

Cage aquaculture

Regional reviews and global overview



Cover photo:

Large salmon cages in the Reloncavi Fjord in southern Chile. D. Soto/FAO.

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Regional reviews and global overview

FAO
FISHERIES
TECHNICAL
PAPER

498

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ISBN 978-92-5-105801-5

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Preparation of this document

This document contains nine FAO commissioned papers on cage aquaculture including a global overview, one country review for China, and seven regional reviews for Asia (excluding China), northern Europe, the Mediterranean, sub-Saharan Africa, Latin America and the Caribbean, northern America and Oceania. The content of the papers is based on the broad experience and sound knowledge of the authors with advice and help received from many experts and reviewers around the globe. The papers were presented to a distinguished audience of some 300 participants from over 25 countries during the FAO Special Session on Cage Aquaculture – Regional Reviews and Global Overview at the Asian Fisheries Society (AFS) Second International Symposium on Cage Aquaculture in Asia (CAA2), held in Hangzhou, China, from 3 to 8 July 2006.

The commissioning of the papers and the presentations at the FAO Special Session were organized by the Aquaculture Management and Conservation Service (FIMA) of the FAO Fisheries and Aquaculture Department and financially supported by regular as well as extra-budgetary programme funds, specifically the Japanese Trust Fund Programme Towards Sustainable Aquaculture: Selected Issues and Guidelines and the Global Partnerships for Responsible Fisheries (FAO FishCode Programme).

Many colleagues from the FAO Fisheries and Aquaculture Department as well as from the FAO Subregional and Regional Offices have contributed to this publication with their expertise and time which is gratefully acknowledged. Particular thanks are due to the current AFS President, Dr Chan-Lui Lee, whose initiative and support have made CAA2 a success.

The final revisions and inputs for the papers were provided by the technical editors, M. Halwart, D. Soto and J.R. Arthur.

Abstract

Cage aquaculture has grown rapidly during the past decades and is presently undergoing swift changes in response to pressures from globalization and an escalating worldwide global demand for aquatic products. There has been a move toward clustering existing cages as well as toward the development and use of more intensive cage-farming systems. In particular, the need for suitable sites has resulted in cage aquaculture accessing and expanding into new untapped open-water culture areas such as lakes, reservoirs, rivers and coastal brackish and marine offshore waters.

This report aims to assess the current situation and the future prospects of cage aquaculture around the globe. It is organized into nine chapters including a global overview and eight reviews covering China, Asia (excluding China), northern Europe, the Mediterranean, sub-Saharan Africa, Latin America and the Caribbean, North America and Oceania. The report recognizes the tremendous importance of cage aquaculture today and its key role for the future growth of the aquaculture sector. Each review, by geographic region, informs about the history and origin of cage aquaculture; provides detailed information on the current situation; outlines the major regional issues and challenges; and highlights specific technical, environmental, socio-economic and marketing issues that cage aquaculture faces and/or needs to address in the future. The global overview discusses trends in cage aquaculture based on the most recent and complete data available; summarizes the information on cultured species, culture systems and culture environments; and explores the way forward for cage aquaculture, which offers especially promising options for multitrophic integration of current coastal aquaculture systems as well as expansion and further intensification at increasingly offshore sites.

Halwart, M.; Soto, D.; Arthur, J.R. (eds.)

Cage aquaculture – Regional reviews and global overview.

FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

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Foreword

The cage aquaculture subsector has grown very rapidly during the past 20 years and is presently undergoing rapid changes in response to pressures from globalization and a growing global demand for aquatic products. Recent studies have predicted that fish consumption in developing and developed countries will increase by 57 percent and 4 percent, respectively. Rapid population growth, increasing affluence and urbanization in developing countries are leading to major changes in supply and demand for animal protein, from both livestock and fish. Within aquaculture production systems, there has been a move toward the clustering of existing cages as well as toward the development and use of more intensive cage-farming systems. In particular, the need for suitable sites has resulted in the cage aquaculture subsector accessing and expanding into new untapped open-water culture areas such as lakes, reservoirs, rivers and coastal brackish and marine offshore waters.

Within the Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO), the Aquaculture Management and Conservation Service (FIMA) is responsible for all programmes related to development and management of marine, coastal and inland aquaculture and conservation of aquatic ecosystems, including biodiversity. The Service provides information, advice and technical assistance to FAO Members on improved techniques and systems for the culture of fish and other aquatic organisms in fresh, brackish and marine waters, promoting sound, environmentally friendly practices in lakes, rivers and coastal areas, in accordance with modern assessment and management standards and best practices for aquaculture. It ensures cooperation and coordination with other institutions and programmes in and outside FAO, both governmental and non-governmental, concerned with responsible aquaculture.

It is within this context that, in 2004, FIMA convened an expert workshop on cage culture in Africa that was held in Entebbe, Uganda, from 20 to 23 October 2004.¹ This activity was given a high priority considering the rapidly-growing interest in cage culture in the region. Among the background papers that FIMA commissioned for this workshop were an overview of the status, lessons learned and future developments of finfish cage culture in Asia; a review of small-scale aquaculture in Asia; and cage culture experiences from selected countries, all of which were highly appreciated by the African workshop participants as valuable background information to shape their own way forward for developing the cage aquaculture subsector in the region. Given the dynamic nature of the cage aquaculture subsector, the value of national and regional experiences, and ongoing FAO activities on developing National Aquaculture Sector Overviews and a Japanese Trust Fund Project “Towards Sustainable Aquaculture – Selected Issues and Guidelines”, FIMA decided to commission reviews also for the other regions in the world.

In 2005, an invitation was received from the Asian Fisheries Society (AFS) to become a partner for the Second International Symposium on Cage Aquaculture in Asia. FIMA welcomed this invitation as a unique opportunity to present the reviews in an international setting and to get feedback on the reviews from the many knowledgeable experts who gathered at this important event. Ultimately, the presentations of the national, regional and global reviews were organized in groups of two or three, bringing together all the participants in plenary before breaking up into parallel symposium sessions (see Annex 1–3).

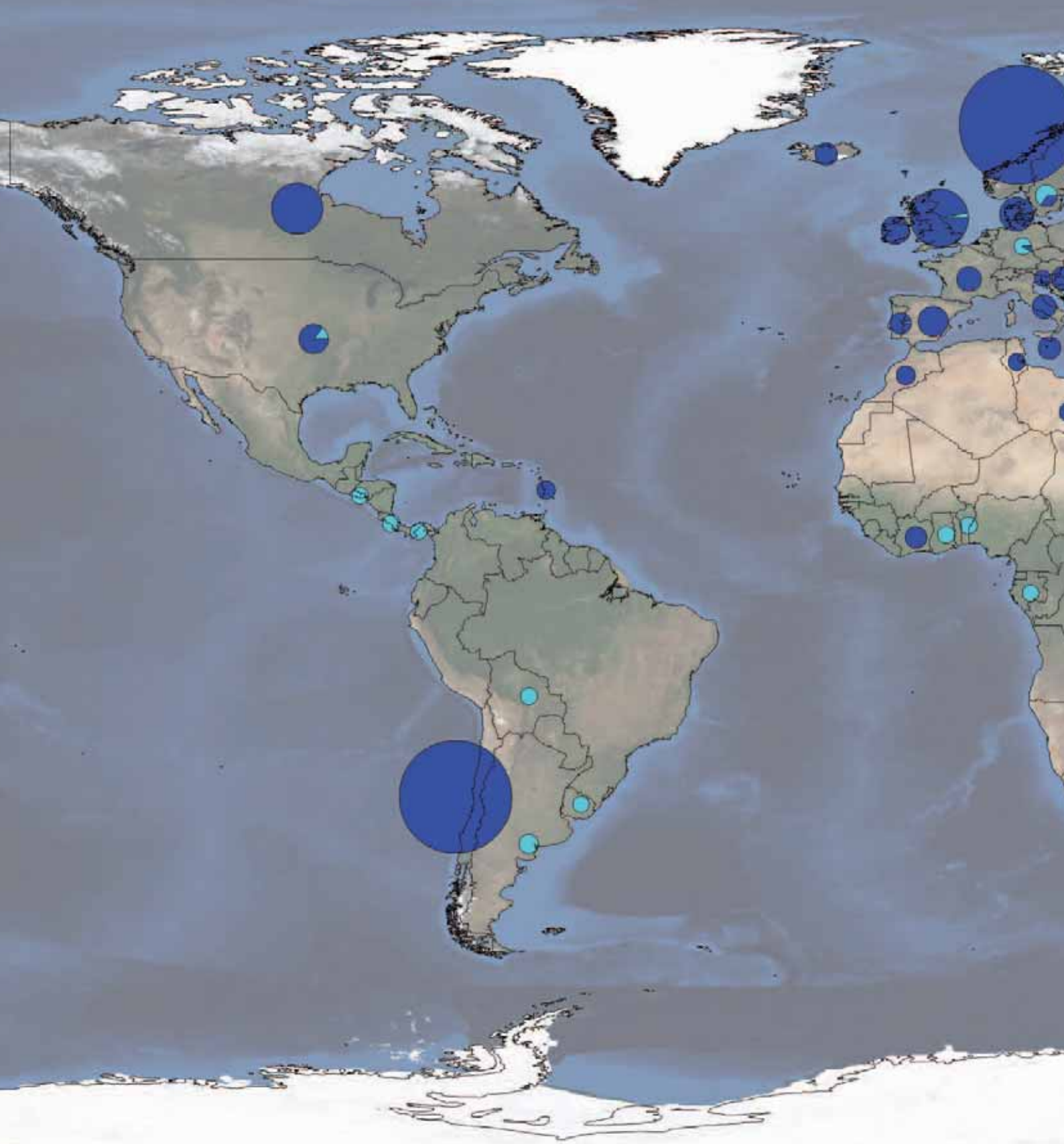
¹ See Halwart, M. and Moehl, J. F. (eds.) 2006. FAO Regional Technical Expert Workshop on Cage Culture in Africa. Entebbe, Uganda, 20–23 October 2004. FAO Fisheries Proceedings. No. 6, 113 pp. Rome, FAO.

As the 2004 workshop highlighted, the successful development of cage aquaculture will depend on many factors. The challenge for both government and private sector is to work together to address these issues comprehensively – at farm, local, national and regional levels. This is true for all regions and all forms of cage aquaculture. It is hoped that the information provided in this document will serve a wide audience of researchers, development practitioners and planners, and provide part of the information base that is needed for informed public-private partnerships and informed policy decisions.



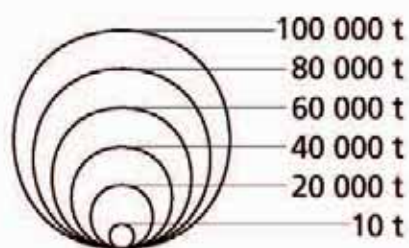
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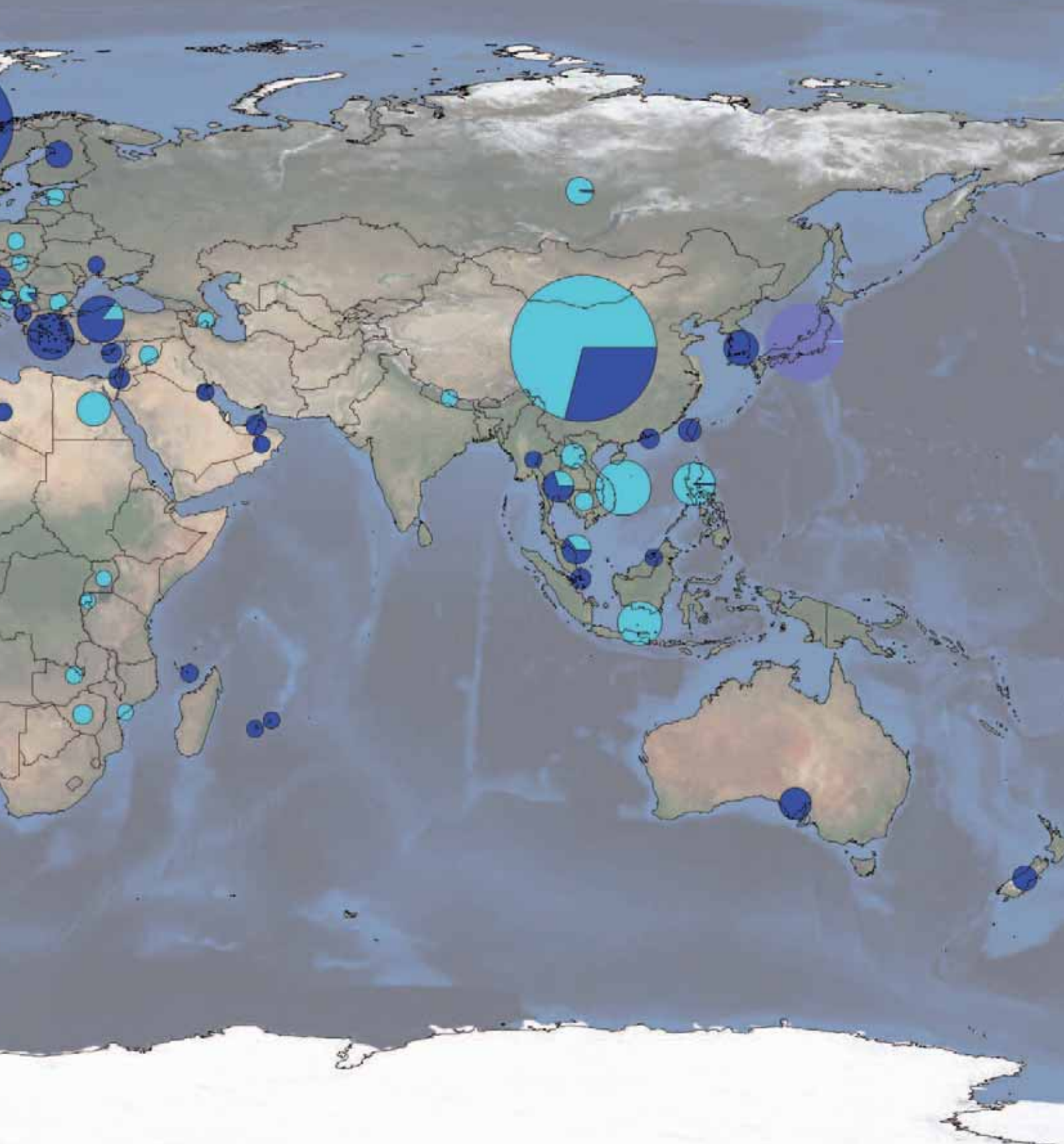
Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.

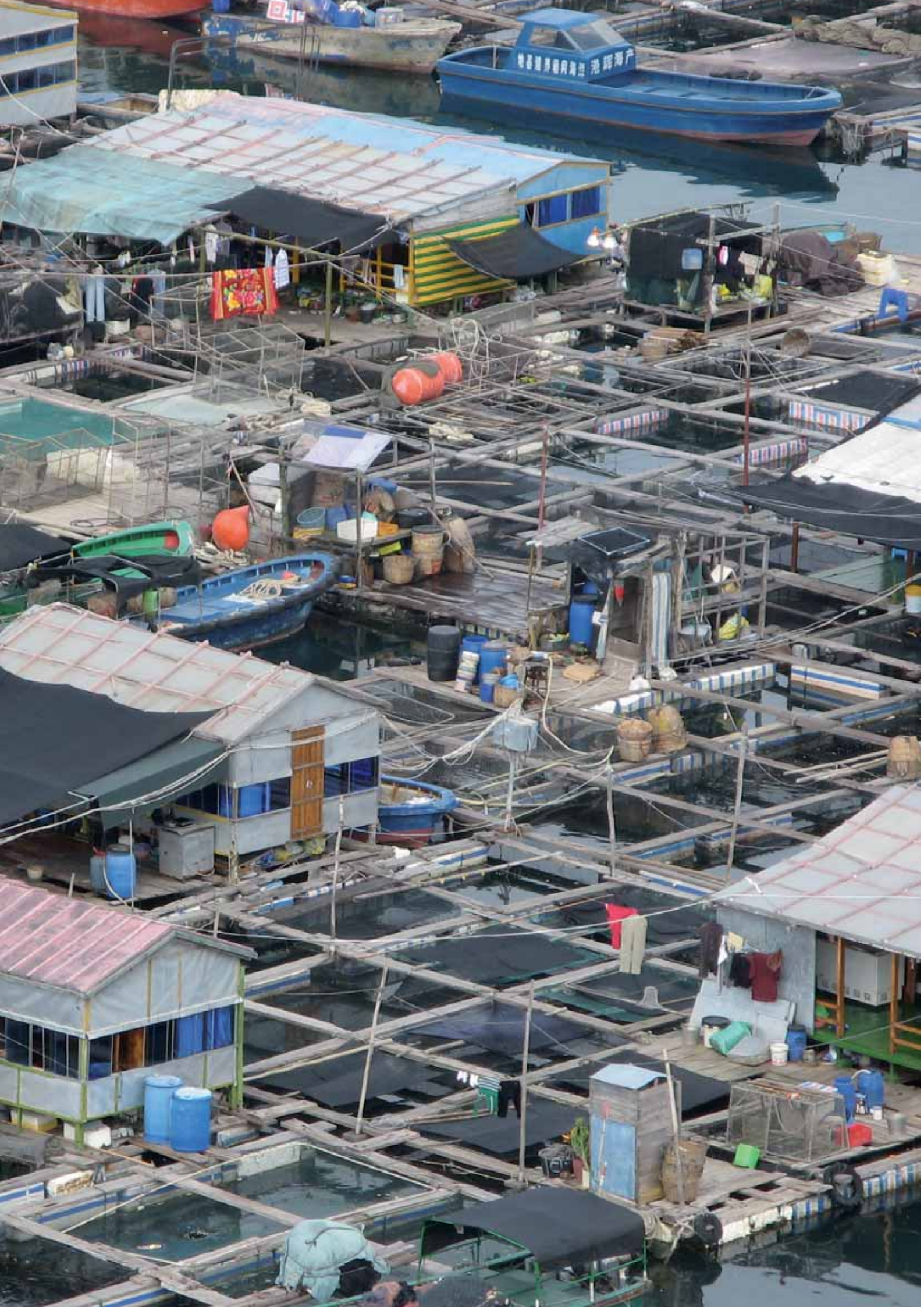


 freshwater

 marine and brackishwater



Cage aquaculture: a global overview



Cage aquaculture: a global overview

Albert G.J. Tacon¹ and Matthias Halwart²

Tacon, A.G.J. and Halwart, M.

Cage aquaculture: a global overview. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 1–16. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

The on-growing and production of farmed aquatic organisms in caged enclosures has been a relatively recent aquaculture innovation. Although the origins of the use of cages for holding and transporting fish for short periods can be traced back almost two centuries ago to the Asian region, commercial cage culture was pioneered in Norway in the 1970s with the rise and development of salmon farming. As in terrestrial agriculture, the move within aquaculture towards the development and use of intensive cage farming systems was driven by a combination of factors, including the increasing competition faced by the sector for available resources (including water, land, labor, energy), economies of scale and the drive for increased productivity per unit area and the drive and need for the sector to access and expand into new untapped open water culture sites such as lakes, reservoirs, rivers, and coastal brackish and marine offshore waters.

Although no official statistical information exists concerning the total global production of farmed aquatic species within cage culture systems or concerning the overall growth of the sector, there is some information on the number of cage rearing units and production statistics being reported to FAO by some member countries. In total, 62 countries provided data on cage aquaculture for the year 2005: 25 countries directly reported cage culture production figures; another 37 countries reported production from which cage culture production figures could be derived. To date, commercial cage culture has been mainly restricted to the culture of higher-value (in marketing terms) compound feed fed finfish species, including salmon (Atlantic salmon, coho salmon and Chinook salmon), most major marine and freshwater carnivorous fish species (including Japanese amberjack, red seabream, yellow croaker, European seabass, gilthead seabream, cobia, sea-raised rainbow trout, Mandarin fish, snakehead) and an ever increasing proportion of omnivorous freshwater fish species (including Chinese carps, tilapia, *Colossoma*, and catfish).

Cage culture systems employed by farmers are currently as diverse as the number of species currently being raised, varying from traditional family-owned and operated cage farming operations (typical of most Asian countries) to modern commercial large-scale salmon and trout cage farming operations in northern Europe and the Americas. The rapid rise and success of the salmon cage farming industry has been due to a combination of interlinked factors, including the development and use of an easily replicated and cost effective technology (which includes hatchery seed production), access to large areas of suitable waters, good species selection and market acceptability, increased corporate investment, and a good and supporting government regulatory environment. The paper discusses the perceived current issues and challenges to cage culture development, and in particular upon the need to minimize the potential environmental and ecosystem impacts of the rapidly growing sector.

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INTRODUCTION

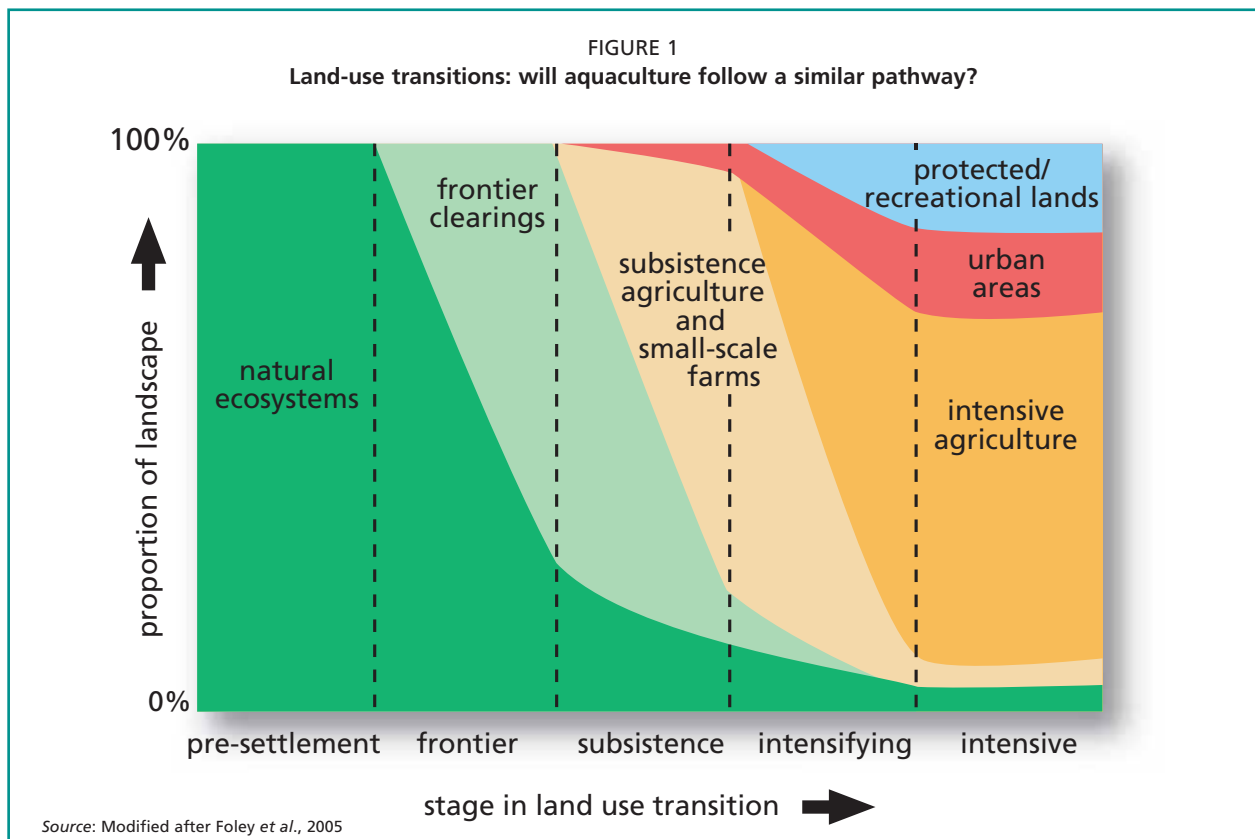
The on-growing and production of farmed aquatic organisms in caged enclosures has been a relatively recent aquaculture innovation. Although the origins of the use of cages for holding and transporting fish for short periods can be traced back almost two centuries ago to the Asian region (Pillay and Kutty, 2005), and may originate even earlier as part of indigenous practices of fisherfolk living on boats on the Mekong (de Silva and Phillips, this volume), marine commercial cage culture was pioneered in Norway in the seventies with the rise and development of salmon farming (Beveridge, 2004). The cage aquaculture sector has grown very rapidly during the past 20 years and is presently undergoing rapid changes in response to pressures from globalization and growing demand for aquatic products in both developing and developed countries. It has been predicted that fish consumption in developing countries will increase by 57 percent, from 62.7 million metric tons in 1997 to 98.6 million in 2020 (Delgado *et al.*, 2003). By comparison, fish consumption in developed countries will increase by only about 4 percent, from 28.1 million metric tons in 1997 to 29.2 million in 2020. Rapid population growth, increasing affluence, and urbanization in developing

countries are leading to major changes in supply and demand for animal protein, from both livestock and fish (Delgado *et al.*, 2003).

As in terrestrial agriculture (Figure 1), the move within aquaculture toward the development and use of intensive cage farming systems was driven by a combination of factors, including the increasing competition faced by the sector for available resources (Foley *et al.*, 2005; Tilman *et al.*, 2002), the need for economies of scale and the drive for increased productivity per unit area. Particularly the need for suitable sites resulted in the sector accessing and expanding into new untapped open water culture areas such as lakes, reservoirs, rivers, and coastal brackish and marine offshore waters.

LACK OF STATISTICAL INFORMATION

Although no official statistical information exists concerning the total global production of farmed aquatic species within cage culture systems or concerning the overall growth of the sector (FAO, 2007), there is some information on the number of cage rearing units and production statistics being reported to FAO by some member countries. In total, 62 countries provided data on cage aquaculture for the year 2005: 25 countries directly reported cage culture production figures; another



37 countries reported production from which cage culture production figures could be derived (Table 1).

Of these 62 countries and provinces/regions, 31 countries provided relevant data to FAO both in 2004 and 2005.

Total reported cage aquaculture production from these 62 countries and provinces/regions amounted to 2 412 167 tonnes or 3 403 722 tonnes if reviewers' data particularly from Chen *et al.* (this volume) for China are included.

On the basis of the above partial reported information, the major cage culture producers in 2005 included: Norway (652 306 tonnes), Chile (588 060 tonnes), Japan (272 821 tonnes), United Kingdom (135 253 tonnes), Viet Nam (126 000 tonnes), Canada (98 441 tonnes), Turkey (78 924 tonnes), Greece (76 577 tonnes), Indonesia (67 672 tonnes) and the Philippines (66 249 tonnes) (Figure 2).

However, it should be noted that, as stated above, meaningful interpretation of above data is constrained by the fact that for more than half of the countries (37 out of the 62) the method of culture had to be extrapolated based on other existing information.

Missing information can seriously distort the overall picture, and China is the most important case

in point. According to the review paper by Chen *et al.* (this volume) total cage aquaculture production in mainland PR China in 2005 was reported as 991 555 tonnes (704 254 tonnes from inland cages and 287 301 tonnes from coastal cages).

In terms of national or regional importance, total cage culture production from China amounted to just 2.3 percent of total reported aquaculture production in 2005 (Chen *et al.*, this volume; FAO 2007).

By contrast, Masser and Bridger (this volume) reported that cage aquaculture production accounted for about 70 percent of total aquaculture production in Canada in 2004, and De Silva and Phillips (this volume) have estimated that cage culture currently accounts for 80 to 90 percent of the total marine finfish production in Asia.

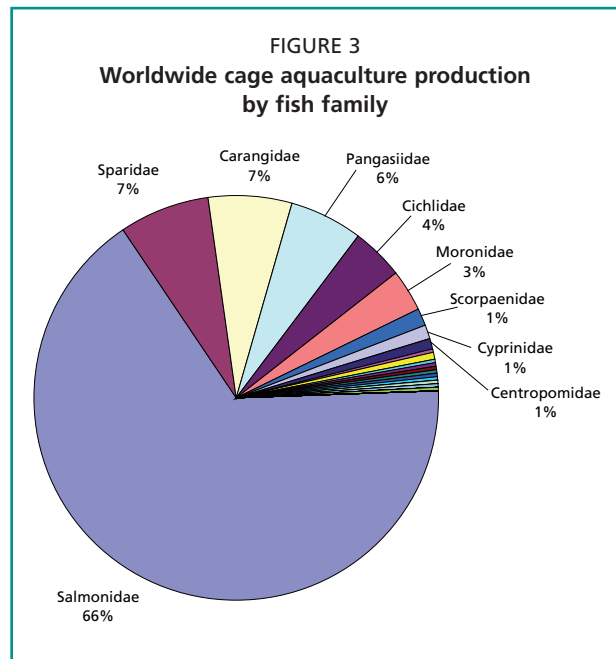
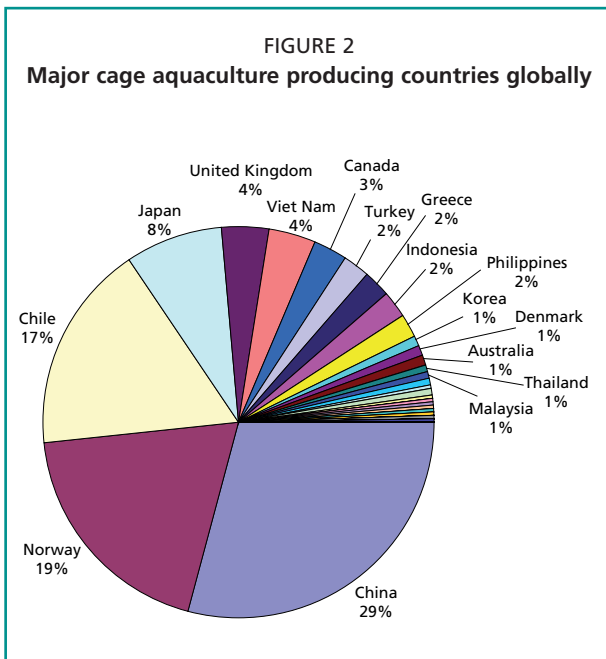
MAJOR CULTURED SPECIES, CAGE CULTURE SYSTEMS AND CULTURE ENVIRONMENTS

To date, commercial cage culture has been mainly restricted to the culture of higher-value (in marketing terms) compound-feed-fed finfish species, including salmon (Atlantic salmon, coho salmon and Chinook salmon), most major marine and freshwater carnivorous fish species (including Japanese amberjack, red seabream, yellow croaker, European seabass, gilthead seabream, cobia, sea-raised rainbow trout, Mandarin fish, snakehead)

TABLE 1

FAO member countries either reporting cage aquaculture production to FAO or otherwise known to be actively engaged in commercial cage aquaculture production, but not currently reporting data on cage aquaculture production to FAO

Countries reporting cage aquaculture to FAO	Countries otherwise known to be actively engaged in commercial cage aquaculture
<i>Latin America and the Caribbean region</i>	
Argentina, Bolivia, Chile, Costa Rica, El Salvador, Martinique (France), Panama, Uruguay	Brazil, Colombia, Guatemala, Honduras, Mexico, Nicaragua
<i>North American region</i>	
Canada, United States of America)	
<i>Northern European region</i>	
Bulgaria, Denmark, Estonia, Finland, Germany, Iceland, Ireland, Norway, Poland, Russian Federation, Slovakia, Sweden, United Kingdom	
<i>Mediterranean region</i>	
Albania, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Libyan Arab Jamahiriya, Malta, Morocco, Portugal, Slovenia, Syrian Arab Republic, Tunisia, Turkey	Spain
<i>Sub-Saharan African region</i>	
Benin, Gabon, Ghana, Mauritius, Mayotte (France), Mozambique, Réunion (France), Zambia, Zimbabwe	Côte d'Ivoire, Kenya, Madagascar, Nigeria, Rwanda, South Africa, Uganda
<i>Asia and Oceania</i>	
Azerbaijan, Brunei Darussalam, Cambodia, Hong Kong SAR, Taiwan Province of China, Indonesia, Japan, Republic of Korea, Kuwait, Lao People's Democratic Republic, Malaysia, Nepal, Oman, Philippines, Singapore, Thailand, Viet Nam	Australia, Bangladesh, China, India, Iran (Islamic Republic of), Democratic People's Republic of Korea, New Zealand



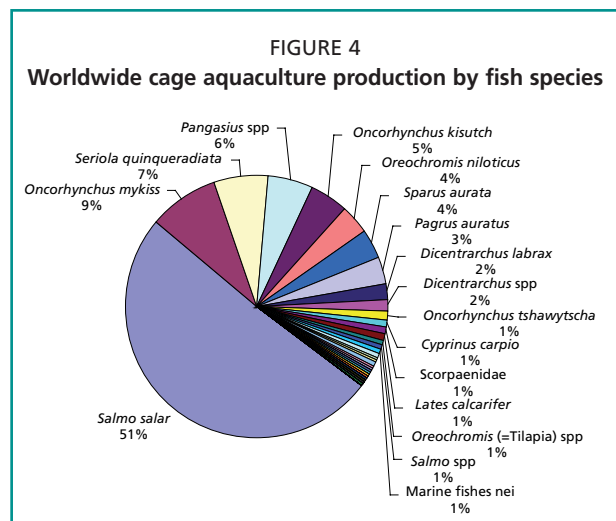
and an ever increasing proportion of omnivorous freshwater fish species (including Chinese carps, tilapia, *Colossoma*, and catfish).

However, cage culture systems employed by farmers are currently as diverse as the number of species currently being raised, varying from traditional family-owned and operated cage farming operations (typical of most Asian countries; De Silva and Phillips, 2007; Pillay and Kutty, 2005) to commercial cages used in Europe and the Americas (Grøttum and Beveridge, this volume; Masser and Bridger, this volume).

In terms of diversity, altogether an estimated 40 families of fish are cultured in cages, but only five families (Salmonidae, Sparidae, Carangidae, Pangasiidae and Cichlidae) make up 90 percent of the total production and one family (Salmonidae) is responsible for 66 percent of the total production (Figure 3).

At the species level, there are around 80 species presently cultured in cages. Of those, one species (*Salmo salar*) accounts for about half (51 percent) of all cage culture production (Figure 4), and another four species (*Oncorhynchus mykiss*, *Seriola quinqueradiata*, *Pangasius* spp. and *Oncorhynchus kisutch*) account for about another one fourth (27 percent).

Ninety percent of total production is from only eight species (in addition to the ones mentioned above: *Oreochromis niloticus*, *Sparus aurata*, *Pagrus auratus* and *Dicentrarchus labrax*); the remaining 10 percent are from the other 70+ species.



On the basis of the information gathered from the regional reviews, Atlantic salmon is currently the most widely cage-reared fish species by volume and value; reported aquaculture production of this coldwater fish species increased over 4 000-fold from only 294 tonnes in 1970 to 1 235 972 tonnes in 2005 (valued at US\$4 767 000 million), with significant production of more than 10 000 tonnes currently being restricted to a handful of countries, including Norway, Chile, the United Kingdom, Canada, the Faroe Islands, Australia and Ireland (Table 2)³.

³ Note that the volume of production in China is taken from Chen *et al.* (this volume). These authors also report the use of species (26 fish, 3 crustaceans, 1 reptile) but do not provide production figures by species.

TABLE 2
Total reported Atlantic salmon *Salmo salar* aquaculture production in 2005 (FAO, 2007)

Country	Quantity in tonnes (and as percentage of global total)	
Norway	582 043	(47.02%)
Chile	374 387	(30.24%)
United Kingdom	129 823	(10.49%)
Canada	83 653	(6.76%)
Faroe Islands	18 962	(1.53%)
Australia	16 033	(1.30%)
Ireland	13 764	(1.11%)
United States of America	9 401	(0.76%)
Iceland	6 488	(0.52%)
France	1 190	(0.10%)
Russian Federation	204	(0.02%)
Denmark	18	
Greece	6	
Total	1 237 977	

Source: FAO, 2007

According to Forster (2006) the spectacular rise and commercial success of salmon farming within these countries can be attributed to a series of different interlinked factors, including:

- Development of a replicable and cost-effective cage farming technology (i.e., use of relatively simple standardized floating cage culture systems for salmon grow-out);
- Access to suitable large areas of pristine coastal waters (Norway and Chile having a 1 800 km and 1 500 km long coastline, respectively);
- Salmon is a good species to farm (over three different species, straightforward hatchery rearing technology, grows well in cages, rapid growth to a large size, high fillet yield ~ 60 percent, highly acceptable meat);
- Good market and product development (including fresh year round availability, good perceived health benefits, numerous value added products, branded programs, generic marketing);
- Benefit of increased corporate investment, economies of scale, and consequent financial stability and regulatory compliance;
- Benefit from good national government support and regulatory environment (allocation of space and predictable permit process, practical regulatory framework, security of tenure, funded public and private sector research and development in support of the sector); and
- Importance placed on optimum salmon health and welfare, and consequent development of

improved fish health management schemes (including optimum juvenile quality, water quality and physical conditions, successful vaccine development, and development of improved general fish welfare, handling, nutrition, feeds and stock management practices).

Nevertheless, global production of Atlantic salmon decreased slightly in 2005 and there seems to be a de-acceleration of the growth rate. Regarding other species cultured in cages it is difficult to separate data according to the type of environment where farming takes place. FAO separates between freshwater, brackish and marine production, however, the reporting by countries to FAO is not always consistent in distinguishing between culture in brackish water and marine environments, and therefore these two have been aggregated below.

In freshwater, China dominates with a production exceeding 700 000 tonnes equivalent to 68.4 percent of total reported freshwater cage aquaculture, followed by Viet Nam (126 000 tonnes or 12.2 percent) and Indonesia (67 700 tonnes or 6.6 percent) (Table 3). While the production in PR China is composed of around 30 aquatic species for which no specific production figures are available (Chen *et al.*, this volume), the production in the other countries is composed mostly of catfish and cichlids (Table 4). Most of the top marine and brackish cage aquaculture producers are found in temperate regions, while the top species include salmonids, yellowtails, perch-like fishes and rockfishes (Tables 5 and 6).

PERCEIVED ISSUES AND CHALLENGES TO CAGE CULTURE DEVELOPMENT

Despite the above obvious economic and technical success of salmon cage farming the sector has faced numerous issues and challenges during its development.

In general, these issues and challenges have related to the use of an open net cage-based culture system and the consequent real and/or perceived impacts of such farming systems upon the surrounding aquatic environment and ecosystem, and have included:

- increased nutrient loss from uneaten feed, faecal wastes and excreta from cage-reared fish and possible impacts (negative and/or positive) upon water quality and surrounding aquatic environment and ecosystem health (Mente *et al.*, 2006; León, 2006);
- increased risk of disease occurrence within cage reared fish (Chen *et al.*, this volume; Merican, 2006; Tan *et al.*, 2006) and the potential risk of transfer of diseases to (and from) natural fish populations (Ferguson *et al.*, 2007);
- increased dependency of cage-reared carnivorous fish species upon fishery resources as feed inputs, including fishmeal, fish oil, and low-value “trash fish” species (Asche and Tveteras, 2004; De Silva and Phillips, this volume; Edwards *et al.*, 2004; Kristofersson and Anderson, 2006; Tacon *et al.*, 2006). Note this dependency is not unique to cage farming systems, and also applies to pond and tank reared carnivorous fish and crustacean species;
- increased dependence of some cage-farming systems upon the capture of wild caught seed, and in particular for those marine fish species where hatchery development is new or production is not currently sufficient to meet demand (FAO, 2006d; Merican, 2006; Ottolenghi *et al.*, 2004; Rimmer, 2006);
- increased risk of fish escapes from cages and consequent potential impacts (negative and/or

TABLE 3
Top ten freshwater cage aquaculture by country

Country	Quantity (tonnes)	in percent of total
China	704 254	68.4
Viet Nam	126 000	12.2
Indonesia	67 672	6.6
Philippines	61 043	5.9
Russian Federation	14 036	1.4
Turkey	10 751	1.0
Lao People's Democratic Republic	9 900	1.0
Thailand	7 000	0.7
Malaysia	6 204	0.6
Japan	3 900	0.4

TABLE 4
Production of the top ten species/taxa in freshwater cage aquaculture (excluding PR China)

Species	Quantity (tonnes)	in percent of total
<i>Pangasius</i> spp	133 594	41.1
<i>Oreochromis niloticus</i>	87 003	26.7
<i>Cyprinus carpio</i>	21 580	6.6
<i>Oreochromis</i> (=Tilapia) spp	16 714	5.1
<i>Oncorhynchus mykiss</i>	14 625	4.5
<i>Salmo</i> spp	12 071	3.7
<i>Channa micropeltes</i>	11 525	3.5
<i>Salmo trutta</i>	8 551	2.6
Freshwater fishes nei	6 914	2.1
Acipenseridae	2 368	0.7

- positive) on wild fish populations, including potential genetic, ecological and social impacts (FAO, 2006d; Ferguson *et al.*, 2007; Hindar *et al.*, 2006; Naylor *et al.*, 2005; Soto *et al.*, 2001);
- increased potential impacts of cage farming activities (negative and/or positive) upon other animal species, including predatory birds and mammals attracted to the fish within the cages (Beveridge, 2004; Nash *et al.*, 2000);
 - increased community concerns (in some countries) regarding the use of shared public inland and coastal water bodies for rearing fish within cage-based farming systems (due to the possible displacement of fishers and others, and/or perceived visual pollution), and the consequent need for increased consultation with all stakeholders (FAO, 2006d);
 - increased need for establishment and implementation of adequate government controls concerning the development of the sector, including planning and environmental monitoring, and implementation of good/better on-farm management practices (Alston *et al.*, 2006; Boyd *et al.*, 2005; Chen *et al.*, this volume; FAO, 2006d); and
 - increased public concerns (in some countries and developed country markets) regarding the long-term environmental and ecological sustainability of the intensive farming systems (Goodland, 1997), and in particular concerning the long-term ecological sustainability of rearing carnivorous fish species within cage-based farming systems based upon the use of fishery resources as feed inputs (Costa-Pierce, 2003; Tacon *et al.*, 2006).
- It is important to repeat here that aquaculture (including the use of cage farming systems) has also numerous important social, economic and environmental benefits, including increased food security and poverty alleviation impacts, increased employment opportunities within rural communities, increased seafood supply and availability, improved human nutrition and

TABLE 5
Production of the top ten marine and brackish water cage aquaculture countries

Country	Quantity (tonnes)	in percent of total
Norway	652 306	27.5
Chile	588 060	24.8
China	287 301	12.1
Japan	268 921	11.3
United Kingdom	131 481	5.5
Canada	98 441	4.2
Greece	76 212	3.2
Turkey	68 173	2.9
Republic of Korea	31 895	1.3
Denmark (including Faroe Islands)	31 192	1.3

TABLE 6
Production (tonnes) of the top ten species/taxa in marine and brackish water cage aquaculture (excluding PR China)

Species	Quantity (tonnes)	in percent of total
<i>Salmo salar</i>	1 219 362	58.9
<i>Oncorhynchus mykiss</i>	195 035	9.4
<i>Seriola quinqueradiata</i>	159 798	7.7
<i>Oncorhynchus kisutch</i>	116 737	5.6
<i>Sparus aurata</i>	85 043	4.1
<i>Pagrus auratus</i>	82 083	4.0
<i>Dicentrarchus labrax</i>	44 282	2.1
<i>Dicentrarchus spp</i>	37 290	1.8
<i>Oncorhynchus tshawytscha</i>	23 747	1.2
Scorpaenidae	21 297	1.0

well-being, increased foreign exchange earnings, improved waste water treatment/water reuse and crop irrigation opportunities, and improved nutrient recycling all of which need to be taken into consideration and weighed by importance in a balanced comparison of food production systems (FAO, 2006d; Halwart and Moehl 2006; Hambrey, 1999, 2001; Tacon, 2001).

THE WAY FORWARD

Cage culture has great development potential. For example, intermediate family-scale cage culture is highly successful in many parts of Asia (Phillips and De Silva, 2006) and one of the key issues for its continued growth and further development will not be how to promote but rather how to manage it (Hambrey, 2006). However, there is also an urgent need to reduce the current dependence of some forms of cage culture farming systems in Asia upon the use of low value/trash fish as feed inputs, including those for Pangasid catfish and high value species such as Mandarin fish, snakehead, crabs and marine finfish (Tacon *et al.*, 2006). Other forms of cage aquaculture at various levels of intensity are emerging in Africa and challenges there mainly relate to the presence of an enabling economic, political and regulatory environment (Rana and Telfer, 2006).

However, the intensive cage culture of high value finfish is growing fastest and there are important social and environmental consequences of this growth and transformation of the sub-sector. Similar to global trends in livestock production, there is a risk that the fast growth of intensive operations can marginalize small-scale producers and high production at different levels of intensity can lead to environmental degradation if not properly planned and managed. Considering that most of the cage aquaculture takes place in the fragile yet already much pressured coastal environments, there is increasing agreement that particular emphasis has to be given to the environmental sustainability of the sub-sector.

Expansion, intensification, environmental pollution and the state of our oceans and inland waters

Despite the lack of reliable statistical information concerning the precise size and status of cage aquaculture production globally, it is evident from the various regional cage culture reviews (with the possible exception of the Sub-Saharan African region) that cage culture is currently one of the

fastest growing segments of global aquaculture production. Expansion is likely to continue though with considerable regional differences: While the Asian region is likely to experience a further clustering of smaller-scale activities as a result of limited site availability in coastal waters (De Silva and Phillips, this volume), Cardia and Lovatelli (this volume) report a wide choice of farming sites for the more capital intensive near and offshore cages along the Mediterranean shoreline, as do Blow and Leonard (this volume) particularly for the Sub-Saharan African freshwaters. However, although cage culture allows the farmer access to new untapped aquatic resources and potential sites (including lakes, reservoirs, rivers, estuaries and the vast offshore marine environment), intensification of aquaculture production also brings increased environmental and economic risks (Figure 5) which in turn necessitate the use of new farm management skills and in-country regulatory controls and environmental monitoring systems for the sustainable development of the sector (FAO, 2006d).

Of particular concern is the need to minimize the potential environmental and ecosystem impacts of most existing cage farms, which for the most part are operated as single species (ie. monoculture) open farming systems (Tacon and Forster, 2003), with little or no regard usually given to the utilization of the waste outputs from these open farming systems as valuable nutrient inputs for the co-culture of other complementary aquatic species.

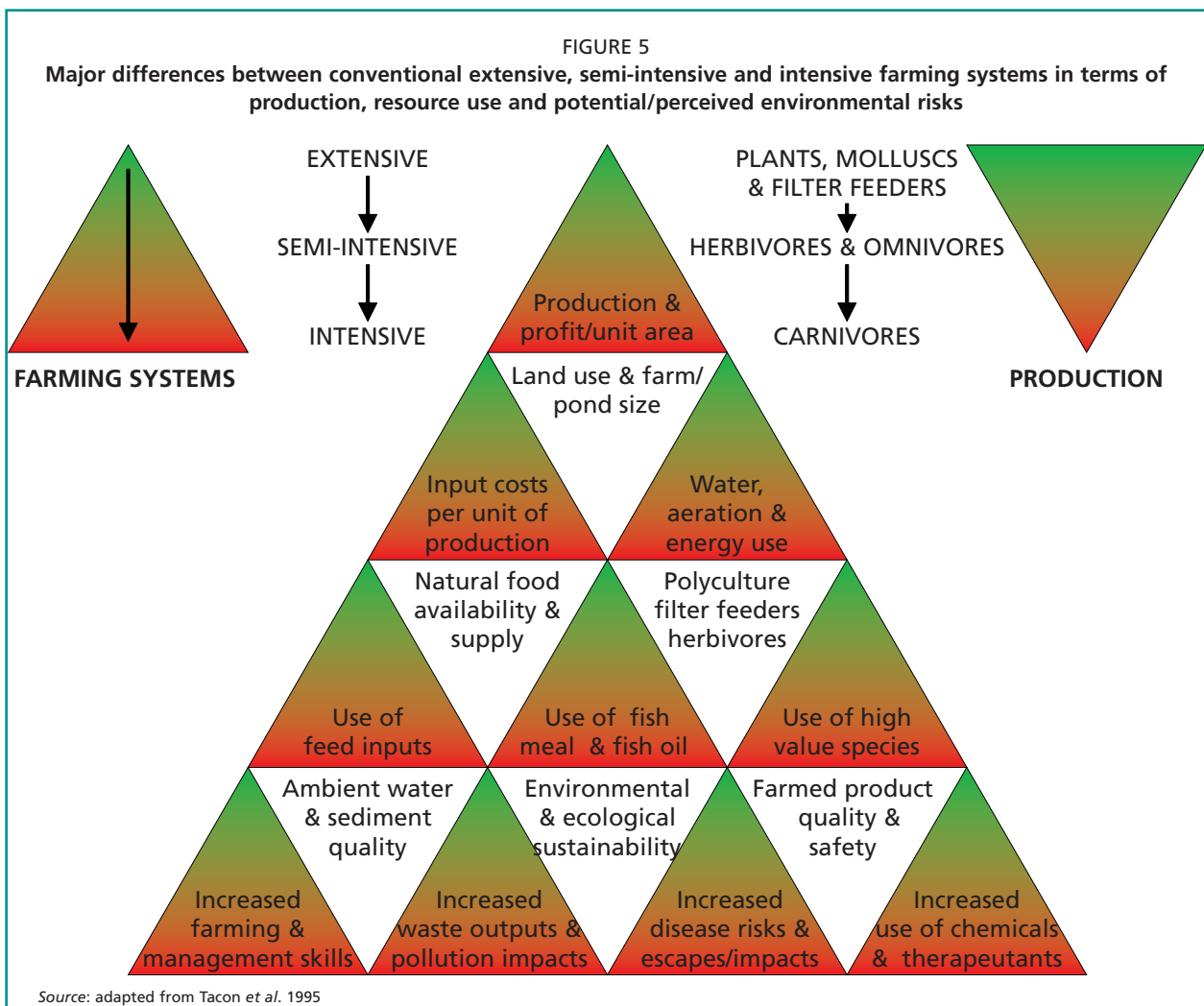
Notwithstanding the above, there is also a growing global concern for the environment, and in particular for the well-being and health of our oceans and aquatic ecosystems due to environmental pollution; the major pollutants entering into the world oceans currently coming from sewage (30 percent), air pollutants (30 percent), farm runoff (20 percent), industrial wastewater (10 percent), marine transportation (10 percent), offshore oil (5 percent), and litter (5 percent: Klesius, 2002). Although aquaculture is still a minor contributor to environmental pollution (in global terms, due to its relatively small size), this may not be the case in the future as the industry grows; environmental pollution from traditional cage culture operations already being reported as a serious problem in the inshore coastal waters of China (Chen *et al.*, this volume; Duqi and Minjie, 2006; Honghui *et al.*, 2006; Xiao *et al.*, 2006) and environmental considerations being reported as the overriding limitation to cage culture development in Australia

and New Zealand (Rimmer *et al.*, this volume). Environmental impact assessment requirements for larger farms can address these issues to a point. However, environmental assessments of individual farms is not in itself sufficient since environmental impacts on cage aquaculture as well as cumulative small-scale developments and longer term cumulative impacts also need to be carefully considered.

