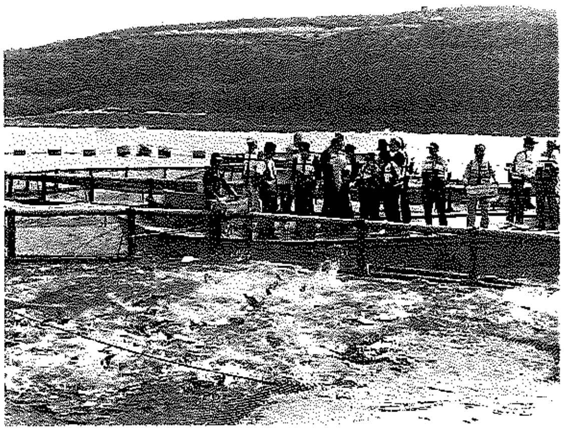


Dr. Heui-Meei Su giving the participants a tour of the hatchery facilities of the Tungkang Marine Laboratory, TFRI

Frozen seafoods on display in one of the exhibition booths

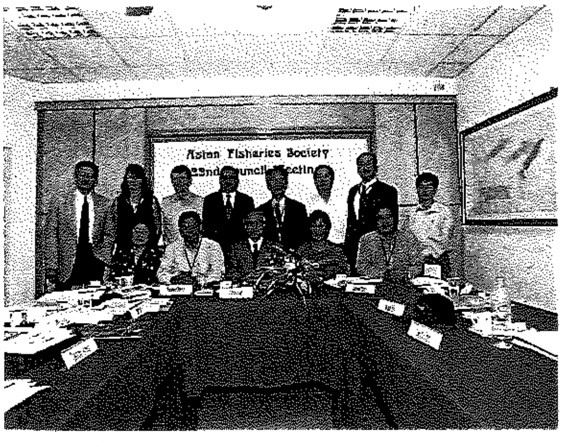


The participants observing some of the facilities at the Tungkang Marine Laboratory, TFRI

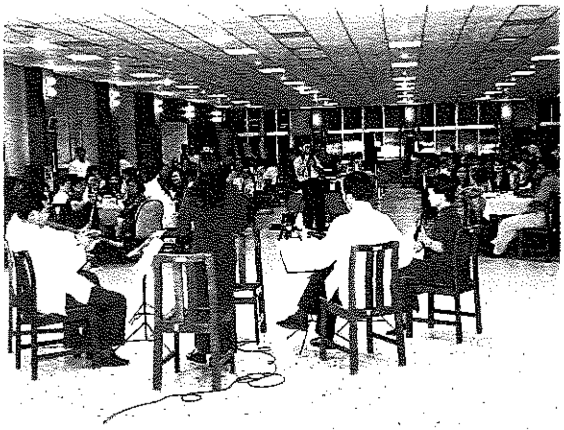


The participants visiting cobia cages in Penghu

Field trip participants in front of the Penghu Marine Resources Museum



The 22nd Council Meeting of the Asian Fisheries Society was held at the Penghu Aquarium in conjunction with the Symposium



Entertainment during the Closing Ceremonies