There needs to be more strategic environmental assessment and management which takes account of all the economic activities affecting the aquatic environment and the capacity of the environment to assimilate wastes (Halwart and Moehl, 2006). On the other hand cage culture offers one of the few solutions to future growth of mariculture as they can move offshore which will offer important opportunities and feasible choices for countries as China where pressure on the coastal zone and also pollution threats to aquaculture itself are very relevant issues.

Moreover, as a direct result of environmental pollution, there is also increasing global concern for food safety, particularly concerning the level of environmental contaminants (including persistent organic pollutants and heavy metals) accumulating within the natural aquatic food chain, including wild-caught fish and forage-fish-fed aquaculture species (FAO, 2006d; Schwarzenbach *et al.*, 2006; Tacon *et al.*, 2006).

Considering the tremendous advancements that cage culture has made in some countries such as Norway in terms of reduction of antibiotics use and replacement by vaccination as well as reductions in feed losses through improved feeds and feeding techniques (Grøttum and Beveridge, this volume) there is much confidence that the sector will successfully tackle its challenges. Government policy, institutional and legal support has been and will be important for the sound development of cage culture if based on key internationally negotiated agreements such as the Code of Conduct



for Responsible Fisheries and advised by advanced science as in the case of the use of geo-referenced tools (such as Global Information Systems – GIS) for site selection and zoning (e.g. Perez *et al.*, 2005), telemetry tools for behavioural monitoring (Cubitt *et al.*, 2005), or fishmeal replacements in fish feeds (e.g. Zhou *et al.*, 2005).

Integrating the system: a multi-trophic approach to cage culture

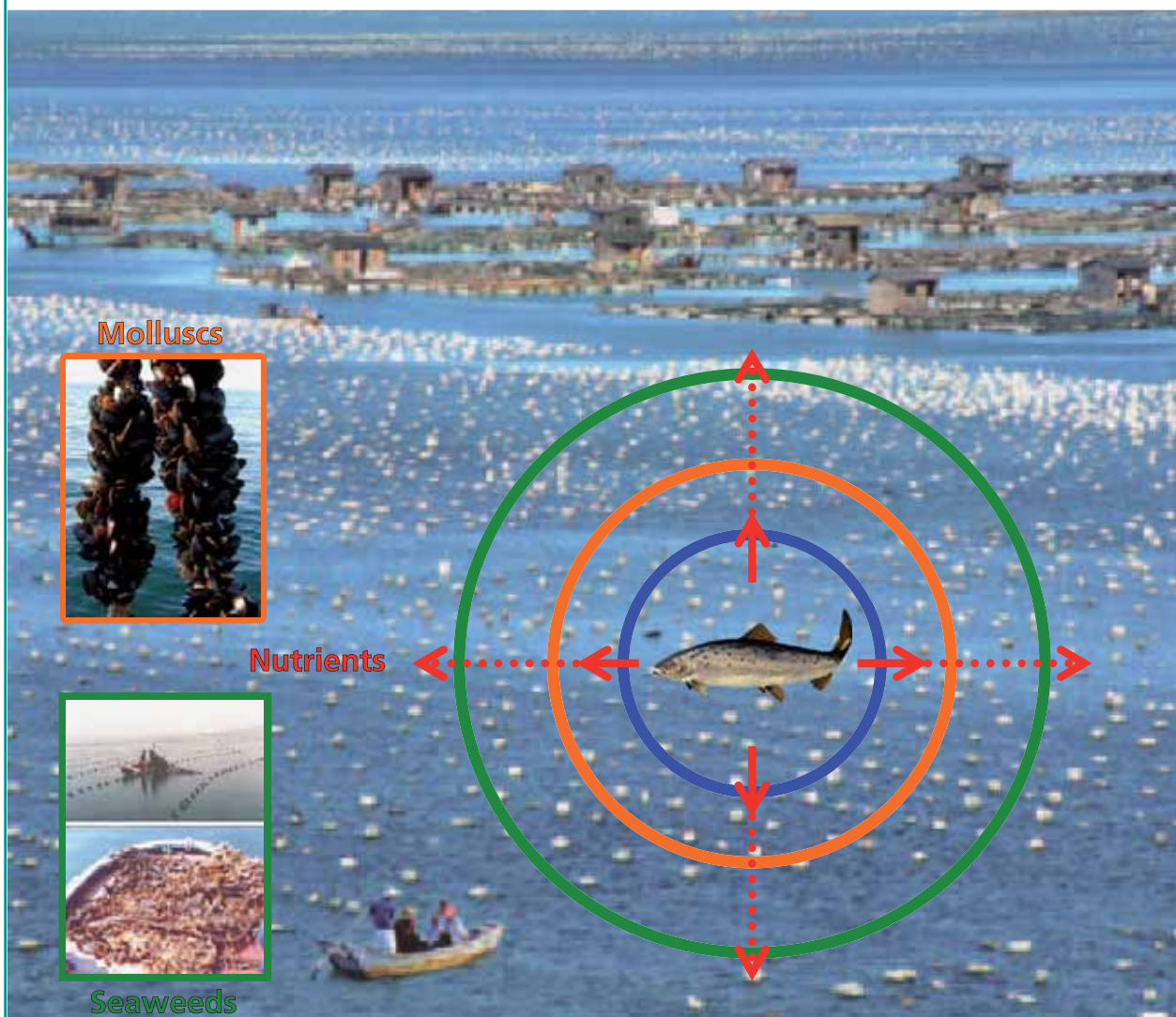
It is clear from the above discussion that cage culture systems need to evolve further, either by going further offshore into deeper waters and more extreme operating conditions (and by so doing minimizing environmental impacts through greater dilution and possible visual pollution: Chen *et al.*, this volume; Cremer *et al.*, 2006; Kapetsky and

Aguilar-Manjarrez, 2007; Lisac, 2006) or through integration with lower-trophic-level species such as seaweeds, molluscs, and other benthic invertebrates (Ridler *et al.*, 2007; Rimmer, 2006; Whitmarsh *et al.*, 2006).

The rationale behind the co-culture of lower-trophic-level species is that the waste outputs of one or more species groups (such as cage reared finfish) can be utilized as inputs by one or more other species groups, including seaweeds, filter feeding molluscs, and/or benthic invertebrates such as sea cucumbers, annelids or echinoderms (Figure 6).

However, while there has been some research undertaken using land-based systems (Neori *et al.*, 2004; Troell *et al.*, 2004), considerably further research is required on open or offshore mariculture systems (Lombardi *et al.*, 2006; Ridler *et al.*, 2007;

FIGURE 6
Integrating the system: traditional finfish cage culture and co-culture of seaweeds in China



Rimmer, 2006; Xu *et al.*, 2006; Yingjie, 2006; Yufeng and Xiugeng, 2006). One of the major challenges of this kind of integrated aquaculture or multi-trophic aquaculture is of a socio-economic nature since it will be needed to either facilitate co-farming by different stakeholders (e.g. mussel farmers plus salmon farmers) or to develop proper incentives for fish farmers to develop such multi-trophic aquaculture themselves. Probably the former option could have more social advantages and should be explored from a multidisciplinary perspective at regional and global levels.

CONCLUDING REMARKS

The opportunities for cage culture to provide fish for the world's growing population are enormous, and particularly so in marine waters with more than 97 percent of all our planet's water being contained in the ocean. Yet, although oceans cover 71 percent of the planet's surface and provide 99 percent of its living space, they represent one of the least understood ecosystems with less than 10 percent of this living space having been explored by humans.

In marked contrast to our terrestrial food production systems (which produce over 99 percent of our current food requirements: FAO, 2006b), the total capture fisheries harvest from our seas and rivers currently supply less than 1 percent of our total calorie intake in the form of edible fishery products (FAO, 2006a); 52 percent of our known fish stocks being fully exploited, 20 percent moderately exploited, 17 percent over-exploited, 7 percent depleted, 3 percent underexploited, and 1 percent recovering (FAO, 2005).

Clearly, with the world's population growing at a rate of more than 80 million people a year,

and expected to reach 9 billion by 2050, there is no doubt that our oceans and precious freshwater resources will have to become more efficient and productive in terms of increased global aquaculture food production.

In addition, while the need for improved efficiency and productivity will be critically important in the development of aquaculture in general and cage culture specifically, so will be other factors, particularly food safety in combination with socially acceptable and economically and environmentally sustainable food production according to agreed and certified principles, with particular attention paid to animal welfare, all of which rank increasingly high in consumer perception and acceptance of aquatic products. Cage aquaculture will play an important role in the overall process of providing enough (and acceptable) fish for all, particularly because of the opportunities for the integration of species and production systems in nearshore areas as well as the possibilities for expansion with siting of cages far from the coasts.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support and constructive comments by many friends and colleagues, particularly J. Aguilar-Manjarrez, J.R. Arthur, P. Balzer, D. Bartley, M. Beveridge, P. Blow, C.J. Bridger, F. Cardia, B. Chakalall, J. Chen, Z. Chen, S.S. De Silva, J. Forster, S. Funge-Smith, J.A. Grøttum, C. Guang, M. Hasan, Hasini, S. Leonard, J. Liu, A. Lovatelli, A. Lowther, M.P. Masser, J. Moehl, M.J. Phillips, B. Ponia, M. Reantaso, M.A. Rimmer, A. Rojas, D. Soto, R. Subasinghe, S. Wadsworth, Y. Wang, H. Xu, P. Xu and X. Yan.

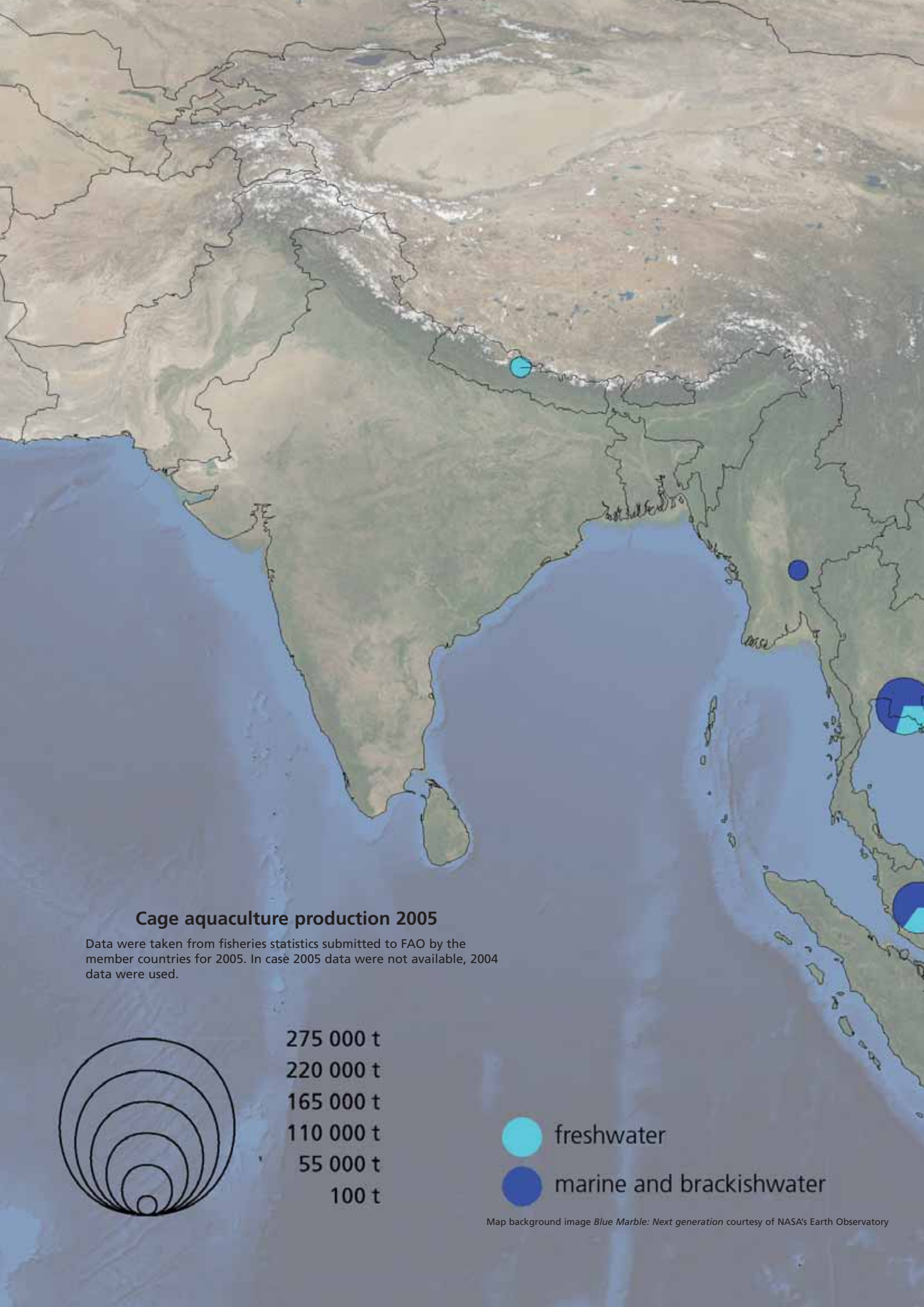
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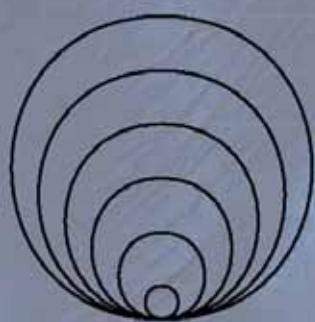
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Cage aquaculture production 2005

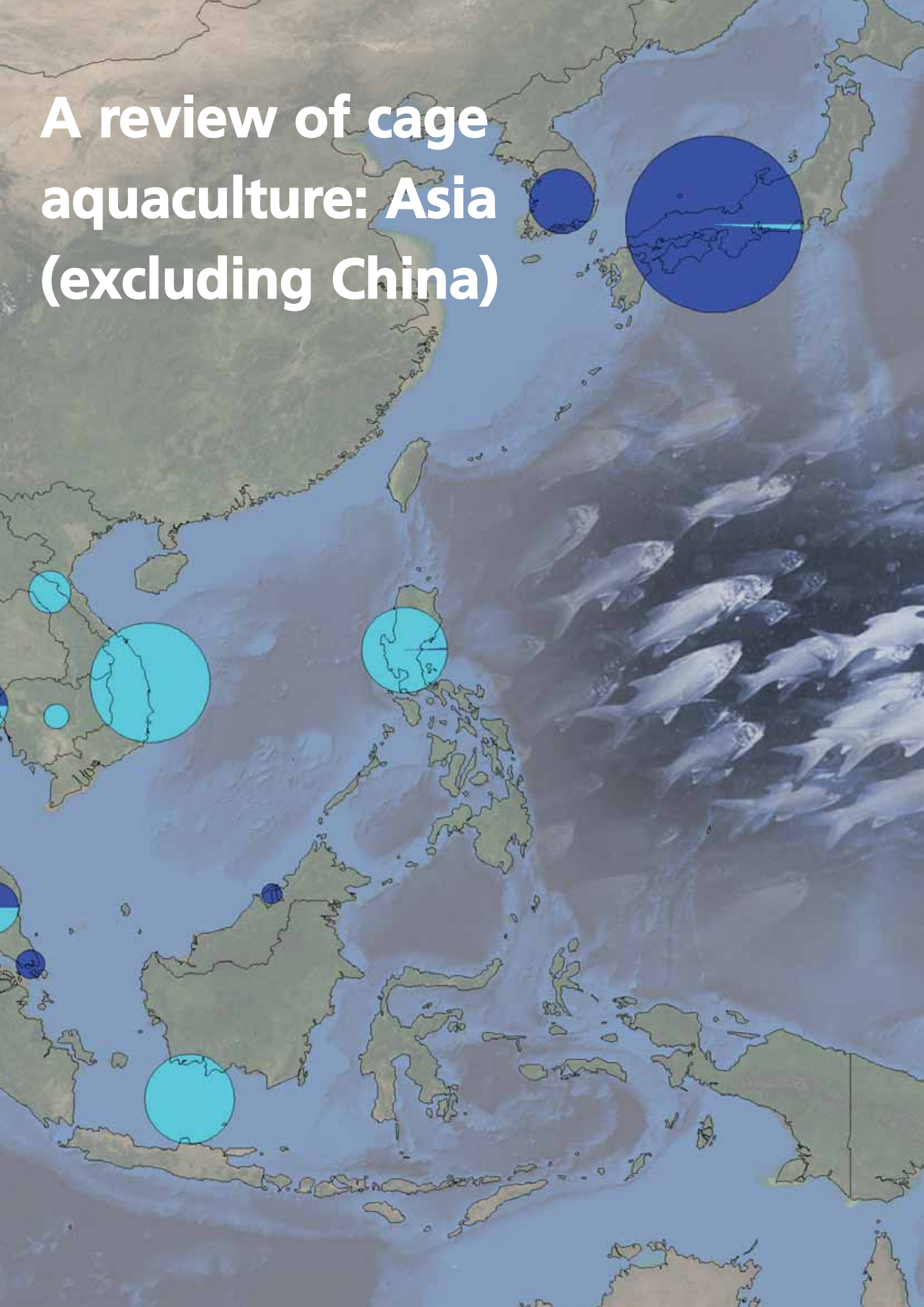
Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.



- 275 000 t
- 220 000 t
- 165 000 t
- 110 000 t
- 55 000 t
- 100 t

- freshwater
- marine and brackishwater

A review of cage aquaculture: Asia (excluding China)





A review of cage aquaculture: Asia (excluding China)

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A review of cage aquaculture: Asia (excluding China). In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 18–48. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

Cage farming in Asia is practiced in fresh, brackish and inshore coastal waters. Freshwater cage farming is a very old tradition that is thought to have originated in some of the Mekong Basin countries. It currently occurs in all freshwater habitats and is extremely diverse in nature, varying in cage design, intensity of practice, husbandry methods and the species farmed. In general, freshwater cage farming is practiced on a small scale, but in some instances clustering of cage operations can contribute a significant level of production, as in the case of pangasiid catfish culture in the Mekong Delta and the combination of common carp (*Cyprinus carpio carpio*) and tilapia (*Oreochromis* spp.) farming in some Indonesian reservoirs. Overall, although clear-cut statistics are not available, cage farming is thought to be the most predominant form of freshwater aquaculture in Asia. In this paper, freshwater cage farming is only briefly considered; it has recently been reviewed by the authors (see Phillips and De Silva, 2006).

Cage farming in brackish and inshore waters in Asia is relatively recent, being started in Japan. It is estimated that over 95 percent of marine finfish aquaculture is in cages. Open sea-cage farming in Asia is not common. Marine and brackishwater cage farming in Asia is also diverse, with a variety of species being cultured at varying intensities. In most nations the individual operations are not large, and often a clustering of farming activities is seen. This clustering is primarily a result of the limited site availability in coastal waters. Cage farming is most dominant in East and Southeast Asia, but not in South Asian nations. The main species farmed in brackishwaters are the barramundi or Asian seabass (*Lates calcarifer*) and the milkfish (*Chanos chanos*). Almost all cage farming of these species is based on hatchery-produced fry and the use of pelleted feed.

In inshore marine cage farming, apart from traditionally farmed species such as amberjacks (*Seriola* spp.) and snappers (*Lutjanus* spp.), in Southeast Asia the cage farming of groupers (*Epinephalus* spp.) and cobia (*Rachycentron canadum*) is gaining ground, the former particularly to cater to the live-fish restaurant trade. Some cage farming in Asia is still dependent on wild-caught seed stock, particularly for grouper species. One of the main constraints to further expansion of marine-cage farming in inshore areas is the extensive dependence on trash fish, directly or indirectly, as a main feed ingredient.

In the synthesis, a number of factors that would impact on the “way forward” in cage aquaculture in Asia is dealt with. Overall, the future prospects for all forms of cage farming look relatively bright for Asia. However, it is suggested that the large-scale, capital-intensive, vertically integrated marine cage-farming practices seen in northern Europe (e.g. Norway) and South America (e.g. Chile) are unlikely to occur in Asia. Instead of large-scale farms, clusters of small farms generating synergies, acting in unison and thereby attaining a high level of efficacy are likely to be the norm, well into the foreseeable future. Off-shore cage farming is unlikely to become widespread in Asia, as its development is likely to be hampered by availability of capital and the hydrography of the surrounding seas, which does not allow the technology available elsewhere to be easily transferred. Despite these limitations and constraints, cage farming in Asia will continue to contribute significantly to global aquaculture production and Asia will also continue to lead the world in total production.

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INTRODUCTION

As with most forms of aquaculture, cage culture probably originated in Asia and perhaps was associated with the “boat people” of the Mekong Basin who kept wild-caught fish in cages in their boats for fattening. Currently cage farming in Asia is conducted in fresh and brackishwaters, as well as in marine inshore areas. Apart from small quantities of crabs, lobsters and crocodiles, it is predominantly restricted to the farming of finfish.

Total aquaculture production of aquatic animals for 2004 was reported to be 45.5 million tonnes with a farm-gate value of US\$63.4 billion. With the inclusion of aquatic plants, the production increases to 59.4 million tonnes with a value of US\$70.3 billion. The reported growth in global aquaculture remains strong, as these figures represent an increase in production of 7.7 percent from the total aquaculture production reported for 2003, and a 6.6 percent increase when only aquatic animals are considered. Considering the ten-year period from 1994 to 2004, total aquaculture production shows an average annual increase of 7.9 percent (FAO, 2006). Of this production volume, around 90 percent comes from Asia.

It is not possible to determine the contribution of cage farming to the total volume and value of aquaculture production in Asia, particularly in respect to that in inland waters, which is the mainstay of cage aquaculture in Asia. On the other hand, 80–90 percent of the estimated one million tonnes of marine fish cultured in Asia probably comes from cage farming. In some countries and locations, cage farming provides an important source of fish production and income for farmers, other industry stakeholders and investors. In modern times, cage culture is also seen as an alternative livelihood, for example, for persons displaced by the construction of reservoirs.

This paper reviews cage culture in Asia, but only briefly that in China, which is covered elsewhere in this volume by Chen *et al.*. Its focus is on brackishwater and marine environments, since the inland sector has been dealt with by the same authors in a review of inland cage farming in Asia (excluding China) that was commissioned by FAO in 2004 (Phillips and De Silva, 2006) and has been recently published as a background paper for cage-culture development in Africa (Halwart and Moehl, 2006).

INLAND CAGE FARMING

It is difficult, if not impossible to estimate the production from inland cage culture. What is important to note is that such practices contribute to rural livelihoods, are generally small scale, and are also relatively less perturbing environmentally, as in most cases finfish feeding lower in the food chain are farmed. However, where clustered, small-scale inland cage farming operations in Asia may have impacts whose sum total is almost equivalent to those of industrial fish farming operations. Some examples are seen in reservoirs in Indonesia and in the Mekong Delta. Collectively, such activities can be environmentally perturbing.

As stated earlier, inland cage farming is the dominant form of cage farming in Asia. It can still be very traditional in some regions, and these small-scale practices tend to support a significant number of livelihoods, particularly along rivers and reservoirs (Plate 1). Such traditional systems have been used in several parts of Asia and elsewhere for many generations (Beveridge, 2004). In general and traditionally, most cage farming in rivers occurs in nursery areas where an abundance of post-fry and early fingerlings associated with suitable food sources, such as macrophytes, are found. These traditional practices continue, with cage farming of Chinese major carps and in some instances, pangasiid catfishes and snakeheads (*Channa* spp.), the latter two species-groups being farmed predominantly in Cambodia and Viet Nam. However, in some countries, primarily those that have not had a tradition of cage farming in rivers (e.g. Lao People's Democratic Republic), species such as tilapias are grown, primarily for the restaurant trade.

In the past few decades such traditional systems have evolved into more “modern” cage farming, involving specially constructed cages having better designs and using synthetic net materials, and the use of hatchery-reared fry and fingerlings, a variety of commercial feeds and better organized management practices. Although such modern systems are increasingly common, there is a diversity of cage-farming systems in Asia, covering a spectrum of traditional to modern practices and involving a wide variety of species, environments, investments and inputs.

PLATE 1
Selected traditional, small scale, rural cage farming practices in Asia



Grass carp farming in Vietcuomg Reservoirs, northern Viet Nam.



Catfish farming in Nam Ngum Reservoir, Lao PDR.



Snakehead farming in the Tonle Sap, Cambodia (I).



Snakehead farming in the Tonle Sap, Cambodia (II).



Chinese carp farming in Kui Yang River, northern Viet Nam.



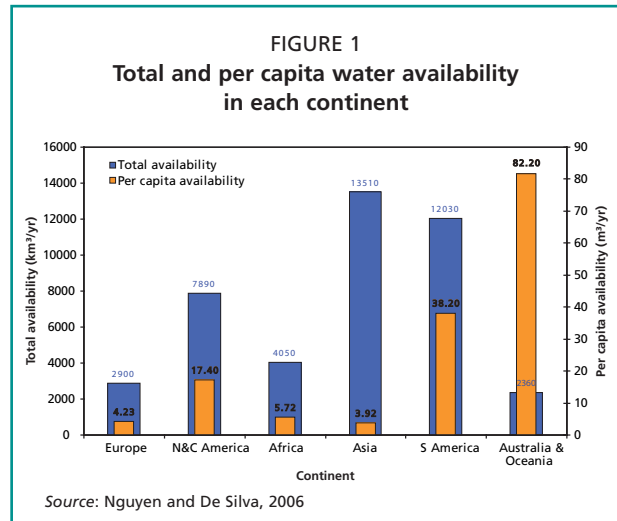
Chinese carp farming in Cai River, northern Viet Nam.

The importance of inland cage farming to Asia

Asia, excluding the Middle East, harbors 56.2 percent of the world's current population and is expected to reach 4.44 billion people, by year 2030 (http://earthtrends.wri.org/pdf_library/data_tables/pop1_2005.pdf). There is less land per person in the Asia-Pacific Region than in any other part of the world; at least ten major countries in the region have less than 0.10 ha compared to the world average of 0.24 ha (UNEP, 2000). Inland water resources in Asia are also rather limited. Although Asia is blessed with the highest quantity of usable freshwater, the per capita availability is the lowest of all continents (Figure 1). The limitations on these primary resources, i.e. land and water, have curtailed and/or discouraged significant increases in conventional pond culture in most countries in the region. Of course there are exceptions, the best example being in catfish culture in the Mekong Delta, where in spite of land limitations pond culture is expanding.

As such there is a need to use available waters effectively for foodfish production, without further demands on land use for such purposes. Reservoir impoundment in Asia, primarily for irrigation and hydroelectricity generation but never for foodfish production, is common although often politically and environmentally controversial. Asia has the largest number of reservoirs in the world, resulting from the impoundment of rivers and streams (Nguyen and De Silva, 2006). In recent times planners and developers have been driven to consider reservoir cage culture as an alternative livelihood for displaced persons and an effective non-water-consumptive secondary use of the reservoir resources in many countries. For example this practice has been successfully implemented in reservoirs (Jatilhur, Saguling and Cirata) of the Ciratum watershed in Java, Indonesia (Abery *et al.*, 2005), in certain newly impounded reservoirs in Malaysia (e.g. Batang Ai in Sarawak, East Malaysia) and in China. In these instances, in each waterbody the cage farming collectively tends to become a relatively large operation, the produce is often not marketed locally and a certain proportion may even be exported. In most of these instances the commonly cultured species tend to be common carp (*Cyprinus carpio carpio*) and/or tilapia, the hybrid red tilapia (*Oreochromis niloticus* x *O. mossambicus*) often being preferred.

In addition in some countries cage farming is also seen as a useful means of rearing fry to



fingerlings for other aquaculture grow-out systems, particularly where there is limited pond capacity (Ariyaratne, 2006). Further more, even in some developed countries such as Australia, cage farming of high-valued species such as the Murray cod (*Maccullochella peelii peelii*) in irrigation tanks is seen as a means of increasing farm income and an effective secondary use of water for food production (G. Gooley, personal communication).

Examples of recent noteworthy developments

The two case studies on catfish, and common carp and tilapia in the Mekong Delta region in Viet Nam and in the reservoirs of the Ciratum watershed in West Java, Indonesia, respectively were presented in detail by Phillips and De Silva (2006) and can be considered as two of the noteworthy developments of relatively large-scale inland cage farming in the region. In the case of the catfish farming in Viet Nam, which commenced primarily as the cage-farming of the pangasiid catfishes *Pangasius hypophthalmus* (sutchi or tra catfish) and *P. bocourti* (basa catfish), production reached 450 000 tonnes in 2005 and is projected to peak at 800 000 tonnes by 2010 (Le Tahn Hung, personal communication). However, with the increasing cost of cage catfish farming in the delta there has been a gradual shift towards pond culture, and it is estimated that cage farming currently accounts for only about 30 percent of the production. Importantly most catfish farming activities are small scale, even though nearly 80 percent of the production is exported to the United States and the European Union. The industry directly and indirectly employs about 17 000 persons (Hung *et al.*, 2006; Nguyen, Lin and Yang, 2006). The catfish farming industry in Viet Nam has had its marketing problems, especially

due to the introduction of a 37 percent tax by the United States of America on imports, based on a claim of “dumping”. Although there were some severe short-term effects on prices and livelihoods of catfish farmers and other people (e.g. women in processing factories) caused by the antidumping measure, intervention of the Government of Viet Nam in assisting producers and processors to diversify markets and improve production practices and quality, combined with the entrepreneurial characteristics of the Vietnamese farmers, ensured that these effects were short lived. Since the case, the catfish industry in Viet Nam has continued to grow with expanded markets and competitiveness, exporting to many countries, including the United States of America and the European Union.

The dual cage-culture system locally referred to as the “lapis dua” in which common carp is cultured in the inner cage and tilapia in the outer cage (7 x 7 x 3/5 m) in reservoirs in the Ciratum watershed, West Java, Indonesia, was initially mooted and encouraged as an alternative livelihood for persons displaced by the impounding of the reservoirs. However cage farming was seen as a lucrative endeavor resulting in high returns relatively quickly compared to most other investments, and the practices were thus bought up by entrepreneurs from outside. These entrepreneurs often had sufficient financial assets and consequently expanded their individual cage farms, often not heeding the regulations in operation. Thus the numbers of cages far exceeded the numbers that were legally permitted based on initial surveys of the carrying capacity of the individual waterbodies. For example in Cirata Reservoir there are nearly 30 000 cages in operation. Initially the total production from each waterbody increased significantly. However, within a five-year period the unit cage production in two reservoirs that had experienced a tripling of cage numbers began to decline, and regular fish kills began to occur, particularly in the drier months (Abery *et al.*, 2005). These changes have also brought about social conflicts and major environmental problems relating to water quality. These problems are currently being addressed, and a cage-culture management plan is being developed (Koeshendrajana, Priyatna and De Silva, 2006). A comparable situation has been reported in Lake Bato, the Philippines, where tilapia cage farming expanded unabated (Nieves, 2006).

In general, the environmental problems arising from unplanned cage farming have exacerbated because the operations tend to be localized in

sheltered bays, with relatively easy access to supporting land facilities. In such areas the water circulation is rather limited and sedimentation rates are higher, leading to increased organic loads in the cage-farming areas.

Asian cage farmers are beginning to integrate cage farming with other forms of husbandry as a means of increasing income. Such practices, however, are not yet widespread. The integration could be with poultry and/or pigs on platforms over the cages, and in most ways conforms to the traditional land-based integrated aquaculture (Little and Muir, 1987). In the extreme case, as found in the Tri An Reservoir, southern Viet Nam, crocodile cages are annexed to fish cages, an interesting and novel diversification of cage farming.

Problems and constraints in inland cage farming

Although individual cage-farming holdings tend to be relatively small, in certain inland waterbodies large numbers of such units co-exist, as in the examples cited in the previous section (Plate 2). These collective, intensive cage-farming practices generate synergies that enable them to be relatively more profitable, and even allow a relatively high proportion of the produce to be exported. However, such positives can at times also be counter-productive and negatively affect the sustainability of the systems. This is evident in the case of Cirata and Saguling reservoirs, where the number of cages has far exceeded the estimated carrying capacities of the two reservoirs (Abery *et al.*, 2005). This has resulted in fish kills, social conflicts and increased susceptibility to disease, the most recent being the mass mortality of common carp brought about by koi herpes virus (KHV) (Bondad-Reantaso, 2004).

The great bulk of inland cage-farmed fish, with the exception of snakeheads in Tonle Sap, Cambodia and the Chinese perch (*Siniperca chuatsi*), are relatively low-valued food fish. Almost all the herbivores and omnivores farmed are destined for local markets, where farm-gate prices are often determined by wholesalers/middlepersons. On the other hand, most cage-farmed tilapia and catfish are marketed extensively, this being made possible because of the large quantities produced in specific areas and proper marketing strategies being developed over the years.

The availability of reliable supplies of good quality seed stocks is a major problem in most inland cage farming, particularly the vast majority that still depend on natural supplies. Apart from

tilapia, adequate selective breeding plans have not been established for species that are farmed on a large scale, such as the catfishes and snakeheads. This lapse could possibly result in reduced production and most importantly, will not enable the full genetic potential of the species to be realized for farming purposes.

There is also considerable dependence on trash fish by some of the major inland cage farming activities in Asia, most notably catfish cage farming in the Mekong Delta in southern Viet Nam. Indeed, the relatively lower efficacy of using trash fish as a major feed resource, among other factors, principally the cost of wood used for cages and poor water flow during the dry season, has resulted in a decrease in cage catfish farming in the region, most farmers turning to pond culture. Cage-fish farmers often see trash fish as a relatively cheap feed resource. Trash fish is also used in catfish farming as the main ingredient in “farm-made” feeds where it is mixed with other ingredients such as rice bran, fortified with commercially available vitamin pre-mixes, subjected to some form of cooking (see Plate 2), and used as semi-dried “feed balls” and the like (Hung *et al.*, 2006; Nguyen, Lin and Yang, 2006). Studies on improving the preparation of such farm-made feeds will not only increase the efficacy of feed utilization, and thereby bring about higher returns, but also may be used in the long term to reduce the reliance on trash fish.

Catfish processors and farmers in the Mekong Delta tend to recycle almost all the processing waste, a practice that needs to be encouraged. However as substantial quantities of waste are being used in feeds, further studies are needed to ensure that potential disease transmission is averted.

By and large most of the hardware used in cage farming, even in the case of large-scale developments, as for example, in the Mekong Delta and the Indonesian reservoirs, rely on bamboo and/or hard woods. Both these commodities are typically obtained from the wild, risking considerable environmental damage. Apart from the direct impacts on forest resources, this practice may also enhance soil erosion of the catchments and increase siltation in the waterbodies, with potential long-term negative effects on the farming activities per se.

One of the main constraints to developments is the relative lack of research on key issues pertaining to inland cage farming. Foremost among these are the carrying capacities of static waterbodies such as reservoirs and lakes, feed usage and related efficacies,

species suitability, adoption of polyculture practices as in the case of the dual cage farming system (“lapis dua”) in Indonesian reservoirs, economic evaluations (e.g. see Dey *et al.*, 2000) and marketing strategies.

BRACKISHWATER AND MARINE CAGE FARMING

Brackishwater and marine cage farming is relatively new in Asia, having first been developed in Japan for marine cage culture for species such as the Japanese amberjack or yellowtail (*Seriola quinqueradiata*) and red seabream (*Pagrus major*) (Watanabe, Davy and Nose, 1989). Over the last 20 years, marine finfish aquaculture, predominantly cage farming, has spread throughout Asia. The predominant countries engaged in this activity are China (see Chen *et al.*, this volume), Indonesia, Taiwan Province of China (Taiwan POC) and Viet Nam. Marine fish aquaculture, particularly in Southeast Asia, relies on the collection of fish seed, juveniles or feed from the wild. Within Southeast Asia, most marine fish aquaculture can be defined as a form of “holding” and not true aquaculture². However, this scenario is changing. In Southeast Asia marine fish culture industries are increasingly reliant on hatchery stock, such as in grouper (*Epinephalus* spp.) farming in Indonesia (Plate 3), and therefore can be defined as “true” aquaculture. Brackishwater fish farming, principally of barramundi or Asian seabass (*Lates calcarifer*) and milkfish (*Chanos chanos*), is more established, being based on hatchery-produced fry and fingerlings.

Production trends

FAO aquaculture statistics include both marine and brackishwater fish, and it is difficult to separate the two. These statistics for the past 13 years show continued positive growth in Asian production (see Table 1) and a regional production of 1.7 million tonnes. The trends in overall production and value

² According to FAO (1997) “Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture while aquatic organisms which are exploitable by the public as a common property resource, with or without appropriate licences, are the harvest of fisheries.”

PLATE 2
Clustered, relatively large-scale cage farming activities in Asia



Cage farms using the “lapis dua” – two cage systems in the Cirata Reservoir, West Java, Indonesia.



Cage farming in BatanAi Reservoir in Sarawak, East Malaysia.



Cage farming of red tilapia in the lower Mekong, South Viet Nam.



Preparation of trash fish for feeding catfish.



Preparation of “home made” feeds for catfish cage farming using trash fish and other ingredients (1).



Working with fishermen to identify the species used as trash fish for cage farming in Cambodia.

TABLE 1
Farmed marine and brackishwater fish production from 1992 to 2004, based on FAO statistics

Country	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
China	58 716	71 672	101 110	144 957	182 155	254 979	306 697	338 805	426 957	494 725	560 404	519 158	582 566
Indonesia	193 136	215 065	208 824	212 733	250 617	195 543	232 708	265 511	278 566	308 692	314 960	316 444	315 346
Japan	263 503	259 273	271 351	279 182	256 223	255 774	264 018	264 437	258 673	263 789	268 405	273 918	262 281
Philippines	153 714	133 580	147 914	144 039	144 868	150 965	154 771	172 574	203 832	231 419	229 708	235 075	256 176
Taiwan POC	22 687	29 915	44 049	51 869	46 047	51 834	50 899	44 157	40 100	55 235	70 326	76 653	64 671
Korea, Republic of	4 595	5 471	6 643	8 360	11 384	39 121	37 323	34 382	27 052	29 297	48 073	72 393	64 195
Viet Nam	-	-	-	-	-	-	-	-	-	-	-	51 893	57 739
Bangladesh	16 000	17 520	17 379	13 301	22 126	26 748	25 851	26 912	27 801	28 044	32 026	34 101	39 493
Australia	4 402	4 977	5 878	8 585	10 466	10 730	9 816	11 796	14 517	17 774	19 728	20 382	21 469
Thailand	3 832	3 794	5 293	5 131	6 235	5 616	8 761	7 359	9 300	9 497	12 238	14 598	16 978
Malaysia	3 561	6 508	5 999	5 767	5 943	6 215	7 548	8 302	9 267	9 508	10 110	11 802	11 969
New Zealand	2 800	3 300	3 800	4 800	6 200	4 200	5 500	5 400	5 685	7 887	6 989	4 800	5 196
India	-	-	-	-	-	1 429	1 740	-	-	-	-	2 644	2 778
Singapore	786	536	480	644	644	818	593	914	1 402	1 088	1 294	1 897	2 366
China, Hong Kong SAR	3 400	3 010	2 989	2 950	3 144	3 032	1 271	1 284	1 787	2 473	1 215	1 492	1 541
Brunei Darussalam	8	31	51	74	72	69	74	77	59	30	39	38	104
Kiribati	41	52	32	17	9	7	4	13	14	18	14	9	9
Tuvalu	-	-	-	-	-	-	-	-	-	-	-	5	1
Cook Islands	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Micronesia, Fed. States of	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tonga	-	-	-	-	-	-	-	-	14	19	14	20	<0.5
Fiji Islands	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1	1	393	133	-
French Polynesia	3	6	-	3	10	2	3	3	10	19	19	19	-
Guam	<0.5	<0.5	4	5	5	5	5	7	7	7	7	-	-
TOTAL	731 184	754 710	821 796	882 417	946 148	1 007 087	1 107 582	1 181 933	1 305 044	1 459 522	1 575 962	1 637 474	1 704 878

Source: FAO, 2006

of brackishwater and marine aquaculture in the Asian region are shown in Figure 2. Based on these statistics, China leads in production, followed by Indonesia, Japan and the Philippines. Taiwan Province of China, the Republic of Korea and Viet Nam are some way behind, but are among the countries reporting more than 50 000 tonnes in 2004. China in particular has shown spectacular growth in marine and brackishwater fish farming in the past decade (see Figures 3 and 4).

FIGURE 3
Trend of production in the leading five Asian countries in marine farmed species

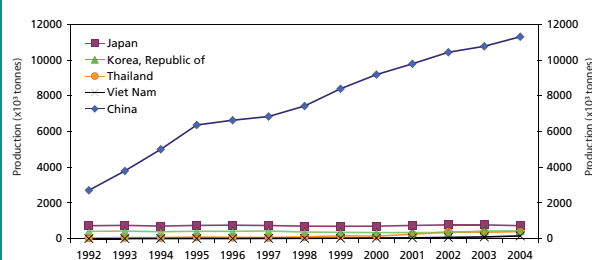


FIGURE 2
Production and value of marine and brackishwater aquaculture in Asia

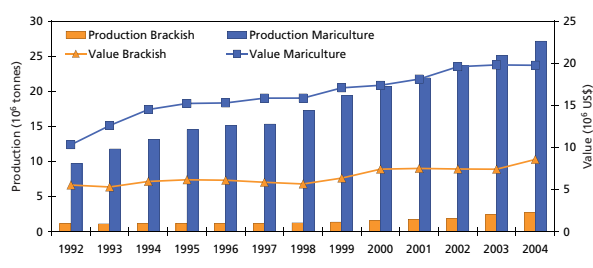


FIGURE 4
Trend of production in the leading five Asian countries in brackishwater farmed species

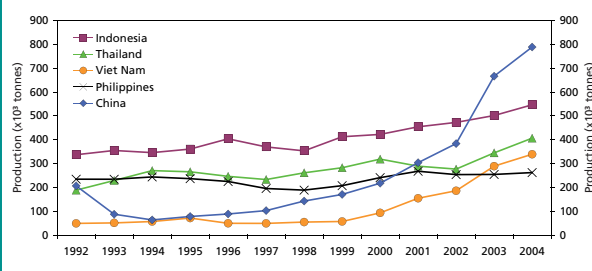


PLATE 3
Cage-farming activities



Grouper farming in Indonesia.



Grouper farming in Thailand.



Grouper farming in Viet Nam.



Cobia farming in Viet Nam.



Preparation of trash fish for feeding grouper in Thailand.



Trash fish for feeding cobia in Cat Ba Island, Viet Nam.

TABLE 2
Farmed brackishwater fish production from 1992 to 2004, based on FAO statistics

Country	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Indonesia	193 136	215 065	208 824	212 733	250 617	195 543	232 708	263 262	275 979	300 155	303 213	302 025	305 424
Philippines	153 714	133 182	147 628	143 818	144 747	150 528	147 103	163 669	194 708	221 145	211 965	212 927	218 390
Taiwan POC	22 395	29 480	43 590	51 159	45 006	50 062	47 891	42 057	35 934	50 046	64 078	69 056	58 743
Viet Nam	-	-	-	-	-	-	-	-	-	-	-	51 893	57 739
Bangladesh	16 000	17 520	17 379	13 301	22 126	26 748	25 851	26 912	27 801	28 044	32 026	34 101	39 493
Australia	4 067	4 341	4 603	6 658	8 453	8 546	8 117	10 194	11 786	13 699	15 716	16 882	17 439
Thailand	3 832	3 794	5 293	5 131	6 235	5 616	8 761	7 359	9 300	9 497	12 238	14 598	16 978
Malaysia	3 561	6 508	5 999	5 767	5 943	6 215	7 548	8 302	9 267	9 508	10 110	11 802	11 969
India	-	-	-	-	-	1 429	1 740	-	-	-	-	2 644	2 778
Brunei Darussalam	8	31	51	74	72	69	74	77	59	30	39	38	104
Singapore	-	-	-	-	-	-	-	1	3	3	4	3	58
Kiribati	41	52	32	17	9	7	4	13	14	18	14	9	9
Cook Islands	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Micronesia, Fed. States of	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tonga	-	-	-	-	-	-	-	-	14	19	14	20	<0.5
China, Hong Kong SAR	187	211	210	207	144	72	71	34	18	5	4	6	-
Fiji Islands	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1	1	393	133	-
French Polynesia	-	-	-	-	-	-	-	-	-	-	7	7	-
Guam	<0.5	<0.5	4	5	5	5	5	7	7	7	7	-	-
TOTAL	396 941	410 184	433 613	438 870	483 357	444 840	479 873	521 887	564 891	632 177	649 828	716 144	729 124

Source: FAO, 2006

TABLE 3
Farmed marine fish production from 1992 to 2004, based on FAO statistics but with brackishwater fish statistical categories removed

Country	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
China	58 716	71 672	101 110	144 957	182 155	254 979	306 697	338 805	426 957	494 725	560 404	519 158	582 566
Japan	263 503	259 273	271 351	279 182	256 223	255 774	264 018	264 437	258 673	263 789	268 405	273 918	262 281
Korea, Republic of	4 595	5 471	6 643	8 360	11 384	39 121	37 323	34 382	27 052	29 297	48 073	72 393	64 195
Philippines	-	398	286	221	121	437	7 668	8 905	9 124	10 274	17 743	22 148	37 786
Indonesia	-	-	-	-	-	-	-	2 249	2 587	8 537	11 747	14 419	9 922
Taiwan POC	292	435	459	710	1 041	1 772	3 008	2 100	4 166	5 189	6 248	7 597	5 928
New Zealand	2 800	3 300	3 800	4 800	6 200	4 200	5 500	5 400	5 685	7 887	6 989	4 800	5 196
Australia	335	636	1 275	1 927	2 013	2 184	1 699	1 602	2 731	4 075	4 012	3 500	4 030
Singapore	786	536	480	644	644	818	593	913	1 399	1 085	1 290	1 894	2 308
China, Hong Kong SAR	3 213	2 799	2 779	2 743	3 000	2 960	1 200	1 250	1 769	2 468	1 211	1 486	1 541
Tuvalu	-	-	-	-	-	-	-	-	-	-	-	5	1
French Polynesia	3	6	-	3	10	2	3	3	10	19	12	12	-
TOTAL	334 243	344 526	388 183	443 547	462 791	562 247	627 709	660 046	740 153	827 345	926 134	921 330	975 754

Source: FAO, 2006

Milkfish, a brackishwater species based on wild and hatchery collection, is the major contributor to these statistics for Indonesia and the Philippines. These two countries account for 70 percent of total brackishwater fish production in Asia (Table 2). The marine production statistics without brackishwater species show (Table 3) a total marine farmed-fish production in Asia of around 975 000 tonnes. China

currently leads both brackishwater and marine aquaculture production in Asia and globally.

Species cultured

A large number of fin fish species are farmed in cages in Asia. As yet there is a significant reliance on wild-caught young for farming of some species, such as in grouper culture in Thailand.

Major species production profiles

The marine fish production statistics presented in Table 4 are obtained from FAO FISHSTAT Plus (FAO, 2006). The species-group classification is based on FAOSTAT species-group and culture

environments (marine and brackishwater). These statistics have filtered out a few main species that are currently being cultured and/or classified as brackishwater or freshwater species. These include milkfish, tilapia, barramundi (Asian seabass) and

TABLE 4
Farmed production of major species groups from 1992 to 2004, based on FAO statistics but with brackishwater fish statistical categories removed

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Marine fishes nei	64 469	77 144	106 713	152 158	188 625	262 279	314 369	348 557	439 217	505 501	573 542	200 843	212 359
Japanese amberjack	148 988	141 799	148 390	169 924	145 889	138 536	147 115	140 647	137 328	153 170	162 682	157 682	150 113
Silver seabream	66 067	72 896	77 066	72 347	77 319	81 272	83 166	87 641	82 811	72 910	73 199	88 082	85 297
Japanese seabass	-	-	-	-	266	-	-	797	605	873	2 006	81 124	82 475
Large yellow croaker	-	-	-	-	-	-	-	-	-	-	-	58 684	67 353
Lefteye flounders nei	-	-	-	-	-	-	-	-	-	-	-	36 227	57 270
Porgies, seabreams nei	156	253	278	296	357	320	372	385	636	728	1 637	45 610	49 514
Red drum	-	-	-	-	-	-	-	-	-	-	-	44 925	43 506
Groupers nei	369	271	255	320	407	379	415	2 271	1 573	4 341	7 845	36 159	40 000
Milkfish	-	-	-	166	78	1 197	7 693	9 070	9 548	10 597	18 437	23 314	39 211
Bastard halibut	10 327	10 804	12 562	13 578	16 553	34 857	29 882	28 583	21 202	23 064	29 569	40 473	37 382
Cobia	-	-	-	3	13	9	961	820	2 626	3 224	2 395	20 667	20 461
Scorpionfishes nei	-	-	-	-	2 036	12 430	14 634	10 180	8 698	9 330	16 636	23 938	19 708
Puffers nei	4 068	4 427	3 456	4 031	5 552	5 961	5 389	5 100	4 733	5 769	5 231	14 602	19 190
Amberjacks nei	-	-	-	2	20	69	406	154	97	119	292	11 847	12 751
Coho(Silver) salmon	25 519	21 148	22 824	13 524	8 401	9 927	8 721	11 148	13 107	11 616	8 023	9 208	9 607
Righteye flounders nei	-	-	-	-	-	-	-	-	-	-	-	5 356	8 048
Chinook(Spring, King) salmon	2 800	3 300	3 800	4 800	6 200	4 200	5 500	5 400	5 685	7 887	6 989	4 800	5 196
Southern bluefin tuna	335	636	1 275	1 927	2 013	2 089	1 652	1 373	2 649	3 889	4 011	3 500	4 030
Flathead grey mullet	<0.5	<0.5	<0.5	<0.5	27	-	-	-	968	1 415	3 938	4 151	3 663
Jack and horse mackerels nei	1 853	2 183	2 391	2 653	2 343	2 217	2 568	2 935	3 058	3 396	2 931	2 313	2 668
Japanese jack mackerel	7 161	6 454	6 134	4 999	3 869	3 526	3 412	3 052	3 052	3 308	3 462	3 377	2 458
Barramundi (Giant seaperch)	396	233	204	288	292	255	248	732	1 076	4 191	1 917	2 521	1 825
Greasy grouper	45	90	89	88	360	562	132	170	419	671	208	677	643
Groupers seabasses nei	-	63	18	10	36	149	115	145	151	97	88	120	171
Areolate grouper	-	512	508	502	750	474	180	110	104	239	117	155	155
Mangrove red snapper	-	572	568	560	690	266	144	321	73	116	24	122	149
Orange-spotted grouper	-	-	-	-	-	-	-	-	-	-	-	76	139
Spinefeet(=Rabbitfishes) nei	<0.5	8	4	<0.5	3	40	4	19	66	51	60	84	120
Snubnose pompano	-	331	329	325	-	30	12	7	32	49	19	26	76
Russell's snapper	-	-	-	-	300	296	192	83	263	392	231	115	72
Snappers nei	93	92	53	42	81	64	36	70	152	61	29	9	51
Jacks, crevalles nei	-	-	-	-	-	-	-	4	13	9	-	4	36
Threadsail filefish	-	-	-	-	7	-	-	35	9	3	-	3	19
Goldlined seabream	1 253	963	956	943	240	799	180	64	86	82	19	6	17
John's snapper	-	-	-	-	-	-	-	-	-	-	-	10	11
Spotted coralgrouper	-	-	-	-	-	-	-	-	-	-	-	16	7
Malabar grouper	-	-	-	-	-	-	-	-	-	-	-	-	3
Tilapias nei	-	-	-	-	-	-	2	33	4	9	12	17	<0.5
Blackhead seabream	118	103	80	-	18	16	13	7	15	24	-	-	-
Croakers, drums nei	-	-	-	31	27	28	39	72	71	148	269	228	-
Daggertooth pike conger	-	-	-	-	-	-	-	-	3	-	-	-	-
Hong Kong grouper	10	30	30	30	-	-	-	-	-	-	-	-	-
Snappers, jobfishes nei	-	-	-	-	-	-	157	61	16	63	311	254	-
Yellowback seabream	-	-	-	-	-	-	-	-	7	-	-	-	-
Crimson seabream	117	122	52	-	-	-	-	-	-	-	-	-	-
Filefishes nei	99	92	148	-	-	-	-	-	-	-	-	-	-
Okhotsk atka mackerel	-	-	-	-	19	-	-	-	-	3	-	5	-
TOTAL	334 243	344 526	388 183	443 547	462 791	562 247	627 709	660 046	740 153	827 345	926 134	921 330	975 754

Source: FAO, 2006

salmonids. A brief description of the different groups is given below, together with some preliminary estimates of fingerling demand for grow-out.

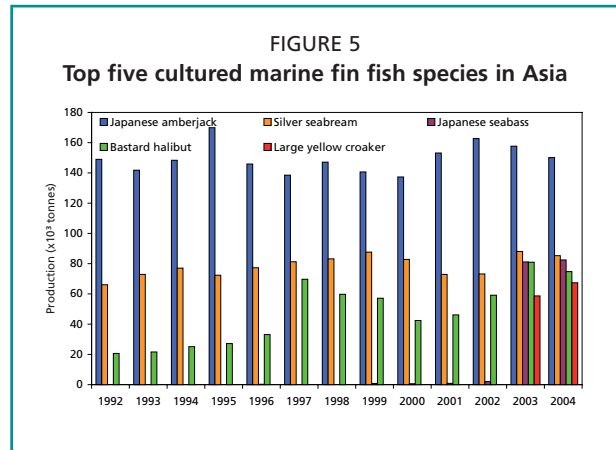
The “Marine fish nei” category consists of marine fish that are not further identified in the statistics. This figure is heavily influenced by China, which until recently reported all its marine fish farming in this category. The reality is that China has a large diversity of species (see Chen *et al.*, this volume) and a fairly well developed hatchery industry that supports it.

Overall both brackishwater and marine farming is dominated by a few species. In the case of marine farming, which is almost entirely cage farming, the leading species are those that have been farmed for a long time, particularly in Japan, and the production of emerging marine species such as groupers and cobia is still in its infancy (Figure 5).

Groupers

Grouper production in Asia was estimated by FAO in 2004 at around 58 000 tonnes. Additional grouper production from Viet Nam (which is not reported separately from other marine finfish production) is likely around 2 000 tonnes per annum, bringing total global production to around 60 000 tonnes (Rimmer, Phillips and Yamamoto, 2006). Probably at least 70 percent of this grouper production relies on the collection of fry, fingerlings and juvenile fish from the wild. Grouper culture is expanding rapidly in Asia, driven by high prices in the live-fish markets of Hong Kong SAR and China, the decreasing availability of wild-caught product due to overfishing (Sadovy and Lau, 2002) and general consumer resistance to the wild-caught “live-fish” trade.

A diversity of grouper species are cultured, but only a few are produced in hatcheries to any significant extent. *Cromileptes altivelis*, *Epinephelus fuscoguttatus*, *E. coioides*, *E. malabaricus*, *E. akaara*, *E. lanceolatus*, *E. tukula*, *E. areolatus*, *E. tawvina* and *E. polyphkadion* are reported (Rimmer, Williams and Phillips, 2000; Rimmer, McBride and Williams, 2004) from hatcheries around the region and are expected to form the mainstay of grouper production in the future. Most grouper grow out is conducted in cages located in marine estuaries or sheltered coastal areas. Groupers are generally sold alive at a size range of 0.5–1.2 kg per fish, with the average weight for table-size fish being 850 g, requiring ready access to markets.



Snappers

There are several species of seabream cultured in Asia, mainly in more temperate parts of the region. These include squirefish (*Chrysophrys auratus*), goldlined seabream (*Rhabdosargus sarba*), black porgy (*Acanthopagrus schlegelii schlegelii*) and red seabream (*Pagrus major*). FAO statistics suggest around 135 000 tonnes were produced in Asia in 2004. Seabreams are a mainstay of Asian finfish mariculture. Most seabream fingerlings are hatchery produced, and there is a well developed hatchery system in East Asia. The market sizes for seabream range from 350 to 450 g. Marine cage culture is the predominant means of culture.

Amberjacks and other Carangids

The Japanese amberjack (*Seriola quinqueradiata*) is the main marine fish species cultured in Asia (Figure 5), comprising 17 percent of total marine finfish production, with just under 160 000 tonnes produced in 2003 (FAO, 2006). Nearly all of this production comes from Japan, where production has been relatively stable at 140 000–170 000 tonnes per annum since the 1980s. Most if not all these fish are cultured in cages. Other carangids that are becoming popular for culture are snubnose pompano (*Trachinotus blochii*) and silver pomfret (*Pampus argenteus*).

Mackerel

Japanese jack mackerel (*Trachurus japonicus*) is the main mackerel species cultured. Okhostk atka mackerel (*Pleurogrammus azonus*) is also farmed, but only contributes a small portion to mackerel production. Some Japanese jack mackerel are cultured in marine cages in East Asia.

Cobia

Cobia (*Rachycentron canadum*) is increasingly being cultured in more subtropical and tropical waters, including in Taiwan Province of China, China, Malaysia and Viet Nam. Production, while still small, has increased significantly over the past three years. Most production currently comes from China and Taiwan Province of China and totaled around 20 000 tonnes in 2003 (FAO, 2006). Production of this fast-growing (to 6 kg in the first year) species is set to expand rapidly, not only in Asia but also in the Americas.

Cobia fingerlings used for aquaculture are mainly hatchery produced, with Taiwan Province of China being one of the first to establish hatchery production. Seed production in 1999 was around three million fingerlings of about 10 cm with a market value of US\$0.50 per fish. The average adult fish for market is quite large, 6–8 kg; however the market size varies from country to country. *Cobia* is becoming a popular fish because of its fast growth and its relatively easy culture. The survival rate in grow out is high, and it is not difficult to obtain 90 percent average survival. Most *cobia* is produced in marine fish cages.

Barramundi

Production of barramundi (also known as Asian seabass, *Lates calcarifer*) increased during the past ten years, and FAO statistics estimated that 26 000 tonnes were produced in 2004 (FAO, 2006). Barramundi farming in Asia is carried out in freshwater, brackishwater and marine environments, with most production based on hatchery-reared stock. Global production has been relatively constant over the past 10 years at around 20 000–26 000 tonnes per annum, although production has decreased in Asia and increased in Australia during this time. Most barramundi is cultured in ponds and cages located in brackishwater estuaries or coastal areas.

Milkfish

Milkfish (*Chanos chanos*) production in Asia is significant, with Indonesia and the Philippines contributing the bulk of the 515 000 tonnes as reported by FAO in 2004. Production, which has been increasing in the past 10 years, is based on wild fry and increasingly, on hatchery-produced fry. Milkfish culture takes place in coastal brackishwater ponds and to some extent in cages and pens. Milkfish aquaculture has a long tradition in the Philippines, where this fish is an important food item. Indonesia is a major producer of seed, much of which comes

from “backyard” or small-scale hatcheries. Most of the milkfish produced in Indonesia is used for bait by the Japanese tuna fishery. There is also a tradition of milkfish culture in some Pacific Islands, including Kiribati, Nauru, Palau and the Cook Islands. Although most milkfish culture is undertaken in brackishwater ponds, there is increasing production from intensive marine cages where the fish are fed pellets or trash fish.

Other species

A wide range of other species are cultured, including pompanos, rabbitfish, threadfins, croakers, drums, gobies, puffers, scorpion fishes and others. Many of these species are grown at least on an occasional basis in marine cages.

COUNTRY PROFILES**South Asia**

South Asia comprises India, Sri Lanka, Pakistan, the Maldives and Bangladesh. This subregion has very little marine fish culture (there is none reported in FAO statistics), although capture and holding of marine fish for the live reef fish trade is carried out in the Maldives and India.

In India, the live reef fish trade is mainly based on capture and holding in cages on the Andaman and Nicobar islands, which have some good coral reef fisheries. There are some new semi-government hatchery developments for barramundi (e.g. Rajiv Gandhi Centre for Aquaculture in Tamil Nadu and the Central Institute of Brackishwater Aquaculture in Chennai), and marine fish farming is expected to develop slowly in the future. A private hatchery near Mumbai reportedly produced around 10 million barramundi fry in 2003; however the present status is unknown. New investments are planned for 2006 for a marine fish hatchery and grow-out farm on the Andaman Islands, with support from the Marine Products Export Development Authority (MPEDA).

There is no marine fish farming in Pakistan or Bangladesh, except for the collection of by-catch of barramundi, mullet and other species in brackishwater shrimp ponds in the latter country. The Maldives has a grouper export industry to the live reef fish trade and is interested in grouper farming, but there have been no marine fish-farming developments to date. Feasibility studies for mariculture are being planned in the Maldives, which may lead to some investments in marine fish farming in the near future.

Southeast Asia

Southeast Asia comprises Brunei, Myanmar, Thailand, Malaysia, Singapore, the Philippines, Indonesia, Cambodia and Viet Nam. This subregion is an increasingly important producer of marine fish from aquaculture, as well as a supplier of marine fish for the live reef fish trade.

Myanmar

Groupers (*Epinephelus* spp.), known locally as “*kyauk nga*” or “*nga tauk tu*”, are exported live and in chilled/frozen forms. Live groupers are exported primarily to Hong Kong Special Administrative Region (SAR) for the live reef fish trade, and a boat carrying live fish travels to Myanmar four or five times per year, reportedly carrying five to six tonnes each time. This suggests a production of 30 tonnes/yr, which is an underestimate, but total farmed production is probably less than 100 tonnes/yr. Marine fish farming occurs in the Ayeyarwady Delta area, in Rakhine and in southern Myanmar. There is some extensive pond culture of barramundi, which is also collected as a by-product of traditional “trap and hold” shrimp ponds. Some fry and fingerlings have been imported from Thailand.

Groupers are cultured using fry and juveniles caught from the wild. Floating net-cage culture is conducted in the coastal areas of southern and western Myanmar (Myeik Archipelago and Gwa Township). Approximately 20 species of groupers are found in Myanmar’s waters, but so far only four have been cultured to any significant scale – orange-spotted grouper (*E. coioides*), greasy grouper (*E. tauvina*), Malabar grouper (*E. malabaricus*) and duskytail grouper (*E. bleekeri*).

No marine fish hatcheries currently exist in Myanmar. A private entrepreneur is planning to establish a grouper hatchery on the western side of the Ayeyarwady Delta, and the government is planning to build two or three marine fish hatcheries in the southern and western parts of the

country. The government also plans to establish a marine aquaculture station at Kyun Su Township in Tanintharyi Division.

Thailand

Six groupers (*Epinephelus coioides*, *E. malabaricus*, *E. areolatus*, *E. lanceolatus*, *E. fuscoguttatus* and *Plectropomus maculatus*) and two snappers (*Lutjanus argentimaculatus* is the main species), as well as barramundi, squaretailed mullet (*Liza vaigensis*) and milkfish are cultured in Thailand. Barramundi and groupers (primarily *E. coioides*) contribute some 99 percent of the marine fish farmed in Thailand, barramundi comprising about 85 percent of the total (14 550 tonnes) in 2004, while groupers accounted for 14 percent (2 395 tonnes) (Table 5).

Marine fish culture in Thailand takes place on the East Coast and the West Coast of the Gulf of Thailand, and on the Andaman Sea Coast. The East and West coasts contribute 30 and 20 percent of the marine fish production in Thailand, respectively, while the Andaman Sea Coast contributes the remaining 50 percent. The Andaman Sea Coast probably has the greatest potential for future development. Eighty percent of Thailand’s marine fish grow out takes place in cages, with the remainder occurring in ponds.

Some statistics on marine production and culture areas are provided in Tables 5 and 6. Barramundi is cultured in marine, brackish and freshwater, whereas groupers are cultured mainly in the sea. Farmers prefer cage culture to pond culture because partial harvesting of live fish for market is easier, cages are more conveniently managed and the costs of initial investment are also lower. For security, cages are always kept in front of farmers’ houses or adjacent to floating guard houses. In the marine environment, farmers prefer to stock groupers due to their higher price. However, they may shift to stocking with barramundi seed if grouper seed is

TABLE 5
Production (tonnes) from brackishwater and marine fish farming in Thailand

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Barramundi (<i>Lates calcarifer</i>)	3 884	4 087	4 090	6 812	6 056	7 752	8 004	11 032	12 230	14 550
Groupers nei	674	774	793	1 390	1 143	1 332	1 443	1 170	2 338	2 395
Mossambique tilapia (<i>Oreochromis mossambicus</i>)	327	602	283	267	128	190	30	27	19	23
Squaretail mullet (<i>Liza vaigensis</i>)	246	363	295	288	32	26	20	9	11	10
Fourfinger threadfin (<i>Eleutheronema tetradactylum</i>)		409	155	4	-	-	-	-	-	-
Total	5 131	6 235	5 616	8 761	7 359	9 300	9 497	12 238	14 598	16 978

Source: based on FAO (2006) statistics

TABLE 6
Production of barramundi and grouper in ponds and cages in Thailand in 2000

Culture system	No. farms	Area (m ²)	Quantity (tonnes)	Value (million US\$)
<i>Barramundi</i>				
Pond	378	4 516 464	1 414.10	2.89
Cage	2 805	265 517 800	6 256.51	14.47
Total	3 183	270 034 264	7 670.61	17.36
<i>Groupers</i>				
Pond	154	1 116 656	357.91	2.05
Cage	1 983	148 876	989.88	5.93
Total	2 137	1 265 532	1 347.79	7.98

Source: Department of Fisheries, Thailand

not available. In brackish and freshwater areas, barramundi is commonly cultured in cages along rivers and canals in close proximity to the live fish markets of main cities and tourist spots, in order to save transportation costs and achieve good survival. Barramundi is also becoming increasingly available in chilled forms through supermarket chains in Bangkok.

There are an estimated 5 000–6 000 farms producing brackishwater and marine fish in Thailand in cages and ponds. Further detailed information from the most recently available Department of Fisheries statistics (for 2000) are shown in Table 6.

Most marine fish farms in Thailand are small-scale, and farmers usually feed the stock with trash fish. Trash fish cost around US\$0.15–0.2/kg, and the food conversion ratio (FCR) for trash fish is around five to six³. Farm-made moist diet is also being tried for grow out, although progress is limited. Commercial floating pellet is also used in hatcheries and for adult fish; however, farmers still believe that growth performance is not as good as with fresh feed.

Barramundi seabass is produced mainly for local markets and is also exported chilled and live to Singapore and Malaysia by land. Some grouper production is exported (live by air) to Hong Kong SAR and China, and some is sold live in local markets, particularly live seafood restaurants. In 2003 the price for table-size barramundi (500–600 g) was US\$2.5–3/kg and for grouper around US\$4–5/kg. Although there is good potential for expansion of barramundi culture, in terms of availability of land, good water sources, fry and fingerling production, know-how, skilled labour, feed and expanding domestic markets, the lack of

export markets for frozen table-size fish is a major constraint. Farmers also consider it not economic to culture large barramundi (e.g. 1–3 kg) for export of fillets because of stunting problems after 600–800 g.

Major problems for the grouper grow-out industry in Thailand include market access and fluctuating prices (because Thai groupers do not have a good reputation among Hong Kong importers), lack of reliable seed supply, feed availability and disease. While there has been some interest in establishing large-scale “industrial” marine fish farms in Thailand, no projects have yet materialized. A new Norwegian public/private investment in southwest Thailand, however, may start in 2006.

Malaysia

In Malaysia, government agricultural policy is actively encouraging investment in aquaculture, and there has been increasing number of marine and brackishwater aquaculture operations. Cage culture has received special attention. Cage farming takes place in protected coastal waters, especially in the states of Perak (26 percent), Johor (21 percent), Penang (20 percent), Selangor (20 percent) and Sabah (9 percent) (year 2000 estimates).

The marine and brackishwater finfish species cultured in Malaysia include barramundi, snappers, groupers, travelly, pompano, threadfin, cobia and tilapia (Table 7).

TABLE 7
Species of interest in Malaysian mariculture

Common name	Scientific name
Barramundi	<i>Lates calcarifer</i>
Yellowstreaked snapper	<i>Lutjanus lemniscatus</i>
Mangrove red snapper	<i>L. argentimaculatus</i>
John's snapper	<i>L. johnii</i>
Crimson snapper	<i>L. erythropterus</i>
Orange-spotted grouper	<i>Epinephelus coioides</i>
Malabar grouper	<i>E. malabaricus</i>
Sixbar grouper	<i>E. sexfasciatus</i>
Brown-marbled grouper	<i>E. fuscoguttatus</i>
Leopard coraltrout	<i>Plectropomus leopardus</i>
Humpback grouper	<i>Cromileptes altivelis</i>
Fourfinger threadfin	<i>Eleutheronema tetradactylum</i>
Cobia	<i>Rachycentron canadum</i>
Red tilapia	<i>Oreochromis sp.</i>
Snubnose pompano	<i>Trachinotus blochii</i>

Source: Department of Fisheries, Malaysia

³ US\$1 = 40 THB

Farmers switch species depending on markets and disease problems. The number of species coming into play has increased drastically over the past five years, following hatchery breeding success.

Barramundi, a traditional species, still leads in culture practice. Snappers (Lutjanidae) are next in importance; these include the yellowstreaked snapper (*Lutjanus lemniscatus*), the mangrove red snapper (*L. argentimaculatus*), John's snapper (*L. johnii*) and the crimson snapper (*L. erythropterus*). Interest in grouper culture has led to at least six species being introduced. Commonly cultured species include brown-marbled grouper (*Epinephelus fuscoguttatus*), orange-spotted grouper (*E. coioides*) and Malabar grouper (*E. malabaricus*). Other minor species include fourfinger threadfin (*Eleutheronema tetradactylum*), cobia (*Rachycentron canadum*), snubnose pompano (*Trachinotus blochii*) and red tilapia (*Oreochromis* sp.).

In Malaysia the main production system for marine fish is still floating net-cages. Pond production may be suitable for high-value fish species that require water of higher salinity than that found in inland ponds. However, fish cultured in ponds are susceptible to an off flavor, and pond systems may not be convenient for producing fish for the live-fish market.

Seeing its potential, the Malaysian Department of Fisheries ventured into mass production using deep sea cages a decade ago. However, progress has been rather limited; as of end of 2005 there were 100 units of the square-type cages measuring 6 x 6 m each and a total of 21 units of round type-cages with a diameter of 15 m each. All of these cages were located at Langkawi Island, off peninsular

TABLE 8
Facilities and operators involved in Malaysian marine fish culture from 2002 to 2004

Facilities	2002	2003	2004
Hatcheries (units)	12	59	56
Cages (m ²)	940 948	1 034 664	1 110 221
Cage operators (individuals)	1 374	1 651	1 623

Source: Department of Fisheries, Malaysia

Malaysia's northwestern coast. The main reason for slow growth of the deep-sea marine farming sector seems to be the seed supply.

Until a new system of fish production or cage culture technology is introduced, traditional floating cages will continue to be the main marine fish production system. As of 2003 and 2004 there were a total of 1.0 million square metres of cage area, an increase of about 14 percent from year 2002 (Table 8). These cages were run by about 1 400 and 1 600 operators during the production years 2002 and 2003/2004, respectively (Table 8). The majority are small-scale farmers who operate small (3 x 3 m) to medium-size (6 x 6 m) cages. Stocking varies from 300 to 1 000 fingerlings per cage, the culture period extending 6-12 months depending on the species. Because of its low price and ready availability, trash fish remains the major feed type, and commercial feed is only occasionally supplemented. Many farmers believe that trash fish produces fish of higher quality and better texture.

In recent years increased intensification in production and area of cage farming has led to many disease problems. Frequent reports of mass mortalities related to water quality and oxygen depletion have occurred. Die-hard farmers seem to

TABLE 9
Production statistics and wholesale value for marine and brackishwater fish farming in Malaysia, 2002–2004

Fish species	Year	2002	2003	2004	2002	2003	2004
		Production (tonnes)			Value (Malaysian Ringgit)		
Barramundi (<i>Lates calcarifer</i>)		4 003.73	4 210.93	4 000.54	46 220.13	49 260.86	46 241.57
Mangrove red snapper (<i>Lutjanus argentimaculatus</i>)		591.44	706.56	572.97	6 157.05	8 415.69	7 742.36
Yellowstreaked snapper (<i>L. lemniscatus</i>)		1 556.15	2 351.55	2 263.33	20 188.00	32 491.55	32 771.81
Crimson snapper (<i>L. erythropterus</i>)		989.68	1 402.09	1 162.85	12 951.31	18 513.27	14 687.02
Groupers		1 210.43	1 977.33	2 283.59	30 385.26	49 954.09	54 628.69
Tilapias		283.97	222.07	264.42	1 683.98	1 049.09	1 387.08
Total		8 635.4	10 870.53	10 547.70	117 585.73	159 684.55	157 458.53

Source: Department of Fisheries, Malaysia

take this for granted and are willing to invest in new operations despite these losses.

In Langkawi, three large projects initiated for cobia using fry imported from Taiwan POC seem to be successful except that the farms have problems with marketing. Plans are on line to breed cobia and also work on giant grouper. Cage-fish production is also growing in eastern Malaysia (Malaysian Borneo), particularly in the Tuaran and Sandakan areas of Sabah, where there are plans to expand large-scale cage farming.

Production of the major species has fluctuated in recent years, and grouper is the only species-group that has shown continuous growth (Table 9).

Indonesia

Indonesia is the largest producer of marine finfish in Southeast Asia and has major development potential. According to government statistics, the potential marine aquaculture area is around 2 million ha and there are also 913 000 ha of land-based brackishwater areas. Present estimates suggest

that 0.17 and 45.4 percent, respectively, are in use. Therefore, the potential for marine aquaculture is considered by both government and some industry sources to be particularly high.

The main species groups cultured are barramundi, milkfish, grouper and snapper (Table 10). Other species that are considered to have potential for future development include the bigeye trevally (*Caranx sexfasciatus*), golden trevally (*Gnathanodon speciosus*), humphead wrasse (*Cheilinus undulatus*) and tunas (*Thunnus* spp.). There is a recent Japanese investment in a tuna hatchery in Bali, which will be interesting to watch over the next few years.

According to FAO statistics, the total production of marine and brackishwater fish in Indonesia was estimated at 305 000 tonnes in 2004. The bulk of this production is milkfish (241 000 tonnes), with smaller quantities of grouper (6 552 tonnes), barramundi (2 900 tonnes), mullet and tilapia. However, these figures are almost certainly under estimated, but more up-to-date or accurate figures are not available.

TABLE 10
Aquaculture species and the status of their development in Indonesia

Common name	Species Scientific name	Status of development ¹	
		Grow out	Hatchery
Milkfish	<i>Chanos chanos</i>	D	D
Barramundi	<i>Lates calcarifer</i>	D	D
Mangrove red snapper	<i>Lutjanus argentimaculatus</i>	ED	R/D
Emperor red snapper	<i>L. sebae</i>	ED	R/D
Rabbitfish	<i>Siganus</i> spp.	D	R/D
Humpback grouper	<i>Cromileptes altivelis</i>	LD	D
Brown-marbled grouper	<i>Epinephelus fuscoguttatus</i>	LD	D
Malabar grouper	<i>E. malabaricus</i>	ED	R/D
Camouflage grouper	<i>E. polyphkadion</i>	ED	D
Giant grouper	<i>E. lanceolatus</i>	ED	R/D
Orange-spotted grouper	<i>E. coioides</i>	ED	D
Leopard coral grouper	<i>Plectropomus leopardus</i>	ED	R/D
Humphead wrasse	<i>Cheilinus undulatus</i>	ED	R/D

D = developed, ED = early development, LD = limited development, R/D = under research and development
Source: Directorate of Aquaculture, Indonesia

TABLE 11
Estimated annual production of fry and fingerlings of marine finfish from hatcheries in Indonesia

Species	1999	2000	2001	2002
Milkfish (<i>Chanos chanos</i>)	227 989 617	NA	240 000 000	NA
Barramundi (<i>Lates calcarifer</i>)	15 000 000	NA	NA	NA
Groupers (<i>Cromileptes altivelis</i> , <i>Epinephelus</i> spp.)	186 100	287 000	2 742 900	3 356 200

NA = not available
2001 data on milkfish are unpublished data from private hatcheries.
Data for grouper seed production are from Kawahara and Ismi (2003).

Milkfish have been cultured in traditional coastal ponds (“tambaks”) for several hundred years in Indonesia. Grouper and barramundi culture is a more recent activity. Grouper farming relies on a mixture of wild-caught and hatchery-produced fingerlings, but is increasingly shifting to the latter. Barramundi production, although small by Indonesian standards, has increased significantly in the past 10 years. However, production peaked in 2001 at 9 300 tonnes and has been constant at around 4 000 to 5 000 tonnes since then.

Grow out is carried out in many areas of Indonesia, and grouper farming in particular is growing fast, especially in the Lampung area of southern Sumatra. Cage culture can be found throughout Indonesia, including the islands Sumatra, Bangka, Bengkulu, Lampung, Kepulauan Seribu, Banten, Java, Lombok, Kalimantan and Sulawesi. However, much of this culture is based on wild fish seed. Recent developments in Lampung have been largely driven by the availability of hatchery-reared grouper seed. The estimated annual hatchery production of marine finfish fry and fingerlings in Indonesia is presented in Table 11. Milkfish make up the bulk, with 240 million produced in 2001. Hatchery production of grouper is expanding, with 3.56 million produced in 2002. Of this total 2.7 million were brown-marbled grouper (*Epinephelus fuscoguttatus*), just less than 0.7 million were humpback grouper (*Cromileptes altivelis*) and the remainder were orange-spotted grouper (*E. coioides*) from the Lampung area.

The increase in grouper hatchery production in Gondol on the island of Bali has been very significant since 2002. Initially hatchery-produced fingerlings targeted export markets, but the demand was not consistent. This created a surplus of grouper fingerlings, particularly for brown-marbled and humpback groupers. To boost the domestic demand for grouper fingerlings, the government encouraged the development of marine fish culture. As a result, there has been a major development of grouper grow out in Indonesia over the last few years, particularly in the Province of Lampung where many large-scale grouper farms have been established. As a result, grouper fingerling production jumped from 2.7 million in 2001 to 3.3 million in 2002.

Constraints to marine fish farming in Indonesia include access to markets, fluctuating prices, insufficient hatchery supply, diseases (particularly viral nervous necrosis, VNN) and iridoviruses, which are both significant in hatcheries) and lack of suitable feeds for grow out.

The Philippines

In 2004 Philippine production of marine finfish reached 23 542.35 tonnes in marine cages and 14 294.42 tonnes in pens. Commodities produced include milkfish, grouper and other marine species (Table 12).

Milkfish is an important aquaculture commodity in the Philippines. For the past five years, production has steadily increased from 194 023 tonnes in 2000 to 269 930 tonnes in 2004, with an average annual growth rate of 8.7 percent (Table 13). Freshwater culture contributed 10 percent to the total milkfish production; brackishwater recorded the highest share (77.4 percent) due to improved practices, increased stocking density and expansion of operations, while marine cages and pens contributed 12.6 percent, an amount that has increased recently.

Major problems affecting marine fish farming in the Philippines include degradation of fingerling quality due to inbreeding, insufficient supply of quality fry in far flung areas, high cost of farm inputs, poor quality of feeds, lack of manpower to transfer technology effectively to the municipal level, marketing layers that stand between producers and consumers, and lost opportunities to participate in global markets for value-added products.

Viet Nam

Viet Nam has a growing marine fish-culture industry and with major government backing is embarking on a significant expansion programme. Government plans call for the production of

TABLE 12
Marine fish production (tonnes) from cages and pens in the Philippines in 2004

Culture system	Total	Milkfish	Groupers	Others
Fish cages	23 542.35	23 179.06	136.45	226.84
Fish pens	14 294.42	14 172.61	33.69	88.12
Total	37 836.77	37 351.67	170.14	312.96

Source: Philippine Fisheries Profile (2004)

TABLE 13
Philippine milkfish production (tonnes), 2000–2004

Year	Production
2000	194 023
2001	225 337
2002	231 968
2003	246 504
2004	269 930

Source: Philippine Fisheries Profile (2004)

200 000 tonnes of marine fish by 2010. Viet Nam therefore, has a potentially significant emerging marine fish-culture industry.

Marine finfish are cultured in three main areas of Viet Nam: the northern coastal areas, which produce around 600 tonnes; the south-central areas, which produce around 900 tonnes; and the east and southern parts, which produce 1 100 tonnes, giving a total production for the country of 2 600 tonnes in 2001. These Ministry of Fisheries figures are probably underestimates, the total farmed marine fish production in 2002 probably being at least 5 000 tonnes. There was considerable investment in hatcheries and cages ongoing during 2003, and the industry is expected to expand significantly in the next five years.

Eleven marine fish species are common in marine cages and ponds in Viet Nam's coastal waters (Table 14). These include cobia, which is increasingly popular in the north and also beginning to be cultured in the south-central provinces, barramundi, several grouper species and snappers. The main grouper species are orange-spotted grouper and Malabar grouper, with smaller amounts of brown-marbled grouper and duskytail grouper being produced.

Marine fish in Viet Nam are grown in cages and ponds. The farms tend to be small family-owned operations, although industrial-scale developments are also starting. According to the Department of Aquaculture (Ministry of Fisheries), the total number of cages in 2004 was 40 059 (not including cages for cultivated pearls). Production of fishes and lobsters for the year 2005 is estimated at 5 000 and 1 795 tonnes, respectively. Cage culture has developed mostly in Quang Ninh, Hai Phong,

Thanh Hoa, Nghe An, Ha Tinh, Phu Yen and Ba Ria –Vung Tau provinces. There are two kinds of cages: wooden frame cages of 3 x 3 x 3 m or 5 x 5 x 5 m are the most popular cages in most provinces, while Norwegian-style cages with plastic frames that can withstand 9–10 level winds and waves are popular in Nghe An and Vung Tau. These Norwegian style cages (Polar circle type) were introduced to Nghe An three or four years ago, and in 2003 a local company started to manufacture similar cages from local materials. A large-scale Norwegian investment is also in the early development stages for Nha Trang in central Viet Nam, and a local company is developing a large-scale operation in Nghe An (possibly 100 plus cages). There is cobia farming with Taiwanese management near Vung Tau in southern Viet Nam, but it is facing problems with low prices and limited markets. The fry are imported from Taiwan POC and are fed with trash fish and a mixture of mash and trash fish.

More than 90 percent of marine fish farms use trash fish, with some farms (perhaps 10 percent) using farm-made feeds with trash fish as the main ingredient, mainly for the first phase of grow out. The use of manufactured feed is not common. In 2004 Viet Nam had 30 feed mills producing 81 000 tonnes of feeds for aquaculture, contributing 55 percent of total consumption; however, as yet there is no domestic production of feeds for marine finfish. Nearly one million tonnes of trash fish is currently used as direct feed in aquaculture in Viet Nam, the bulk of it in mariculture (Edwards, Tuan and Allan, 2004).

Viet Nam is in the process of expanding marine fish farming, with a production of 200 000 tonnes predicted in government plans for the industry by 2010. Several trials and species look promising, however there are still several constraints. These include a need to develop markets, hatchery and nursing technologies, and feed alternatives to trash fish, and problems with disease control and health management. Feeds are likely to be a major constraint, and hatchery development will be essential to support future growth.

Singapore

Singapore has a small marine fish-farming industry, supplying mainly fresh and live fish to local markets. The total production of brackishwater and marine fish in 2004 as reported in FAO statistics was only 2 366 tonnes, the majority (2 308 tonnes) being marine fish. Most marine fish are produced in cages, and a smaller number are grown in

TABLE 14
Main finfish species used for mariculture in Viet Nam

Species	Sources of seed
<i>Epinephelus coioides</i>	Hatchery + Wild
<i>E. tauvina</i>	Wild + Hatchery
<i>E. malabaricus</i>	Wild
<i>E. bleekeri</i>	Wild
<i>Rachycentron canadum</i>	Hatchery
<i>Lates calcarifer</i>	Hatchery + Wild
<i>Psammoperca waigensis</i>	Hatchery
<i>Lutjanus erythropterus</i>	Wild
<i>Rhabdosargus sarba</i>	Wild
<i>Sciaenops ocellatus</i>	Hatchery
<i>Siganus</i> sp.	Wild

brackishwater ponds. Fry for stocking of cages are mainly imported.

Although marine cage culture has been conducted in Singapore for several decades, the government is now promoting the development “industrial” aquaculture. A Marine Aquaculture Centre (MAC) has been opened at St John’s Island for mariculture development activities. The centre was set up to develop and harness technology to facilitate the development and expansion of large-scale hatcheries and fish farming in Singapore and the region. The Centre aims to promote the reliable supply of a variety of tropical foodfish to local consumers as well as establish benchmarks on price and quality of fish in the market; help stabilize Singapore’s fish supply and reduce dependence on foodfish caught from the seas, since this is not sustainable in the long term; and promote the culture of fish using good quality and healthy fry that can be grown to market size using good and safe farming practices (e.g. minimal use of antibiotics and other drugs).

East Asia

East Asia comprises China, the Republic of Korea, Hong Kong Special Administrative Region (Hong Kong SAR), Japan and Taiwan Province of China. This subregion is the region’s largest producer of marine fish from aquaculture, as well as a major market for other parts of Asia. As far as the authors are aware there is no cage farming in the Democratic People’s Republic of Korea and therefore it is not considered here.

Hong Kong Special Administrative Region

There are about 1 400 mariculture farms with an average size of 250 m² covering a total area of 335 500 m² of sea and one land-based private experimental farm using a water recirculating system. Cage culture is the only commercial marine aquaculture system being used in Hong Kong SAR, and there is no major expansion plan for mariculture. The industry has suffered various setbacks in recent years, including devastating red tides, and fish farmers have found it difficult to compete with the neighboring provinces of China. The total marine fish production in 2001 was 2 468 tonnes valued at HK\$136 million⁴.

The consumption of live marine fish, popularly referred to as the live fish restaurant trade, in Hong Kong SAR was about 19 200 tonnes in 2001. Aquaculture production contributed

only 13 percent; capture fisheries accounted for 8.2 percent; and the remaining 74 percent was derived from importation, which was worth US\$128 million.

There are about 14 marine fish species being cultured in Hong Kong SAR (Table 15). Grouper is the main species group, contributing 37 percent of the total marine fish production. The second main species group is snapper, which accounted for 29 percent of the total marine fish production in 2001.

Trash fish, moist diet and dry pellets are used for grow-out culture. There are no precise data on the volume of feed used. The price of trash fish is about HK\$1/kg, while the price of dry pellets ranges from HK\$5-10/kg, depending on the nutritional content.

There is no marine fish hatchery in Hong Kong SAR, but local fishfarmers have established a few hatcheries and nurseries in Guangdong, China. According to the fry/fingerling traders in Hong Kong SAR, many of the fish originate from such hatcheries, as well as from Taiwan Province of China, Thailand, the Philippines and other Southeast Asian countries. The normal price for green and brownspotted (*E. chlorostigma*) grouper fingerlings ranged from HK\$8 to 12 (10–15 cm length), and for seabreams and snappers, from HK\$1 to 2 (for fish of 2.5 cm length). The value of fingerlings imported to Hong Kong SAR in 2001 was US\$7.8 million.

TABLE 15
Major marine fish species cultured in Hong Kong SAR in 2001

Species	Percentage of total
Greasy grouper (<i>Epinephelus tauvina</i>)	27
Cobia (<i>Rachycentron canadum</i>)	17
Russell’s snapper (<i>Lutjanus russellii</i>)	16
Brownspotted grouper (<i>E. chlorostigma</i>)	10
Red mangrove snapper (<i>L. argentimaculatus</i>)	5
White blotched snapper	5
Head grunt	5
Crimson snapper (<i>L. erythropterus</i>)	3
Goldlined seabream (<i>Rhabdosargus sarba</i>)	3
Japanese meagre (<i>Argyrosomus japonicus</i>)	2
Pompano	2
Red drum (<i>Sciaenops ocellatus</i>)	2
Black porgy	1
Yellowfin seabream (<i>A. latus</i>)	1
Others	1

⁴ HK\$8=US\$1.

China

The development and current status of cage and pen culture in China is described in detail elsewhere in this volume (see Chen *et al.*, this volume), and thus will only be briefly mentioned. China has a coastline of 18 400 km with 1 million km² of area suitable for aquaculture, and 0.13 million km² of area suitable for marine finfish culture. The country has a large marine area covering both temperate and subtropical waters, so there are many finfish species found in Chinese aquaculture. At present, more than 50 species of marine finfish are being cultured. China is the region's largest producer of farmed marine fish, and its marine fish farming is certain to expand further. In line with the country's rapid economic development, the market demand for marine fish is very large, especially the demand for high-value species.

Japan

The importance of mariculture production to Japanese fisheries is growing, and it presently provides around 20 percent of products by quantity. The gross value of Japanese mariculture production is around US\$3.8 billion. Major mariculture species include seaweeds, yellowtail, red seabream, Japanese oyster, amberjack and scallops. New target species for marine fish farming include northern bluefin tuna (*Thunnus thynnus*), barfin flounder (*Verasper moseri*) and groupers (*Epinephelus* spp.).

The most serious problem faced by mariculture in Japan is self-pollution from marine net cages. The level of pollution by Japanese mariculture is estimated to be equal to that produced by five to ten million people. These results clearly show the importance of environmental management of marine aquaculture.

Recently there has been considerable interest in bluefin tuna because of its high market value and demand in Japan, the decreased wild fish populations, and increased regulation of pelagic fisheries, the technical development of methods for the production of high-quality fish and the successes in production of artificial seed. The barfin flounder is an important species that can grow to a large size. Because of its high commercial value and rapid growth in the cold waters of northern Japan, the culture of this species has been expanding in Hokkaido and Iwate prefectures. Grouper culture has been practiced in the western part of Japan, but many aquaculture producers have hesitated with this species because of disease problems, particularly viral nervous necrosis (VNN).

Taiwan Province of China

Taiwan Province of China has a well-developed marine fish industry and is a major supplier of seed to other countries throughout the region. In 1998 over 64 species of marine fish were under culture, 90 percent of which were hatchery produced. The total production of marine and brackishwater fish in 2004 is estimated at around 58 000 tonnes. The cultured species include grouper, seabream, snapper, yellowtail, cobia, barramundi and pompano. Recent developments include expansion of cobia culture using large "offshore" cage technology, with cages that can be submerged during typhoons.

Some 2 000 freshwater and marine fish hatcheries are estimated to be operating in Taiwan Province of China, with a production worth over US\$70 million. In recent years Taiwanese hatchery operators have increasingly been involved in the establishment and operation of hatcheries in China and in other countries. Connections with Fujian Province seem to be particularly strong.

Marine finfish production is typified by highly specialized production sectors, e.g. one farm may produce grouper eggs from captive broodstock, a second will rear the eggs, a third may rear the juveniles through a nursery phase (to 3–6 cm TL) and a fourth will grow the fish to market size.

Taiwanese hatcheries typically use either indoor (concrete tanks up to 100 m³ with intensive greenwater-culture systems) or outdoor (extensive pond-culture systems) rearing systems for larviculture. Indoor rearing systems are used for high-value species such as groupers. Other species such as some snappers and cobia are only cultured in outdoor systems because of their specific early feed requirements. The orange-spotted grouper (*Epinephelus coioides*) is the main grouper species cultivated. More recently, there has been some production of giant grouper (*E. lanceolatus*), which is popular with farmers for its hardiness and rapid growth (reported to grow to around 3 kg in its first year). Despite the high level of fingerling production, Taiwanese farms also rely on wild-caught fry and fingerlings, which are generally imported. Information from Taiwanese hatcheries suggests that more than 40 species of marine fish can be raised in large numbers. Among these are *E. coioides*, *E. lanceolatus*, *Trachinotus blochii*, *Lutjanus argentimaculatus*, *L. stellatus* and *Acanthopagrus latus*. Cobia production in Taiwan Province of China is well advanced, and the technology is gradually expanding through the region.

Republic of Korea

Total marine and brackishwater fish production in the Republic of Korea was estimated as 64 000 tonnes in 2004. Lower production in 2000 and 2001 was considered to be due to increasing constraints on using coastal waters for mariculture and to environmental problems. The species cultured include Okhostk atka mackerel (*Pleurogrammus azonus*), bastard halibut (*Paralichthys olivaceus*), flathead mullet (*Mugil cephalus*), small numbers of groupers (*Epinephelus* spp.), Japanese amberjack (*Seriola quinqueradiata*), Japanese seaperch (*Lateolabrax japonicus*), squirefish (*Chrysophrys auratus*) and threadsail filefish (*Stephanolepis cirrhifer*). FAO statistics for 2004 show that the major cultured species are the bastard halibut (*Paralichthys olivaceus*) with 32 141 tonnes and the scorpion fishes (Scorpaenidae) with 19 708 tonnes.

Culture of marine fishes is mainly in cages, although some land-based farms have also been constructed in recent years. The marine subsector has experienced a sharp growth in recent years in terms of total quantity and value, with the production topped by two high-value species, bastard halibut (*Paralichthys olivaceus*) and Korean rockfish (*Sebastes schlegelii*) (Table 16). Bastard halibut is cultured in onshore tank farms while rockfish is farmed in offshore floating net-pens.

Currently, efforts are being made to further develop the offshore aquaculture technology in the Republic of Korea.

TABLE 16
Finfish mariculture production and species produced in the Republic of Korea in 2003

Species	Quantity (tonnes)
Bastard halibut (<i>Paralichthys olivaceus</i>)	34 533
Rockfish (<i>Sebastes schlegelii</i>)	23 771
Barramundi (<i>Lates calcarifer</i>)	2 778
Japanese amberjack (<i>Seriola quinqueradiata</i>)	114
Mullet (<i>Mugil cephalus</i>)	4 093
Red seabream (<i>Sciaenops ocellatus</i>)	4 417
Black porgy (<i>Acanthopagrus schlegelii schlegelii</i>)	1,084
Parrot fish (<i>Oplegnathus fasciatus</i>)	
Puffer (<i>Takifugu obscurus</i>)	14
Filefish (<i>Monacanthus</i> spp.)	
Convict grouper (<i>Epinephelus septemfasciatus</i>)	39
Okhostk atka fish (<i>Pleurogrammus azonus</i>)	
Total	72 393

Source: The Fisheries Association of Korea (2004)

CONSTRAINTS AND CHALLENGES TO BRACKISHWATER AND MARINE CAGE CULTURE DEVELOPMENT IN ASIA

The majority of constraints to development in brackishwater and marine cage culture in Asia are common to most nations. In considering the major constraints one has to bear in mind that, as yet, marine cage culture in Asia is still mainly restricted to the inshore areas, is often small scale, and apart from some practices in Japan, is of recent origin.

Availability of suitable sites

The rather simple cage designs utilized in the current practices, apart from a few exceptions, make it imperative that cages are sited in sheltered areas. This fact imposes a limitation on site availability for marine cage culture.

Experiences with larger, more robust cages such as those of Norwegian design have been less successful than expected, as exemplified by the case in Langkawi Island, Malaysia. This is primarily due to the fact that the supporting facilities to maintain such large cages have not been adequate, and consequently most cages have been not been used to their full capacity. Open-ocean cage farming in Asia, apart from in Japan and perhaps in the Republic of Korea and Taiwan Province of China, is believed to be a long way off. The South China Sea, which is shared by current and emerging aquaculture nations such as China, Viet Nam, Malaysia and others, is relatively shallow and has strong surface and bottom currents but less wave height, except during the seasonal severe typhoons. Accordingly, open-ocean cages for such areas need to be modified to reduce drag rather than to withstand wave height, as in the case of the Chilean and Norwegian operations.

Available sites for brackishwater cage farming in lagoons and estuaries in the main cage-farming countries are now almost fully utilized.

Fingerling supplies

The availability of hatchery-produced fry and fingerlings of truly tropical species such as groupers is rather limited. Unlike in Indonesia, grouper culture in countries such as Thailand and Viet Nam is almost entirely dependent on wild-caught juveniles, the availability of which is often unpredictable and of varied species composition. The cobia is the only emerging tropical mariculture species for which the life cycle has been fully closed and fingerling availability is not a limiting factor (Nhu, 2005).

TABLE 17
Average small-scale grouper hatchery operating costs
(as % total) in Indonesia

Operating expenses	Gondol	Situbondo	Average
Brown-marbled grouper (<i>Epinephelus fuscoguttatus</i>)			
Fertilized eggs	7.4	8.7	8.0
Feeds	41.7	49.6	45.7
Chemicals and drugs	4.7	5.6	5.2
Electricity and fuel	4.1	4.9	4.5
Labour	36.3	24.2	30.2
Maintenance and miscellaneous	5.9	7.0	6.4
Humpback grouper (<i>Cromileptes altivelis</i>)			
Fertilized eggs	10.3	13.3	11.8
Feeds	31.5	40.6	36.0
Chemicals and drugs	3.3	4.2	3.8
Electricity and fuel	2.9	3.7	3.3
Labour	47.9	32.8	40.4
Maintenance and miscellaneous	4.1	5.3	4.7

Source: Sih, 2006

The above constraints are, however, being gradually overcome. For example, large quantities of grouper (*Epinephelus fuscoguttatus*, *E. coioides* and *Cromileptes altivelis*) are hatchery produced in Indonesia, *E. fuscoguttatus* and *C. altivelis* being commercially produced by the private sector. *Epinephelus coioides* and *E. fuscoguttatus* are two of the main species produced in Thailand, while the former is also produced in Viet Nam (Sih, 2006). According to Sih (2006) the grouper hatcheries in Indonesia are mostly small scale but profitable. Even though the survival rate to fingerling stage averages only 10–15 percent, it is often compensated by the high fecundity of groupers. Information on the cost of hatchery production of grouper fry in Indonesia is given in Table 17. Hatcheries are considered to be financially viable only if the price of grouper fingerlings is above 700 Indonesian rupiah (IDR)/fingerling⁵. Currently grouper cage culture in Indonesia is primarily sustained through fry and fingerlings supplied by government hatcheries.

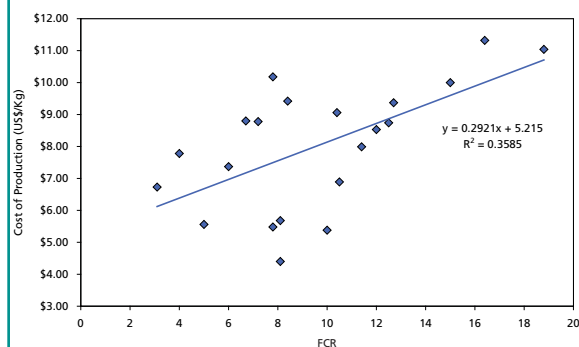
Feeds

The total amount of trash fish used in Asian aquaculture is estimated to be about 4 million tonnes per year (Edwards, Tuan and Allen, 2004), the great bulk of which is used in marine cage farming in China, Hong Kong SAR, Indonesia, Thailand and Viet Nam. Trash fish in marine cage

farming, particularly for grouper culture, is used directly (chopped into pieces whose size depends on the size of the stock), and the food conversion rates in Indonesian cage farms are reported to range from 6 to >17 (Sih, 2006). According to Sih (2006) the cost of producing a kilogram of grouper in cage-culture farms using trash fish in Indonesia, Thailand and Viet Nam, as expected with all types of feed, is directly correlated to the FCR (Figure 6). This relatively large range in FCR among grouper cage-farming practices indicates that there is significant scope for improving the efficacy of the use of trash fish, leading to greater cost effectiveness, less pollution and most importantly, a significant reduction in the quantity of trash fish used.

When marine cage culture initially started in Japan, it was almost entirely based on trash fish (Watanabe, Davy and Nose, 1989). It took a certain length of time to develop formulated feeds, and a major breakthrough in that era was the development of a soft-dry diet with high palatability for Japanese amberjack. This development continued to revolutionize feed development for marine cage farming and literally removed its dependence on trash fish (Watanabe, Davy and Nose, 1989). Of course, feed formulations and feed manufacturing technology for finfish have progressed much further now. Currently much research effort is being expended on feed formulation for emerging marine-cage-farming species in the Asian tropics such as grouper and cobia (Rimmer, McBride and Williams, 2004).

FIGURE 1
Relationship of cost of production to food conversion rate (FCR) in grouper cage farming in Indonesia, Thailand and Viet Nam using trash fish as the primary feed



Source: Sih, 2006

⁵ 8 500 IDR = US\$1.

The main reasons for the continued use of trash fish in grouper culture and in marine cage farming in general, are:

- farmer perceptions that stocks perform better on trash fish;
- the lower price of trash fish as compared to commercially available pelleted feed, and its continued ease of availability;
- the lack of availability of suitable commercial pelleted feed for all stages of the life cycle of cultured stocks; and
- social and economic constraints, including the availability of capital or credit to purchase commercial feed and the fact that collection and/or purchase of smaller quantities of trash fish on a regular basis is more compatible with the existing livelihood strategies of many coastal fish farmers as compared to more “organized” commercial feed lot farming.

Diseases

Increased intensification of culture practices has resulted in an increase of incidence of all forms of disease in marine finfish farming in Asia (Bondad-Reantoso, Kanchanakhan and Chinabut, 2002).

Arthur and Ogawa (1996) identified the principal diseases that are caused by environmental and management affects, nutritional causes, and viral, bacterial, parasitic and fungal pathogens in cultured marine finfish in Asia. Bondad-Reantoso, Kanchanakhan and Chinabut (2002) reported that several viruses affect cultured grouper species:

- nodavirus – viral nervous necrosis (VNN);
- iridoviruses – grouper iridovirus-1 (GIV-1), grouper iridovirus-2 (GIV-2), Singapore grouper iridovirus (SGIV) and Taiwan grouper iridovirus (TGIV);
- lymphocystis virus;
- herpes virus;
- astro-like virus (golden eye disease); and
- red grouper reovirus.

Although there have not been major disease outbreaks, except in isolated instances, there is much concern that further intensification and clustering of marine cage farming in restricted areas will lead to major epizootics.

It is also important to note that there is high degree of trans boundary movement of broodstock, fry and fingerlings across much of Asia. When such movements occur, little attention is often paid to their potential to spread serious exotic diseases, pests and invasive alien species, with

related potential impacts on biodiversity and socio-economic well being.

Markets

One of the primary reasons for the recent increase in marine cage farming in the region, particularly of species such as grouper, is the increasing demand for live fish for the restaurant trade, particularly in China, Hong Kong SAR and Singapore, among others.

This increase in demand, hand in hand with consumer resistance to wild-caught “reef fish”, particularly because of the destructive methods often used for catching (poisoning, dynamiting, etc.), has been responsible for the demand for farmed marine fish from this sector.

However, the live food-fish trade is a sensitive market, often being significantly affected by the economic conditions of importing countries and global catastrophic events such as the 9/11 terrorist attack, the occurrence of severe acute respiratory syndrome (SARS) and wars in general (Sih, 2005).

In such circumstances the demand is reduced significantly, and to obtain a fair price the farmers have added costs associated with holding their stock until conditions return to normality. Small-scale marine cage farmers often find it difficult to sustain themselves when such conditions prevail.

Technological challenges

Fry and fingerling survival rates of the major species raised in marine cage farming in Asia, groupers foremost among these, remain too low. For example, the current average rate of grouper survival is less than 15 percent. These low survival rates increase the current dependence on wild-caught seed stock.

Marine cage farmers do not yet accept the importance and cost effectiveness of using dry pelleted feeds for the long-term sustainability of the sector, and perhaps even for marketing purposes. In the future some importing nations may enact legislation to curtail the use of trash fish as a feed in marine fish farming and consequently place the farmers at a disadvantage.

Vaccines for preventing disease in such major species farmed as groupers and cobia are lacking.

Genetically improved strains of selected species that are pivotal to the development and sustenance of cage farming in Asia for faster growth and enhanced disease resistance have not yet been developed.

THE WAY FORWARD

This final section identifies some likely future trends in Asian cage culture and gives recommendations that will assist countries to meet the challenge of achieving continued growth of the sector while addressing the marketing, environmental and other challenges that have been mentioned in the preceding section:

- Most countries in the region have plans for the future expansion of marine fish farming, Viet Nam perhaps being the most ambitious. The next five years will see a transition of marine fish farming to hatchery-based aquaculture, as wild stocks diminish, production expands and restrictions are imposed on collection of wild fish for stocking of cages⁶.
- The multiple use of coastal waters in countries such as the Republic of Korea will restrict further development of marine fish farming, and it is possible that local cage-culture industries will in some cases decline or at best remain static in the coming few years.
- Brackishwater cage farming in Asia uses relatively simple technology and occurs in clusters, a trend that is likely to continue in the foreseeable future.
- As hatchery techniques develop, marine fish demand increases and various constraints appear with wild stock collection, the industry is expected to focus increasingly on a few key species based on hatchery production.
- Cobia is set to become a global commodity, in the same manner that Atlantic salmon (*Salmo salar*) has become a global commodity in temperate aquaculture.
- As marine cage farming in Asia is based mainly on small-scale holdings, the management practices currently employed have considerable scope for improvement. The most potential for improvement lies in proper feed management, which is the single highest recurring cost in all practices. Other improvements to management practices that are required include reducing the use of chemicals and antibiotics, improving fry and fingerling transport and developing market chains and strategies.
- The optimum stocking densities for the species and systems currently in use in Asian marine cage culture should be established, and farmers should be encouraged to adopt polyculture where applicable.
- Farmers should be encouraged to use formulated feeds by stressing the negative impacts the use of raw fish may have on the environment. High-energy feeds with high digestibility should be formulated and used so as to reduce the nutrient load in effluents.
- The current dependence of the marine cage culture sector on trash fish should be reduced. This could be done in stages by:
 - initially demonstrating to the farmers ways and means of increasing the efficacy of using trash fish, such as through the adoption of better feeding management strategies;
 - using trash fish to prepare suitable “on-farm” moist feed using other additional agricultural products such as soybean meal, rice bran, etc.;
 - demonstrating the efficacy of dry-pelleted feeds over the former through demonstration farms; and
 - perhaps providing market incentives for farmers to adopt more environmentally sound feeding methods using formulated diets.
- Efforts are needed to transfer the findings of current research on feed formulation for species such as grouper and cobia into practical application by the commercial sector.
- In order to ensure an adequate supply of healthy fry and fingerlings of grouper so that the cage-culture sector can continue to expand and intensify, the private sector should be encouraged to develop sufficient viable grouper hatcheries.
- Important lessons in disease prevention and water usage can be learned from the shrimp-farming sector. Siting of marine cages should take into account the suitability of the environment for the species to be cultured and avoid problems caused by self-pollution.
- To address the increasingly stringent requirements imposed by importing nations such as the United States of America and the members of the European Union, Asian countries need to develop internationally accepted systems for ecolabeling of their aquatic produce.
- To ensure that their aquaculture products remain acceptable on international markets and fully conform to international standards, small-scale

⁶ For example, Asia Pacific Economic Cooperation (APEC) economies in Asia have drafted a set of “standards” for the live reef-fish trade that emphasize the use of hatchery-reared stocks in aquaculture.

Asian cage farmers must further reduce their reliance on antibiotics and other therapeutants.

- Given the volatile nature of the live food-fish market for the restaurant trade, farmers should diversify the range of stock that they farm to include both exportable products and those that can be sold on domestic markets.
- There is an urgent need to develop better management measures in relation to disease prevention and to accelerate the development of vaccines for specific diseases of farmed marine finfish.
- Countries should take appropriate biosecurity and risk management measures to prevent the introduction of exotic diseases, pests and invasive aquatic species along with their international and domestic trade in live aquatic animals.
- Currently most Asian nations have inadequate regulatory measures in place for marine cage farming, a situation that could lead to the use of available inshore sites beyond their carrying capacities. More governmental intervention in stream lining cage-farming activities may be desirable and would also help to develop firmer market chains and vertically integrate the different sectors, bringing about more efficacy and cost effectiveness.
- The sustained development of finfish cage farming in Asia will only be ensured if proper regulatory measures are in place. Thus national governments have to be pro-active and work in cooperation with the farmers.

Overall the future prospects for all forms of cage farming look relatively bright for Asia. However the large-scale, capital-intensive, vertically integrated marine cage-farming practices seen in northern Europe (e.g. Norway) and South America (e.g. Chile) are unlikely to occur in Asia. Instead of large-scale farms, clusters of small farms generating synergies, acting in unison and thereby attaining a high level of efficacy are likely to be the norm. Off-shore cage farming is unlikely to become widespread in Asia, as its development is hampered by availability of capital and the hydrography of the surrounding seas, which does not allow the technology available elsewhere to be easily transferred. Despite these limitations and constraints, cage farming in Asia will continue to contribute significantly to global aquaculture production and Asia will also continue to lead the world in total production.

ACKNOWLEDGEMENTS

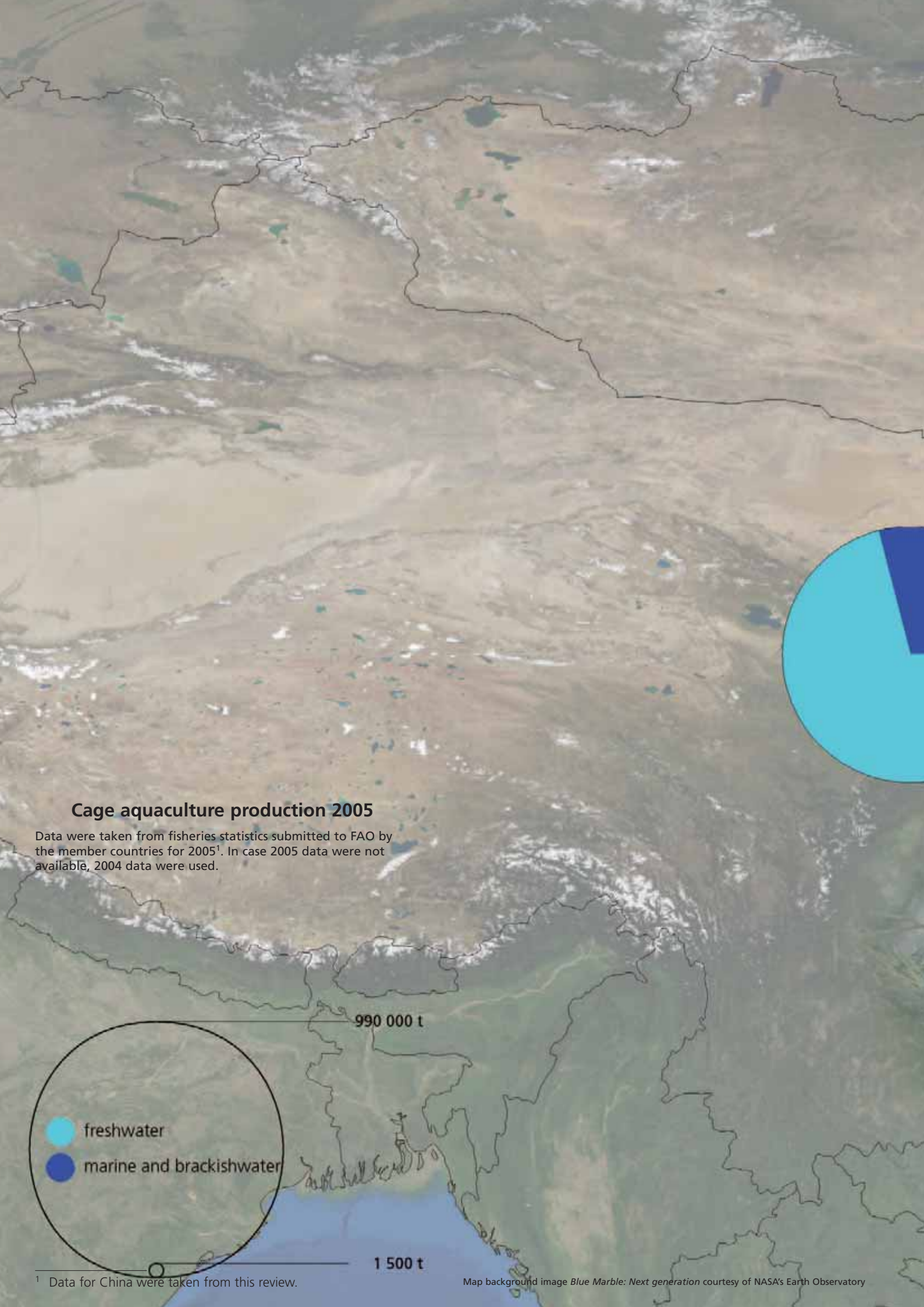
We wish to thank Mr Koji Yamamoto, Mr. Koshi Nomura and Dr. Thuy Nguyen of NACA for extraction of data from the FAO databases and preparation of some of the figures, respectively; Mr Sih Yang Sim of Agriculture, Forestry and Fisheries Australia for permitting to the use of Ph.D. thesis material; and Dr Le Thanh Hung of Ho Chin Minh Agriculture and Forestry University for providing information on the catfish farming industry in the Mekong Delta, Viet Nam.

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Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005¹. In case 2005 data were not available, 2004 data were used.

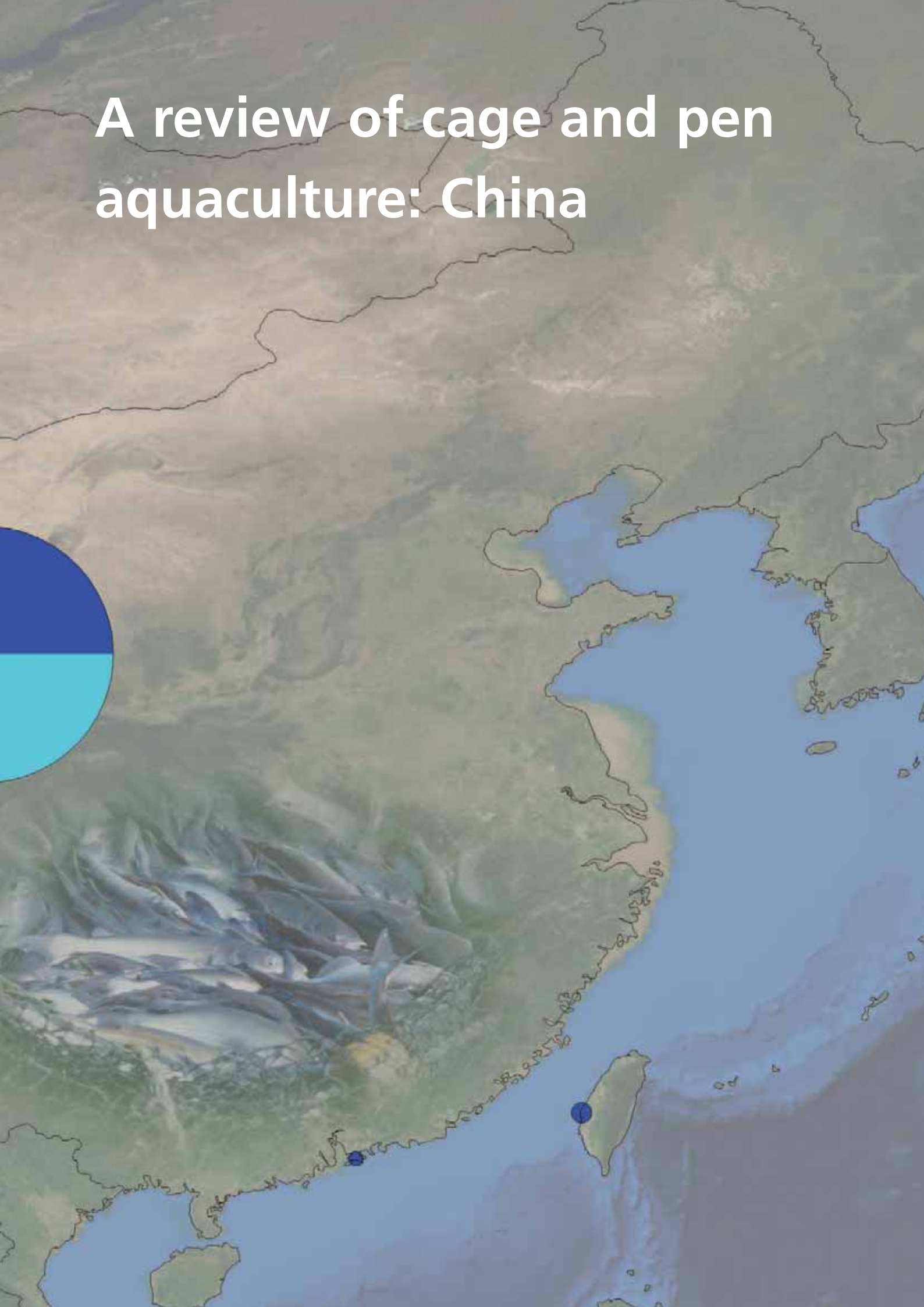
990 000 t

- freshwater
- marine and brackishwater

1 500 t

¹ Data for China were taken from this review.

A review of cage and pen aquaculture: China





A review of cage and pen aquaculture: China

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A review of cage and pen aquaculture: China. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 50–68. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

Cage and pen⁶ culture has a long history in China, but the development of modern intensive cage culture for food production and ornamental purposes dates from the 1970s. Cage/pen culture was first adopted in freshwater environments and more recently, in brackish and marine systems. Due to advantages like land and energy savings, high yields, etc., cage/pen culture has quickly expanded countrywide since the 1970s. In 2005, inland cages and pens occupied areas of 7 805 and 287 735 ha, respectively. The number of freshwater species cultured now exceeds 30 and includes fish such as carps, tilapias, breams, catfishes, trout, bass and perch, as well as crustaceans, turtles and frogs. Cages and pens in freshwater lakes and rivers yielded 704 254 tonnes and 473 138 tonnes of fish and other aquatic animals, respectively, in 2005.

The number of traditional marine fish cages distributed in coastal provinces, cities and zones is estimated at one million units. Since the 1990s, offshore cage culture has been considered a priority as a means to culture suitable marine fish in the twenty-first century. At present more than 40 marine fish species are being farmed, of which 27 species are reared in hatcheries. Six models of offshore cages have been developed, and around 3 000 units are currently under production. The volume of traditional cages and offshore cages reached 17 million and 5.1 million cubic metres, respectively, in 2005; and the yield harvested from all coastal cages was 287 301 tonnes in the same year.

In some aquaculture sites, especially those in lakes, reservoirs and inner bays, the ecological balance has been affected due to an overload of cages or pens, with consequent disease problems. Direct losses caused by disease amount to US\$10 million or more annually, accounting for about one percent of the total losses in aquaculture.

The fishery policies of the Chinese Government require local authorities to limit the number of cage and pen culture operations to a reasonable level in order to maintain an ecological balance and a harmonious environment.

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⁶ **Pen:** Fenced, netted structure fixed to the bottom substrate and allowing free water exchange; the bottom of the structure, however, is always formed by the natural bottom of the waterbody where it is built. A pen generally encloses a relatively large volume of water. **Cage:** Floating rearing facility enclosed on the bottom as well as on the sides by wooden, mesh or net screens. It allows natural water exchange through the lateral sides and in most cases below the cage.

BACKGROUND

This study was commissioned by the Food and Agriculture Organization of the United Nations (FAO) as one of a series of reports on the global status of cage aquaculture and was presented at the Second International Symposium on Cage Aquaculture in Asia, held in Hangzhou, China, 3–8 July 2006.

This paper reviews the history and status of cage and pen aquaculture in China, discusses the issues affecting their development and proposes a way forward for their sustainable development within the Chinese context. Data on cage and pen culture in China are rarely disaggregated and hence, are also reported in aggregated form here. However, to the extent possible, the paper attempts to differentiate between the two production systems.

HISTORY AND ORIGIN OF CAGE AND PEN CULTURE IN CHINA

Modern cage and pen culture in China has a history of over 30 years, dating from the early 1970s (Hu, 1991; Wang, 1991). During this period, cage culture became an indispensable part of Chinese fisheries. In 2005, the production from cage/pen culture attained 1.46 million tonnes, accounting for 4.4 percent of the total aquaculture production by value and 2.9 percent of the total by volume in that year (Fisheries Bureau, 2005). Although these percentages represent only a small fraction of the country's total aquaculture output, the advantages of these production methods have been recognized as important factors stimulating the growth of fish culture. As a result of the experience gained from cage and pen culture, Chinese farmers have made significant advances in cage and pen design and in management methods. At the same time, cage/pen culture has promoted the development of secondary industries such as net production and has created new employment opportunities for rural labourers. However, farmers have also faced many constraints, including: (i) environmental problems caused by overloading of aquaculture sites with cages and pens; (ii) financial problems for small-scale farmers and investors due to excessive investment in offshore cages; and (iii) a shortage of operational techniques for offshore cages and associated facilities. Cage farmers, policy-makers and investors have thus had to face the problem of how to deal with these constraints in order to achieve the sustainable development of cage and pen culture.

Inland fish cage culture

China has a long history of inland cage culture of freshwater fishes. Some 800 years ago, Chinese fish farmers began using densely meshed cages to culture fry collected from rivers, holding them temporarily in the cages for 15 to 30 days before their sale (Zhou, 1243).

These methods of natural fry collection and small-scale pond fish culture are still practised today (modern large-scale cage culture started only in 1973) (Hu, 1991; Xu and Yan, 2006). Cages were established to culture fingerlings of silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) using primary production (phytoplankton) from a reservoir. The use of large-size fingerlings (>13 cm) improved survival rates when they were stocked back into the reservoir. This method is still being used today. Later, the method was further developed to culture two-year-old silver and bighead carp fingerlings in cages. Since 1977, techniques have been developed for the cage culture of table-sized silver and bighead carps without the application of supplementary feeds. At the same time, the cage culture of grass carp (*Ctenopharyngodon idella*), Wuchang bream (*Megalobrama amblycephala*) and common carp (*Cyprinus carpio carpio*) with the application of feeds was also launched.

Aiming to find more efficient ways to utilize China's water resources, cage culture entered a period of great expansion in the 1980s. During this period, the main characteristics of Chinese cage culture were: (i) the culture of silver and bighead carp fingerlings for stocking into reservoirs using natural plankton productivity; (ii) the culture of silver and bighead carps from fingerlings to grow-out without applying feeds; and (iii) the cage polyculture of two or more species of fish. At this stage cage culture yielded some production, but the per-unit-area output and economic returns were not considered satisfactory. Since the late 1980s, experiments on various kinds of cage-culture techniques have all aimed at increasing fish yields or economic returns. During this period the technological basis for models for (i) the cage monoculture of common carp at high stocking density with complete culture from fingerling to grow-out using an all-nutrient feed application and (ii) the cage culture of grass carp with the application of aquatic plants were fully developed and extended rapidly.

In the 1990s, China experienced some great breakthroughs in the development of cage-culture techniques. Many new species were cultured,

and the use of formulated feeds was applied. The species farmed in cages expanded to include Crucian carp (*Carassius carassius*) and Wuchang bream, which are normally cultured in ponds, as well as rainbow trout (*Oncorhynchus mykiss*), tilapias (*Oreochromis* spp.) and channel catfish (*Ictalurus nebulosus*), exotic species introduced from other countries, as well as carnivorous fishes like braco grunter (*Scortum barcoo*), Chinese perch (*Siniperca chuatsi*) and white Amur bream (*Parabramis pekinensis*).

With the extension of small-scale cage culture and the increase in the number of species cultured, individual fish farmers with little capital have increasingly taken up cage culture. The integration of the excellent environmental conditions associated with open waters with high-yielding cage-culture techniques has led to the production of high-quality aquaculture products, higher production efficiency, and excellent market competitiveness, which has enabled China's cage culture sector to continue to develop.

History of pen culture

For more than 50 years, Chinese fish farmers have practised aquaculture by enclosing large areas in lakes and rivers with dykes on two or three sides. However, this method, which results in limited water exchange, and the extensive culture methods used, resulted in low yields and economic returns. In the 1970s, the overstocking of grass carp in "aquatic plant-type" lakes (i.e. lakes whose aquatic flora is characterized by aquatic plants such as *Chara*, *Isoetes*, *Ceratopteris*, *Alternanthera*, etc. that can be used as feed by herbivorous fishes and crabs) turned these lakes into "aquatic algae-type" lakes. In order to utilize the aquatic plant resources in a sustainable way, pen culture experiments were carried out in the main areas of the aquatic weed-type lakes. In the late 1980s, pen culture expanded rapidly and became widely applied for aquaculture production. China's pen culture is based mainly on the principle of culturing herbivorous fishes that feed primarily on submerged plants. Research and monitoring studies indicated that: (i) the submerged plants had high biological productivity; (ii) adoption of techniques to increase aquatic plant production would not only lead to quite high fish yields and economic returns from pen culture, but would also delay lake eutrophication (i.e. the deterioration of lakes into marshes); and (iii) pen culture can be an ecologically sound method of fish farming that is suitable for sustainable

development. Since the 1990s, pen culture has become a preferred culture method, mainly for culturing Chinese mitten crab (*Eriocheir sinensis*).

History of marine cage culture

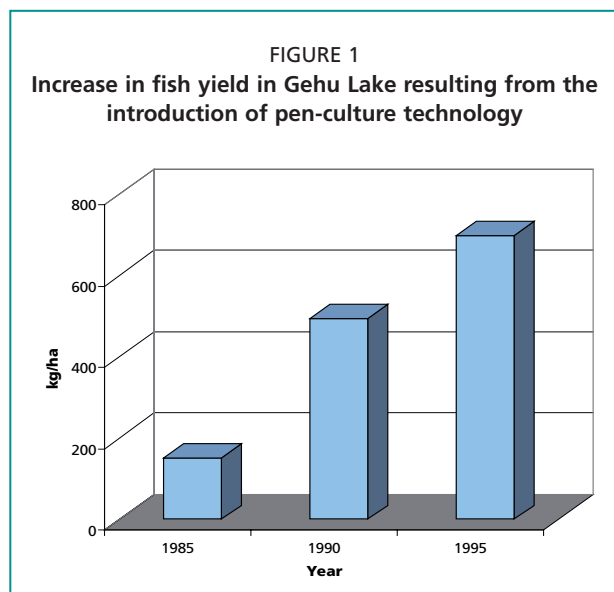
In the late 1970s, Huiyang County and Zhuhai City, Guangdong Province tried to farm marine fishes, including groupers and seabream, in cages. These successful experiments were the first trials of marine cage farming in China (Chen and Xu, 2006; Xu and Yan, 2006). By 1981 experimental marine cage farming had been expanded to a commercial scale. Almost all marine cage production was exported to markets in Hong Kong Special Administrative Region (SAR) and Macao Special Administrative Region, providing significant economic benefits. Beginning in 1984 other counties and provinces (e.g. Fujian and Zhejiang provinces) also began to farm marine fish in cages. According to survey data, the number of marine fish cages in the three provinces of Guangdong, Fujian and Zhejiang had exceeded 57 000, and more than 40 species of marine fish were farmed. In its early stages of development, cage farming was conducted at an artisanal level. Research leading to the development of modern cage systems has only taken place since the 1990s, primarily in line with the development of techniques for the culture of such marine fishes as red seabream (*Pagrus major*), Japanese seaperch (*Lateolabrax japonicus*), cobia (*Rachycentron canadum*) and croceine croaker (*Larimichthys crocea*). The rapid development of marine cage culture in China has continued since the beginning of the twenty-first century. Currently the total number of marine cages has reached an estimated one million units, which are distributed in China's coastal provinces and zones: Liaoning, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong and Hainan provinces and Guangxi Zhuangzu Autonomous Region. Among them, some 3 000 offshore cages have been installed.

THE CURRENT SITUATION

Advantages of cage and pen culture

In China, great importance is attached to the development of cage and pen culture because these aquaculture farming systems:

- directly and efficiently utilize natural water resources;
- save national land resources because there is no need to dig ponds; (For example, cage/pen culture yielded a production of 69 111 tonnes in Jiangsu Province in 1995, equal to the yield



example, in 1985 fish production in Gehu Lake, which mainly resulted from a capture fishery, was 150 kg/ha. In 1990 when pen culture was initiated, the production rose to 495 kg/ha, an increase of 3.3 times and by 1994 it reached 698.52 kg/ha or a total increase of 460 percent in ten years [Figure 1].)

Present status of inland cage and pen culture

Prior to initiating cage or pen culture in the lakes, reservoirs or rivers of China, the waterbody must first be checked to assure that its conditions are suitable. Cage culture is suitable for the monoculture of fish at high stocking density, mainly with the application of feeds. Oligotrophic waterbodies with quite deep water or showing a wide fluctuation of water levels are suitable. Pen culture is suitable for multispecies, high-density polyculture, either with the use of natural feeds or the supplementary application of commercial feeds. Waterbodies having water level fluctuations of less than 1 m, a water depth less than 3 m and an abundant supply of aquatic plants are suitable. They are also suitable for the application of the high-yielding techniques used in China's pond integrated fish farming as applied to open waters.

In 2004, China's inland natural waterbodies comprised 939 700 ha of lakes, 1 689 600 ha of reservoirs and 377 400 ha of rivers, fisheries-based activities yielding 1 147 000 tonnes, 2 051 000 tonnes and 773 000 tonnes of production, respectively (Table 1). Within these waterbodies 5 310 ha were allocated for cage culture, yielding 592 333 tonnes, and 301 900 ha were allocated for pen culture, yielding 487 751 tonnes. It is noteworthy that the yield per hectare from cage culture is much higher than that from either natural waters or pen culture. Thus, following their initial extension, cage-culture techniques for farming fish in open waters have developed rapidly and maintained a trend of continuous development.

The technology used in the introduction of the two aquaculture methods is briefly summarized below:

Species cultured in freshwater

The principal species cultured in freshwater are given in Annex 1. Feed-fed fishes mainly cultured in cages include common carp, grass carp, Crucian carp, rainbow trout, tilapia, channel catfish, other catfishes, Chinese perch and white Amur bream. Nonfeed-fed fishes cultured in cages include silver and bighead carps, both adults and fingerlings.

obtained from 9 213 ha of ponds with an average output of 7 500 kg/ha.)

- provide energy savings, as there is no need for facilities for irrigation or aeration;
- are high-yielding intensive culture methods; (Compared with artificial leasing, they are strongly controllable with regard to both inputs and outputs. Moreover, they can fully utilize the advantages of open waterbodies, which include good water quality, efficient water exchange, the presence of relatively few diseases and the ability to produce high yields.)
- create employment opportunities for rural labourers and contribute to poverty alleviation in some inland areas;
- conserve natural fish resources and increase the total fishery output of a given lake area. (For

TABLE 1
Fish yields from natural waterbodies in China

System	Acreage (A) (ha)	Yield (Y) (tonnes)
Open waters		
Lakes	939 700	1 147 000
Reservoirs	1 689 600	2 051 000
Rivers	377 400	773 000
Subtotal	3 006 700	3 971 000
Open water production (Y/A)		1.32 tonnes/ha
Cages	5 310	592 300
Cage production (Y/A)		111.54 tonnes/ha
Pens	301 900	487 700
Pen production (Y/A)		1.61 tonnes/ha

Source: Fisheries Bureau, 2004; Xu and Yan, 2006

Herbivorous fishes are mainly cultured in pens. About 85–90 percent of the fishes raised are grass carp and Wuchang bream, the rest being silver, bighead, common and Crucian carps.

Size and type

The cages used in cage culture are mainly traditional cages measuring 4×4×2.5 m or 5×5×2.5 m and small-sized cages measuring 2×2×1.5 m or 3×3×1.5 m. All cages used in the reservoirs are floating, while in shallow-water lakes, fixed cages are also used. In northern China, some of the lakes and reservoirs may be frozen in winter; hence submersible cages that can be lowered to a depth of 2 m below the ice are widely adopted. Boat-shaped cages are available for use in flowing rivers. In flowing irrigation channels small metal cages measuring 2×2×1 m are effective for farming feeding fishes. The mesh size of the nets used in the cages varies with the size of the stocked fish, starting at 1.0 cm mesh for fish averaging 3.9 cm in length and gradually increasing to 3.0 cm mesh for fish averaging 11.6 cm and thus being equal to about 25 percent of the body length.

The pens used to culture freshwater fish are mostly of about 0.6–1 ha in area and are fixed in shallow lakes having little fluctuation of water level. Pens for farming crabs are also mostly fixed and of about 2–4 ha in area. High-dike, low-barrage pens are also designed according to local conditions, taking into account the annual changes in water levels.

Stocking densities

The stocking density varies with the type of cage, the species farmed and the local conditions. Four examples are given below:

- 1) **Filter-feeding fish:** Silver carp and bighead carp for nursing from fry to large juveniles.

The small juveniles should be farmed in eutrophic water (the biomass of phytoplankton should be > 2 million cells/litre; zooplankton biomass > 2 000/litre). The cage stocking densities are 200–300 summer fry of bighead carp with 20–30 percent of silver carp (stocking ratio of 9:1), or vice versa. Additionally, 20–30 common carp or tilapia are stocked in each cage to control fouling weeds that attach to the nets.

- 2) **Carnivorous fish:** Chinese perch or mandarin fish (*Siniperca* spp.).

Chinese perch is a typical carnivorous fish farmed in China. Normally fry and juveniles

of silver carp, bighead carp and mud carp (*Cirrhinus molitorella*) are used as feed fish. The size of the feed fish is correlated with the mouth gape of the Chinese perch, ranging from 1.5–4.0 cm in length for feeding perch of 3–7 cm body length to 10–18 cm in length for perch 21–26 cm in length. The stocking density in the cage is about 10–15 individuals per square metre; the size of the juveniles used for stocking is about 50–100 g.

- 3) **Fish fed pellet diet:** largemouth bass (*Micropterus salmoides*).

The largemouth bass is an exotic fish introduced from the United States. The stocking density in the cages depends on their size, being 500, 300, 200–250 and 120 fish/m² for bass of 5–6, 50, 50–150 and 150 g, respectively.

- 4) **Omnivorous fish:** common carp.

The stocking density of common carp farmed in cages is similar to that for largemouth bass being fed formulated pellets. As the size of juveniles is 50–150 g per fish, the stocking density is about 100 fish per square metre. When ambient conditions are quite suitable, the density can be increased to 200 fish or more.

Pen culture is based on the polyculture of multiple species, and the stocking densities are closely related to the size of the main cultured fishes stocked, their individual growth rates and the expected recapture rate. When pens are used for the farming of mitten crab, the stocking density of young crabs (about 10 g each) is around 15 000 individuals per ha.

Culture period and yield per unit area of waterbody

Normally the culture period is between 240 and 270 days. The yield per unit area of waterbody is determined by the size of the cage or pen, the type of culture technique applied and the objectives of the culture operation, and thus there can be wide variation: yields can be as high as 200 kg/m³ (with feed application) and as low as 2–3 kg/m³ (without feed application). Based on 2004 national data, the production from cage monoculture averaged 11.15 kg/m², while that from pen monoculture averaged 0.16 kg/m². This indicates that the total level of production is very low (Xu and Yan 2006).

Marketable size and price

China has a very large domestic market for aquatic products. Local market demand is related to local customs. In general, Chinese prefer to cook round fish, not fillets or other processed fish products.

FIGURE 2
Traditional cages, simple and rough



FIGURE 3
Inshore cages crowded into inshore waters



Thus, a fish weighing 500–600 g can be marketable. The marketable size of grass carp and black carp (*Mylopharyngodon piceus*) is above 3 000 g in the region of the low reaches of the Changjiang River.

The market price varies depending on the fish species. Normally the price of fish originating from

TABLE 2
Numbers and distribution of traditional marine fish cages in China

Year	Location	Number of cages
1993	Guangdong, Fujian, Zhejiang provinces	57 000
1998	All coastal provinces	200 000
2000	All coastal provinces	> 700 000 (450 000 in Fujian Province)
2004	All Provinces and Zones	1 million
Specifically:	Fujian	540 000
	Guangdong	150 000
	Zhejiang	100 000
	Shandong	70 000
	Hainan	50 000
	Other provinces & zones	100 000

Source: Guan and Wang (2005); Chen and Xu (2006)

traditional aquaculture is 6–30 Yuan/kg. Some famous rare fishes may be priced at 50–100 Yuan/kg or more. A characteristic of pricing is that wild fishes are typically higher priced than aquacultured fishes, fish cultured in cages are higher priced than those from pond culture, and rare species are higher priced than traditional fish species.

Among freshwater fishery products, the prices of oriental river prawn (*Macrobrachium nipponense*), Chinese white prawn (*Exopalaemon modestus*) and Chinese mitten crab are generally higher than that of fish.

Present status of marine cage-fish culture

Traditional cages still account for the majority of marine cages in use today. The total number of cages that are distributed in China's coastal provinces and zones is about one million. These

TABLE 3
Numbers and distribution of offshore cages in China

Model	Zhejiang ^c	Shandong	Fujian	Guangdong	Other Provinces	Total
HDPE circle	640	495	488	60	100	1 800
Floating rope	1 083	–	–	150	–	1 300
Dish-formed submersible	13	–	–	–	–	13
Other	51	110	–	–	100	180
Total	1 787	605	488	210	200	3 293

Source: Guan and Wang (2005) and Chen and Xu (2006)^{a,b}

^aCage volume: >500 m³.

^bOffshore cages are cages located in sites distant from the coastal line, where swift currents and high waves are normally encountered.

^cData for Zhejiang Province were collected in the first half of 2004; other data were collected in 2005.

cages are operated at an artisanal level; they are small (normally 3 x 3 m to 5 x 5 m in size, with nets of 4–5 m in depth), simple (square in form) and roughly fashioned (Figure 2).

The materials used for these cages are collected from local markets and include bamboo, wooden boards, steel pipes and PVC or nylon nets. The operating principles of their owners are low investment cost and ease of manipulation; thus, most inshore cages are made by the farmers themselves. Due to the fact that these cages cannot withstand the waves generated by typhoons or swift sea-currents, they must be installed in inshore waters and sheltered sites. In some locations, the cages are connected to form a large floating raft that fills small inner bays (Figure 3).

Most of the marine cages (80 percent of the total number in China) are located in Fujian, Guangdong and Zhejiang provinces (Tables 2 and 3). There are more than 40 species of fish farmed in these cages (see Annex 2), almost all of which can be bred in hatcheries, the exception being some rare species.

Size and type of cages used for marine fish culture

Traditional cages used for farming marine fish are simple and small, in general being 5 x 5 x 5 m, and are mostly constructed from wooden boards, bamboo, steel pipe or other local materials.

Traditional cages are usually made by the farmers themselves and therefore, their cost is much lower

than that of an offshore cage. According to the results of a survey conducted by the authors, their construction cost is about US\$250 per cage (for the size previously mentioned), including nylon nets. The life span of these traditional cages is on the order of 8 to 10 years.

The stocking density used during the grow-out stage is 500–600 fish per cage. Trash fish are typically used for feed, as the farmers believe the cost is lower than that of pelleted feed. The cost of feeding with trash fish is approximately US\$1.5 for each kilogram of fish produced. Wholesale (farmgate) prices of farmed fish in Fujian Province in 2005 were US\$2.0–2.5/kg for croceine croaker, US\$3.0–3.5/kg for red seabream, US\$1.6–2.0/kg for red drum (*Sciaenops ocellatus*), US\$3.0–4.0/kg for Japanese seaperch and US\$30–40/kg for grouper.

Since the 1990s offshore cages have been imported from other countries, including Norway, Japan, the United States and Denmark as part of offshore cage-culture projects that have received priority from local governments and other relevant authorities. At present about six models of offshore cages are manufactured by local companies and research institutes. More than 3 000 sets of offshore cages are installed along the coastal provinces (Table 3). All of these offshore cages have been briefly discussed in the papers of Xu (2004), Guo and Tao (2004), Guan and Wang (2005) and Chen and Xu (2006). Their characteristics are summarized in Table 4.

TABLE 4
Summary of the main characteristics of different types of marine cages used in China

Cage Type1	FRC	HDPE	MFC	DFC	PDW	SLW
Anti-wind (grade)	12	12	12	12	12	12
Anti-wave (m)	7	5	5	7	6	7
Anti-current (m/s)	≤0.5/0.5	≤1/0.5	≤1/0.8	≤1.5/1.7	≤1.0/1.2	≤1.5/1.7
Cubage rate (%)	50	70	70	90	80	90
Frame material2	PPPE	HDPE	steel	steel	steel	steel
Site installed	semi-open	semi-open	inshore	offshore	semi-open	offshore
Installation	easy	easy	easy	laborious	easy	laborious
Maintenance	laborious	easy	easy	laborious	easy	laborious
Harvesting	easy	easy	easy	laborious	easy	laborious
Fishes raised	pelagic	pelagic	pelagic	pelagic	benthic	pelagic
Relative cost	low	medium	medium	high	medium	high

EMERGING ISSUES IN INLAND CAGE AND PEN CULTURE

Technical problems

China has an abundant supply of fish seed for use in cage and pen culture. However, long-distance transportation and vehicle transfer may cause the death or injury of fingerlings or lead to disease. The use of too many species in cage culture might result in inadequate production of special feeds. Lack of immunization, nutritional deficiencies caused by the random use of feed, and other causes may lead to disease occurrences.

Socio-economic problems

In order to develop production, enterprises engaged in cage and pen culture should always first consider the potential market likely to be encountered, and then consider the possible production problems. However, individual fishermen often consider production costs first. They may lack adequate knowledge and capability for marketing and thus have to depend on middlemen or brokerage institutions and individuals. The separation of production from marketing activities is likely to lead to over-production.

Environmental problems

Catastrophic pollution of waterbodies is the most severe disaster affecting the fish-farming industry. While cages can be moved, pens cannot and will thus suffer destruction.

Other catastrophes that can affect cage and pen culture operations include unpredictable gales and floods, which can completely destroy fish farms. In some waterbodies, wild terrestrial or aquatic animals may also cause problems to cage and pen culture. For instance, turtles and water rats can bite through the nets to eat dead fish, and in doing so, release the cultured stock, causing aquaculture losses.

Legal constraints

In China different levels of government have adopted various policies to encourage fish farming, including waiving of rents for the use of open waters, providing interest-free or low-interest loans and dispatching experts to extend aquaculture techniques and experimental demonstration.

When the techniques of cage and pen culture are extended and become popular, phenomena such as the unplanned distribution of cages and pens in open waters, the use of inappropriate feeds and inconsistent feed application may occur.

These problems are difficult to prevent due to the faultiness of the legal system. In recent years culture certificates have been issued to control aquaculture development, but China still lacks appropriate legal mechanisms and the legal basis needed to support sustainable aquaculture development.

Other problems

Various stakeholders attach great importance to cage and pen culture because of the impacts they may have on open waterbodies.

When culture techniques are comparatively mature, a considerable amount of scientific data is required in order to manage cage and pen culture under the conditions of aquatic conservation, i.e. so that aquaculture is developed within the ability of each open waterbody to sustain it. This is difficult multidisciplinary work that requires significant capital input.

CONSTRAINTS TO MARINE CAGE CULTURE

Due to the fact that traditional cages cannot withstand the waves caused by typhoons or swiftly flowing currents, they have to be installed in inshore waters or in sheltered sites.

The clustering of too many cages in inshore waters may cause a series of problems (FAO, 2001, 2003; Qian and Xu, 2003; Huang, Guan and Lin, 2004). These include:

- Water pollution caused by cage culture; The primary problem is pollution caused by the metabolites excreted by fishes and by unconsumed feeds. Cages linked in series may block inner bays during periods of low current and water exchange, such that metabolites and residual feed may start to accumulate on the sea bed. According to Xu (2004), the accumulated waste in some severely affected locations is as high as one metre or more in depth. In such situations the ability of the local aquatic environment for self-depuration may be exceeded.
- Diseases caused by polluted seawater; Eutrophication, epidemic disease outbreaks and lowered quality of farmed fish may occur when poor seawater quality occurs due to pollution that causes red tides or otherwise negatively influences the aquatic ecology. This may jeopardize other farmed animals such as oysters and scallops; the loss to aquaculture caused by diseases and red tide is estimated to be as high as US\$one billion annually (Yang, 2000; FAO, 2001, 2003), of which about 1 percent is in cage culture.

- Natural disasters;
The inability to protect cage and pen culture operations against the devastating impacts of typhoons causes severe economic losses. For example, in 2001 the direct financial losses caused by typhoon “Chebi” attacking Fujian Province reached US\$150 million.

THE WAY FORWARD

In order to meet market demands and improve people’s health, increase the income and well-being of farmers and protect aquatic environments, China needs the sustainable development of cage and pen culture. This section briefly outlines the directions that should be taken and the objectives that need to be obtained.

Sustainable development of cage and pen culture

At an early stage, farmers and policy-makers saw the advantages of cage and pen culture, but they neglected the potential issues that might arise during the sector’s development. Thus there was neither planning of areas to be used for cage or pen culture nor estimates of the potential yields that could be derived. All the provinces and metropolises need to work out individual plans and objectives for cage and pen culture development to their local conditions. In order to protect and improve China’s freshwater environments, a decision on whether to permit or prohibit cage culture or pen culture in a specific waterbody is made based on the state-issued standards for lake and reservoir water quality (the Surface Water Environment Quality Standard) and on the primary function of the waterbody (e.g. drinking water, irrigation or floodwater storage). If permitted, cage culture will be monitored all year round; if the water quality of lakes and reservoirs used for cage or pen culture does not meet the minimum standards, it must be terminated or reduced. For example, cage culture is prohibited in Yuqiao Reservoir of Tianjin Metropolis. In 2004 all cage and pen culture facilities were removed from Changshou Lake of Chongqing Metropolis. In Taihu Lake, Jiangsu Province, the area of the lake that can be used for cage and pen culture is limited to the eastern aquatic-weed type part of the lake. In Qiandao Lake, Zhejiang Province (area of 573 ha), 73 ha of non-feed-applying cages and 33 ha of feed-applying cages are certified for cage culture in order to protect water quality (Xu and Yan, 2006). This indicates the care that China is taking in the development of cage and pen culture.

Establishing production chains for cage and pen culture

In China, most cage and pen culture models employ a family-operated system. Even when the model is of the enterprise-type, most of the employees are still members of the same family. In recent years many fish-farming households have started to organize various types of “fish-culture associations” and to establish production chains that involve seed culture, feed supply, fish culture, marketing and processing. Obviously this newer model of association benefits Chinese aquaculture by decreasing the level of risk faced by the family-operated farms.

The relationship between the environment, aquaculture and formulating regulations and standards for cage/pen culture

The present situation in China is one of too large a population and too little land. This has led to great importance being attached to the production of grain and livestock, and also to aquaculture, and involves the rational utilization of water resources such as lakes, reservoirs and the seas. This policy will promote national food security and heighten the capability of China’s regions to supply their own needs. In order to guarantee the sustainable development of fishery production, it is necessary to regulate the acreage under culture, the use of chemicals and choice of species.

Protecting aquatic plants is a priority for pen culture

Successful pen culture depends on an abundant supply of aquatic plants. Therefore, the conservation of aquatic plants is of primary importance. China’s experience with pen culture during the past 20 years indicates the aquatic plants within a pen culture area will be consumed after one month of fish farming. However, if the pen culture facilities are removed, the aquatic plants will resume growth in the second year. Therefore China has implemented the policy, “Pen Culture of Fishes in Moveable Underwater Meadow”, which is detailed as follows:

- Administration of control and monitoring;
There are fishery administration institutions for each open-water region, and all of them work out fishery administration regulations. Through the issuance of culture certificates, the area under culture is controlled and reasonably organized, so that deterioration of water quality due to overly high density of cages is prevented. The facilities to monitor the water quality are

also used to monitor changes in species and the amount of aquatic plants, in order to provide a basis for the layout of pens.

- Regulation of techniques;

The Fisheries Bureau has recently drafted the Technical Regulation of Cage and Pen Culture in Aquatic Weed Type Lake (under examination and verification). The Regulation includes standardized cage and pen culture techniques with estimates of fish yield and is designed to protect aquatic plant resources which, in turn, leads to protection of water quality. This serves not only aquaculture development but also other fishery interests. Thus, the abundant aquatic plant resources that occur in aquatic-weed-type lakes are rationally used to provide fishes with a large amount of inexpensive feed. The Regulation includes basic operating procedures for maintaining the environmental conditions of waterbodies, the design and construction of cages and pens, the stocking densities for fish fingerlings and crab seed, feed quality and application techniques, the requirement for feed application management and techniques for harvesting and temporary culture.

Cage culture management

Technical regulations for the cage culture of certain species have been formulated since the end of the last century, but they are focussed purely on culture techniques, with no consideration of the negative effects that cage culture may have on waterbodies. In the new century, China will continue to implement these technical regulations for aquaculture; however, waterbody administrations need to supervise cage layouts and control the production and release of wastes based on scientific planning and the issuance of culture certificates. Fish farmers will decide on the species of fish to be cultured and the type of feed and will manage both the feeding regimes and health of their stocks. However, the quality and safety of feed and the use of fish medicines and chemicals must be supervised by fishery supervision stations that will integrate aquatic product security examination, environmental monitoring and fish disease prophylactic systems at different levels.

Technical measures to prevent pollution

Unscientific cage culture can have negative impacts on waterbodies due to feed residues caused by the over application of feeds, wastes excreted by the fish being cultured and the inappropriate use

of fish medicines. Therefore, administrators and fish farmers need to be better trained, and some additional measures need to be adopted to ensure healthy aquaculture. These include:

- controlling the total amount of fish farming in a given area based on the area's capacity to sustain fish culture;
- ensuring that the general layout of cages is appropriate to the type of waterbody and the nature of its bottom substrate. In order to prevent the transmission of diseases and pests, cages should be linked in a lineal style, the distance between lines of cages being at least 10 metres; they should not to have a chessboard-style layout;
- selecting the species to be cultured based on their feeding behavior. Whether or not feeding will be required often depends on the species to be raised (if silver carp are stocked, for example, no supplementary feeding is needed because this fish can use natural plankton as its food).
- improving feeding techniques by adopting scientific methods for feed application and controlling the feed efficiency;
- improving feed formulations by promoting the use of high-quality, low-waste, floating feed, which will reduce feed residues;
- stocking appropriate aquatic animals in open waters to improve water quality; for instance, silver and bighead carps can be stocked to reduce eutrophication; and common carp, Crucian carp and other feed-fed fishes can be used to reduce the feed residues from cage culture, preventing accumulation of residues on the bottom; and
- protecting or transplanting large aquatic plants to clean water.

The importance of developing offshore cage culture

Cage culture plays an important role in inland fish culture; additionally, it makes a significant contribution to marine aquaculture. The developing offshore cage-culture industry has recently become a significant component of the marine fish farming sector. The reasons for this are as follows:

- China has a population of more than 1.3 billion, and its land resources are lower on a per capita basis than the world's average. Official data show that China has a land area of 9.6 million km², making it the third largest country in the world. However, the land area per capita is only 0.008 km², much lower than the world's

TABLE 5
Proportion of total output from marine fisheries derived from mariculture and marine capture fisheries

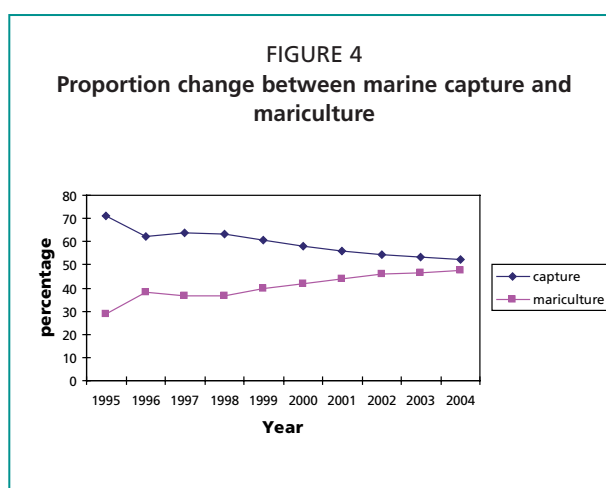
Year	Total output of marine fisheries (tonnes)	Marine capture fisheries		Mariculture	
		Output (tonnes)	% Total	Output (tonnes)	% Total
1995	14 391 297	10 268 373	71.3	4 122 924	28.7
1996	20 128 785	12 489 772	62.0	7 639 013	38.0
1997	21 764 233	13 853 804	63.6	7 910 429	36.4
1998	23 567 168	14 966 765	63.5	8 600 403	36.5
1999	24 719 200	14 976 200	60.5	9 743 000	39.5
2000	25 387 389	14 774 524	58.2	10 612 865	41.8
2001	25 721 467	14 406 144	56.0	11 315 323	44.0
2002	26 463 371	14 334 934	54.2	12 128 437	45.8
2003	26 856 182	14 323 121	53.3	12 533 061	46.7
2004	27 677 900	14 510 900	52.4	13 167 000	47.6

Source: Anon., 1998; Fisheries Bureau, 2000, 2003, 2004.^a

^a Editors' note: The figures presented here differ from the ones reported in FAO (2006), however, the discrepancy can be accounted for by the conversion of the Chinese reported figures on dry weight to wet weight for aquatic plants. So, for example, aquatic production excluding aquatic plants in 2004 was 10 778 640 tonnes, aquatic production with aquatic plants (dry weight) was 13 167 000 tonnes, and aquatic production with aquatic plants (converted to weight) was 21 980 595 tonnes.

average of 0.3 km² per capita. The agricultural land area per capita in China is only 7 percent of the world's total (Anon., 1998; National Development and Reform Commission, 2003). It is estimated that the demand for grain and other food products will reach 160 million tonnes by 2030. As a major developing country with a long coastline, China, in facing up to these serious facts, must make the exploitation and protection of the ocean a long-term strategic task in order to achieve the sustainable development of its national economy.

- In developing an oceanic fishing industry, China adheres to the principle of "speeding up the development of aquaculture, purposefully conserving and rationally utilizing offshore resources, and actively expanding deep-sea fishing" (Anon., 1998; Yang, 2000). Since the mid-1980s, China's mariculture has been rapidly developed, with a large increase in the number of species raised and in the breeding areas utilized. In accordance with the current state of its marine fisheries resources, China has actively readjusted the structure of this sector and made efforts to conserve and rationally exploit off-shore space, constantly adapting its mariculture industry to changes in marine fisheries production. Since the 1990s, the Government of China has been carrying out a series of comprehensive reforms and new policies in the fishery sector:



- Since 1995, China has practised a new “mid-summer moratorium system”.¹ Every year, for two to three and a half months during summer, fishing is banned in China's Bohai, Yellow, East China and South China seas

¹ The “midsummer moratorium system” is a regulation for protecting natural resources, especially commercially important fish and crustaceans. The regulation was initiated in 1995 in the Yellow, East China and South China seas. According to the regulation, in midsummer (the exact period depends on the seas), fishing vessels must anchor in harbors and stop all fishing activities. For example, in 2002 the moratorium was in effect for the Yellow Sea beginning at 12:00 on 1 July and ending at 12:00 on 16 September; in 2005 the period was extended to three months, starting on 1 June and ending on 1 September. The regulation is supported by the provincial governments and welcomed by fishermen, as the fishery resources are seen to be gradually recovering.

- (Yang, 2000). During this period, there are about 100 000 fishing vessels with one million fishermen that lay anchored in harbors;
- In 1999 a policy of “zero gain” in marine capture fisheries was implemented, and in the following year, a policy of “minus gain” was put into practice;
 - Between 2003 and 2010, some 30 000 fishing vessels of various types will be removed from the industry, and more than 300 000 fishermen will have to find employment in other sectors, including mariculture.

The goal in implementing these new policies is to establish sustainable fisheries by protecting marine resources and promoting mariculture and sea ranching. To date substantial progress has been achieved: for example, the total marine production was 14.39 million tonnes in 1995, of which mariculture accounted for only 28.7 percent (4.1 million tonnes). Since then mariculture’s contribution has continuously increased, the landed volume reaching 47.6 percent (13.1 million tonnes) in 2004 (Table 5 and Figure 4). It is expected that mariculture will contribute the majority of China’s total marine output in the near future. Thus any gains in production from the marine fishery will shift from the marine capture fishery to mariculture. Developing offshore cage culture has thus become a priority for the Government of China, as well as for investors. Experts have estimated that the output of farmed marine fish will increase to one million tonnes (Wang, 2000), and coastal cage culture will, no doubt, contribute greatly to this increase.

Besides favorable policies supporting the development of offshore cages, both farmers and research institutes have obtained financial support from the relevant authorities. Developing offshore cage culture requires high investment and entails high risk. Because individual farmers are unable to finance offshore cage development or assume the associated risk, China’s central government and provincial authorities are strongly supporting this project. Investments in the project from various sources are estimated to have reached more than US\$10 million.

For example, 20 projects dealing with offshore cages had been granted and have obtained as much as 20 million Yuan (Renminbi) in financial support during the last five years. In addition, since 2001 Zhejiang, Fujian, Guangdong and Shandong provinces have arranged special funds (more than 50 million Yuan) for developing offshore cages. The funds are partially for research

and development (R&D) and directly support the purchase of offshore cages by fishermen. These financial incentives and favorable policies promote the development and extension of offshore cage culture. According to survey data, about 3 300 offshore cages of different models have been installed in coastal provinces, of which there are 1 800 plastic hose (high density polyethylene or HDPE), circular cages (both floating and submersible) distributed in Zhejiang, Shandong, Fujian and Guangdong provinces. Another 1 300 floating rope cages have been installed in Zhejiang, Guangdong and Hainan provinces.

According to the most recent fisheries data (Fisheries Bureau 2003, 2004, 2005), marine fish production currently accounts for less than 5 percent of China’s total yield from mariculture, the bulk of production being from the culture of seaweeds, molluscs and crustaceans.

In order to meet the demand for high-quality marine fish, offshore cage-fish culture is recognized as an indispensable measure. The reason for this is that (i) the capacity for inner bays and sheltered sites to accommodate traditional cages has already been met, and thus there is no space available for further expansion of this sector, and (ii) coastal lands are so valuable that it is impossible to use them for the construction of ponds for mariculture. Given these factors, offshore fish cage culture is considered a first option for increasing the output of marine fish. Although most mariculture is done on a family scale, offshore cage culture, being beyond the capacity of most of Chinese fish farmers, is suitable for large-scale operation.

Thus we believe that offshore fish cage culture is an indispensable means to increase the yield of quality finfish, however, the realization of its full potential is still at least five or ten years or more in the future.

CONCLUSIONS AND RECOMMENDATIONS

China has addressed the issue of rational utilization and protection of resources of both marine and freshwater environments in the overall, cross-century plans for national economic and social development, and has adopted incorporation of sustainable development within its environmental programmes as a basic strategy. With the continuing growth of the forces of social production, the further build-up of comprehensive national strength and the gradual awakening of the people’s awareness of the importance of environmental protection, China’s cage and pen culture programmes will definitely

enjoy still greater development. Together with other countries and with international organizations, China will, as always, play its part in bringing mankind's work for aquaculture development and environmental protection onto the road towards sustainable development.

Developing cage and pen farming is a long-term aquaculture strategy, and thus the increased

attention given to its development will continue for many years to come. Its social effects and environmental impacts will be far-reaching.

Beyond all doubt, it is essential to improve its current status, using rational planning and science-based decision making to ensure sustainable aquaculture in China as well as in the world's fisheries.

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Annex 1:

Freshwater fish and other aquatic animals farmed in cages and pens in China

Chinese name	English Name ^a	Scientific Name	Origin
青鱼	Black carp	<i>Mylopharyngodon piceus</i>	Native
草鱼	Grass carp	<i>Ctenopharyngodon idella</i>	Native
鲢	Silver carp	<i>Hypophthalmichthys molitrix</i>	Native
鳙	Bighead carp	<i>Aristichthys nobilis</i>	Native
鲤	Common carp	<i>Cyprinus carpio carpio</i>	Native
锦鲤	Koi	<i>Cyprinus carpio carpio</i>	Exotic
鲫	Goldfish	<i>Carassius auratus auratus</i>	Native
鳊	White Amur bream	<i>Parabramis pekinensis</i>	Native
三角鲂	Black Amur bream	<i>Megalobrama terminalis</i>	Native
翘嘴红鲌	Predatory carp	<i>Culter erythropterus</i>	Native
鳊	Chinese perch	<i>Siniperca chuatsi</i>	Native
虹鳟	Rainbow trout	<i>Oncorhynchus mykiss</i>	Exotic
香鱼	Ayu	<i>Plecoglossus altivelis altivelis</i>	Native
罗非鱼	Nile tilapia, blue tilapia	<i>Oreochromis niloticus</i> , <i>O. aurea</i> , and their hybrid	Exotic
澳洲宝石鲈	Barcoo grunter	<i>Scortum barcoo</i>	Exotic
加州鲈	Largemouth bass	<i>Micropterus salmoides</i>	Exotic
长吻鮠	Long-nose catfish	<i>Leiocassis longirostris</i>	Native
黄颡鱼	Yellow catfish	<i>Pelteobagrus fulvidraco</i>	Native
乌鳢	Snakehead	<i>Channa argus argus</i>	Native
大口鲶	Largemouth catfish	<i>Silurus meridionalis</i>	Native
斑点叉尾鮰	Channel catfish	<i>Ictalurus punctatus</i>	Exotic
革胡子鲶	North African catfish	<i>Clarias gariepinus</i>	Exotic
短盖巨脂鲤	Pirapitinga	<i>Piaractus brachypomus</i>	Exotic
黄鳝	Swamp eel	<i>Monopterus albus</i>	Native
泥鳅	Oriental weatherfish	<i>Misgurnus anguillicaudatus</i>	Native
鲟	Sturgeon	<i>Acipenser</i> spp.	Native
匙吻鲟	Mississippi paddlefish	<i>Polyodon spathula</i>	Exotic
中华绒螯蟹	Chinese mitten crab	<i>Eriocheir sinensis</i>	Native
青虾	Freshwater prawn	<i>Macrobrachium nipponense</i>	Native
罗氏沼虾	Giant river prawn	<i>Macrobrachium rosenbergii</i>	Exotic
龟	Freshwater turtle	<i>Chinemys</i> spp. (and others)	Native

^a Scientific and English language common names (where available) are taken from Froese and Pauly (2006).

Annex 2:

Economically important fishes bred in hatcheries of China and farmed in cages

Chinese Name	English Name ^b	Scientific Name	Origin
鲻	Flathead mullet	<i>Mugil cephalus</i>	Native
梭鱼 ^a	So-iuy mullet	<i>Mugil soiyuy</i>	Native
鲈鱼 ^a	Japanese seaperch	<i>Lateolabrax japonicus</i>	Native
遮目鱼/虱目鱼	Milkfish	<i>Chanos chanos</i>	Native
军曹鱼, 海鲷	Cobia	<i>Rachycentron canadum</i>	Native
尖吻鲈	Barramundi	<i>Lates calcarifer</i>	Native
赤点石斑鱼 ^a	Hongkong grouper	<i>Epinephelus akaara</i>	Native
青石斑鱼 ^a	Yellow grouper	<i>Epinephelus awoara</i>	Native
锐首拟石斑鱼 (驼背鲈/老鼠斑)	Humpback grouper	<i>Cromileptes altivelis</i>	Native
大黄鱼 ^a	Croceine croaker	<i>Larimichthys crocea</i>	Native
鮟状黄姑鱼	Amoy croaker	<i>Argyrosomus amoyensis</i>	Native
眼斑拟石首鱼 ^a (美国红鱼)	Red drum	<i>Sciaenops ocellatus</i>	Exotic
真鲷 ^a	Red seabream	<i>Pagrus major</i>	Native
黑鲷	Black porgy	<i>Acanthopagrus schlegelii</i>	Native
平鲷	Goldlined bream	<i>Rhabdosargus sarba</i>	Native
笛鲷	Snappers	<i>Lutjanus spp.</i>	Native
胡椒鲷	Sweetlips	<i>Plectorhinchus spp.</i>	Native
大泷六线鱼	Fat greenling	<i>Hexagrammos otakii</i>	Native
黑平鲷	Black rock-fish	<i>Sebastes pachycephalus nigricans</i>	Native
牙鲆 ^a	Bastard flounder	<i>Paralichthys olivaceus</i>	Native
漠斑牙鲆 (南方鲆)	Southern flounder	<i>Paralichthys lethostigma</i>	Exotic
夏鲆	Summer flounder	<i>Paralichthys dentatus</i>	Exotic
石鲈	Stone flounder	<i>Kareius bicoloratus</i>	Native
黄盖鲈	Marbled flounder	<i>Pseudopleuronectes yokohamae</i>	Native
大菱鲆 ^a	Turbot	<i>Psetta maxima</i>	Exotic
半滑舌鲷	Tongue sole	<i>Cynoglossus semilaevis</i>	Native
红鳍东方鲷	Torafugu	<i>Takifugu rubripes</i>	Native

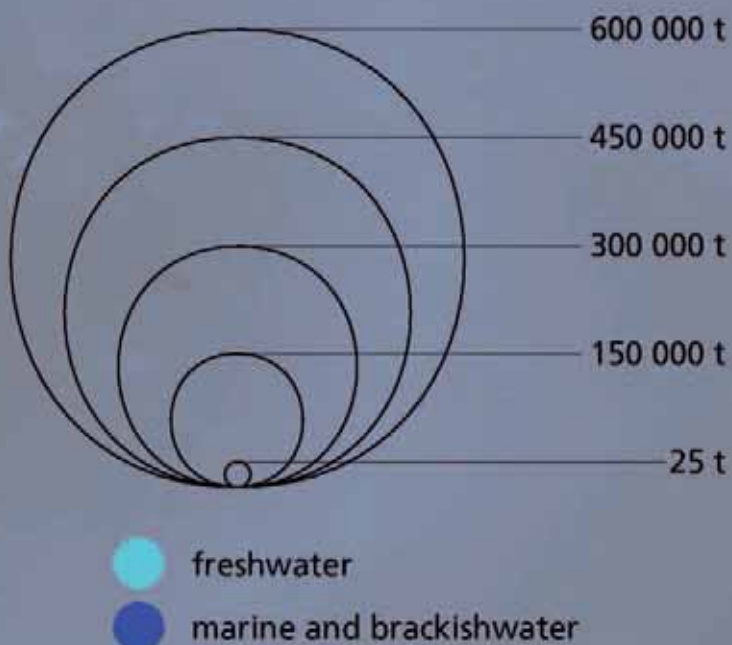
^a Main species cultured on a large commercial scale.

^b Scientific and English language common names (where available) are taken from Froese and Pauly (2006).



Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.



A review of cage aquaculture: Latin America and the Caribbean





A review of cage aquaculture: Latin America and the Caribbean

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A review of cage aquaculture: Latin America and the Caribbean. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 70–100. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

Aquaculture is a significant commercial activity throughout Latin America and the Caribbean with 31 of the 44 countries in the region involved in aquaculture and the industry generating more than 200 000 jobs. The development of the aquaculture sector is highly uneven, with two countries, Chile and Brazil, accounting for 72 percent of the total production, of which an estimated 70 percent is derived from cage culture. Twenty three countries produce only two percent of the total. Eighty-one of the 332 species cultured throughout the world are farmed in the region, with a total aquaculture production of 1.3 million tonnes valued at US\$5.2 billion in 2004. These figures represent 2.9 percent of the world aquaculture harvest and 8.2 percent of the value. Most of these are high-value finfish (almost 900 000 tonnes), with the majority produced in cage systems from the sub-Antarctic waters of southern Chile to the Gulf of California, northern Mexico. The majority of the cages (more than 90 percent) used in Latin America and the Caribbean are located in Chile and are dedicated to salmon farming. This document focuses mainly on two species groups: salmonids (salmon and trout) and tilapia, species that are farmed both in cages and also in tanks and ponds.

Regional aquaculture development has been heavily dependent on the existence of development plans and the commitment of local governments. This has been the case in Chile where salmon aquaculture has shown an impressive growth during the last 20 years. In Chile, cage culture occurs in freshwater, brackish and marine environments. Because of the significant environmental pressures caused by aquaculture, especially the impact of cage culture in freshwater systems, the salmon industry has introduced some closed recirculation systems in the lakes of southern Chile. In the case of seawater production, the use of cages has grown at a rate of 10 to 15 percent annually. Research is needed to find ways to mitigate the environmental impacts of cage culture and to better understand the dynamics and interrelations between all the users of the aquatic resource. The rapid growth of aquaculture has led to a close interaction with the agricultural sector in order to find new raw materials that can replace fishmeal and fish oil, whose availability and price are limiting factors to both sectors' growth.

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INTRODUCTION

Aquaculture production in the region³

In 2004 total world aquaculture production (excluding aquatic plants) reached 45.5 million tonnes valued at US\$63.5 billion (Table 1). Of this, Latin America and the Caribbean produced 1.3 million tonnes valued at US\$5.2 billion (Tables 1 and 2). This compares to the 4.8 million tonnes (valued at US\$7 billion) of wild capture fisheries products exported from the region. Aquaculture is recognized as an increasingly important commercial activity throughout South America (Hernández-Rodríguez *et al.*, 2001). With the rising demand for fish products and current pressure on finite wild stocks, aquaculture production is predicted to increase significantly throughout the region over the next 10 years.

During 2004 a total of 31 out of 44 countries in the region were involved in aquaculture (Table 3), producing 81 species with a commercial value of US\$5.2 billion and employing over 200 000 people. Chile and Brazil dominate, together accounting for more than 70 percent of total production. Shrimp production is significant in terms of both value and volume. Aquaculture production of finfish species in the region is dominated by salmonids Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*) and chinook salmon (*O. tshawytscha*) with a production of 578 990 tonnes in 2004, while production of tilapias (*Oreochromis* spp.) and common carp (*Cyprinus carpio*) reached 220 058 tonnes (Figure 1). During the period 2001–2003, salmonids and Pacific white shrimp (*Litopenaeus vannamei*) represented 64 percent of the volume and 69 percent of the value of aquaculture production in Latin America and the Caribbean (Table 4).

Many of the aquatic species farmed in the region are high-value finfish, and it is estimated that over 60 percent of the production occurs in cage systems from the sub-Antarctic waters of southern Chile to the Gulf of California off northern Mexico.

³ The region is composed of **Mexico** and **Central America**: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, **South America**: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Fr. Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela (Bolivarian Republic of); **The Caribbean**: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Bermudas, Cayman Is., Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Jamaica, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, Saint Lucia, St Kitts and Nevis, Trinidad and Tobago, Turks and Caicos Is., British Virgin Islands, US Virgin Islands.

FAO (2005) shows that 57 percent of the total aquaculture production excluding plants comes from the sea, 30 percent from freshwater environments and the remaining 13 percent from brackish water. Despite the wide dispersal of aquaculture activity throughout the region, 88 percent of the production of fish and shrimp is concentrated in the five top producing countries (Figure 2, 3 and 4). Chile, which produces salmon and trout and Brazil, which produces freshwater fish and shrimp, are the leading aquaculture producers of the region.

South America produces 85 percent of the region's aquaculture total by volume and 84 percent by value. Central America represents 10.1 percent of the volume and 14.3 percent of the value, while the Caribbean represents 5.6 percent of the volume and 2 percent of the value. Compared to Europe, Latin America and the Caribbean's aquaculture production is much lower in terms of volume, but is about equal in terms of value, which shows that the products farmed in the region have a higher average value (Table 4). This is mainly due to the farming of high-value species like salmonids and shrimp. In 2004 the average value of the region (US\$3.96/kg) was higher than the average value of the rest of world (US\$1.40/kg) (Table 4).

PROJECTION FOR AQUACULTURE DEVELOPMENT IN THE REGION

The growth of aquaculture for high-value species (shrimp and salmon) has had an important impact on international fish trade. Nevertheless in recent years, species of lower economic value such as tilapia have also successfully entered the international markets.

Although the market is there and the favorable geographical and environmental conditions make significant aquaculture development possible in Latin America and the Caribbean, the region must overcome some limitations. One of the greatest problems faced by the region (with the exception of few countries such as Chile), is the lack of continuity of political and economic process, which generates certain instability. This makes aquaculture unattractive for investors because many projects are slow-progressing businesses. Also the complete redefinition of a country's development strategies each time a new government comes to power prevents having relatively permanent policies to support research and development. Both are important requirements for the industry to generate new farming technologies applicable to the main native or exotic species of commercial interest.

TABLE 1
World aquaculture production for the year 2004

Region	Volume		Value		
	Tonnes	%	US\$(000)	%	US\$/kg
Africa	561 019	1.2	890 641	1.4	1.59
North America	751 984	1.7	1 308 838	2.1	1.74
Latin America & Caribbean	1 321 304	2.9	5 234 714	8.2	3.98
Asia	40 474 631	89.0	50 029 036	8.8	1.24
Europe	2 238 430	4.9	5 583 257	8.8	2.49
Oceania	134 009	0.3	446 798	0.7	3.33
Grand Total	45 481 377	100	63 493 284	100	1.40

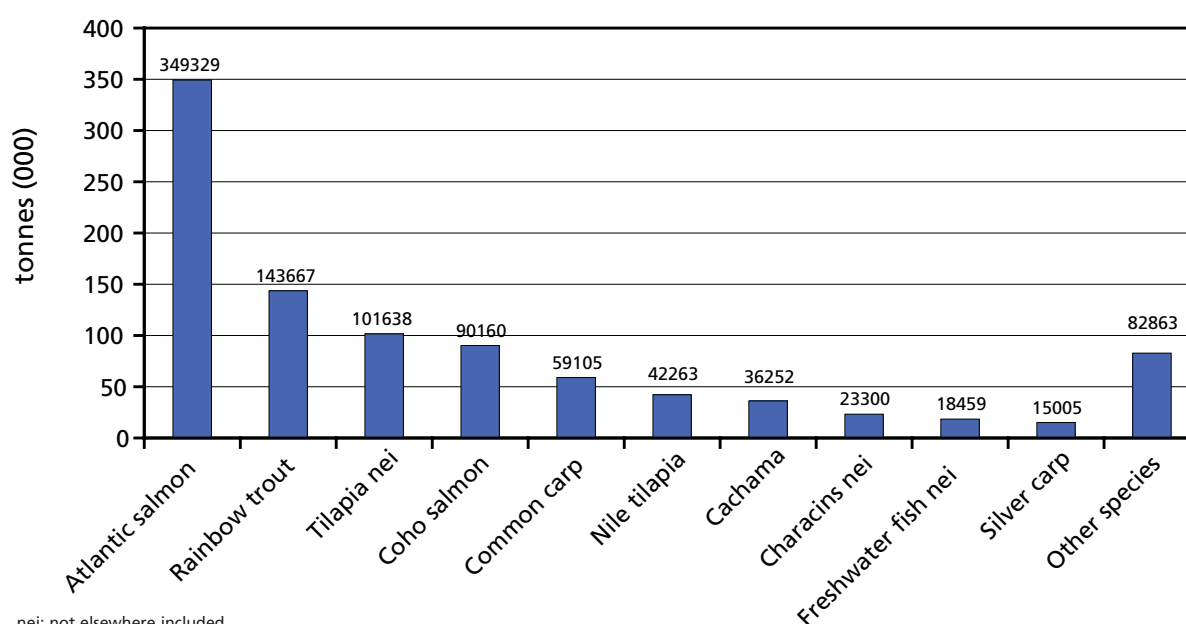
Source: FAO, 2005a,b

TABLE 2
Aquaculture production (tonnes) in Latin America and the Caribbean, 2000–2004 - aquatic plants not included

Commodity	2000	2001	2002	2003	2004
Crustaceans	154 569	187 317	221 462	294 646	289 928
Diadromous fish	359 391	52 1092	498 461	502 534	586 289
Freshwater fish	251 293	263 873	293 581	292 955	310 841
Marine fish	2 584	2 803	2 832	1 114	929
Misc. aquatic animals	811	693	688	719	713
Molluscs	69 079	82 085	83 381	105 577	132 604
Total	837 727	1 057 861	1 100 405	1 197 545	1 321 304

Source: FAO, 2005

FIGURE 1
Total fish production from aquaculture in Latin America and the Caribbean in the year 2004



nei: not elsewhere included
Source: FAO, 2005a

TABLE 3
Aquaculture in Latin America and the Caribbean: volume and value of commodities produced – note that the listing of commodities is according to FAO 2005

#	Commodity	Volume			Value		
		1996 – 2000	2001–2003		1996 –2000	2001–2003	
		tonnes (000)	tonnes (000)	% of total	US\$(million)	US\$(million)	% of total
1	Pacific white shrimp	165	209	18.8	979	1 057	26.8
2	Atlantic salmon	110	267	24.0	404	969	24.6
3	Rainbow trout	81	126	11.3	262	381	9.7
4	Coho salmon	77	112	10.1	307	329	8.3
5	Tilapias	50	73	6.6	152	219	5.5
6	Carp	48	68	6.1	142	183	4.6
7	Peruvian scallops	17	22	2.0	87	141	3.6
8	Cachama	9	30	2.7	35	109	2.8
9	Other shrimps	10	18	1.6	69	108	2.7
10	Other crustaceans	6	21	1.9	28	93	2.3
11	Nile tilapia	16	34	3.0	39	75	1.9
12	Chilean molluscs	13	44	3.9	11	71	1.9
13	Freshwater fish	27	23	2.1	81	65	1.6
14	Others	76	66	5.9	190	147	3.7
	Total	706	1 113	100	2 785	3 947	100

Source: FAO, 2005

TABLE 4
Aquaculture production per region (average volume and value) for 2004

Region / Area	Volume		Value	
	tonnes	%	%	US\$/kg
Asia	40 474 631	89.0	78.8	1.24
Europe	2 238 430	4.9	8.8	2.49
Latin America & Caribbean	1 321 304	2.9	8.2	3.96
North America	751 984	1.7	2.1	1.74
Africa	561 019	1.2	1.4	1.59
Oceania	134 009	0.3	0.7	3.33
Total	45 481 377	100	100	1.40

Source: FAO, 2005

However the main issue is not whether Latin America and the Caribbean will be able to have sustained research and development for innovative technology, but whether there are sufficient human and financial resources to be correctly used in research and development. In order to optimize the efficiency and capacity for the region to compete in the world market, it is important to look at the technological resources available in other countries together with local knowledge.

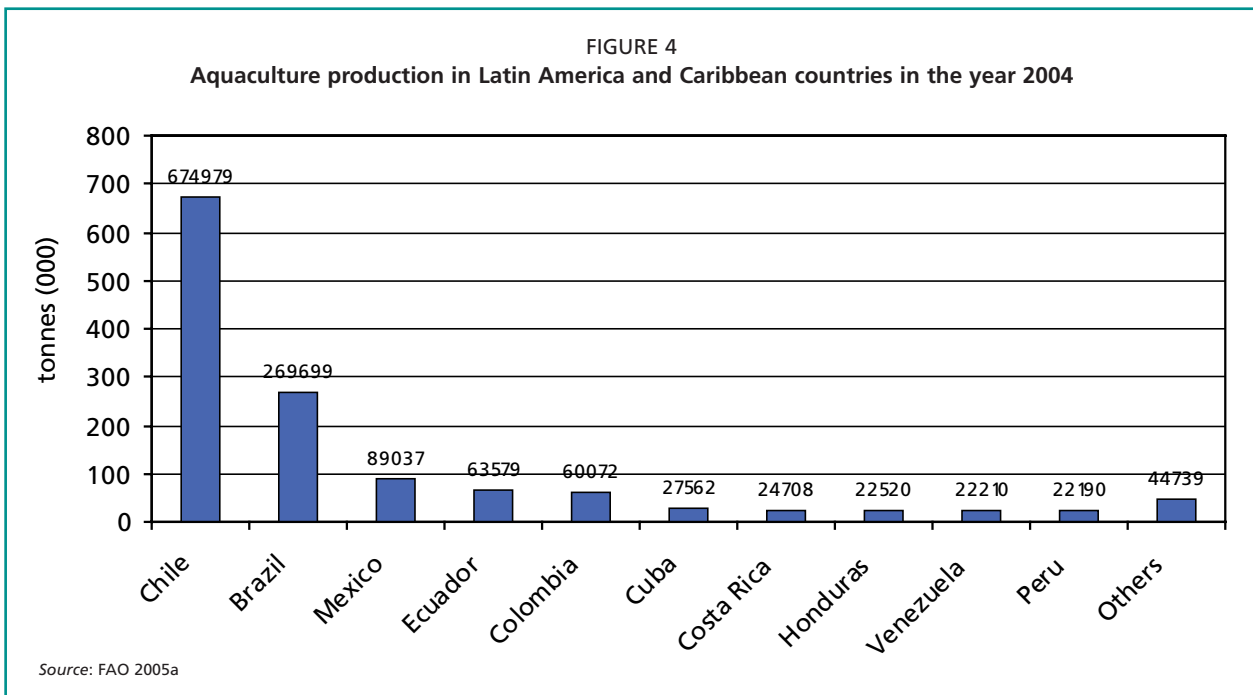
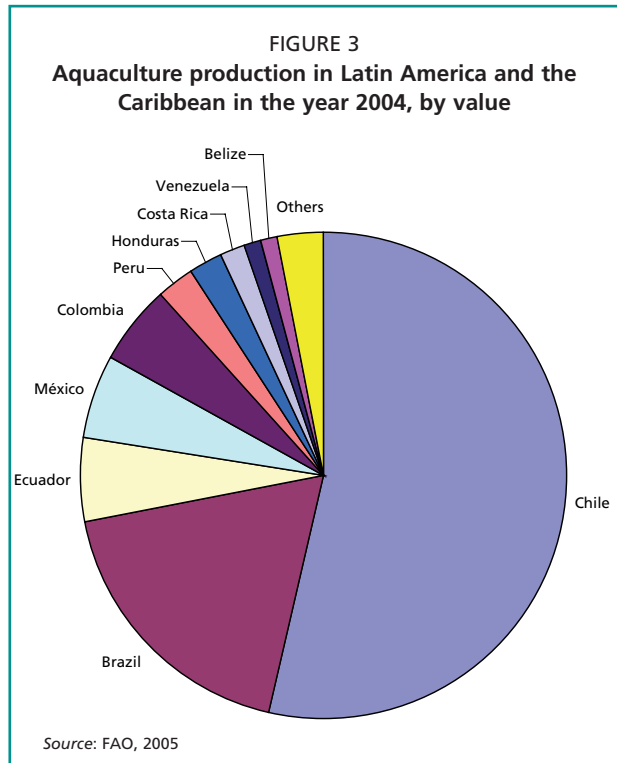
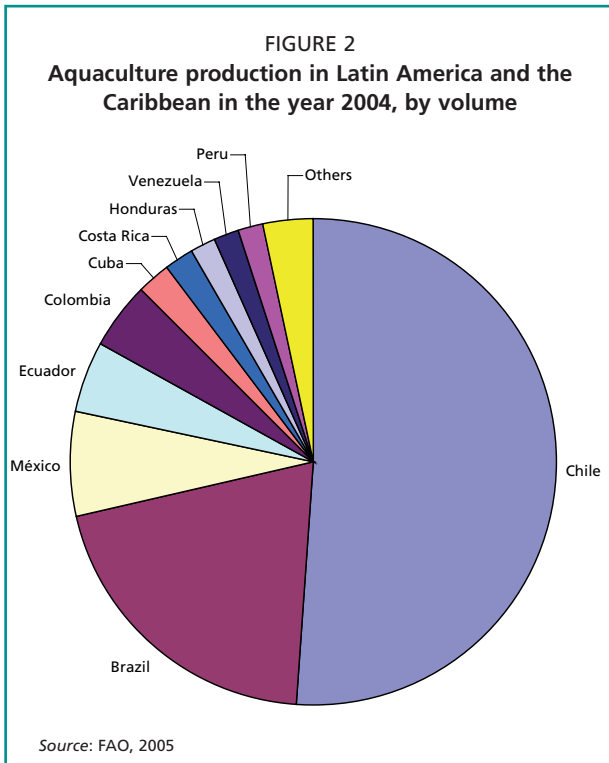
From the 1970s to the 1990s, the focus was on production, but now other areas such as genetics, health and pathology, environmental improvements, harvest processes and the market have become

very important in the development of aquaculture. Training programmes in planning, regulations, financing and bioeconomics are also important. Adequate roads, transportation infrastructure and other services are still not available in all countries. Therefore, although aquaculture has a promising future in the region, there are still many problems to be overcome.

SALMONID PRODUCTION

Chile

Rainbow trout and coho salmon were first introduced into Chile in the nineteenth century for sport fishing. Farming commenced in 1978 and by



1988 over 4 000 tonnes of coho salmon were being produced. Eggs from Atlantic salmon were imported from Norway in 1982 and within ten years this species had become the dominant species produced (Tiedemand-Johannessen, 1999). Between 1993 and 2003, total salmon and trout production increased at an average rate of 15.5 percent, compared to a world average of 7.7 percent. By early 2005 Chile

nearly lead the world in terms of the total volume of salmonids produced (Carvajal, 2005a).

In addition to the introduction of valuable genetic material, Chile has benefited from a variety of both capital and technology transfers from other salmon-producing countries such as Norway, Scotland and Canada that has facilitated the rapid growth of the industry. Relevant fields

of technology have included nutrition, fish health management and husbandry techniques, as well as cage culture systems.

Following transfer from land-based hatcheries, all salmon production in Chile is cage based (Table 5), initially in freshwater or estuarine environments until smoltification and then in seawater cages. In 2000 new recirculation technology was introduced in the industry, allowing the land-based development of the freshwater phase of culture and even the smoltification process in closed systems. These systems were introduced because of the strong environmental pressure and also the need to control diseases and use antibiotics in the presmolt stage. Today 16 percent of the smolts come from these systems, 33 percent from cages located in estuaries and 51 percent from cages located in lakes. In Chile rainbow trout are also cultured in seawater, and this accounts for 85 percent of the total Chilean trout production of 106 000 tonnes (Gilbert, 2002).

The distribution of salmonid culture in marine, brackish and freshwater environments

Salmonid farming in Chile occurs in Regions X, XI and XII (Figure 5 and Table 6), from Puerto Montt to the south of the country. The most important growth of the sector has taken place in the Region X until early 2000, when cage culture started moving south to Region XI.

Due to the availability of undeveloped sites, further expansion of the industry will occur predominantly in regions XI and XII; however extensive infrastructure development will be required before these areas realize their full production potential. Only relatively small volumes of biomass are produced in freshwater prior to transfer to seawater sites for on-growing. Generally fish are transferred from freshwater cages at less than 100 g,

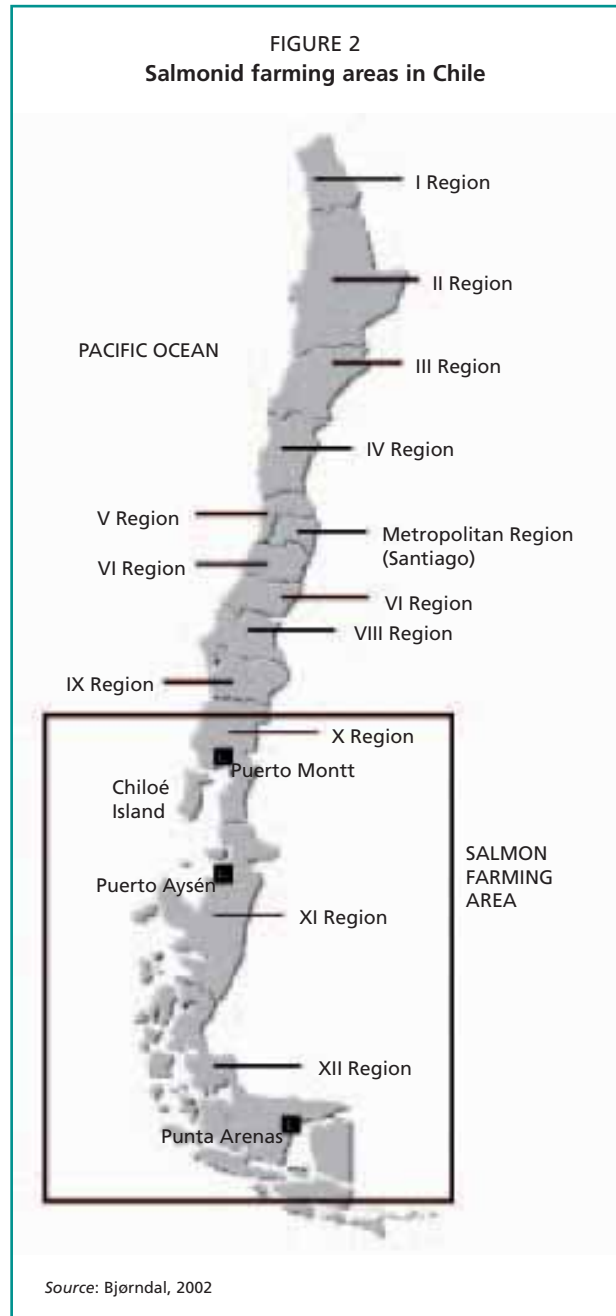


TABLE 5
Chilean salmon and trout exports (million US\$ FOB Chile)

Species	1997	1998	1999	2000	2001	2002	2003	2004	2005
Atlantic salmon	298	340	350	492	525	570	687	876	1 070
Coho salmon	189	170	280	263	230	206	211	232	284
Chinook salmon	2	0	0	0	0	0	0	0	0
Rainbow trout	178	203	188	215	208	193	242	330	352
Others	1	0	0	3	1	5	7	2	6
Total salmon	668	714	818	973	964	973	1 147	1 439	1 721

Source: Chilean Salmon Association

while they may be harvested from seawater cages at more than 5 kg individual weight. Legislation restricts salmonid on-growing to seawater. The majority of the freshwater production in Region X is concentrated in Lake Llanquihue. A number of companies have recently developed freshwater production operations in other areas to reduce the biosecurity risk of sourcing the entire smolt production for the industry from a single location. Also full recirculation systems are slowly replacing cage culture in lakes for smolt production.

Cage farming systems

The floating cage system is the dominate technology used for salmonid farming in Chile. The systems are either circular-plastic (Figures 6 and 7) or square-metal frames (Figure 8) with nets suspended from these structures. Individual cages are grouped together in varying numbers to comprise a farm site. These are moored to the sea bed in a static grid structure using concrete blocks and specialized anchors (Beveridge, 2004). Installation requires detailed data on environmental conditions and sea bed composition. Although there is no legislation controlling installation specifications, many companies comply with the Norwegian standard NS9415 to reduce insurance premiums associated with this critical operation. This has reduced the number of mooring failures as well as equipment and fish losses over recent years.

At marine sites with less exposed conditions, there is often a barge containing feed storage capacity and crew accommodation (Figure 9). The crew accommodation is important to provide 24-hour presence on the cages to prevent poaching.

Dimensions and cage type vary significantly, depending on a number of factors. Cage systems in freshwater environments are usually limited to ≤15 m² (metallic) frames. The use of smaller cage sizes in freshwater allows greater access and control and facilitates more intensive husbandry techniques such as grading, fish movements, vaccination and

TABLE 6
Distribution of salmonids farms and production in Chile in 2005

Region	Seawater farms	Freshwater farms	Distribution of total production
X	375	70	80%
XI	143	20	19%
XII	15	11	1%

Source: Servicio Nacional de Pesca Chile (SERNAPESCA).

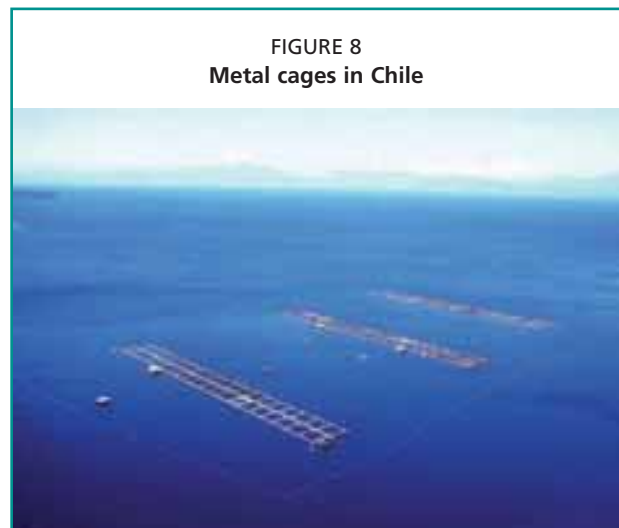


FIGURE 9
Floating barge/house in cages with crew
accommodation and feed storage area



FIGURE 10
Typical marine site in Chile



FIGURE 11
Centralized feeding silo supplying feed to a farm site in
Chile



TABLE 7
Number and type of cages in Chile in 2003

Cage type	Number	Percentage (%)	Approximate cost per unit (US\$)
Plastic	1 357	13	30 000
Metal	8 931	87	25 000
Total	10 228	100	

Source: cage builders and salmonid producers

net changing. In seawater the fish are rarely handled and it is possible to use larger, more extensive structures. Plastic cages of 90 m circumference with 20 m deep nets (12 900 m³) are common in seawater. There are also metal cages of 20 x 20 m with 20 m deep nets (8 000 m³). The maximal density-biomass varies between 16 and 20 kg/m³ in marine sites.

Metal cages are more solid structures and are generally easier to work on than plastic cylinders. This allows greater physical access and more stable working conditions for routine marine operations such as changing fouled nets, removing mortalities, grading and harvesting. A disadvantage of metal cages is that they are susceptible to metal fatigue as well as corrosion in saltwater environments and are less robust in high energy sites (Willoughby, 1999). As metal cages are physically attached to one another, the water exchange can be reduced in some cages. During periods of low oxygen, limited water exchange may exacerbate negative effects on growth rates, increasing variability among cages.

Recent advances in hot-galvanization have reduced corrosion and improved cost effectiveness by extending the operational lifespan of many metal cages to over ten years. As most salmon development

FIGURE 12
Feed is conveyed to individual cages from the silo via
compressed air



in Chile has occurred in relatively sheltered inshore waters, there are a higher proportion of metal cages in operation (Table 7). This proportion may change as the industry expands and more exposed sites in offshore waters are utilized.

Increasing mechanization has been a feature of salmon cage operations over recent years. At some sites capital intensive, centralized feeding systems are now being introduced to improve feed management and increase efficiency of operations. These systems are comprised of a floating centralized silo (Figure 11) supplying feed to the individual cages through plastic pipes via compressed air (Figure 12). The feed is controlled automatically by monitors in the individual pens that can detect uneaten pellets leaving a population of feeding fish. When these pellets are detected the feed delivery will stop. Underwater cameras and surface delivery systems (Figures 13 and 14) connected to waste collectors are also utilized to assess feeding response. With feed costs representing over 50 percent of operating costs, reducing waste and improving growth performance are essential. Reduced environmental impact from waste feed and improved bulk handling in operations are additional benefits of efficient feed management.

With the continued expansion of the industry, increased mechanization has not caused an overall reduction in manpower (Intrafish, 2003). Employee numbers per farm are still significantly higher in salmon farming operations in South America as compared to other regions, reflecting a lower wage structure than that of their competitors in Norway, Canada and Scotland. The lower wage level is a significant competitive advantage for the industry and has been an important factor in the continued successful development in Chile (Barrett, Caniggia and Read, 2002).

Environmental effects and relevant legislation

The intensive production of a large biomass of any aquatic species in a reduced space has a number of

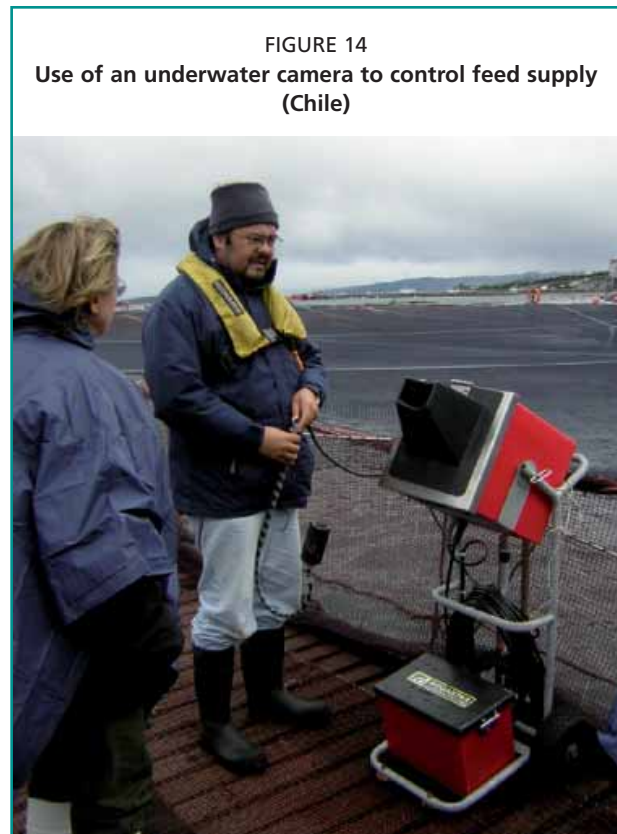


TABLE 8
Typical cage arrangement in a marine salmonid farm site in Chile

Number of cages	Size of cages	Number of smolts at beginning of cycle	Production (tonnes)	Maximum density
14	30 m diameter	700 000	2 500	20 kg/m ³
21	30 m diameter	1 050 000	3 675	
24	30 m diameter	1 200 000	4 200	
20	30 x 30 m square	600 000	2 100	

Source: Salmonid producers

environmental consequences. The rapid expansion and development of the salmon industry has increased environmental concerns and questions have been raised about possible ecological impacts. Regulators have already pointed out the necessity of minimizing environmental impacts if productivity is to be sustainable.

Research conducted since 1996 suggests that there is a local adverse impact on the seabed in the licensed farming area that is associated with physical and chemical changes to sediment and a loss of benthic biodiversity. These impacts include modification of benthic communities, increased nutrient loads in coastal waters and the associated problem of harmful algal blooms, use of different types of chemicals and escapes of farmed salmon into the wild (Buschmann *et al.*, 2006).

Studies by Soto and Norambuena (2004) showed that a salmon farm has no effects on water column variables such as nitrate, ammonia, orthophosphate and chlorophyll, which may indicate the possibility of high dilution rates and recycling processes. Nevertheless there is a significant change in the sediment variables such as nitrogen, phosphorus and organic carbon, among others. There is also an important loss of biodiversity that appears to be related not only to organic matter loading and low oxygen levels in the sediments, but also to the deposition of copper (due to the use of antifouling paint in the net cages). Moreover, environmental deterioration due to high organic matter concentration in the sediment may affect the health of farmed fish and hence profitability.

It is clear that further research is urgently required in Chile to increase the understanding of these impacts, especially considering that the industry will expand to the far south. It is impossible to describe or predict ecosystem behaviour without knowing how ecosystem components are distributed in time, space or with respect to each other and understanding the relationship and processes that explain their distribution and behaviour. Geographical information systems (GIS) can be used as powerful tools to organize and present spatial data in a way that allows effective environmental management planning. Nevertheless these systems are complementary to field surveys and risk assessment.

In Chile the expansion of salmon farming has also been associated with an increased mortality of sea lions (*Otaria flavescens*) due to net entanglement and shooting by fish farmers following attacks on salmon sites (OECD, 2005). Control methods

include the use of acoustic devices and physical deterrent techniques, however, only the deployment of anti-predator nets around the cages (Figure 15) has allowed a permanent reduction in sea lion attacks (Sepúlveda and Oliva, 2005). Despite this protection, some sea lions have learned to jump over the surrounding anti-predator nets and into fish cages. This has required additional nets that are deployed above water level to foil these intelligent, adaptive and acrobatic predators (Figure 16).

Damage to the nets by sea lions or other causes can result in significant losses of fish into the environment. The worst single incident to date was the escape of approximately 1 million salmon during a heavy storm in July 2004. Such large-scale escapes of carnivorous salmonids can have a serious impact on indigenous fish populations due to increased predation, disease introduction and other habitat interactions (Soto, Jara and Moreno, 2001). This is particularly true of freshwater environments, where a very high proportion (93 percent) of the freshwater species are already classified as threatened (OECD, 2005; Soto *et al.*, 2006). Salmon escaping



into the marine environment may impact on other stakeholder operations such as coastal commercial and recreational fisheries. The 2001 *Environmental Regulation for Aquaculture* (RAMA) requires each fish farm to have an emergency plan addressing the risks due to fish mortality, fish escapes and accidental feedstuff spills. Operators have to demonstrate a viable contingency plan ensuring the capture of escaped fish within 400 m of the farm for five days (this may be increased up to 5 km and 30 days in extreme cases). However it is still not clear how these contingency plans they will really work and how efficient the different capture methods are. Each event of fish escapes must be reported to the local harbour authority and to the National Fisheries Service SERNAPESCA.

With the intensification of the industry in Chile, a number of diseases have become prevalent, including those caused by bacterial pathogens (*Vibrio* sp., *Streptococcus*), sea lice (*Caligus* sp.) and infective pancreatic necrosis virus (IPNV). *Piscirickettsia salmonis* is a small, intracellular bacterium that causes a fatal septicaemia of salmonids. Since its initial isolation in the late 1980s, *P. salmonis* has been the primary cause of mortality in the industry in Chile. During 1995 alone, more than 10 million salmon died during marine cage-farming operations, the economic impact being estimated at US\$49 million. Effective health monitoring, rapid diagnosis and early intervention with antimicrobials have greatly improved control. However the continued use of antibiotics has raised concerns. It is now a requirement that all batches of harvested salmon destined for both the United States of America and Japanese markets to be tested for antibiotic residues. SERNAPESCA is revising three general sanitary programmes (disease management, feed management and vaccination) to establish compulsory reporting on the use of antibiotics in salmon farms. The 2001 *Sanitary Regulation for Aquaculture* (RESA) on prevention and control of high-risk diseases in aquatic species provides for sanitary control, epidemiologic monitoring and eradication of infectious diseases in fish farms. SERNAPESCA's residue control programme has been given more resources with the number of site inspections increasing (OECD, 2005).

In salmon producing nations such as Norway and the United Kingdom, the development of effective vaccines for other bacterial infections has replaced the reliance on antibiotics. Due to the intracellular nature of the organism, vaccines have proven less effective against *P. salmonis* than

against other bacterial pathogens, despite being used in increasing frequency. Further development of more effective vaccines is being conducted by the industry (Birkbeck *et al.*, 2004).

Antifouling is used to prevent fouling growth on the nets and to secure the water flow through the cages. Antifouling paint containing copper as an active ingredient can cause an environmental impact (Barrett, Caniggia and Read, 2002). RAMA requires that net changing and washing operations are conducted at specialized inshore sites, utilizing water treatment to reduce environmental effects.

RAMA introduced the concept of preliminary site characterization, which requires any new production licence request (inland or marine) to be subject to an environmental impact assessment (EIA). Additionally all existing farms must conduct annual environmental monitoring as part of an environmental information programme (INFA). If anaerobic conditions prevail in top sediments under cages for two consecutive years, the farm site must reduce by 30 percent the biomass produced in the third year and every year thereafter until oxygen conditions in sediments improve.



Because growth in the industry has been largely export driven, corporate environmental responsibility is improving, particularly among the largest farms and companies and a Clean Production Agreement (“*Acuerdo de Producción Limpia*”–APL) was signed by the producers in 2002. The agreement set a two-year target for sewage treatment and solid waste management in fish farms and processing plants to bring producers in compliance with current environmental standards. It also addressed the control and eradication of high-risk diseases. Environmental certification of salmon farming has increased and all the largest farms are ISO 14001 certified. The certification process led to the elaboration of a Code of Good Environmental Practices that includes sustainability criteria for all stages of salmon farming (OECD, 2005).

The 1991 General Fishing and Aquaculture Law established specific fish-farming areas at sea to ensure that fish farming does not conflict with other activities such as fishing, navigation, tourism and nature protection. Concessions cannot be authorized in Marine Reserves (reproduction areas for fish stocks) and in the recently created Marine Parks. Aquaculture areas and boundaries in marine waters have been defined by decree in eight regions. No further aquaculture areas can be authorized in Chilean lakes. This restriction has contributed to the spread of inland aquaculture in ponds as well as inland freshwater production facilities (OECD, 2005). In 2003 the National Aquaculture Policy (“*Política Nacional de Acuicultura*”–PNA) was implemented as a legal framework to regulate the system and join together the varying policies and legal bodies that relate to aquaculture activity in such a way that a “single window” has been opened for the practical paperwork, permits and license processing, most of these through the Internet.

Salmon farms now consume one-third of the domestic fishmeal output. Recent forecasts indicate that demand on finite fishmeal resources will increase significantly within the near future, especially following the dramatic increase in demand from P.R. China. Sourcing alternative protein sources from terrestrial production in order to substitute the already expensive fish oil and fishmeal within the region will become increasingly important (Barlow, 2003). This process has been faced by the salmon industry since 2000, when 50 percent of the raw material was fishmeal. Today this percentage has been reduced to 27 percent. In the case of fish oil, usage has decreased from more than 25 percent to 16 percent in 2006.

These achievements were possible thanks to concerted research done by feed companies and research centers both in Chile and also abroad, and demanded an important economic effort. These studies considered the formulation of new diets, their productive efficiency and also the welfare, quality, nutritional and health aspects of the fish. The substitution of fishmeal must also be accepted by the consumer, and their raw materials must be sustainable and friendly to the environment. A deficiency in any of the essential nutrients will reduce growth and increase food conversion ratio (FCR). Nutritional pathologies may also result from extreme chronic deficiency. Therefore there is a considerable pressure on feed manufacturers to deliver a good balance of products that are acceptable with regard to their price, composition, palatability, digestibility, nutrients/anti-nutrients, microbiological safety and functional properties.

Soy bean, lupine, canola raps, peas, corn, wheat, proteins coming from the poultry industry, bioproteins etc are some of the ingredients that have been used to replace fishmeal. Fish oil can be replaced to 50 percent by vegetal oils without affecting the productive yield, well-being or nutritional quality of the fish. Currently (year 2006) 35 to 50 percent of the oil added into the diets has a vegetal origin.

The increasing demand for new raw materials has generated a remarkable impact on the agricultural sector of southern Chile, specially in the culture of canola raps, wheat and lupine. In the case of canola raps, the number of hectares cultivated has increased by more than 10 times in the last three years and is expected to increase by another 20 percent during the 2006 season. Regarding lupine, the number of hectares under cultivation has increased by approximately 75 percent in the last four years and is expected to increase by another 13 percent in 2006.

Economic aspects and markets

Salmonids account for approximately six percent of Chile’s total exports, recently eclipsing wine exports in commercial importance (Carvajal, 2006). In 2004 Chile’s export of salmonids (by value) to its main markets of the United States, Japan and the European Union (EU) consisted of 61 percent Atlantic salmon, 23 percent trout and 16 percent coho salmon. Fresh salmon products are exported to the United States via air freight, while frozen salmon is exported by sea to Japan and Europe. Value-added products account for over half of the

industry's export, with 37 percent fresh fillets and 36 percent frozen fillets. Other markets in both Asia and Latin America (particularly Brazil) and the Caribbean have been increasing in importance (Table 9).

A major challenge for Chile remains the distance to its main export markets, as well as the dependency on the United States and Japanese markets, which has made Chilean exports vulnerable to international economic trends and trade policies (Bjørndal, 2002). Chile has several bilateral and multilateral free-trade agreements, including agreements with the United States (2003) and the European Union (2002). In addition the Southern Common Market Agreement (MERCOSUR) has stimulated export to South American countries.

Social factors

Over the last ten years, salmonid farming in Chile has been an important factor for economic growth and development, particularly in Region X, which now has some of the highest employment levels in the country (Instituto Nacional de Estadísticas-INN, 2006). The concentration of cage-culture operations in specific locations has attracted other related activities such as manufacturers, veterinary services and insurance companies to form an industrial cluster comprising over 200 companies. This "salmon cluster" has had an important effect on a region that previously had one of the country's lowest standards of living (Salmon Chile, 2005).

However despite the initial progress, there are still improvements to be made, with recent studies showing that the national poverty level in the period 2000–2003 decreased from 24.7 percent to 21.6 percent in Region X, as compared to a reduction from 20.6 percent to 18.6 percent at the national level (Cárdenas, Melillanca and Cabrera 2005). In 2004 the salmonid industry provided direct and indirect jobs to 45 000 people in total, 80 percent concentrated in Region X. A total of 35 percent of the workers in the Chilean salmon industry are women (Carvajal, 2005a).

For other stakeholders in the coastal zone there has been some conflict of interests. Artisanal fishermen have lost traditional fishing and diving grounds in the proximity of salmonid cages, as companies are often enforcing informal additional exclusion zones around the salmonid sites without legal justification. Local fishing communities are however seeking methods to adapt to the new circumstances and one of them is by obtaining self-management marine concession areas. For example, with financial and administrative support an artisanal syndicate has been successful in gaining the first maritime concession on "Isla Grande" of Chiloe, where oysters and algae are cultivated for sale by 25 members. Although globalization has had a noticeable modernizing effect in the region, there is little evidence that people are leaving the traditional fishery, selling off land or losing their traditional lifestyle due to the impact of salmon

TABLE 9
Chilean salmon and trout export to main markets (value and volume)

Value (million US\$FOB Chile)											
Market	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Japan	295	295	366	337	471	477	436	403	427	566	638
United States	136	177	214	270	259	358	364	414	544	575	606
European Union	35	31	37	45	34	57	77	62	58	118	240
Latin America	16	26	37	47	39	53	51	47	56	79	84
Other markets	7	9	15	15	15	29	37	48	62	101	153
Total	489	538	668	714	818	973	964	973	1 147	1 439	1 721
Volume (tonnes x 000)											
Market	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Japan	58	80	93	105	92	111	158	162	119	154	151
United States	29	41	46	52	45	65	88	108	117	124	119
EU	6	6	8	10	7	11	22	21	14	24	48
Latin America	3	6	9	11	9	13	17	19	17	23	24
Other markets	1	2	4	4	3	6	16	21	19	29	43
Total	98	135	160	182	155	206	300	331	286	355	384

Source: Salmon Chile (2005)

farming (Barrett Caniggia and Read, 2002). On the contrary, salmon farming has had an important effect by reducing migration of young people from rural areas to cities because the availability of new jobs within this aquaculture sector.

In spite of the successful development of this industry in Chile, some non-governmental organizations (NGOs) have criticized the environmental impacts of aquaculture and now also the violation of what they consider labor rights. According to these agencies, the salmon industry does not permit sustainable development and its employment-generating capacity does not translate into better income rates in the region. These criticisms have demanded arduous work on the part of the salmon industry to justify its development and to address those areas of concern that can be improved.

Salmonid production in the region (excluding Chile)

Other salmonid production in the region (excluding Chile) consists mainly of rainbow trout culture, the majority of which occurs in land-based, freshwater systems such as earthen ponds and raceways (Table 10). Some small-scale cage production of trout has developed in Peru and Bolivia in natural lakes such as Lake Titicaca and also in man-made lagoons such as Corani in Cochabamba (Collao, 2003). Many of these projects are aimed at reducing poverty and benefit from external capital assistance, including funding from the United States Agency

FIGURE 15
Trout farming operations in Lake Titicaca where 50 percent of the operations are conducted by women



FAO/A. Odou

for International Development (USAID), CARE, the International Potato Centre, the EU and the Inter-American Development Bank. Peruvian operations on Lake Titicaca have assisted some 200 families in setting up 33 micro-enterprises. More than 50 percent of the operations are run by women (Figure 17). In many cases this has led

TABLE 10

Production of rainbow trout in Latin America and the Caribbean (tonnes). Note that cage culture is not specified for freshwater

Country	Environment	1998	1999	2000	2001	2002	2003
Chile	Marine	71 073	47 164	78 911	109 142	108 771	106 464
Colombia	Freshwater	6 241	7 816	9 016	7 000	5 000	4 248
Mexico	Freshwater	1 517	2 272	2 520	3 309	3 444	3 444
Chile	Freshwater	4 035	3 250	655	753	2 910	3 114
Peru	Freshwater	1 479	1 608	1 857	2 675	2 981	3 111
Brazil	Freshwater	791	1 229	1 447	1 939	2 377	2 275
Argentina	Freshwater	1 000	781	952	950	900	1 231
Costa Rica	Freshwater	104	181	250	210	500	500
Bolivia	Freshwater	320	328	335	250	328	274
Venezuela (Bolivarian Rep. of)	Freshwater	540	540	500	300	500	99
Ecuador	Freshwater	0	54	33	33	33	0
Total freshwater culture	Freshwater	16 027	18 059	17 565	17 419	18 973	18 296
Total rainbow trout	All	87 100	65 223	96 476	126 561	127 744	124 760

Source: FAO Fishstat Plus Database (2005).

to a radical change in family structure in which the men stay home to take care of children while their wives handle the various stages of production. The business organizations have set up three modern pilot farms for production and training in Capachica, Juli and Chucuito to demonstrate and transmit improved technologies to member micro-enterprises in the area (IDB, 2005).

Titicaca is the world's highest navigable lake (3 900 m above sea level) and covers 8 200 km². The impact of trout farming has not been fully documented, but the introduction of salmonids in such environments has been implicated in the decline of native species in Lake Titicaca as well as the disappearance of other Andean *Orestias* and *Trichomycterus* species in Colombia and Chile (FAO, 1988). Another concern is the increase in nutrient inputs, especially phosphorous and nitrogen, into such upland freshwater systems.

Tilapia production

Tilapia production reports impressive growth, making it, after salmon and shrimp, one of the most successful aquaculture products entering international trade. Tilapia, a finfish native to Africa and the Middle East, has become one of the most important food fishes in the world. In Latin America

and the Caribbean, the genus *Oreochromis* is most important to aquaculture (including Nile tilapia (*O. niloticus*), Mozambique tilapia (*O. mossambicus*), blue tilapia (*O. aureus*) and their hybrids (e.g. red tilapia)). These species are produced throughout the region (Table 11) under a variety of culture systems, but mainly in ponds.

Tilapias are hardy and omnivorous, feeding at a low trophic level. This makes them relatively inexpensive to feed within extensive systems and suitable for farming under less optimal environmental conditions. Within intensive systems, the fish can be fed formulated diets containing a high percentage of plant proteins and oils (Watanabe *et al.*, 2002). Many countries in the region can produce crops such as soybean and maize, suitable to support the fish feed industry (Kubitza, 2004a). Other freshwater species such as tambaqui (*Colossoma macropomum*) and pacu (*Piaractus brachypomus*) are also being farmed together with tilapia (Alcantara *et al.*, 2003; Gomes *et al.*, 2005).

Tilapias can be farmed under extensive, semi-intensive and intensive systems. The most intensive systems usually involve cage aquaculture (Figures 18 and 19). However the largest proportion of the production is probably derived from extensive aquaculture through landbased farms. There

TABLE 11
Aquaculture production of tilapia in Latin America and the Caribbean (tonnes); note that cage culture is not specified

Country	1998	1999	2000	2001	2002	2003
Brazil	24 062	27 104	32 459	35 830	42 003	62 558
Colombia	17 665	19 842	22 870	22 500	23 000	23 403
Costa Rica	5 398	6 588	8 100	8 500	13 190	14 890
Ecuador	1 730	4 400	9 201	5 159	6 903	9 727
Mexico	5 398	7 023	6 726	8 845	7 271	7 271
Honduras	506	792	927	1 244	2 000	3 508
Jamaica	3 360	4 100	4 500	4 500	6 000	2 513
Guatemala	1 570	2 832	1 888	2 000	2 000	2 000
Dominican Rep.	446	445	994	612	766	766
El Salvador	277	139	56	29	405	654
Cuba	540	1 060	730	480	500	650
Guatemala		428	392	415	415	415
Guyana	180	366	366	366	366	366
Peru	85	60	47	225	121	112
Venezuela (Bolivarian Rep. of)	2 010	2 320	970	1 250	560	108
Panama	55	634	900	1 181	500	95
Others	100	152	263	202	104	56
Total	63 382	78 285	91 389	93 338	106 104	129 092

Source: FAO Fishstat Plus Database, 2005

are also many cases where tilapia production is complementing hydroelectric plants (e.g. Central Hidroeléctrica Paula Afonse in Bahía, Brazil).

CAGE FARMING SYSTEMS

Cage-culture systems currently account for less than 10 percent of total aquaculture production of tilapia in the Latin America and Caribbean region, although this proportion is predicted to increase up to 30 percent by 2010 (Fitzsimmons, 2000a). Tilapia cage culture is expanding in some countries, including Mexico, Brazil, Colombia (Watanabe *et al.*, 2002), Honduras, Nicaragua and Cuba. Cage-culture operations require lower capital investment, offer increased management flexibility and have lower production costs as compared to ponds and raceways. In addition the breeding cycle of tilapia is disrupted in cages, allowing mixed-sex populations to be reared without the problems of sexual maturity and stunting (Orachunwong, Thammasart and Lohawatanakul, 2001; Gupta and Acosta, 2004). Initial trials have also been successfully conducted to assess production of red tilapia in estuarine and marine conditions (Fitzsimmons, 2000a).

Tilapia can be cultured at high densities in cages that maintain free circulation of water. Cage construction varies widely from simple bamboo enclosures to complex steel and plastic designs. Floating surface cages (*jaulas*), standing surface cages that rest on the bottom (*corrales*) and wooden corrals that enclose portions of a lagoon (*encierros*) are all used for tilapia culture (Fitzsimmons, 2000b). Standing cages are tied to stakes driven into the bottom substrate. Floating cages can utilize metal or plastic drums, sealed PVC pipe or styrofoam

(Figure 20). Cage sizes vary from 1 m³ to more than 1 000 m³ (Figure 21). Feeding rings are usually used in smaller cages to retain floating feed and prevent wastage (McGinty and Rakocy, 2003).

Intensive production systems involve the use of more technology, an increase in densities, higher water exchange, special fish feed, etc. Production performance is also higher. The technology introduced here is mainly the use of small cages (“*gaviolas*”) with nets (Figure 22), which are placed in hydroelectric reservoirs and lakes. The production level will depend on the water quality (temperature, size, depth, exchange, natural feed productivity, etc.)

Brazil dominates the tilapia cage-culture industry, and commercial cage-culture operations are the major suppliers of the fish sold domestically and outside Brazil. Five varieties of red tilapia are being cultivated, with an annual estimated production of 80 000 tonnes. Semi-intensive culture of red tilapias in 4 to 18 m³ cages has allowed Brazilian producers to reach productivity levels of 100 to 305 kg/m³ per cycle (Gupta and Acosta, 2004) (Table 12). Note that smaller cages have better performance because of better water exchange and thus are more popular among fish growers.

TABLE 12
Example of semi-intensive tilapia production systems in Brazil

Cage size	Stocking density (fingerlings/m ³)	Productivity (kg/m ³)
Small (< 5 m ³)	100 – 600	150
Large (> 5 – 100 m ³)	25 – 100	50

FIGURE 18
Tilapia cages in Costa Rica



FIGURE 19
Tilapia cages in Costa Rica



Other examples of production in the region are:

- At a stocking density of 550 fingerlings/m³, production could be 330 kg/ m³ of fish harvested at 500 g in four months.
- At a water temperature of 26 °C, fish weighing 0.5 g (2 cm long) can be harvested at 400 g in 116 days.

Male tilapia introduced in small cages or “gaviolas” (5 m³) at 200–600 fish/m³ can yield 50–300 kg/m³, as such cages are more productive due to more efficient water exchange.

Tilapia cage culture in Latin America and the Caribbean

Production of tilapia in the region is predicted to reach an estimated 500 000 tonnes by 2010, and about 30 percent of this will come from cage-culture operations (Fitzsimmons, 2000a).

Brazil alone has over 6.5 million ha of reservoirs, lakes and dams with a potential capacity to produce 700 000 tonnes of tilapia annually. With its favourable year-round climate and abundant, low-cost water resources, Brazil has one of the largest and fastest growing tilapia industries in the region.

Cage culture currently accounts for less than 10 percent of the 175 000 tonnes of aquaculture production in Brazil (Kubitza, 2004b), the majority of farming being conducted in pond systems. The use of cages to raise tilapia and native fish (tambaqui and pacu) is becoming more popular, with small fish cages now being found in all the major reservoirs in the country. Currently production is concentrated in the south and southeast of the country (Paraná, Sao Paulo and Santa Catarina). Since 2000 there has been a trend to expand production towards

the tropical northeastern states, mainly Bahia and Ceará. With extensive areas of reservoirs suitable for cage culture and the proximity to international markets, Ceará is one of the most promising states for tilapia producers in Brazil (Kubitza, 2004a). Within Brazil there is a high level of integration between private and public enterprises, including production operations, research institutions, feed manufacturers and support services (Alceste and Jory, 2002).

Brazilian aquaculture is expected to become increasingly competitive in international markets, with production continuing to increase on an industrial scale. With the creation of the national Special Secretariat of Aquaculture and Fisheries (SEAP) in 2003, the aquaculture sector is experiencing a period of improved organization

FIGURE 21
Tilapia cages in Brazil



COURTESY OF F. KUBITZA

FIGURE 20
Tilapia cages in Costa Rica



FACIOA. Rojas

FIGURE 22
Tilapia cages in Costa Rica



and development. As legislation becomes more clearly defined, investment in cage-aquaculture projects has increased.

Mexico also has extensive freshwater and marine resources, and cage culture has been developed throughout all regions of the country. There are two main aquaculture stakeholders; the private sector, which is comprised of wealthier investors, and the social sector, which includes agrarian reform communities and communal organizations and production cooperatives that are mainly comprised of resource-poor individuals. According to FAO (2003), cage culture in Mexico consists of about 87 units (out of 1 963 units in total) with a volume of 88 913 m³.

The Government of Mexico has developed a National Aquaculture Development Project in conjunction with the World Bank to further develop tilapia production at the national level. There is a plan to establish three tilapia parks with floating cage complexes. Each complex will include 100 cages of 6.5 m³ each. Mexican and international experts will conduct the environmental and social impact studies that are required for World Bank-supported projects for each site. The intent is to support further intensification of tilapia production by large-scale demonstration of the efficacy of tilapia cage culture (Fitzsimmons, 2000b).

In Colombia, tilapia is produced in large reservoirs constructed for hydroelectric generation. Cages range from 2.7 to 45 m³ in volume, with total volume exceeding 13 000 m³ in 1997. Sex-reversed males produced in land-based hatcheries are stocked into growout cages at 30 g and are raised to 150–300 g in six to eight months. Fish are fed extruded feeds with 24–34 percent crude protein. Streptococcal infections have been problematic, and survival averages 65 percent. Annual yield at final densities of 160–350 fish/m³ are 67–116 kg/m³ (Fitzsimmons, 2000a). Red tilapia is produced in octagonal 75 m³ cages in the Poechos Dam in the district of Lancones, Peru (Carvajal, 2006). Production is estimated at 600 tonnes per year from this region. There is also another tilapia cage facility in Laguna Encantada (Provincia del Huaura), with 50 tonnes of production per year.

In Panama a floating cage system in Lake Gatún containing 18 cage units of 48 m³ produced over six tonnes of fish per cage, with an average live weight of 1 kg. This was processed into fresh fillets for the market in Miami (Alceste and Jory, 2002). In 2006 red tilapia production in cages will start in Lake Chagres.

In Honduras the majority of the projects related to tilapia production are performed in ponds, with approximately 1 600 producers and 19 000 people working directly in the industry and 50 000 working indirectly.

In 1999 cage culture of Nile tilapia was introduced in Lake Yojoa as part of a research project between DIGEPESCA (Office of the General Directorate of Fisheries and Aquaculture) and the Taiwanese Technical Mission to Honduras in 1998. In 1999 the project consisted of 52 cages and had an annual production of 118 tonnes of live fish. The project was then handed over to three cooperatives of ex-fishermen. The operation was expanded to 76 cages and the production increased to 173 tonnes per year. Each cage measures 6 x 6 x 2.5 m and has a volume of 90 m³. The fish are grown in four stages up to an average harvest size of 500–600 g. Marketing of tilapia is done by direct sales and through intermediaries. The cages are managed at 44 percent of their installed capacity due to a lack of financial resources required to attain full-production (funds for purchase of fingerlings and operating capital). Fish harvests and sales are principally during the months of January thru May. The rest of the year is dedicated to restocking the cages and to sporadic sales. Their production surpasses 1 290 kg/cage in grow-out cycles of about eight months duration. Feed represents about 44 percent of production costs.

Since the farming environment is uncontrolled, some risks to production such as rapid changes in water temperature and low dissolved oxygen levels are encountered.

In Nicaragua there are 32 cages producing Nile tilapia in the “Gran Lago” de Nicaragua, but with many complaints arising from environmentalists.

In 2006 a tilapia farming project started in Cuba in regions San José del Jobo, Palma Hueca, La Yaya, Cascorro 88, La Chorrera, San Juan de Dios, Las Piedras and Najasa. The project called for the assembling of a total of 800 cages with a production of between 470–500 kg per cage. The project targets both domestic and export markets (300–350 g fish). (www.aqua.cl-21-09-2006)

In summary, cage culture of tilapia is expanding in many countries in the region, including Peru, Costa Rica, Honduras, Panama, Nicaragua and Cuba (Watanabe *et al.*, 2002). Production in these countries is predicted to become more intensive, with further investment, improved nutrition, aeration, water re-use and disease control. Cage culture will also continue to replace tilapia stocking

and recapture fisheries operating in many of the reservoirs of these countries (Fitzsimmons, 2000a).

Environmental effects and relevant legislation

Intensification of aquaculture in reservoirs may lead to conflicts with other stakeholders, especially with the increase of nitrogenous wastes. Generally there is little fouling or waste build up below the cages, as tilapia faeces float and break up readily. However this leads to a greater dispersal and may eventually result in eutrophication of freshwater systems, increasing algal production and biological oxygen demand (Pullin *et al.*, 1997). If the reservoirs are sources of water for human use, there may be health issues associated with increased nitrification as well as bacterial infections such as *Streptococcus*. Perhaps the greatest concern is the release of a non-native, highly adaptive and successful fish species into the aquatic environment, either through escapes or intentional release-capture fisheries. This is especially relevant to natural water systems such as Lake Cocibolca, Nicaragua, the largest freshwater body in Latin America, where tilapia culture has recently been initiated. Central American cichlid species may be particularly vulnerable to displacement by tilapias.

There are a number of institutional frameworks throughout the region concerned with aquaculture projects. In Mexico the administration of the relevant aquaculture legislation (Fisheries Law 2001) is the responsibility of the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA). The National Commission for Aquaculture and Fisheries (CONAPESCA) is the department directly dealing with aquaculture. Other administrative institutions can be found at the local, municipal and state levels. The tasks and responsibilities of SAGARPA include designating areas suitable for aquaculture, regulating the introduction of species and promoting aquaculture development. SAGARPA has developed the Sectoral Program for Agriculture, Livestock, Rural Development, Fisheries and Food 2001–2006, which addresses the sustainable exploitation of fishery and aquaculture resources and the promotion of profitability, both in economic and social terms, of the fishery and aquaculture sector.

The Mexican legislation includes comprehensive legislation both at the planning and operational stages. The setting up of an aquaculture facility in federal water bodies is managed and controlled by a system of concessions, permits and authorizations issued by CONAPESCA. The application should be

accompanied by an environmental impact assessment (EIA), preventive report or authorization. The Environmental Law requires an EIA for activities that may cause ecological imbalances or surpass established limits and conditions. Where highly hazardous activities produce emissions, discharges, natural resources exploitation and in general, if there is any environmental impacts caused by the production activity, the EIA must include a risk study containing preventive scenarios and measures that arise from the analysis of environmental risks involved in the project, a description of the facilities' protected zones, and an indication of the environmental safety measures. Aquaculture facilities must obtain a discharge permit from the National Water Commission and all waste water must be treated. There are regulations regarding exotic species, drugs, feeds and hormones and the use and application of antibiotics is regulated. New pharmaceuticals have to be approved. All fish and seafood products must meet food safety regulations. The implementation of The National Water Law (1992) removed many of the restrictions on use of water for aquaculture, especially opening reservoirs and irrigation canals for cage culture (Fitzsimmons, 2000b).

In Brazil the Special Secretariat of Aquaculture and Fisheries (SEAP) was created in 2003 and is the main authority for the management and development of fisheries and aquaculture. SEAP is currently in the process of preparing a National Plan to ensure the development of a sustainable aquaculture industry. SEAP also functions as a consultative service through the National Council for Aquaculture and Fisheries (CONAPE), which is comprised of representatives from the government, public and production sectors. The Brazilian Institute for the Environment (IBAMA), another institution for the management of fisheries, has responsibilities that mainly concern environmental issues such as natural resource conservation (including aquatic resources), environmental licences and water quality control.

The federal government is making strategic investments in the aquaculture sector, building hatcheries, installing aquaculture demonstration units and at the same time providing special financial credit lines for the industry. National programmes in support of aquaculture cooperatives, extension services, research and marketing are also now being planned (FAO, 2004). Cage culture developed rapidly after the government increased the number of permits allowing cage culture to be conducted

in public waters (Lovshin, 2000). For example the use of reservoirs for aquaculture is one of the main development programmes to have been put in place by SEAP. The national programme focuses on the six largest reservoirs, which are located in different regions of the country, and projects a potential production of 18 million tonnes, even if only one percent of the area contained within these reservoirs is utilized for aquaculture. The government is currently setting regulations for cage culture in the reservoirs and other public waters that will limit the cage area to one percent of the total reservoir area (Kubitza, 2004b).

The establishment of aquaculture is subject to environmental licensing and to the presentation of an environmental impact study; however, the Brazilian environmental licensing system does not automatically entail the presentation of an environmental impact study. The requirement of a proper study as a licensing condition is made mandatory, at the constitutional level, only for the establishment of activities that may significantly harm the environment (FAO, 2004).

The main health problems in cage culture are due to bacteria such as *Aeromonas hydrophila*, *Flavobacterium columnare* and *Streptococcus iniae*, to parasites like *Ichthyophthirius multifiliis*, *Trichodina* sp, *Argulus* sp. and *Lernaea* sp. and to fungi, such as *Saprolegnia* sp. Most recently, Costa Rica is facing a new intracellular rickettsial-like pathogen (*Francisella* sp.) that causes high mortality during the initial stages (1 g and above).

Economic aspects and markets

Latin America and the Caribbean are relatively small producers and markets compared to China and other Asian countries (Fitzsimmons, 2000a). Latin America (Ecuador, Honduras and Costa Rica) is the main exporter of fresh tilapia fillets to the United States, of America and in 2005 fresh fillets accounted for 35 percent of the total import value. Frozen tilapia

(both whole and fillets) mainly originates from China, Taiwan Province of China and Indonesia. Tilapia consumption has grown significantly in the United States over the past few years and this has stimulated the growth of tilapia farms in Latin America. In 2000, 40 469 tonnes of tilapia valued at US\$101.4 million were imported into the United States of America, a figure that had increased to 134 869 tonnes valued at US\$393 million by 2005 it (USNMFS, 2005).

Further development of the United States market is also important, particularly to obtain better prices for fresh tilapia over frozen tilapia from Asia (Watanabe *et al.*, 2002). Tilapia imports into the United States of America have been growing by the impressive average of 25 percent per year over the past five years. Thus 2005 saw a new record of 135 000 tonnes of imports (Table 13).

Frozen tilapia imports into United States stayed stable in 2005, with China and Taiwan Province of China accounting for 98 percent of total supply. The real dominator of the United States tilapia market, however, is the frozen fillet from P.R. China, imports of which grew by an impressive 54 percent in one year. All main exporters of this product reported some type of growth, however, P.R. China, which accounts for 80 percent of the total supply of frozen tilapia fillets to the United States market, represented the bulk of the increase, from 28 000 tonnes in 2004 to 44 000 tonnes.

Thus the United States tilapia market is neatly split into two segments, the frozen tilapia market at low prices and the fresh tilapia fillet market at a higher price. Prices of fresh tilapia fillets in this market have stabilized at US\$3.85/lb, apparently still an interesting price for exporters, even though the overall trend during the past ten years has been a steady decline in price. Prices of frozen tilapia fillets are much lower than that of fresh fillets. The price of frozen tilapia fillets stabilized in the course of 2005 at a low US\$1.68/lb, less than half the fresh fillet price.

TABLE 13
Total tilapia imports by the United States of America – by product (in tonnes)

Product	1997	1998	1999	2000	2001	2002	2003	2004	2005
Whole frozen	19 122	21 534	27 293	27 781	38 730	40 748	49 045	57 299	56 524
Frozen fillets	2 499	2 696	4 971	5 186	7 372	12 253	23 249	36 160	55 615
Fresh fillets	2 823	3 590	5 310	7 502	10 236	14 187	17 951	19 480	22 729
Total	24 444	27 820	37 575	40 469	56 337	67 187	90 246	112 939	134 860

Source: Tilapia Market Report. FAO, February 2006

Fresh tilapia fillets also show a very interesting trend, growing by 17 percent in 2005 over 2004 (Table 14). The huge increase is almost exclusively coming from Honduras, one of the success stories of tilapia culture in Central America. The other one is Brazil, which tripled its exports between 2004 and 2005. Latin American countries dominate the United States fresh tilapia fillets imports. Brazil is expected to take over from Ecuador as the top supplier of fresh tilapia fillets to the United States market in the near future.

Disease problems experienced by the Brazilian shrimp industry will lead to more tilapia culture in the coming years. P.R. China dropped out completely, underlining the closeness and competitiveness of Latin American countries to the lucrative United States market, including lower air shipment costs. Nevertheless a high dependence on the United States market makes many producers vulnerable to trade restrictions. International standards for food safety, quality and environment are becoming increasingly important (Carvajal, 2005a).

Besides export markets, there are also growing—but still small—domestic markets in some producing countries in South and Central America, especially in Brazil, Mexico, Colombia and Cuba. In Colombia and Mexico for example, the domestic demand has absorbed local production and exports to the United States of America have declined. This diversification is beneficial to producers, as local markets reduce shipping and processing costs.

The domestic markets for tilapia in the region are generally poorly developed and there is a need for strong marketing programmes to sustain industry growth. Little work has been done on the

potential to develop domestic markets for tilapia in the region. This is particularly important for smaller-scale growers, who have greater difficulty in meeting the volume and size requirements of export markets.

In Brazil, for example, the commercialization of tilapias is done as live fish, fresh harvested, salted, frozen and filleted. Prices vary according to the type of fish in the market, the price in US\$ per kg being 0.87–1.05 for live fish, 0.53–0.70 for fresh fish, 0.35–0.70 for salted fish and 2.10–3.51 for fillets (El Periódico de Acuicultura, Marzo 2004, # 2, año 1).

In the region cage culture accounts for less than 10 percent of total tilapia production, and the further development of small producers will probably be based on pond culture considering the lower investment requirements. Nevertheless it is expected that cage aquaculture will continuously grow, particularly in the case of countries such as Nicaragua, Honduras and Cuba where some foreign investment has already happened and good environmental conditions allow a faster growth.

It is noteworthy that in 2005 one of the largest Chilean salmon companies and a tilapia farming company based in Costa Rica announced a strategic alliance. The combination of these market leaders will yield significant synergies through the sharing of technology and know-how in the areas of genetic selection, fish nutrition, information systems and general farming and processing methods. This move will have a major impact on the world market for tilapia, especially with regard to the growth of consumption in the main market, the United States of America.

TABLE 14
United States imports of fresh tilapia fillets by country of origin (in tonnes)

Country	1997	1998	1999	2000	2001	2002	2003	2004	2005
Ecuador	602	646	1 806	3 253	4 924	6 616	9 397	10 164	10 600
Costa Rica	1 656	2 206	2 310	2 684	3 109	3 206	3 996	4 090	3 734
Honduras	164	436	771	1 038	1 438	2 874	2 857	4 042	6 572
China	0	0	38	59	191	844	857	0	0
Taiwan Province of China	8	85	155	82	76	247	281	90	0
Brazil	1	0	0	2	0	112	208	323	963
El Salvador	0	0	0	0	0	78	189	258	307
Panama	61	4	20	159	350	147	96	93	84
Others	331	213	209	225	148	64	71	420	470
Grand total	2 823	3 590	5 310	7 502	10 236	14 187	17 952	19 480	22 729

Source: Tilapia Market Report. FAO, February 2006.

OTHER MARINE SPECIES

Tuna farming

Tuna is one of the major traded international seafood products, with world landings of over 3.5 million tonnes per annum. This accounts for five percent of total fisheries for human consumption. One third of the tuna is produced as fresh, chilled or frozen fish and exported to the major markets of Japan, the United States and the European Union (Paquotte, 2003). In addition to tuna fisheries, a capture-based aquaculture industry has developed where juveniles are captured from the wild and then on-grown in large seawater pens. World aquaculture production of northern and southern bluefin tuna using these “farming” techniques exceeded 20 000 tonnes between 2001 and 2002. There are major producers located in Australia, Europe and Mexico (with Mexico accounting for 3 percent of this volume) (Sylvia, Belle and Smart, 2003).

Mexico is the largest aquaculture producer of bluefin, bigeye (*T. obesus*) and yellowfin tuna (*T. albacares*) in the region. In 2003 bluefin tuna farms in Mexico produced 2 00 tonnes, a figure which increased to 5 000 tonnes in 2005 (Figure 23). Further growth is predicted if Japanese investment in the industry continues (ATRT, 2005). Tuna ranching started in Mexico in 1996 with marginal success. This was mainly due to weather events such as El Niño and Hurricane Nora, but also due to a general lack of experience, which led to high mortalities. However the development of many innovative techniques for both fishing and farming by Mexican tuna operations in recent years has allowed some companies to emerge as significant competitors in a relatively young but growing industry. Mexico is particularly suited for tuna

farming due to its temperate weather conditions, an abundant supply of locally caught feed, proximity to major international airports in the United States of America, favourable regulations and low labour costs (Sylvia, Belle and Smart, 2003).

Farming is conducted in oceanic conditions, so cages must be able to withstand the high energy of waves, currents and winds of the open sea. Tuna cage systems are typically 40–50 m in diameter, 15–20 m deep, and with holding volumes of 18 000–20 000 m³ (Figures 24, 25 and 26). Fish densities can range from 2–5 kg/m³, while water currents range from <1–2 knots, depending on the farm site (Sylvia, Belle and Smart, 2003). In Mexico ranching activities are located around the Baja California and Baja California Sur areas. The largest company operates over 15 cages (50 m diameter), which produced around 1 000 tonnes of tuna during 2004.

In 2004 the value of Mexico’s tuna export was about US\$89 million, less than half of which (US\$30 million) was exported to Japan. Future exports to Japan will be facilitated by the free trade agreement signed between the two countries during 2005 (ATRT, 2005). The United States market for tuna is also expanding rapidly, although prices for premium quality products are lower than those achieved in the Japanese market. Higher prices are also achieved in Japan for larger fish. Generally Mexico produces smaller fish than other markets such as Europe, and this is reflected in the price obtained (US\$25/kg versus up to US\$34/kg for larger fish) (Paquotte, 2003). Another positive economic effect of the tuna industry is the resurgence of Sauzal sardine catches in Mexico, as this is the main food of the farmed tuna (ATRT 2005).

FIGURE 23
Tuna culture in Mexico



FIGURE 24
Tuna farming in Baja California, Mexico



PHOTO COURTESY OF MARIA TERESA VIANA

FIGURE 25
Bluefin tuna (*Thunnus thynnus*) juveniles being raised in cages



FAO/ID. Cedrone

FIGURE 26
Bluefin tuna (*Thunnus thynnus*) juveniles being raised in cages



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Environmental effects and legislation

It can be argued that many closed-cycle aquaculture systems have the potential to alleviate the pressure on wild-caught populations by providing a more sustainable supply (e.g. farming of Atlantic cod (*Gadus morhua*) in Norway and the United Kingdom). However the tuna farming industry is dependent upon the capture of juveniles that are then on-grown and culled before they are able to breed, thus increasing the pressure on the wild populations.

Tuna capture quotas exist in all regions and act as a constraint to industry growth; however these quotas tend to be poorly regulated (Sylvia, Belle and Smart, 2003). There has been some progress in rearing tuna in captivity, and juveniles have now been produced from farmed (i.e. second generation) Pacific bluefin tuna (*Thunnus orientalis*) (Sawada *et al.*, 2005). However these techniques remain to be effectively commercialized.

Most operations still rely upon whole wild-caught fish such as sardines, mackerel and squid for the feed. In some cases these “feeds” can be obtained and transported globally. In Australia there are concerns that the importation and feeding of non-indigenous fish species to tuna farms were responsible for the viral infections that decimated indigenous Australian sardine populations, resulting in huge ecological impact (Dalton, 2004).

Many areas along the coastline of Mexico and its associated islands support large colonies of sea lions. They are attracted to tuna farms by the excess feed that falls through the cages or that is discarded. Due to the size of the cages many farms

do not use predator nets on the cages but instead use fences around the perimeter to prevent sea lions from hauling onto the cages and jumping in. Some farms use electric fences around the cage surface perimeter. Although there are several different techniques, significant predator effects continue to be a problem. Stress and poor growth performance are common in most of the farms. Although many fish survive attacks due to their size, their value is significantly decreased in the market place due to damage (Sylvia, Belle and Smart 2003). Other predators such as sharks are also attracted to the cages and are killed after becoming entangled in the nets (ATRT, 2005).

Other potential operations in the region include Costa Rica, where ten cages have been placed approximately 2 km off the coast. The project will start up with a production of 480 tonnes of yellowfin tuna per cycle, with two or three cycles a year depending on catches (Carvajal, 2005b).

New aquaculture species—new cage technology

The feasibility of producing other marine species such as cobia (*Rachycentron canadum*) and mutton snapper (*Lutjanus analis*) in the Caribbean region is currently being examined. Advantages of culturing of cobia production are its high market value (US\$8.80/kg) and fast growth rate, reaching individual sizes of 6–7 kg one year after hatching. This is approximately three times the growth rate of Atlantic salmon. Commercial cobia production has been successfully undertaken in Taiwan Province of China, with large numbers of juveniles

now routinely being produced from specialized hatcheries.

In May 2002 a pilot cobia project in Puerto Rico was launched by the industry, in cooperation with the University of Miami and other collaborators. The operation has installed two off-shore Ocean Spar submersible cages (3 000 m³) (Figure 27), with one cage containing 12 000 cobia (Figure 28) and the other cage containing 4 000 mutton snapper in the waters off the island of Culebra.

The Ocean Spar design consists of a central spar surrounded by a round steel rim 25 m in diameter. Each frame is covered with taunt netting attached to spoke lines conforming to the sea cage's shape. Zippered doors in the net provide easy diver access. The cage system can be rapidly (<5 min) lowered and raised by varying the buoyancy of the spar. The cages are 30 m wide, 15 m high and moored in at least 30 m of water. They are held down by four heavy anchors and ballast of 10 000 kg, and they are invisible from the surface—the only clue to their presence is a small buoy attached to a tube that can be pulled to the surface and used to introduce tiny hatchlings, feed up to 20 000 captive fish at a time, and then pump them out again when they reach market size. The nets are cleaned periodically (Radford, 2005).

Submersible cage technology will facilitate the development of true offshore aquaculture into exposed areas where wave height would have previously precluded cage operations. Fully submersible cages will also allow marine aquaculture to be conducted in areas prone to hurricanes such as the Caribbean. Further developments producing cobia in submersible cage systems are planned in Belize (Schonwald, 2006), the Bahamas and Nevis-St Kitts.

Disadvantages of the system are the reliance on diver support for routine operations and lack of close eye contact with the fish stocks. The cages also appear highly attractive to shark populations that have caused problems with net damage and fish escapes (Schonwald, 2006). Legislation addressing the issue of offshore aquaculture has not been fully established (Dalton, 2004; Alston *et al.*, 2005). Some species such as salmon are not suitable to farm in continuous sub-surface environments because of their need to inflate their swimbladders at the surface.

THE WAY FORWARD

There has been significant development of cage aquaculture within Latin America and the Caribbean

FIGURE 27
Fully submersible Ocean Spar cage with service diver,
Culebra, Puerto Rico



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FIGURE 28
Cobia (*Rachycentron canadum*), Culebra, Puerto Rico



COURTESY OF NOAA

over recent years, bringing profound changes to the regional economies and communities. This has been especially true in Chile, which is now shares the position of world's largest salmon producer with Norway. Success in Chile has been greatly facilitated by the country's commitment to free trade and open markets. This has been complemented with a series of trade agreements with the United States, the European Union and Republic of Korea among others. Alongside the neo-liberal economic policies, a range of legislation has evolved to address the critical issues associated with the rapid expansion of aquaculture. These will assist in the development of an economic, ecological and socially sustainable industry. It is important that other countries within the region clearly recognize the need to rapidly expand cage aquaculture while

at the same time effectively mitigating the resulting environmental impacts.

Controlling the number of escapes, especially of non-indigenous species, remains a major challenge with no single remedy. Improved husbandry, replacing old nets and equipment, and effective control of predators have shown to significantly reduce losses. The production of sterile animals has been more controversial, and although this would limit the effect of propagation of populations in the wild, this control measure remains to receive widespread acceptance from consumers.

Until recently bacterial diseases of salmon had been largely controlled with the use of antibiotics. Modern vaccines have proven highly effective in other regions, and progress is now being made against specific pathogens such as *Piscirickettsia salmonis*. Integrated management, area fallowing, coordination of treatments between sites and shared health information are also improving control and reducing the use of antimicrobials. These techniques and technology are available for use in the culture of other species in the region.

New cage technology and the provision of fully submerged systems offer new possibilities for offshore aquaculture, as well as in areas prone to hurricanes (i.e. most of the Caribbean). The high costs of fully submerged operations are likely to remain an issue and restrict this technology to production of high-value species such as cobia. An effective alternative could be cages that have the capability to submerge until the adverse conditions have passed.

Intensive cage aquaculture produces localized impacts on the environment, with increased nitrogen and phosphorous loadings and a "footprint" of enrichment under the cages (Soto and Norambuena, 2004). There will be ecological changes observed within this footprint and a succession of species occurring in the sediments. With effective monitoring and management, it has been shown that these effects could be reversible (Black, 2001). Freshwater systems are more vulnerable to ecological change from nitrogenous inputs than seawater culture sites. Further development of large-scale cage aquaculture in freshwater systems will need careful management to be truly sustainable.

It is impossible to predict the behaviour of an ecosystem without knowing how its components are distributed in time, space and respect to each other, and understanding the relationship and processes that explain their distribution and behaviour (Perez *et al.*, 2002). As well as requiring knowledge of spa-

tial distributions and relationships, the ability to make reliable predictions often demands knowledge about temporal trends. In this sense geographical information systems (GIS) are powerful tools that can assist integrated planning, particularly for coastal zone management. The use of carrying capacity approaches is important in order to evaluate the effect of the cages throughout the whole system, instead of just their localized effects (e.g. under the cages). Although these studies already have been done in some lakes in southern Chile, they must be continued and the water resources continuously monitored.

The quality of human resources is not homogenous throughout the region. As aquaculture has grown, new problems have arisen and more specialized expertise is required in areas such as health, nutrition, genetics, environment, harvests, marketing, planning, legislation, financing and bioeconomics, both at private companies and also in the government sector. In addition there is an increased demand on applied research to respond to these new challenges.

Aquaculture has produced significant socio-economic impacts in the areas of the region where it is developed, as in the case of Chile and Ecuador. Nevertheless the service infrastructure provided by civil works (roads, electricity, communications, transport, etc.) has not undergone significant development. A similar situation is seen in the areas of health and education, where the infrastructure and professional capacities are also limited. In many cases the private sector has taken the initiative by investing in basic infrastructure and also training their personnel. Local and regional governments still have important challenges to face.

It is evident that the development of the aquaculture industry in the region is to a great extent reflection of the degree of commitment shown by the local governments. The existence of an aquaculture development plan plays a very important role and the coordination of work between the public and private sectors will promote the growth of the aquaculture industry and avoid duplication of effort. This development must take place through the efficient and responsible use of natural resources.

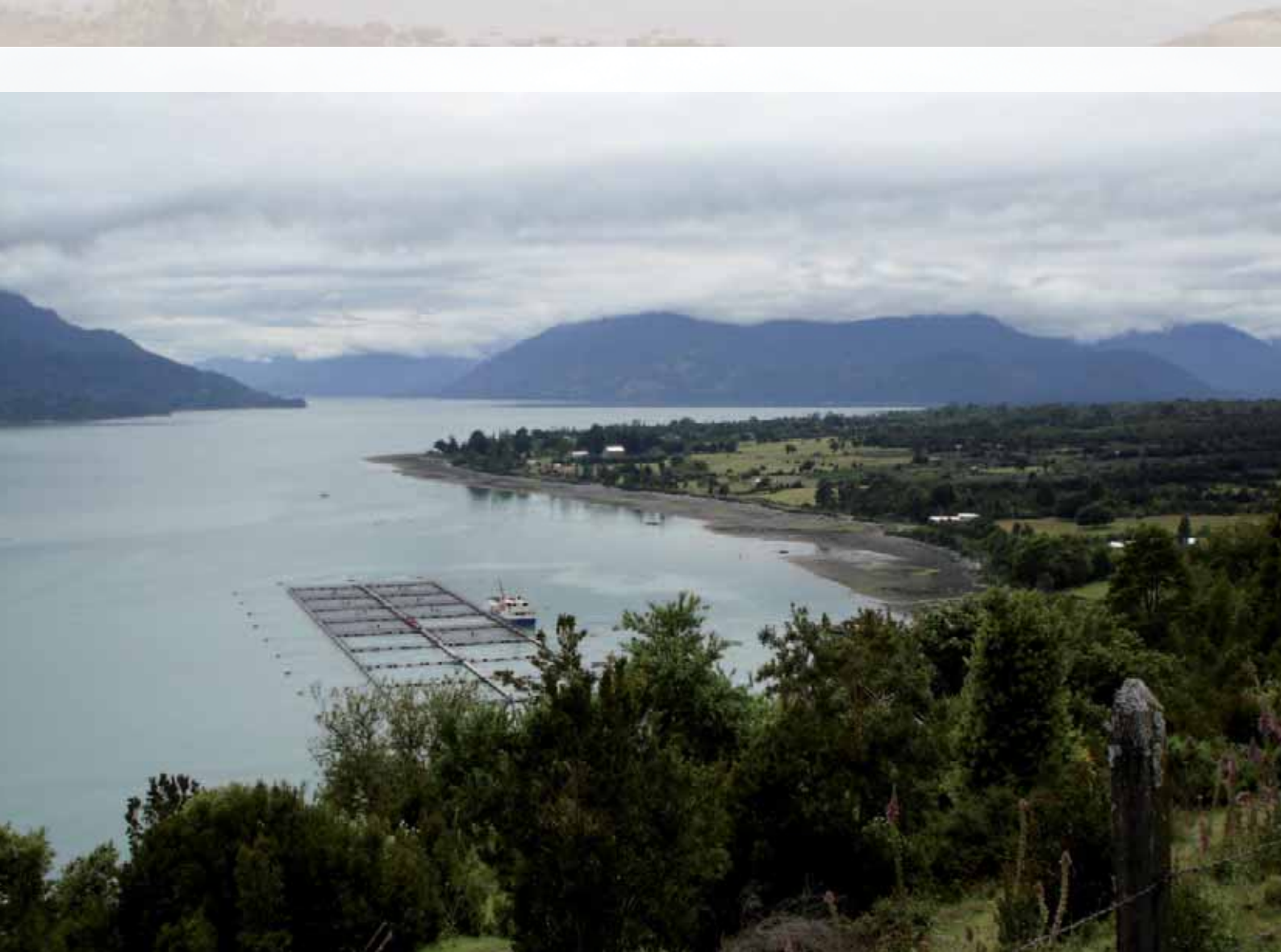
Given the limited availability of fishmeal and fish oil, it is important that the aquaculture industry and the agriculture sector work in a highly coordinated manner in order to assure that the required quality and quantity of raw materials needed for their expansion will be available.

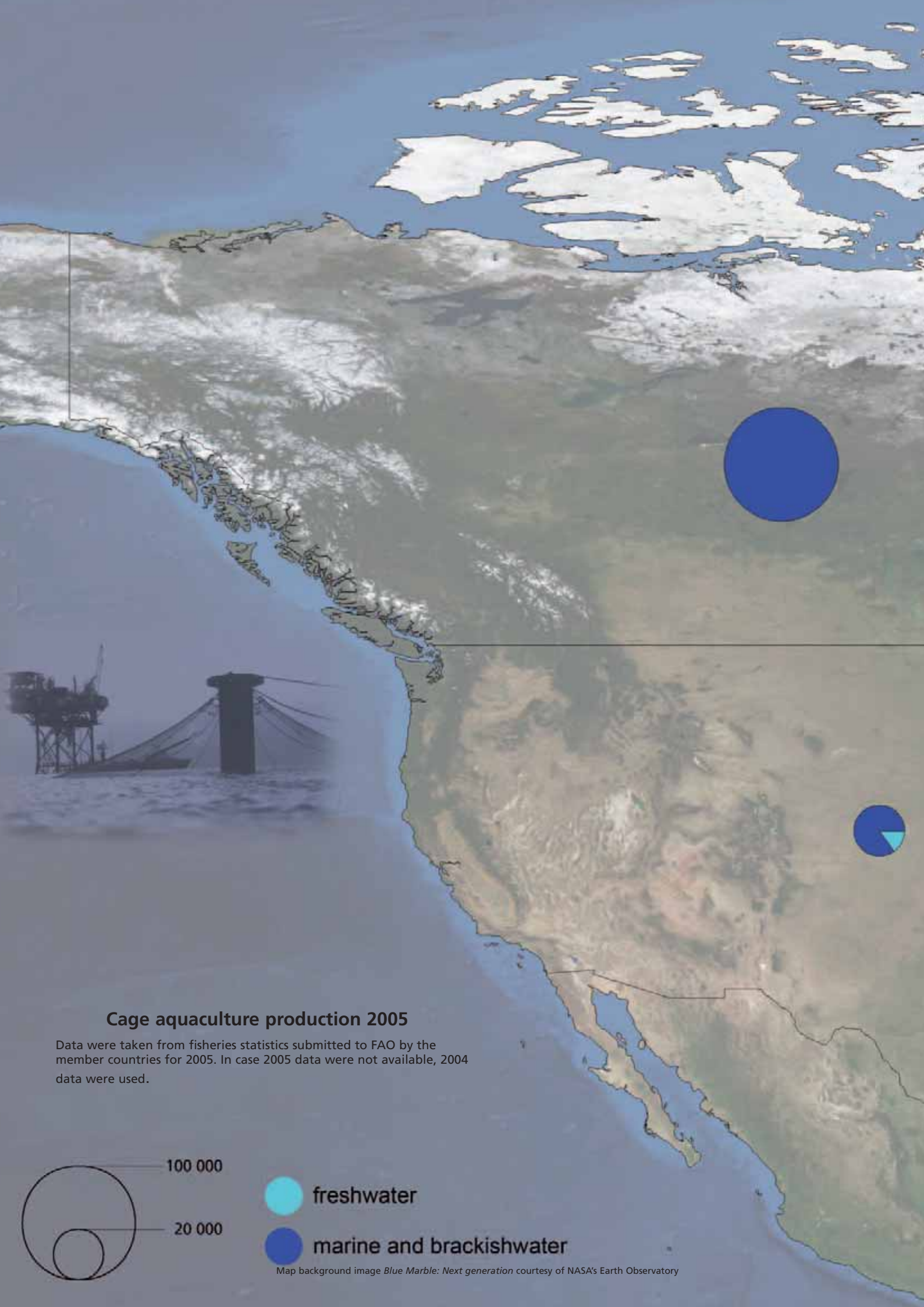
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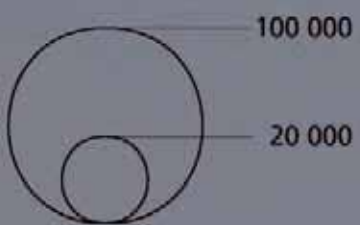
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Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.



-  freshwater
-  marine and brackishwater

Map background image *Blue Marble: Next generation* courtesy of NASA's Earth Observatory

An aerial photograph of North America, showing the continent in shades of green and brown against the blue oceans. A prominent feature is a large, dark, geodesic dome structure overlaid on the Gulf of Mexico, near the Florida peninsula. The dome has a complex, spherical framework. The text "A review of cage aquaculture: North America" is centered over the map in a bold, white, sans-serif font.

A review of cage aquaculture: North America



A review of cage aquaculture: North America

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A review of cage aquaculture: North America. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 102–125. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

This paper is an overview of the status and future prospects of cage aquaculture of marine and freshwater finfish in North America (excluding Latin American countries), covering Canada and the United States of America. Cage culture has a fairly recent history in North America compared to Asia. After four decades of evolution and growth, North American cage culture production and diversity is growing and future development and sustainability appears bright. Main species cultured are Atlantic salmon (*Salmo salar*), steelhead trout (*Oncorhynchus mykiss*), chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), rainbow trout (*Oncorhynchus mykiss*), channel catfish (*Ictalurus punctatus*), arctic char (*Salvelinus alpinus*), blue catfish (*Ictalurus furcatus*), cutthroat trout (*Oncorhynchus clarkii*), yellow perch (*Perca flavescens*), hybrid striped bass (*Morone* spp.), sunfish (*Lepomis* spp.) and tilapia (*Oreochromis* spp.). The total estimated aquaculture production in 2004 was 6 300 tonnes and 105 000 tonnes in freshwater and marine environments, respectively. No official data is available related to production and value of specific species in cage culture in freshwater or marine systems in the United States of America because such operations occur on private land or data cannot be kept anonymous (e.g. only one salmon producer in Washington State). Total production levels are tabulated by species and not by culture system employed. In all freshwater species cases, open pond aquaculture dominates the industry with cage culture activities providing a negligible quantity of production.

A great deal of public research and private innovation in cage culture technology, development of new species, and advancement of management techniques have taken place in North America. However, much more technological development will have to take place if open ocean aquaculture is to meet its projected potential. Currently, Canada leads the United States of America in expansion of commercial cage aquaculture and in developing policies, regulations and public perceptions that accept and promote the future growth and sustainability of its industry. The USA is making slow progress in developing policies that could permit cage aquaculture in the marine environment. However, the prospect of utilizing public freshwater sources for cage culture in the United States of America appears dismal. Most United States state natural resource agencies, which regulate access to public water bodies, have no desire or public/political pressure to allow or promote cage culture in public waters.

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BACKGROUND AND AIM OF STUDY

This paper presents an overview of the status of cage aquaculture in North America, with examples of historical and current cage farming and impediments to future development. Cage aquaculture has experienced enormous evolution and growth in North America over the past four decades. We have chosen to discuss cage aquaculture in North America primarily based upon water salinity (i.e. freshwater versus marine) rather than by country. We felt that this approach ensures common topics are discussed together in a more logical arrangement. Within this framework, specific examples and discussion points by country are discussed as appropriate.

The information presented comes from numerous sources, including current research of the US Cooperative State Research Education and Extension Service (CSREES) Regional Aquaculture Centers and National Oceanographic and Atmospheric Administration (NOAA) Sea Grant, Government of Canada and provincial government agency statistical sources, scientific and popular literature (FAO, 2006) and recent reviews of cage aquaculture (Huguenin, 1997; Beveridge, 2004).

HISTORY AND CURRENT STATUS OF CAGE AQUACULTURE IN NORTH AMERICA

Canada and the United States of America cover a vast area of land that occupies approximately 91 percent of continental North America. The two countries extend temperate and sub-tropical environments, three oceans and is the home of disparate cultures. Aquaculture production for both countries combined including all species was 577 641 metric tons having a total farm-gate value of US\$1.46 billion in 2003 (compiled data from the above sources). Cage aquaculture operations exist throughout the two countries in marine and freshwater environments raising a wide diversity of species.

In Canada, aquaculture production was 145 018 metric tons valued at Can\$ 518 million in 2004. Species raised in cages (salmon, steelhead trout and other marine species) recently accounted for approximately 70 percent of the total production volume but nearly 84 percent of total aquaculture value (Statistics Canada, 2005).

The scale and value of cage aquaculture operations is largely attributed to the rapid growth of the Atlantic salmon sector compared with 1986 data (Figure 1). Grow-out of other finfish species (including chinook salmon, coho salmon, trout,

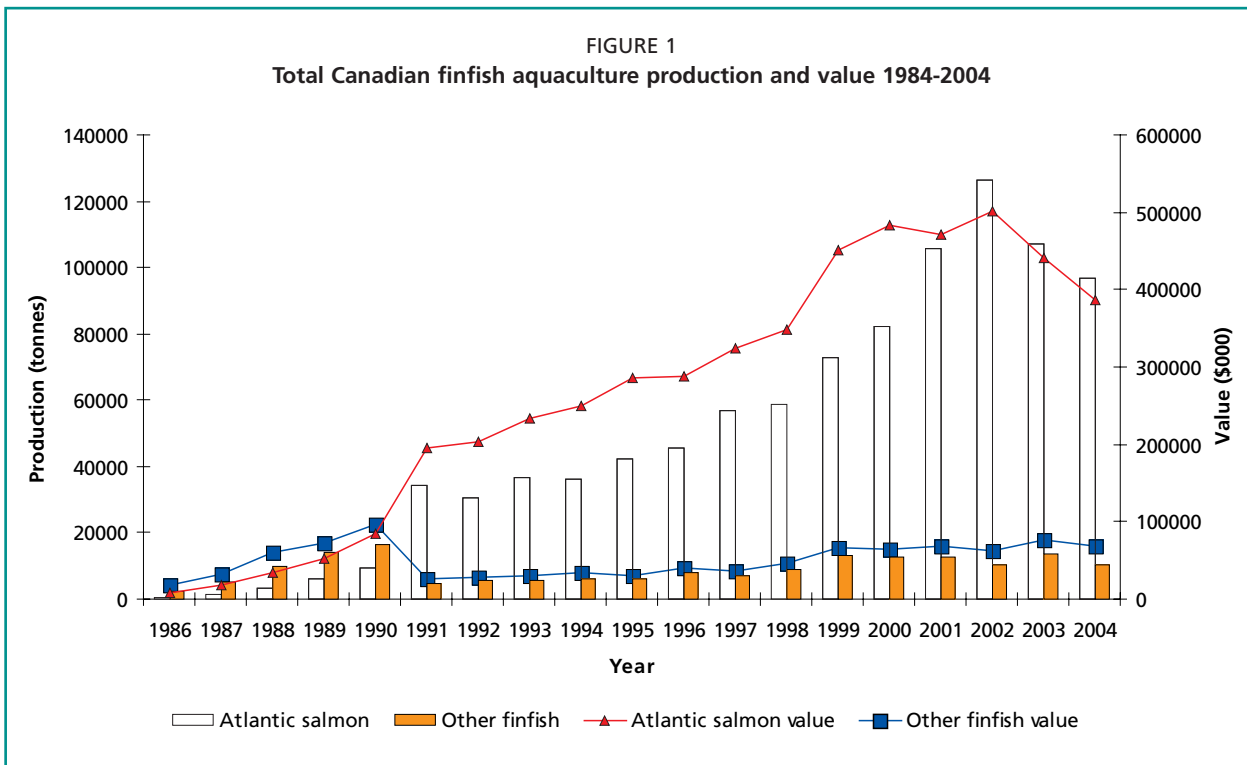
steelhead, cod and other species) has remained low despite industry and government investments to diversify the marine aquaculture industry. Atlantic salmon is raised in waters along both the Atlantic and Pacific coasts of Canada. British Columbia, Canada's only Pacific Ocean province, accounts for the majority of all Atlantic salmon production despite being a non-native species to the region and having initial grow-out trials and commercialization along the east coast of Canada in the Atlantic Ocean (Figure 2). Expansion of the Atlantic salmon industry is expected to increase as companies continue to make use of economies of scale and attempt to offset decreasing average prices. Prices have plummeted in recent years in large part due to increasing international competition and an excess of product in the marketplace (Figure 2).

The total area licensed for aquaculture production in Canadian waters for all species is approximately 30 971 hectares or equivalent to a square measuring of 17.6 km x 17.6 km (OCAD, 2003).

This small patch of water resource produced approximately 14 percent of all Canadian seafood landings in 2003. The opportunity for continued growth of the Canadian cage aquaculture industry is tremendous having a total national coastline of 202 080 km. Given an appropriate regulatory policy framework coupled with increased environmental stewardship and consumer confidence, conservative projections for anticipated growth expects an increase in aquaculture product value from Can\$0.5 billion in 2000 to Can\$2.8 billion by 2010–2015 (anticipated multiplier effects of this value should equate to Can\$6.6 billion to the Canadian economy [OCAD, 2003]).

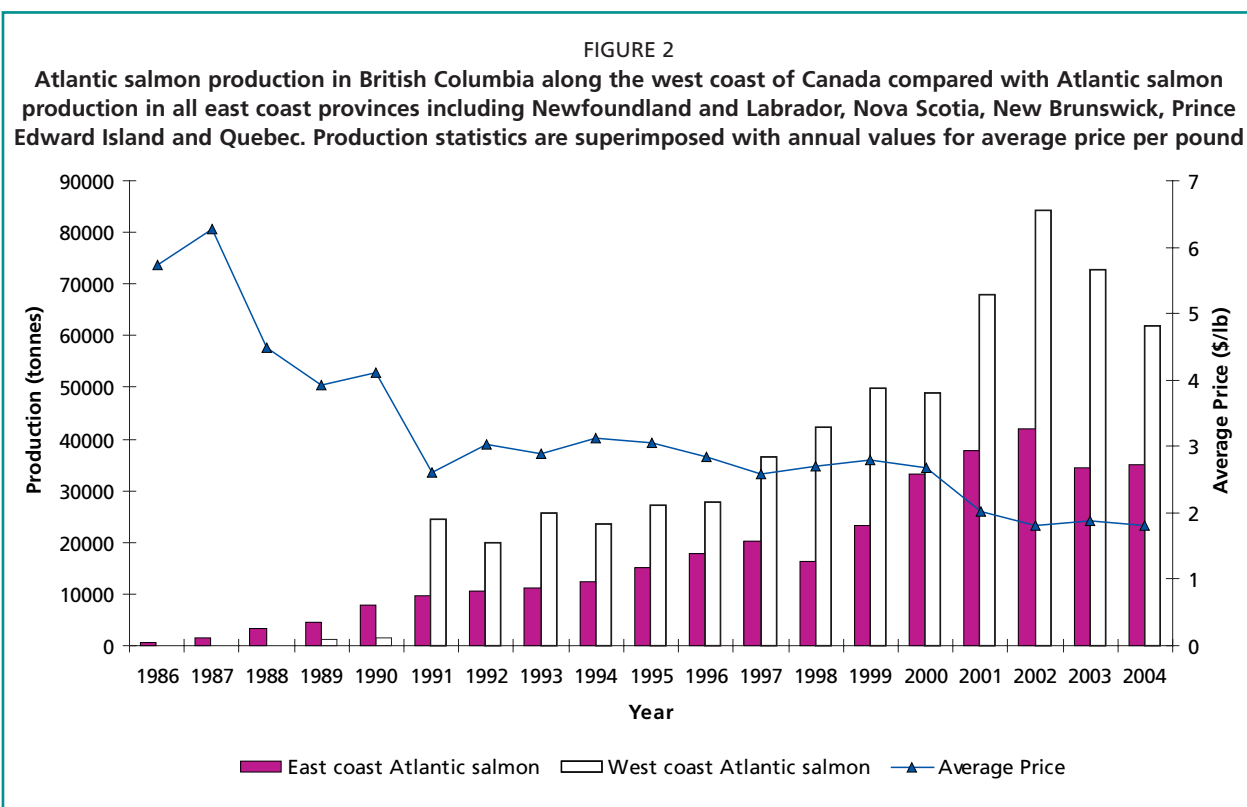
Cage culture of Atlantic salmon (*Salmo salar*) in Canada followed its inauguration in Norway in the 1970s. The first attempts at full-cycle culture in marine cages occurred in the 1970s off Nova Scotia and New Brunswick, but failed due to lethal winter temperatures. A later successful venture was conducted in the southwest Bay of Fundy through a cooperative agreement between private enterprise and the provincial and federal governments. Their first production was 6 metric tons in 1979, which convinced other private investors to engage in Atlantic salmon aquaculture in the region (Saunders, 1995).

Farm-raised Atlantic salmon represents the single largest crop from the entire New Brunswick agri-food sector at 23 percent of total agriculture revenue (equivalent to the provincial production of potatoes, poultry, vegetables, fruits, berries



and grain combined) and a farm-gate value of Can\$175 million in 2004. This level of production requires the services of 1 849 individuals in direct employment including hatcheries, marine grow-out, processing, direct services and administration (NBDFA, 2005).

Steelhead trout (*Oncorhynchus mykiss*) was initially cultured off Cape Breton, Nova Scotia in the 1970s. Atlantic salmon production off Nova Scotia has been slower to develop than New Brunswick and is impeded today off much of the province owing to cold winter temperatures



(most Atlantic salmon aquaculture is presently concentrated in the Bras d'Or Lakes, the Annapolis Basin, Shelburne Harbor and parts of St Margaret's Bay). Steelhead trout are raised in the Pubnico and Lobster Bay areas and the Bras d'Or Lakes. These two species combined accounted for approximately 36 percent of the total Nova Scotia aquaculture production sales in 2004. This value is lower than the 67 percent produced in 2003 due to industry financial difficulties and several catastrophic ice and superchill (extremely cold seawater) events during the winter of 2004. However, the industry recovered and the figures for 2005 were back up at 67 percent (<http://www.gov.ns.ca/nsaf/aquaculture/stats/index.shtml>).

Salmonid aquaculture (involving Atlantic salmon and steelhead trout) was not initiated in Newfoundland and Labrador until the mid-1980s. The present salmonid aquaculture is concentrated on the south coast in Bay d'Espoir and Fortune Bay. Grow-out of cod (*Gadus morhua*), the practice of catching small wild cod and feeding them to market size in ocean cages, was implemented in the 1980s following collapse of the once rich Grand Banks groundfish fishery. Research trials of cod egg-to-plate grow-out continued in 2004 with little more than 50 000 cod fingerlings stocked in sea cages along the province's south coast (NL DFA, 2005).

Salmon aquaculture in British Columbia began in the early 1970s with chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon operations. The industry gradually switched to Atlantic salmon cultivation owing to poor economic returns and reduced growth rates and stocking densities associated with Pacific salmon species. Anti-salmon farming organizations gained momentum throughout the 1980s and early 1990s culminating in 1995 when the second moratorium on aquaculture expansion was initiated and held until completion of a review of salmon aquaculture in British Columbia by the Environmental Assessment Office (the first moratorium on new site approval occurred in 1986 and resulted in the Gillespie inquiry). This review was finalized in 1997, following broad public consultation and literature analyses, with an overall conclusion that "salmon farming in British Columbia, as presently practiced and at current production levels, presents a low overall risk to the environment". The Salmon Aquaculture Review provided 49 recommendations to the Minister of Environment, Lands and Parks and Minister of Agriculture, Fisheries and Food as a means to move forward (EAO, 1997). Opposition

to the local salmon aquaculture industry did not end with this review and expansion of the British Columbia salmon aquaculture industry has been slow despite the lifting of the moratorium. Salmon production in sea cages represents a very important industry to rural coastal British Columbia communities with 61 774 metric tons produced in 2004 valued at Can\$ 212 million (Statistics Canada, 2005).

Marine cage culture in the states of Maine and Washington occurred in tandem with their neighboring Canadian provinces of New Brunswick and British Columbia, respectively. In both cases, marine aquaculture expansion has been stifled by continuous anti-aquaculture demonstrations mainly by a few environmental NGOs in Maine while Washington opposition tends to originate from those supportive of the wild salmon fishery. In both cases, these organizations are influencing policy for rural coastal areas that would otherwise benefit from having aquaculture operations along these working coastlines. Most United States coastal states lack the intricate coastline of Canadian marine provinces, the latter having numerous islands, bays, inlets and fjords for aquaculture development. Recognizing these limitations coupled with complex user conflicts for limited coastal space and a growing seafood trade deficit resultant from increasing dependence on foreign seafood products, the USA has invested quite substantially in the development of open ocean aquaculture since the late 1990s. On 10 August 1999, the United States Department of Commerce approved an Aquaculture Policy (<http://www.nmfs.noaa.gov/trade/DOCAQpolicy.htm>) to promote the development of an environmentally sustainable and economically feasible aquaculture industry with a vision:

"To assist in the development of a highly competitive, sustainable aquaculture industry in the United States that will meet growing consumer demand for aquatic foods and products that are of high quality, safe, competitively priced and are produced in an environmentally responsible manner with maximum opportunity for profitability in all sectors of the industry."

Today a nascent aquaculture industry is operating in the open ocean off the coasts of Hawaii (Ostrowski and Helsley, 2003) and Puerto Rico (O'Hanlon *et al.*, 2003). The University of New Hampshire has operated a government funded research site off the coast of New Hampshire since 1997 (Chambers *et al.*, 2003). The Gulf of Mexico region has also witnessed previous attempts at open

ocean aquaculture, but no industry yet exists in the region (Chambers, 1998; Kaiser, 2003; Bridger, 2004).

CURRENT SITUATION OF CAGE FARMING Freshwater cage culture farming systems

Freshwater cage culture in North America is often limited to private impoundments, as few states or provinces allow commercial fish production in public waters. No official data is available related to production and value of specific species in cage culture in freshwater systems in the United States of America because such operations occur on private land or the data collected would not be considered anonymous. Total production levels are tabulated by species and not by culture system employed. In all species cases, open pond aquaculture dominates the industry with cage culture activities providing a negligible quantity of production. In the United States of America, a few states (e.g. Oklahoma, Oregon and Arkansas) allow cage culture in public waters on a special permit basis. In Canada, freshwater cage culture is practiced in some public waters (i.e. Lake Huron, Ontario) through a permitting system.

Cage design and construction

Freshwater cages tend to be relatively small in volume as compared to marine cages but rearing densities are typically higher. Freshwater fish cages in the United States of America are typically utilized in private impoundments with no natural water flow. Freshwater cages usually range in volume from 1 m³ up to 7 m³ and are made from small mesh (i.e. 13–25 mm) nylon netting, solid plastic mesh or plastic coated welded wire mesh. Cage frames have been constructed from wood, polyvinyl chloride (PVC) pipe or galvanized steel with flotation provided by styrofoam, PVC pipe or plastic bottles (Figure 3) (Masser, 1997a).

Species and farming systems

North American freshwater cage culture historically was limited to rainbow trout (*Oncorhynchus mykiss*) and channel catfish (*Ictalurus punctatus*). Raceway and pond culture industries are well developed for these species. Many universities have broadly researched cage culture of these two species and some private production has grown fish in marginal areas where topography, springs/groundwater and/

FIGURE 3
7 m³ freshwater cage used for channel catfish aquaculture



COURTESY OF M. P. MASSER

or infrastructure were not suitable for traditional pond or raceway culture. Most freshwater cage culture is practiced in private watershed type impoundments. These typically release water only during heavy rainfall events and most discharge is during the cooler and wetter winter months. Exceptions to private impoundment culture include the Lake Huron and Columbia River production facilities discussed below.

Currently most marine cage culture operations are located close to shore although the home base of operations might be located a considerable distance away. These nearshore sites are located in deep-water fjords, protected coves, or bays with sufficient currents to limit localized water quality problems. The industry trend has been to develop more exposed high-energy sites. In a few instances cage culture operations are sited further from land thereby increasing the exposure of the cage systems to the oceanographic conditions.

Densities in small freshwater cages are high, ranging from 200 to 700 fish/m³ depending on species cultured and preferred market size. Production levels vary with species produced but usually range from 90 to 150 kg/m³ (Masser, 1997b). Common problems in freshwater cages are localized poor water quality and diseases (Duarte *et al.*, 1993).

Commercial cage production of catfish has never developed into a substantial industry (i.e. only 0.002 to 0.003 percent of the total United States catfish production) compared to open-pond culture in the United States of America. Most of the cage production is scattered throughout the South, Midwest and West and are small-scale, family operations producing fish for personal use and/or local niche markets. Alabama has had a viable cage catfish industry in its Piedmont region since the 1990s (Masser and Duarte, 1994), but currently has only 30 to 40 farmers producing 50–100 metric tons per year. These producers organized to form the Piedmont Association of Caged Fish Producers and trademarked a brand (i.e. Piedmont Classics) in 1993. However, trademarking did not result in an increase in sales or markets. The major reason for poor sales is probably related to the small size of cage operations and the higher sale prices necessary for producers to profit.

Traditionally these producers have marketed their catfish in the round for US\$2.20/kg while pond-raised fish are sold for less than US\$1.65/kg. An additional problem is the smaller size of fish produced. Typically, caged catfish seldom

grow to over 0.6 kg in size in a single growing season and suffer high mortalities if over-wintered. Therefore, most cage-produced fish are marketed as small whole fish, while the industry (i.e. pond-raised) standard is a 0.8 to 1 kg fish processed and marketed as a fillet. The higher price and whole fish product make the cage fish non-competitive except in small-scale local niche markets.

Large catfish cage operations have existed on private lakes in central Missouri and in one public lake, Lake Texoma in Oklahoma (Lorio, 1987), but are no longer in operation. These failed because of diseases, slow growth, and/or water quality problems (Veenstra *et al.*, 2003). No surveys have been conducted since the early 1990s to determine the catfish production in cages. However, estimates would put total cage North American cage production of catfish at 300–500 metric tons per year.

Cage culture of rainbow trout in the United States of America is minor compared to raceway culture. There are scattered individuals producing trout in cages for local niche markets in the east and upper midwest. In Washington State on the Columbia River 16 river miles (9.4 km) below Grand Coulee dam is the single largest caged trout operation in the USA with 80 000 m³ total growing volume provided from numerous large cages (1 000–6 000 m³). Its annual production is in the range of 1 800–2 000 metric tons with maximum production of 30 kg/m³. Stocking density varies based upon fish size.

Other attempts at large-scale cage culture of rainbow trout and chinook salmon (*Oncorhynchus tshawytscha*) were attempted from 1988 to 1995 at two abandoned iron ore pit lakes in the state of Minnesota (Axler *et al.*, 1998). These operations met with strong and emotional opposition related to perceived pollution of the regional aquifer, which supplied water to nearby communities and recreational lakes. The operations were closed due to bankruptcy in 1995. Part of the reason for bankruptcy was the inability to meet new restrictions on water quality imposed by state regulators after permitting the operation. Approximately 2 000 tonnes of fish were produced during the seven years of operation. Later studies showed that the mine pit lakes totally recovered with minimal remediation and with no lasting impacts to the aquifer (Axler *et al.*, 1998).

In Canada, arctic char (*Salvelinus alpinus*) was cultured in cages in Newfoundland, Nova Scotia, Prince Edward Island and Ontario in the early 1990's (Glebe and Turner, 1993; Proc of Arctic

Char, 1993). Currently none of these facilities are producing arctic char in cages. Failures appear to have been caused by combinations of water quality, limited markets, and environmental concerns.

In Ontario, Canada, rainbow trout are cultured in large marine type cages in Georgian Bay of Lake Huron (Figure 4). Culture of rainbow trout started in this area in 1982 and has grown to 3 500 tonnes today. Currently ten sites in the Bay are utilized producing a market size trout averaging 1.2–1.4 kg (Figure 5). Cage culture in Georgian Bay represents over 75 percent of the total trout production in the province of Ontario (Figure 6). Total farm-gate value in 2004 was US\$17 million or a value of approximately US\$4.00/kg (Moccia and Bevan, 2004). The smallest farm consists of six cages measuring 15 m x 15 m with a production of 160 000–180 000 kg/yr. Operations smaller than this do not appear to be economically viable. The largest farm operation consists of twenty cages measuring 15 m x 25 m with a production of 450 000 kg/yr. Site investigations, water quality monitoring, permitting and oversight by government regulators are required for these operations.

The Arkansas Department of Game and Fish Commission produce catchable size fish in cages for stocking into public waters at three sites: Lake Wilhelmsia, Pot Shoals and Jim Collins. Species produced include channel catfish, blue catfish (*Ictalurus furcatus*), rainbow trout (*Oncorhynchus mykiss*) and cutthroat trout (*Oncorhynchus clarkii*). Annual production is approximately 900 000 fish with a combined weight of 230 tonnes. Annual cost of production is US\$2.09 per kg.

Other species currently cultured in freshwater cages include yellow perch (*Perca flavescens*), hybrid striped bass (*Morone* spp), sunfish (*Lepomis* spp) and tilapia (*Oreochromis* spp). The culture of these species is primarily limited to private impoundments for personal consumption or sales to small-scale local niche markets. Therefore, there is a lack of information as to the quantity of these species produced or their value.

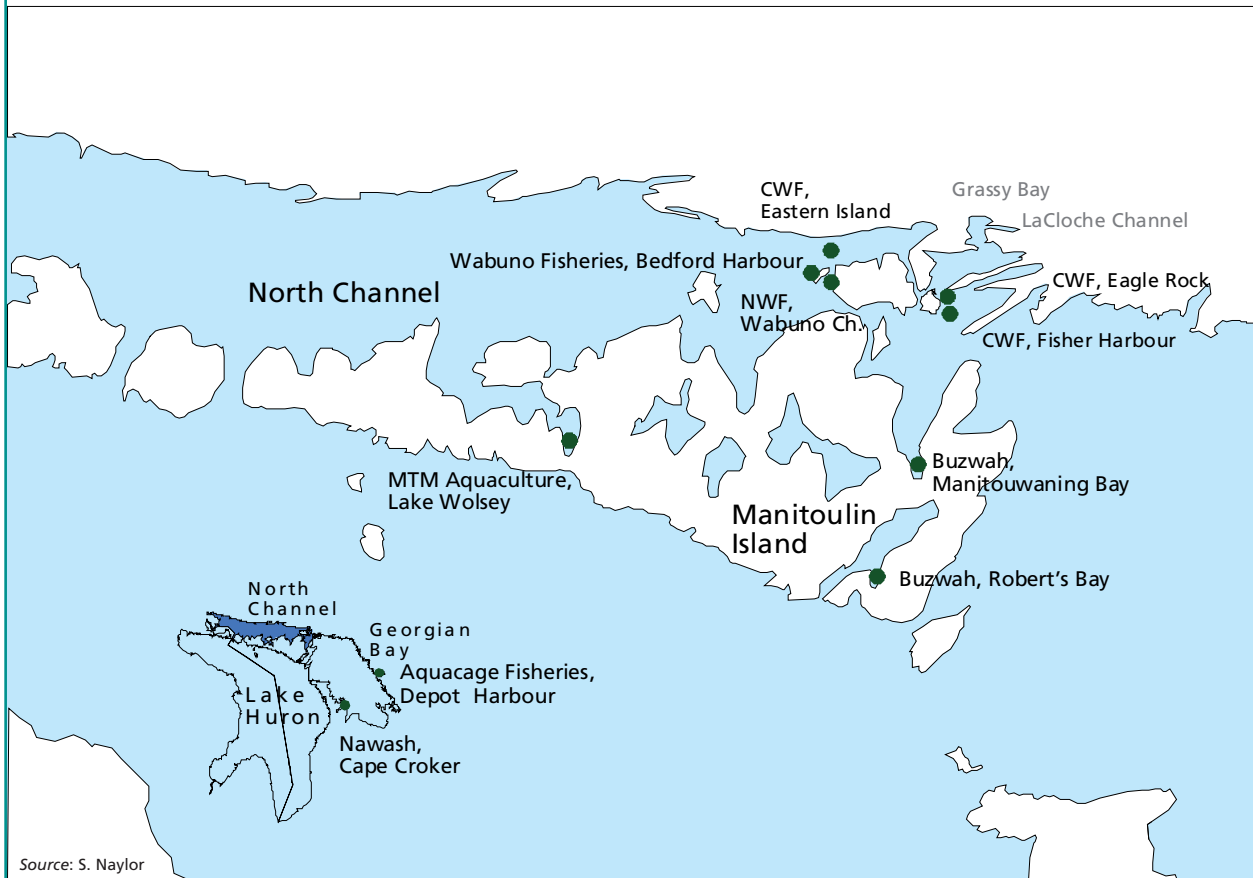
Marine cage culture farming systems

Marine cage aquaculture systems vary immensely throughout Canada and the United States of America. Main criteria considered when choosing

FIGURE 4
Freshwater rainbow trout cages in Georgian Bay of Lake Huron, Ontario, Canada



FIGURE 5
Map of freshwater rainbow trout cages in Georgian Bay and other sites in Lake Huron, Ontario, Canada

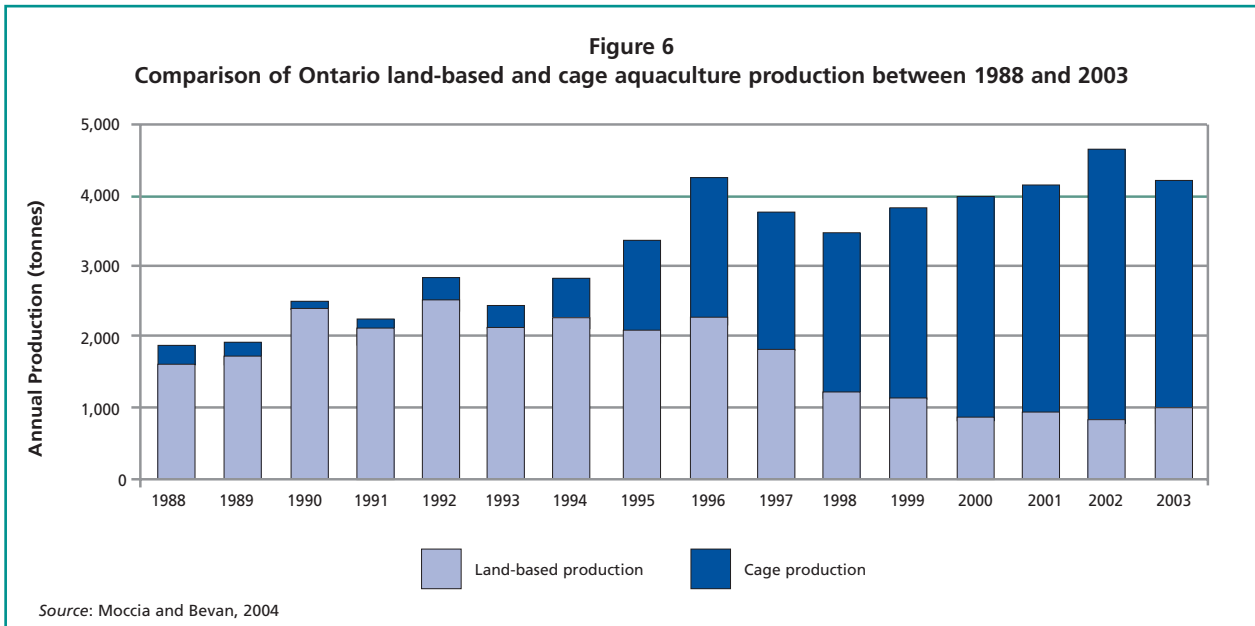


a marine cage farming system include: water body characteristics, degree of exposure, scale of operation, target species, market and economic outlook, and whether the farm is to be operated at or below the surface. Further, specific peripheral support systems (such as feed delivery systems and moorings) are chosen based upon many of the same criteria, but bottom soil characteristics, anticipated environmental loads, and in some cases the absolute need for an integrated system design whereby all individual components act as a single unit to minimize effects from environmental loading also must be considered. Indeed, marine aquaculture operations located in protected coastal bays and fjords have been successful at gradually increasing the scale of their operations coupled with increased technological sophistication. However, if a move to open ocean conditions occurs it will not be accomplished by simply moving existing coastal systems offshore. To the contrary, the entire system must be considered in a holistic manner from the outset to ensure operation efficiency and worker safety while reducing risks to the fish stock, capital infrastructure, the environment and other user groups of the open ocean.

Cage design and construction

In recent years, the global cage culture industry has witnessed a surge of novel containment system designs. Despite these innovative concepts, marine cage culture operations raising commodity species such as salmon at coastal sites is reasonably uniform throughout North America and the globe. Nearly all of these cages can be classified as “gravity” type cages according to the classification scheme proposed by Loverich and Gace (1998).

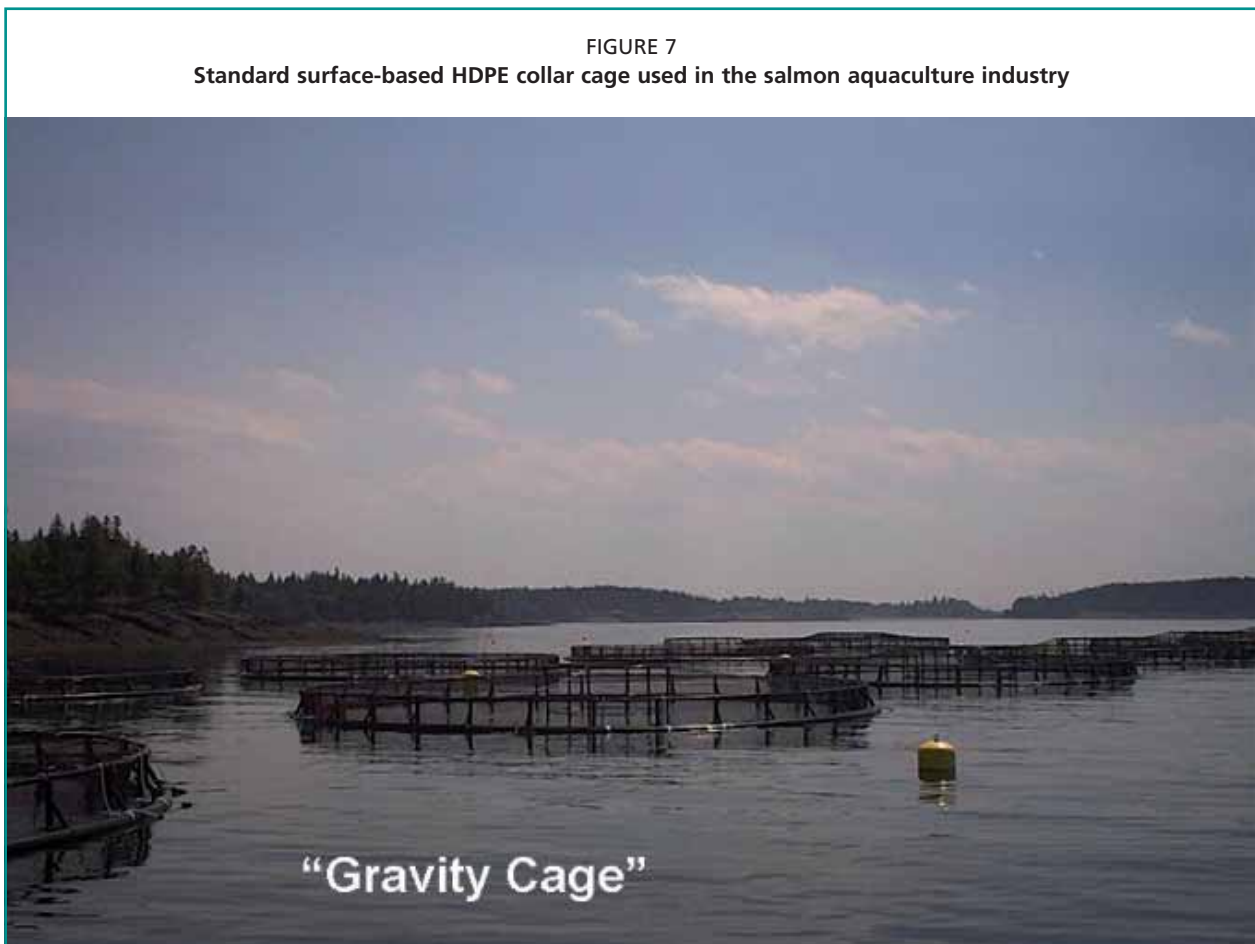
In North America these cages have a surface collar structure from which a net is supported and hung into the water column (Figure 7). These collars are generally constructed of steel or high density polyethylene (HDPE) in coastal aquaculture systems in Canada and the United States HDPE is preferred in Atlantic Canadian operations owing to the reduced capital costs associated with using this material and the fact that HDPE collars are considered wave conformers (i.e. bend as necessary with passing energy as opposed to remaining rigid). Steel collars are hinged to allow some wave conformation between connecting cage units. Steel collars also offer stable work platforms



by providing a walkway along their sides that might be used by workers for feed and equipment storage and a stable platform to manage the farm operations. This is not the case for HDPE collar cages where two flotation rings are at the water surface. HDPE cages are not conducive to safe

worker use and are not designed for storage thereby requiring separate barges on site.

Nets are typically hung from the inner plastic ring or inner portion of steel cage walkways while predator nets might be draped from the outer plastic ring on HDPE collars or the outer portion



of steel cage walkways. Gravity cages do not have rigid nets and bagging occurs at times of high tidal current thereby decreasing the total cage volume. Indeed, Aarsnes *et al.* (1990) observed that up to 80 percent of the expected growing volume in surface collar cages may be lost in currents of 1 m/sec (approximately two knots). This issue was traditionally minimized by attaching weights to the lower portion of the net at frequent intervals to reduce net deformation. More recently, bagging has been eliminated by deploying a sinker tube from the surface collar and attached to the lower portion of the net to maintain the overall shape and cage volume.

Marine cages are moored as a group, or flotilla, typically within submerged grid mooring systems (Figure 8). These grids frequently provide upwards of eight mooring lines connected to each cage to maintain its position within the grid.

Salmon aquaculture cages have large growing volumes thereby providing an excellent return on investment. For example, a smaller surface-based HDPE cage might have a 100 m circumference with a net depth of 11.21 m and, therefore, provides a total growing volume equal to 8 925 m³. A larger cage of similar structure with a 120 m circumference and having a net depth of 20 m will provide a total growing volume of 22 921 m³. Assuming a target final stocking density of 15 and 18 kg/m³ these

volumes will hold 133 875 kg (133 metric tons) and 412 578 kg (412 metric tons) of salmon per cage, respectively.

In British Columbia, the salmon aquaculture industry is experiencing a constant campaign from anti-salmon farming environmental NGOs. Their efforts have stifled industry expansion over the past few years while government scientists have studied salmon farming and its environmental impacts to develop science-based policy as a way forward. While science strongly indicates that responsibly managed salmon farms have limited negative impacts on the ocean environment one company has been developing a novel cage design that could conceivably eliminate any risk of deleterious environmental consequences. Future Sustained Environment Aquaculture (SEA) Technologies Inc. was founded in 1994 to develop an enclosed water-tight SEA system that is supplied with water pumped into the fish grow-out enclosure from optimum locations, including depth, to regulate temperature, oxygen levels, and overall water quality while increasing waste management capabilities and minimizing fish escapement (Figure 9; <http://futuresea.com>). In 2001, Marine Harvest Canada began tests to compare the Future SEA system with conventional steel cage systems as part of the British Columbia Salmon Aquaculture Policy Framework. Over the 14-month trial period the

FIGURE 8
Typical near shore submerged grid mooring system maintaining multiple cages within a flotilla

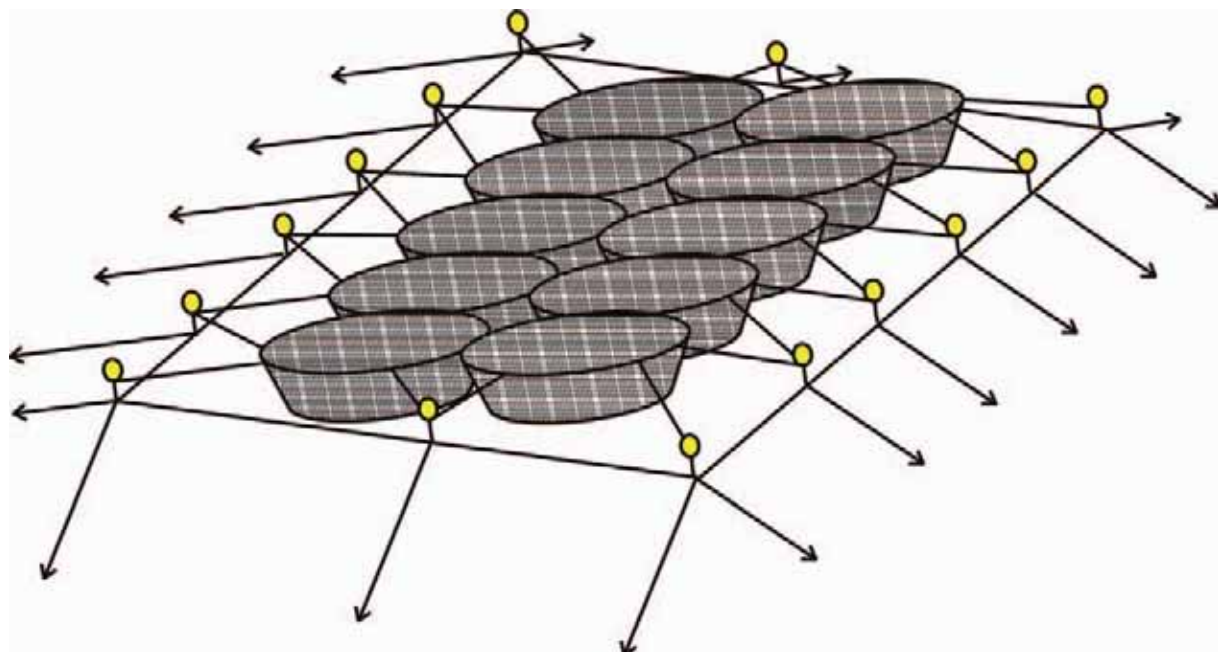
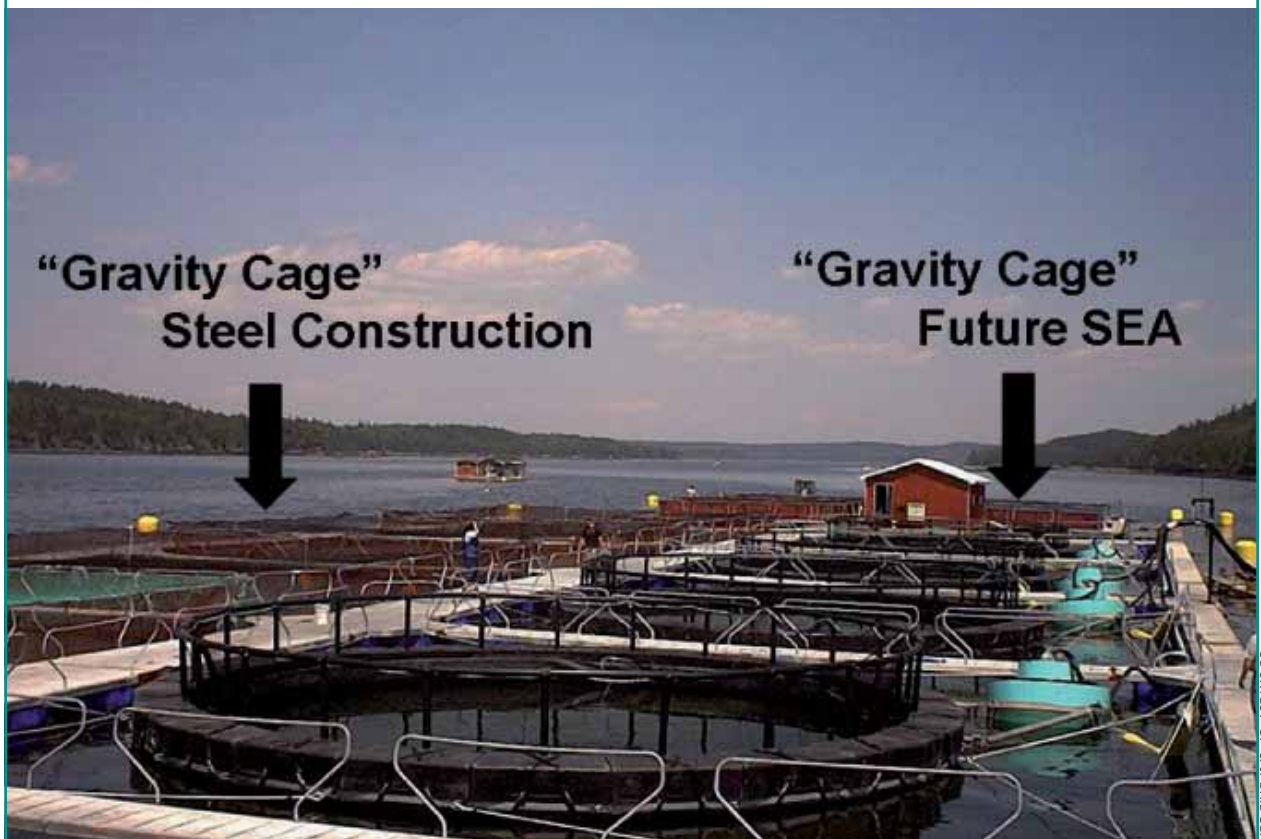


FIGURE 9
Comparison of standard surface-based steel collar cages and the Future SEA system



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SEA system performed well and comparable to conventional steel cages with regards to survival, feed conversion and overall fish health (Hatfield Consultants Ltd, 2002). The future SEA system did not perform as well economically, however, with the farm gate cost of production for the system being 29 percent higher compared with conventional steel cage systems. This level of increase translated to a difference of US\$0.85/kg at the time of harvest.

Numerous cage designs have been proposed and deployed in open ocean conditions in North America. In the USA, the predominant cage system at the moment is the Ocean Spar Sea Station cage (Figure 10; <http://www.oceanspar.com>). The Sea Station is a self-tensioned cage around a single spar buoy (Loverich and Goudey, 1996). Detailed descriptions of the Ocean Spar Sea Station cage can be found in Tsukrov *et al.* (2000) and Bridger and Costa-Pierce (2002). The experimental cages used in the Gulf of Mexico (Bridger, 2004) and New Hampshire (Chambers *et al.*, 2003) provide a growing volume of 595 m³. Sea Station volumes up to 35 000 m³ have been designed (Loverich and Goudey, 1996) although the largest used

commercially to date provides a 3 000 m³ internal volume (Ostrowski and Helsley, 2003; O'Hanlon *et al.*, 2003) but recently a 5 400 m³ cage has been introduced for use by Ocean Spar. Ocean Spar Sea Station cages are all operated well below the water surface in the United States of America. Submerged operations in high-energy open ocean sites do seem intuitive to avoid or at least minimize environmental loads experienced at the surface. On the surface, wave particles rotate at a diameter equal to the wave height and therefore provide the greatest amount of wave energy. This rotation decreases with increasing depth thereby reducing the environmental loads affecting aquaculture structures operated well below the water surface. Tsukrov *et al.* (2000) further substantiates this point by reporting mooring line tension to be 60 percent less for submerged cages compared to surface positions under identical environmental loads. Equally important is the ability of submerged operations to minimize oceanographic effects on contained fish. However, benefits associated with submerged operations have also come at a price as no turn-key or proven farm management options

FIGURE 10

An Ocean Spar Sea Station cage moored offshore in the Gulf of Mexico adjacent to a gas production platform



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are presently available. Numerous farm operations will need to be automated to minimize reliance on scuba diving to perform such farm chores. Until such automation occurs to provide safe and efficient farm management options, submerged operations will have no other option but to remain at a relatively small scale while relying upon divers.

Another innovative example is the Aquaculture Engineering Group in New Brunswick, Canada (<http://www.aquaengineering.ca>). This company has developed a 'swing site' configuration that also deploys a current deflector to reduce oceanographic conditions experienced on-site. Key to the system's design is the continued use of conventional surface-based cages widely accepted in the salmon farming industry.

Inventory and record keeping are critical for optimal farming practices. Maintaining a record of the number of mortalities removed from the cage and frequent estimates of growth (and calculated biomass) is required for calculating feeding rates, determining quantity of medication to be provided when necessary, and for planning production and harvest schedules. In the least sophisticated

operations, a random sample of the entire population is removed from the cage at a meaningful time interval (monthly), anesthetized and weighed to gather necessary growth data.

More technologically advanced farms do not actively disturb the fish stock to reduce stress. Alternatively, fish sizing technologies using video or acoustic image analysis is employed that measure individual fish without physically disturbing them.

Species and farming systems

By far, Atlantic salmon (*Salmo salar*) is the species of choice for marine cage culture operations in North America. This species is native to the Atlantic Ocean but a vast quantity of Atlantic salmon is farm-raised along the Pacific coast of Canada.

Other salmonid species raised in sea cages are chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*). Atlantic salmon in particular is farmed at such a great volume that it has become a commodity species. While this is excellent news for the consumer wanting to purchase wholesome, nutritious and affordable seafood this

greatly reduces the profitability of salmon farming operations. Given the reality in which they operate, many salmon farming enterprises have directed a substantial amount of time and investment into species diversification both to supply a broader range of products to the consumer and reduce risks associated with producing only one species all the time.

Candidate species for salmon producers include Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) in the Atlantic Ocean and sablefish or black cod (*Anoplopoma fimbria*) in the Pacific Ocean.

The United States of America possesses a varied environment that is also home to a variety of candidate aquaculture species. In New England, many of the same species are candidates as those studied by present salmon producers for their aquaculture potential.

Further along the United States Atlantic Coast and into the Gulf of Mexico the list of candidate aquaculture species impressively expands to include: cobia (*Rachycentron canadum*), greater amberjack (*Seriola dumerili*), red snapper (*Lutjanus campechanus*), and red drum (*Sciaenops ocellatus*). In the United States Pacific (including Hawaii) equally appealing candidate species for grow-out include Pacific threadfin (*Polydactylus sexfilis*) and kahala amberjack (*Seriola rivoliana*).

REGIONAL ISSUES

Freshwater cage culture

Issues that negatively impact small scale cage producers are:

- 1) limited or no access to large bodies of water (i.e. no public water bodies);
- 2) higher price paid for fingerlings and feed because of the small size of operations and a location typically outside of traditional aquaculture areas;
- 3) lack of processing and marketing infrastructure; and
- 4) diseases.

While high quality fingerlings and commercial feeds are available, usually the cost of shipping and small quantities needed increase the production cost far above what is paid by larger commercial pond or raceway producers.

Finding and servicing niche markets is also difficult for small-scale producers with limited physical and financial resources and/or marketing experience. Where cooperatives and associations have attempted to buy in bulk and market to larger

buyers, they have not succeeded probably due to the higher production costs and therefore higher sales prices.

No environmental problems have been associated with freshwater cages in private impoundments. Associated water quality, escapement and other ecological impacts are contained within the impoundment. Private impoundments generally have multiple uses including recreation and livestock watering, are seldom if ever drained, and usually only discharge water during the winter-rainy season. Therefore, few conflicts exist with cage culture practices. Most fish species cultured are native species, with the exception of tilapia. Tilapia production in cages is restricted in only a few states (e.g. Texas and Louisiana). Most states have no restriction on tilapia culture since they will not survive North American winters.

The larger cage operations in public waters for rainbow trout in the province of Ontario and Washington state have gone through an extensive permitting process and are regularly monitored for water quality and other related environmental impact issues. The owner of the operation in Washington felt that he had spent US\$1.5 million to set up and permit his farm (Swecker, personal communication). Issues with site location, public perceptions, permitting costs, environmental NGO's involvement in permitting and negative public dialog, and the lack of clear policies and legal frameworks for permitting in most states in the United States of America, has and continues, to hinder development of cage culture in public waters. It is estimated that the cage permitting process in Ontario would require one to two years and a cost of around US\$60 000. This cost is primarily for the site evaluation studies necessary to obtain a permit. Permitting involves several Federal and Provincial ministries and numerous Acts (Moccia and Bevan, 2000). Objections or conflicts with shoreline property owners (NIMBY = not in my backyard, syndrome) surface as the major problem faced by cage culture entrepreneurs attempting to obtain permits. Therefore, locations where these types of operations have been or can be permitted at freshwater sites in North America are extremely restricted and future expansion is likely limited.

Marine cage culture

Marine cage culture operations are established in many areas of North America. However, total production from these operations is somewhat limited when compared with potential and

anticipated growth over the next decade. Numerous constraining issues will need to be addressed before the promise of many of the involved industry sectors comes to fruition.

Marine cage culture systems used in protected bays and fjords are largely a known entity. However, the industry trend in both Canada and the United States of America is for expansion to more exposed open ocean conditions where they experience fewer human conflicts. Near shore aquaculture technologies and operations will not be able to simply move to these new high-energy environments and ensure continued worker safety and efficient farm operations. Novel open ocean aquaculture technology has been developed over the past decade to begin meeting the needs of this new cage culture sector. However, much technology development remains. One of the critical needs for development is the automation of farm operations. Dependable automation will at minimum ensure fish are effectively fed during inclement weather, but will also be important for other farm chores including fish sizing, net cleaning, mortality removal, fish health monitoring and cage/mooring inspections. Fish feeders might also incorporate technology for long-distance communication to enhance control afforded to site managers. Adoption of these technologies will ensure that site visits will only be necessary for general maintenance and feed delivery when conditions are safe.

Social aspects

Industry expansion for marine cage culture will require access to additional space for sites. This aspect is quite different from much of the freshwater cage culture that occurs on private land. In marine aquaculture, the operations are located in the ocean – a resource always considered to be common property. Marine cage culture companies will have to conduct their business in such a manner that the public is informed at all times. This does not imply that company accounting should be open to public scrutiny. However, industry plans for a region or coastline must be discussed within open public forums to ensure that public concerns are addressed at each stage of expansion. In addition, appropriate integrated coastal zone management plans must be developed. Areas appropriate for aquaculture should be chosen that also minimizes interactions between traditional uses of the marine environment including capture fisheries, tourism, land owners rights, shipping, extractive industries, and areas having frequent visits by marine mammals. An

excellent example of this sort of exercise was recently published concerning expansion of the salmon aquaculture industry in the Bay of Fundy (Chang *et al.*, 2005).

Marine aquaculture also presents an excellent opportunity to maintain coastal communities that are presently reliant upon over-harvested commercial fisheries. Many of these wild fish harvesters represent a highly trained workforce that have extensive knowledge of the ocean, boat handling, net mending and maintenance, and fish harvesting and quality control that aquaculture companies can easily adapt to their own operations. In these cases, previous wild fish harvesters would require some basic training associated with standard farm operations and fish health management. Numerous Atlantic cod fishermen converted to cod grow-out aquaculturists in Newfoundland and Labrador following the collapse of the northern groundfish stocks (these operations entailed live capture of small cod for further grow-out in sea cages prior to harvest for market). These operations have for the most part ceased to exist owing to limited access to small cod around the province for grow-out. However, this experimental period demonstrated that wild fish harvesters can easily adapt to the needs of aquaculture enterprises if the opportunity exists.

In addition to employing wild fish harvesters, any region developing an open ocean aquaculture sector will reap the economic benefits associated with the production and sale of fish grown in marine cages. Recent economic analyses concluded that a single farm operation directly employing only seven individuals for offshore production will provide an additional annual regional economic output of at least US\$9 million and provide additional employment for at least 262 persons, related to processing, feed production, distribution, etc. (Posadas and Bridger, 2004). These impacts must be conveyed to local policy makers to ensure many of the coastal communities presently devastated by collapsing wild fisheries have a new source of sustainable income for generations to come.

The aquaculture industry must also become more proactive in shaping public perception of their industry. At present, the environmental NGOs are winning battles for public sympathy on many fronts. The aquaculture industry must rely on science-based information to garner public support while resisting involvement in the usual environmental NGO antics including the use of manipulated, outdated, and/or misleading information regarding

aquaculture and its practices. Increased public trust will open additional markets for farm-raised products and potentially allow industry expansion to new sites that are presently contested.

Economics and markets

Aquaculture industry consolidation is a global phenomenon as large multi-national companies seek appropriate economies of scale throughout their entire production and supply chain. This allows them access to increased market-share in the competitive global marketplace for seafood products. In Canada, industry consolidation is recently most pronounced on the Atlantic coast (the Pacific coast has also experienced several rounds of industry consolidation in the past). Here, a local salmon aquaculture company has been successful at industry consolidation within Southwest New Brunswick and Maine while also expanding its operations through new site development in Nova Scotia and Newfoundland and Labrador. Such industry consolidation will undoubtedly result in greater efficiency but also some local loss of employment. However, this degree of consolidation will also ensure a greater degree of control over the company's entire production chain while gaining additional access to its primary market in New England.

The United States of America represents the main export market for Canadian aquaculture products. Aquaculture companies in Canada are well aware of this; in a recent survey of British Columbia aquaculture firms, proximity to markets and the Canadian/US dollar exchange rate ranked as the top two of 35 business factors considered (PricewaterhouseCoopers, 2003). Having direct access to the United States market greatly benefits the Canadian aquaculture industry. However, this dependence also subjects the Canadian aquaculture industry to the vagaries of international factors such as fluctuating currency exchange rates. The Canadian dollar has steadily appreciated against the United States dollar over the past four years – in 2002 the United States exchange rate averaged 1.57 but decreased to 1.21 in 2005. This rate of appreciation is substantial and represents a net loss of 36 cents on each dollar of sales between 2002 and 2005. This loss drastically diminishes industry profit in the absence of increased market prices, production and economies of scale, or efficiency.

Ecological and environmental aspects

Aquaculture operators must act as professional environmental stewards to ensure a pollution-free

environment to raise fish and earn a profit. Without a clean, consistent water supply the product to be grown would be stressed with resultant slow growth rates and potential high mortality. Potential environmental impacts associated with marine cage culture operations can be grouped into four broad categories:

1. *Benthic and water column impacts* – Benthic and water column impacts are often associated with poor site selection, management decisions, site overproduction, or some combination of the three. These effects are reversible and can be mitigated through careful farm management and by adapting a site following policy between successive grow-out cycles (McGhie et al., 2000).
2. *Impacts on the frequency of harmful algal blooms* – Fish farming activities will result in increased nutrients in the surrounding environment. However, most studies to date have concluded that aquaculture activities sited in preferred locations have not resulted in increased abundance of phytoplankton species (Parsons et al., 1990; Pridmore and Rutherford, 1992; Taylor, 1993). In fact, Arzul et al. (2001) reported inhibited phytoplankton growth when in the presence of excretion from selected finfish species (sea bass and salmon). These results were in stark contrast to the excretion from shellfish species (oysters and mussels), which stimulated phytoplankton growth rates.
3. *Impacts to local and migratory marine mammals* – Unlike fishing gear, entanglement of marine mammals into aquaculture gear has not been frequently documented and therefore generally represents a low concern of aquaculture operators. However, when such interactions occur the costs to both the aquaculture site (in lost stock and negative public perception) and the marine mammal involved tends to be great. The aquaculture industry must do everything possible to avoid such incidents.
4. *Escapement and implications to wild populations* – Aquaculture companies can only remain in business if they manage to contain their fish stock for sale. The most logical approach to mitigate impacts of escaped aquaculture fish is prevention. Myrick (2002) discussed escapement of cultured species in general while Bridger and Garber (2002) specifically reviewed salmonid escapement occurrence, implications and solutions for mitigation. In cases that escapement does occur, salmonid escapees –

specifically steelhead trout – have been observed to remain in the vicinity of aquaculture cages and displayed a homing response to aquaculture facilities if escapement occurs away from established aquaculture sites (Bridger *et al.*, 2001). These results indicate a much lower risk from escapement to wild stocks than portrayed by environmental NGOs. Further, developing recapture strategies to return escapees to cages for additional growth and decreased economic losses should be feasible.

Policy and legal frameworks

Policy and legal frameworks associated with marine cage aquaculture differs immensely based upon the specific jurisdiction involved. In Canada, both federal and provincial levels of government have a role in developing and ensuring the aquaculture industry has the ability to expand while being managed in an environmentally and socially responsible manner. In recognition of this joint role, Canadian Ministers of Fisheries and Aquaculture (national and provincial) have agreed to Interjurisdictional Cooperation and creation of a Canadian Action Plan for Aquaculture that commits both levels of government to improve the regulatory environment, strengthen industry competitiveness, and increase public confidence in both industry and government. In nearly all cases, provincial government departments have assumed responsibility for site allocation of aquaculture in the oceans through federal-provincial Memoranda of Understanding. Many provincial departments have created appropriate Bay Management Plans and single year class management systems (i.e., one generation of fish on a site at a time) to improve fish health management and environmental quality.

In the United States of America, all marine cage aquaculture to date occurs within specific state waters. States manage aquaculture industries individually, which can result in some inconsistency between states. “Offshore aquaculture” serves as a legal term in the United States of America, which refers to aquaculture operations sited in United States federal waters. Federal waters represent the expanse of ocean existing outside of state waters within the United States Exclusive Economic Zone, typically occurring three miles outside of the furthest state controlled land (including islands) to 200 miles offshore. The existing policy framework for aquaculture in United States federal waters has been frequently cited as the prime reason for no industry development. Presently unregulated, Senate Commerce Committee Co-

Chairs introduced S. 1195, the National Offshore Aquaculture Act of 2005, on 8 June 2005 to:

“...provide the necessary authority to the Secretary of Commerce for the establishment and implementation of a regulatory system for offshore aquaculture in the United States Exclusive Economic Zone and for other purposes.”

Introduction of this Act represents the first of many essential steps necessary for aquaculture to be established in United States federal waters. Following adoption, the Department of Commerce will have authority to create the necessary regulations to govern an offshore aquaculture industry. This process will require many years, numerous public comment periods and revisions prior to completion.

THE WAY FORWARD

The importance of markets cannot be overemphasized. As discussed earlier, Canada looks to the United States of America as its main export market. Many other countries also export heavily to the United States of America and Canada, so international development and competition is expected to drive seafood markets in developed countries. Many “unfair trade” issues have already surfaced with seafood imports to the United States of America. These will undoubtedly increase in the future as competition and a perceived “fair playing field” will be fought in political arenas.

The United States of America probably more than Canada or most other countries has had a great deal of opposition to marine cage culture in public fresh and near-shore waters. Therefore, as discussed earlier, aquaculture farmers must take a more proactive role in engaging the public and countering non sustained accusations of environmental NGOs. They must develop public trust and work closely with legislators and public officials, demanding scientific studies and a science-based policy for future development.

The prospect of utilizing public freshwater sources in the United States of America for cage culture is remote. Most United States state natural resource agencies, which regulate access to public water bodies, have no desire or public/political pressure to promote cage culture in public waters.

It appears that most expansion of cage aquaculture in the United States of America will involve open ocean cages. At the moment, new open ocean aquaculture entrants are limited in many jurisdictions and the species of choice frequently has limited competition from wild

harvests thereby yielding excellent demand for cultured products. At some point, these direct benefits to early business entrants will diminish as candidate species become a commodity and established markets are flooded. Operators using many of the existing or proposed open ocean aquaculture cage systems may experience economic difficulties in raising commodity species owing to limited growing volume with new cage designs and high capital outlay costs. These operators will have to become more efficient in their farm operations or deploy more cost-effective cage technologies to be profitable. Cage manufacturers will be required to design and supply systems that are indeed lower cost per unit volume. Some companies are already considering these possibilities.

Other peripheral support systems are critically important for coastal marine cage culture operations, most importantly feed delivery systems. Marine cage culture operations in North America are all intensive, i.e. requiring feed inputs. However, few fish are hand fed (Figure 11).

Nearshore operations have reached a scale of operation that requires minimizing manual labor

costs. In such cases, service vessels ferry feed to the site (either daily quantities or sufficient amounts for multiple days that are stored on barges or rafts moored on site) and onboard blowers are used for feed delivery to each cage, typically twice a day. Camera systems have been adopted by much of the industry to provide efficient feeding by monitoring for excess feed (e.g. falling through the stock of fish or change in fish behavior). Larger sites have increased their feed capacity through deployment of cone or silo barges that store large quantities of feed and use computer controlled centralized feeding technology to provide individual cages with appropriately allocated amounts of feed. Feed barges are moored on site either using their own independent mooring system or integrated within the cage flotilla mooring.

Many of the new open ocean cage designs have not concurrently developed effective feed delivery systems. In some cases, feeding is performed from a boat through a feed hose extending to the cage. For other sites, feed barges have been considered and modified for open ocean conditions. Finally, novel spar type feed buoys have been constructed

FIGURE 11
Fish farmer manual feeding fish stocked in a standard surface-based collar cage. Manual operations are popular on smaller sites that do not require automation to achieve economies of scale



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and tested for use in high energy environments. Regardless of the final concept, all industry experts accept that vessel based feed delivery is a short-term strategy and onsite feed storage and delivery systems will need to be adopted for industry expansion.

Open ocean aquaculture operations must become dependent on technologies that will size fish using video or acoustic image analysis that measure individual fish without physically disturbing them. These must also minimize the amount of time wasted on site for fish sizing when other more urgent tasks must be performed during limited periods of good weather.

A further benefit to deploying video technology to open ocean sites would be the potential use of these same images for reconnaissance fish health surveillance. In these cases, video imagery might be analyzed to look for the presence of gross anatomical fish health signs that would prepare an industry veterinarian prior to visiting the site and potentially solve issues before it becomes unmanageable without severe economic consequences. Ideally, the same video data could be collected for feed delivery, fish sizing and fish health management thereby decreasing the necessary technology investment required.

Food quality and safety are paramount issues of importance to North American consumers. Environmental NGOs have accused aquaculture farmers of using illegal chemicals and have pressured regulatory agencies to increase surveillance measures for seafood. This trend will continue and it behoves North American cage culture producers to develop,

self-impose and adhere to strict quality assurance standards. Industry and researchers need to work together to develop novel and non-chemical means of dealing with fish health issues. Finally, organic aquaculture standards need to be developed/legally established in the United States of America so that local producers can service these highly lucrative niche markets.

CONCLUSIONS AND RECOMMENDATIONS

Cage culture in North America may be poised on the brink of rapid expansion if the current policy changes and regulatory improvements continue to develop. Particularly, Canada has made significant progress in the last decade toward improving the regulatory setting and public perception of cage aquaculture.

Cage aquaculture in the marine environment in the United States of America lags behind Canada but newly proposed policy legislation could start development in United States federal waters. Cage culture has a short and, in particular in freshwater, a somewhat disappointing history in much of North America and will probably not expand rapidly in the near future. While the opportunity for marine cage culture to expand is good, the United States of America lags behind Canada in sustainable implementation and guidance. Impediments of governmental regulations and inconsistencies of policy, environmental concerns, aesthetics, and market uncertainty need to be addressed before sustainable development can progress.

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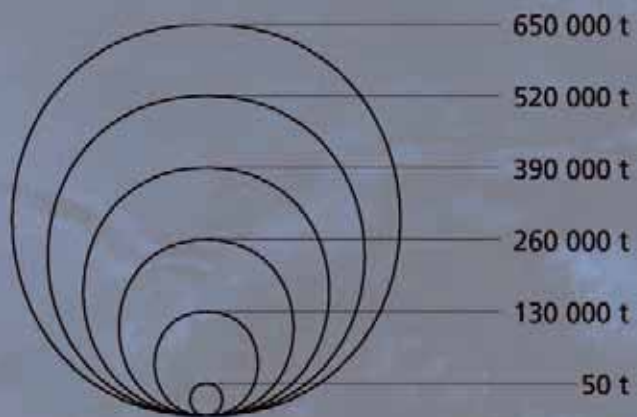
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Cage aquaculture production 2005

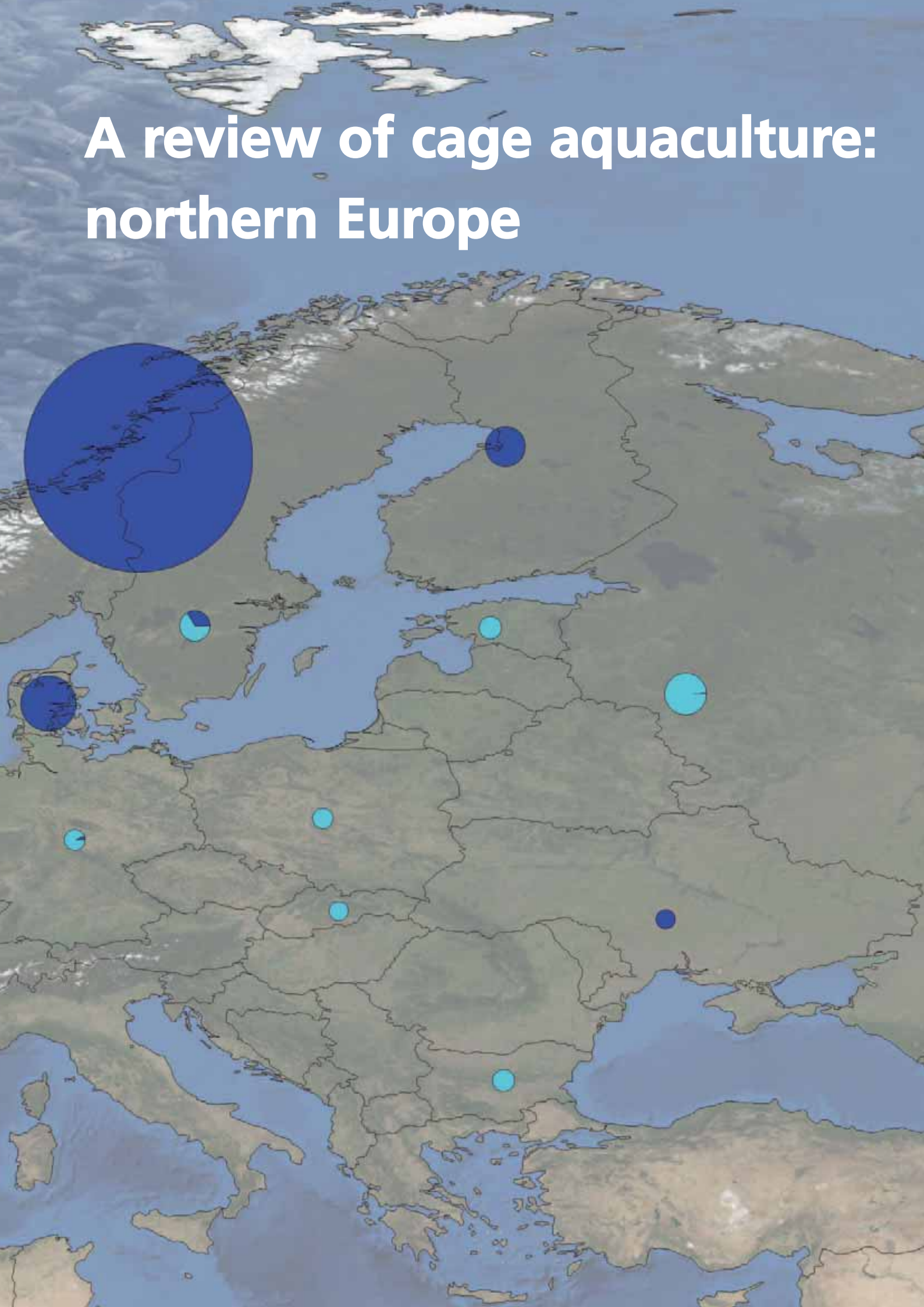
Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.



 freshwater

 marine and brackishwater

A review of cage aquaculture: northern Europe





A review of cage aquaculture: northern Europe

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A review of cage aquaculture: northern Europe. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 126–154. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

Thirty years after the cage aquaculture industry in Europe began, the industry has matured. The main species in northern Europe are the Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). The majority of production is in Norway, Scotland, Ireland and Faroe Islands. However, also countries as Finland, Iceland, Sweden and Denmark have a cage culture industry. All relevant aquaculture production using cage technology in northern Europe is carried out in marine waters. The production volume in 2004 is about 800 000 tonnes of Atlantic salmon and about 80 000 of rainbow trout. The production volume of Atlantic salmon is expected to grow further, while rainbow trout for the moment shows a negative trend. There is an increasing interest to expand the production of other species, such as cod and halibut.

There are of course huge differences among European countries in, for example, the degree of exposure at sites, ranging from rainbow trout production in rather sheltered locations in the Baltic Sea to the cultivation of Atlantic salmon in heavily exposed locations in the Faroe Islands. Not all of Europe is appropriate for aquaculture development, as many different factors affect the output and the viability of aquaculture operations (e.g. water quality, availability and cost of space, climatic conditions, etc.). When considering the location of aquaculture sites, it is critical to perform a systematic, integrated assessment of both the positive and negative impacts of new aquaculture developments. Despite the variation in locations, cage culture production in the different European countries is somewhat uniform in terms of use of technology. The cage systems used in modern aquaculture have essentially changed little compared to the first used. Cages are moored or floating, square, hexagonal or circular units with a suspended closed net bag. Fabrication materials have changed from wood to steel and plastic.

Genetic improvement by implementing selective breeding programmes has contributed significantly to increasing the performance and productivity of Atlantic salmon and rainbow trout. However, as these breeding programmes are highly specialized and costly, they tend to become centralized in very few countries and companies. Improved genetics at a reduced cost and a year-round egg availability represent an important motivation for international trade of salmonid eggs. Preventive measures that are acceptable from a biological and environmental point of view have been used to keep disease problems in aquaculture at an acceptable level. Vaccination is now the single most important measure for prevention of bacterial diseases in farmed fish, especially in salmonids. The best indicator of the effect of vaccination as prophylactic measure is the reduction in use of antibiotics in fish farming. Most of the population of Atlantic salmon and rainbow trout is vaccinated against at least three major bacterial diseases (vibriosis, cold-water vibriosis and furunculosis) prior to stocking into sea-water. During a 10 year period the usage of antibiotics has been reduced to an absolute minimum, mainly due to the use of vaccines.

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Even if there has been a significant decrease in the environmental impact from the cage culture industry in Europe, there are still some challenges: escapes, marine eutrophication, sea lice and access to sea areas. Despite many problems there has been a more or less continuous growth in production, and the industry has become an important economical contributor to some of the remoter rural regions of Europe. While some concerns remain, the industry has managed to reduce environmental impacts and improve fish health. However, a further increase in production and introduction of new species will provide new challenges in the coming years. There is a great interest to further develop this industry, providing essential profitable activities to sustain communities living at the margins of Europe. Aquaculture may create new economic niches, leading to increased employment, a more effective use of local resources, and opportunities for productive investments. The contribution of aquaculture to trade, both local and international, is also increasing. Most of the countries involved in aquaculture have developed strategies to promote the development of the aquaculture sector. Development must not be at the expense of product quality, however, or of the environment. It must also be sufficiently efficient that it can compete with other food producers, both within and outside Europe.

BACKGROUND

This paper provides an overview of cage culture farming in Europe, with the exception of the production in the Mediterranean, which is covered in a separate chapter of these proceedings.

The aquaculture industry along the coastline from Gibraltar in the south, via Great Britain, Faroe Islands, Iceland and the Baltic Sea, to the Russian border in the north today plays a major role for many small communities located close to the sea. This role will probably become even more important in the near future because of an increasing demand for fish of high quality, and a decrease in wild catches.

The countries with the greatest production are Norway, followed by Scotland and Ireland. The dominant role of these countries is reflected in the content of this article. The international nature of ownership of today's cage farming businesses is reflected in the similarity in use of technology and in farming practices.

The major species for cage culture in northern Europe are Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). However, several new species are becoming increasingly important for the cage culture industry in Europe.

Because this article covers more or less all aspects of cage farming, most of the content is based on review articles, which have been chosen as good introductions to more comprehensive information about the different topics.

HISTORY OF CAGE CULTURE IN THE REGION

The activity of cultivating the water goes back many centuries and was already described in the Far East several thousand years ago (Beveridge and Little, 2002). In Europe, too, cultivation has a long

tradition. On an old farm in Norway a stone was found from the 11th century with the inscription: "Eiliv Elg carried fish to Raudsjøen" (Osland, 1990). This shows that new species were introduced into lakes where they bred independently of human intervention. These fish were subsequently harvested by fishing.

In Western Europe in the 19th century, the first fish were hatched and reared under artificial conditions. The motivation was to restock lakes and rivers with fish for anglers. The experience gained through hatching and rearing provided the beginnings for understanding the conditions needed to breed and rear these fish (FEAP, 2002).

Cage fish farming was pioneered in Norway in the late 1950s, in an attempt to produce rainbow trout and Atlantic salmon in the sea. In Scotland the White Fish Authority commenced salmon cage rearing trials around 1965. However, commercial production in Norway didn't begin until the beginning of the 1970s. The industry has since expanded to Scotland and Ireland. The farming of Pacific salmon (coho salmon, *Oncorhynchus kisutch*) began after that of Atlantic salmon, and Norwegian and Scottish technology was transferred to Canada and the USA. Later, significant developments occurred in South America, mainly in Chile, which has now become a major producer (FEAP, 2002; Beveridge, 2004, see also related review for Latin America and the Caribbean).

Cage farming was later adapted to other species in Europe, and has become a profitable business. The rearing of seabream and seabass in net cages in particular has proven to be very successful, and there is also an increase in promising species such as tuna, cod and halibut.

The development of the European aquaculture industry shows an exponential growth in production volume during the last fifty years (Figure 1). In 1950 mariculture represented 86 percent of total aquaculture production, mainly as shellfish (oyster and mussels). Freshwater production was based on carp and portion-sized rainbow trout. Total aquaculture production in Europe was then 169 000 tonnes. More than fifty years later (2004), European aquaculture production has reached a level that is twelve times higher, i.e. 2 204 000 tonnes. At present mariculture and brackishwater culture account for 79 percent of the total production (FAO, 2006). Freshwater aquaculture is currently based on a larger number of species, although carp and rainbow trout are still the dominant species. In mariculture, shellfish is still very important. However, the production share of Atlantic salmon, rainbow trout, seabream and seabass has increased considerably and contributes today 42 percent of the total aquaculture production in Europe. Rearing of these species is mainly based on cage culture technology.

THE CURRENT SITUATION REGARDING CAGE CULTURE IN EUROPE

Aquaculture has become an important source of seafood products in Europe. It is a highly diverse industry and consists of a broad spectrum of species, technology and practices. The contribution of aquaculture to trade, both local and international, is increasing.

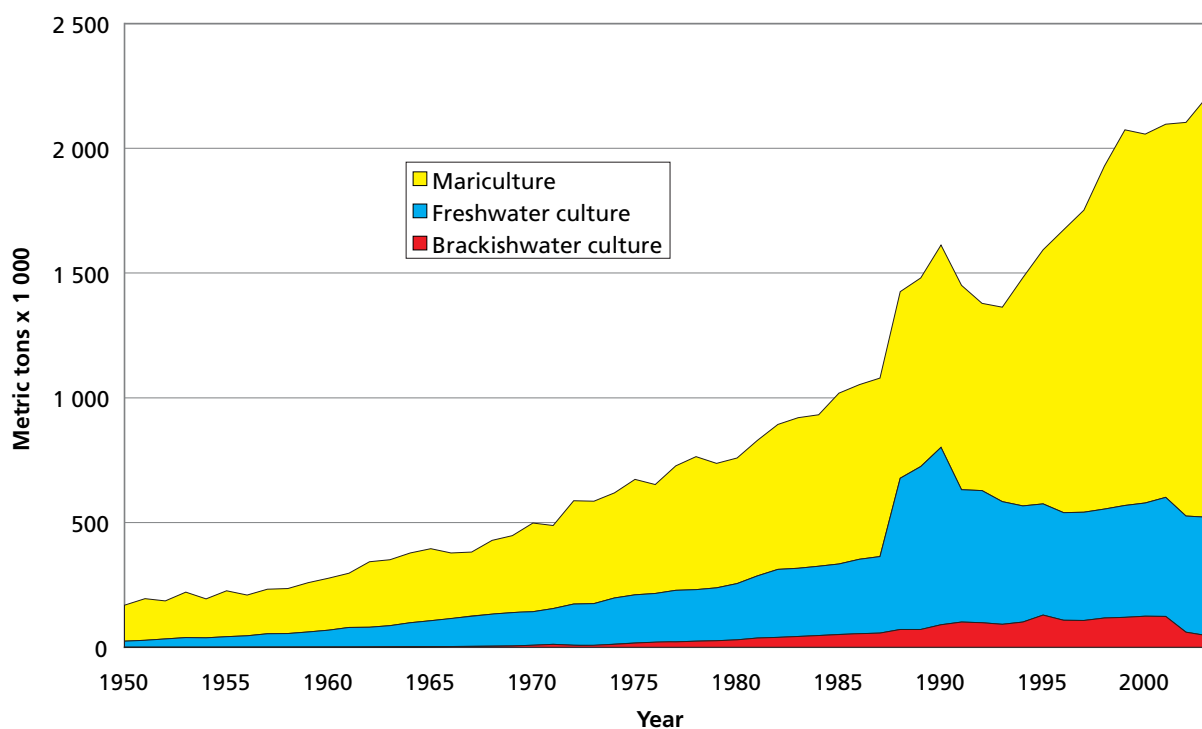
The main species in cage production

At the start of the development of cage culture in Europe, the main species was rainbow trout. Within a few years, however, an increasing share of the production capacity was used for Atlantic salmon. During the last fifteen years, seabass and seabream farming has also grown rapidly in Europe (Figure 2).

Atlantic salmon

Atlantic salmon is an anadromous species with a life cycle of 1–3 years in freshwater (fry-parr stages). After a process of physiological adaptation (smoltification), in which the parr stage transforms

FIGURE 1
Development of total aquaculture production in Europe 1950–2004



Source: FAO, 2006

into smolts, the salmon migrate to the sea where they remain for at least one year, before returning to the river of origin to spawn. Females excavate a shallow depression in the river substrate with their tails in which they lay their eggs that are then fertilized by the males. A few adults survive spawning and return to the sea, and an even smaller proportion return a year or two later to repeat the spawning process.

The natural distribution of Atlantic salmon is throughout the North Atlantic, from North Portugal and Cape Cod (Massachusetts, United States of America) in the south, to the Barents Sea and the Peninsula of Labrador (Canada) in the north (Souto and Villanueva, 2003).

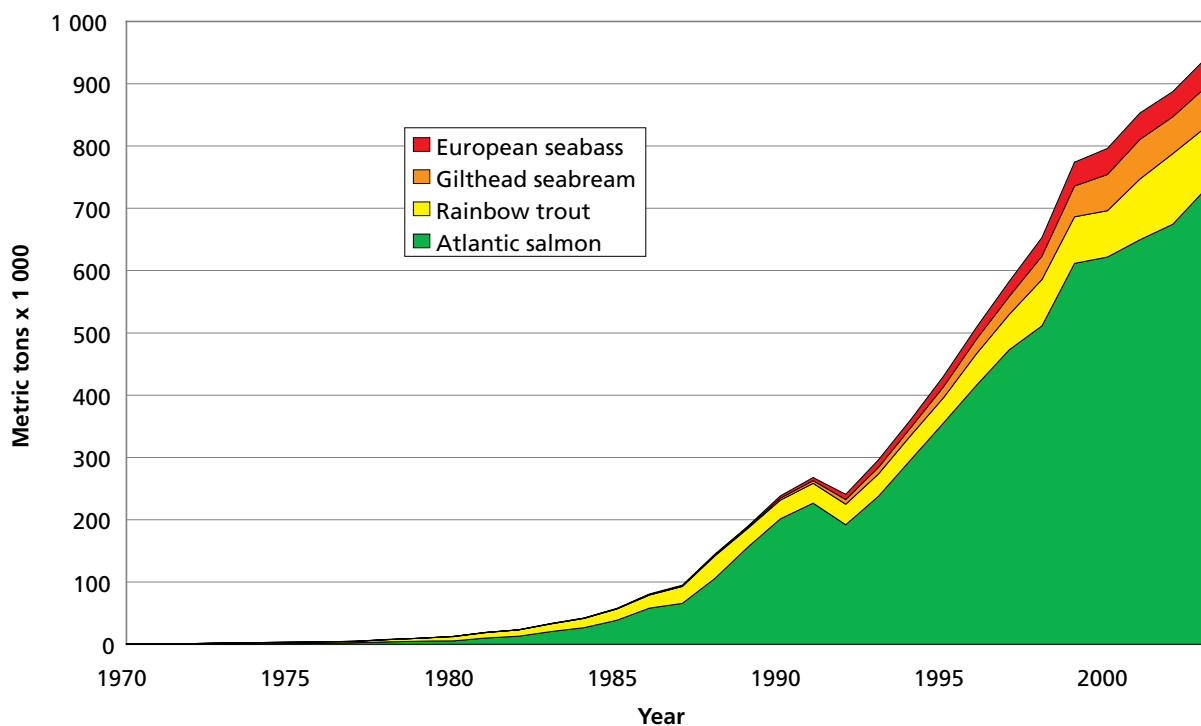
Norway is the main producer of salmon amounting to 72 percent of total European production (Figure 3). In absolute terms, 2004 production figures were highest in Norway (566 000 tonnes) followed by the United Kingdom of Great Britain and Northern Ireland (158 000 tonnes), Faroe Islands (37 000 tonnes) and Ireland (14 000 tonnes). Other countries outside Europe that farm Atlantic salmon include Chile (376 000 tonnes, 2005) and Canada (103 000 tonnes, 2005) (FHL, 2005).

Rainbow trout

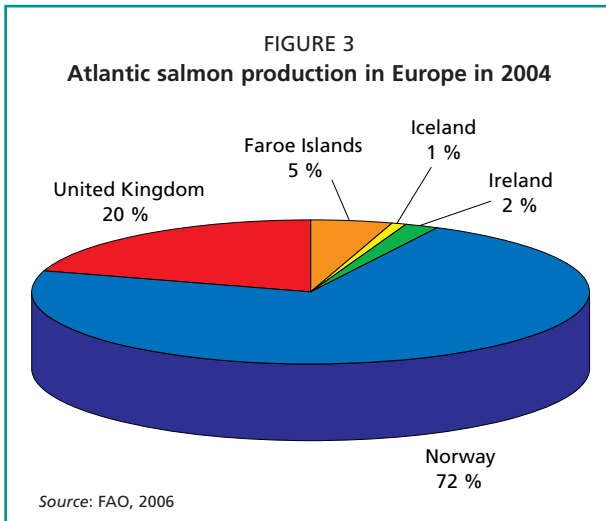
The natural habitat of rainbow trout is freshwater with temperatures of about 12–15 °C in summer. It is unclear whether anadromy in the species is a truly genetic adaptation or simply an opportunistic behaviour. It seems that any stock of rainbow trout is capable of migrating, or at least of adapting to sea-water, if the need or opportunity arises. Within their natural range they require well-oxygenated, moderate to fast running water for breeding, although they also are found in cold lakes. Adults feed on aquatic and terrestrial insects, molluscs, crustaceans, fish eggs, minnows, and other small fishes (including other trout); the young feed predominantly on zooplankton. Natural strains of rainbow trout are found in the Eastern Pacific. Rainbow trout is probably one of the most widely introduced fishes and may be regarded as global in its present distribution (Fishbase, 2005). Fish reared in freshwater are usually sold portion-sized (less than 1200 g/fish), and rainbow trout from seawater cages as larger sizes (above 1200 g/fish).

Norway is the main producer of rainbow trout amounting to 79 percent of total European production (Figure 5). In absolute

FIGURE 2
Cage culture production in Europe



Source: FAO, 2006

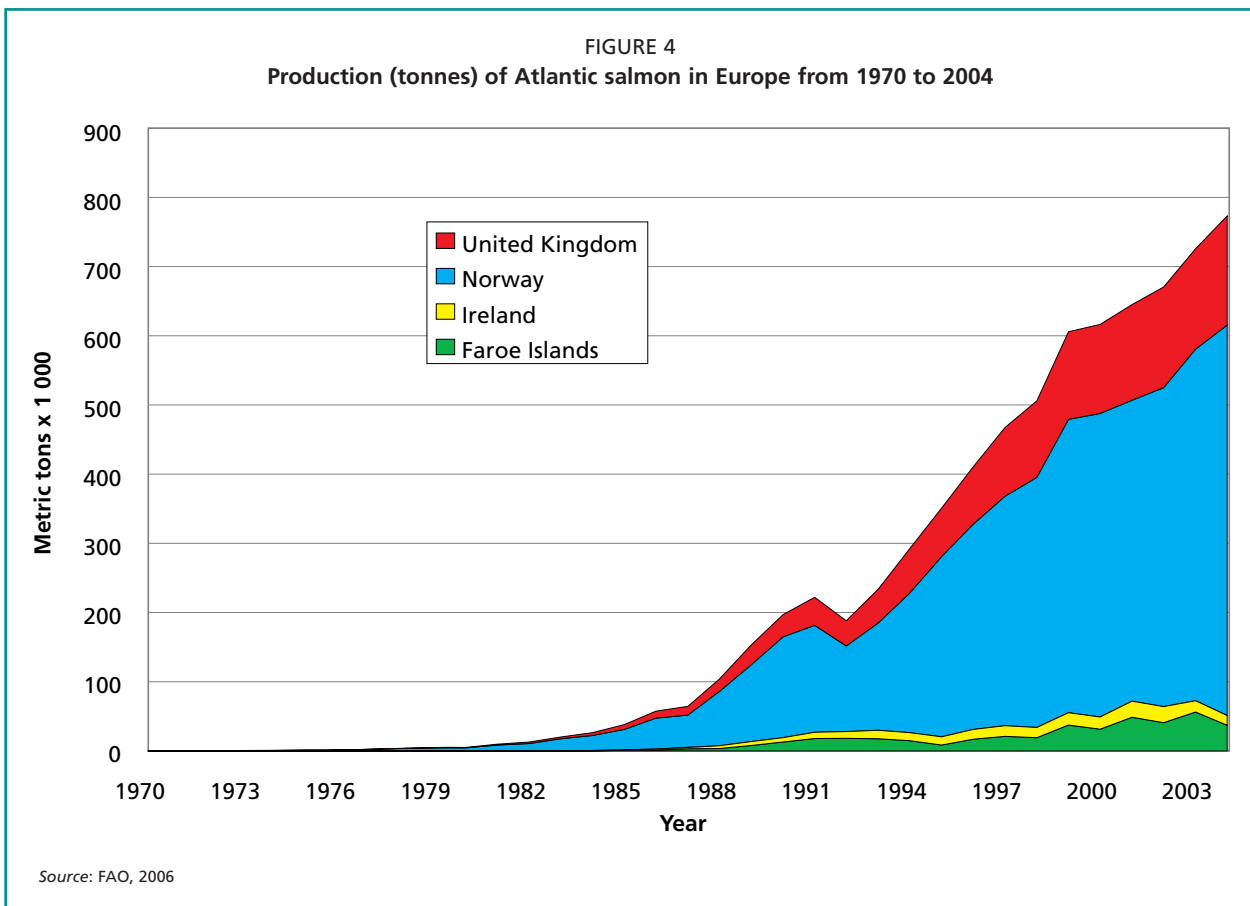


terms, 2004 production figures were highest in Norway (63 401 tonnes) followed by Denmark (8 785 tonnes), Faroe Islands (5 092 tonnes), the United Kingdom of Great Britain and Northern Ireland (1 664 tonnes) and Sweden (1 316 tonnes) (Figure 6). The key country outside Europe that farms rainbow trout is Chile with a production of 118 413 tonnes in 2004 (FAO, 2006).

Other species

There has always been an interest to further develop the aquaculture production of new marine species. Conventional cage designs have been successfully used for flatfish such as halibut (*Hippoglossus hippoglossus*) and for cod (*Gadus morhua*). The main bottleneck in sea cage aquaculture development of new species has been the reliable supply of sufficient numbers of good quality juveniles. It has also proved difficult to establish an economically sustainable industry.

In contrast with the establishment of the salmon and rainbow trout cage culture industries, marine fish producers have had to compete with established fisheries in terms of price. Salmon and rainbow trout were sold at very high prices because of their exclusivity. Production costs could therefore be high from the outset of the development of cage culture production of these species, and the farms would still be profitable. This is not the case for the marine species. As a consequence the establishment of aquaculture production of marine species is dependent on higher starting venture capital. However, because of the fisheries, there is an already established market for marine species.



Cod: Among the new marine species cod has been the most successful. In Scotland there are currently 14 companies involved in cod farming. Production over the past five years has oscillated between just a few tonnes and 250 tonnes in 2005. In Norway more than 350 licenses have been registered for cod production. However, only about 100 are in use. The production in 2005 was about 5 000 tonnes, and is expected to increase considerably in the next few years (FRS, 2005).

Halibut: Halibut is a cold water flatfish in which a significant amount of research has already been invested with the aim of establishing economically viable aquaculture production. The market price

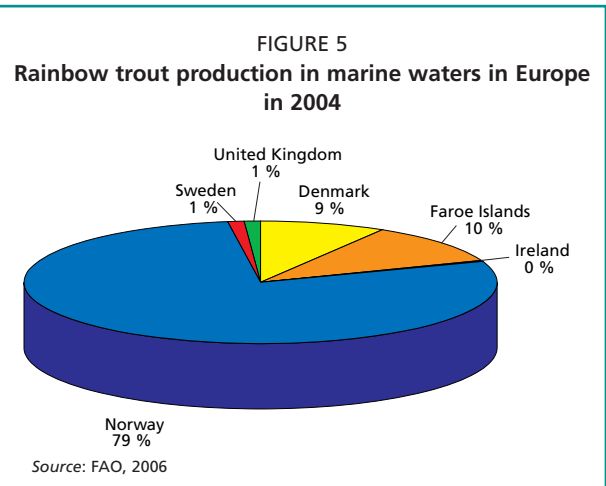
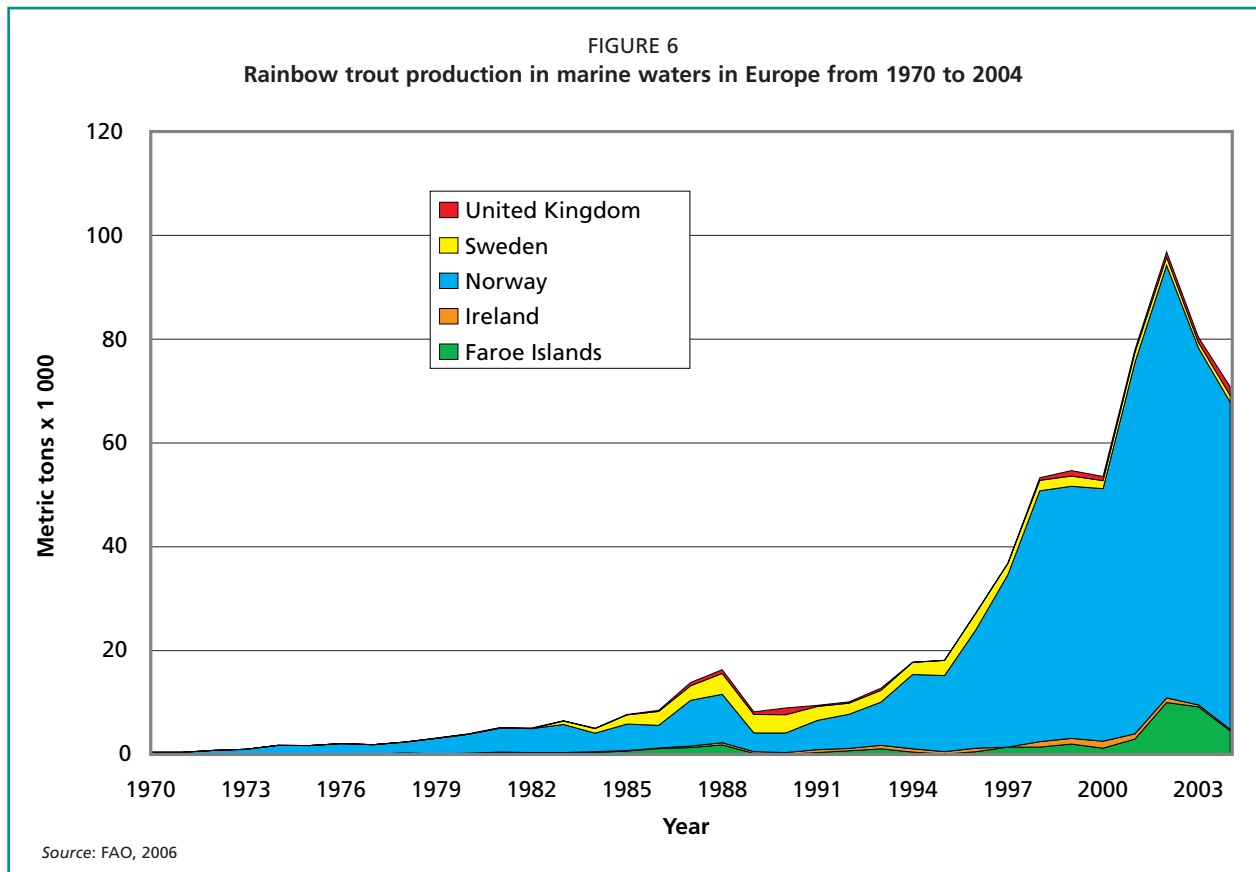


TABLE 1
Production of selected cage-raised fish species in Europe in 2004

	Production (tonnes)			
	Iceland	Norway	United Kingdom of Great Britain and Northern Ireland	Total
Haddock	72			72
Chars		365		365
Atlantic halibut		631	187	818
Atlantic cod	636	3 165	8	3 809
Total	708	4 161	195	5 064

Source: FAO, 2006



for halibut is high. However, the production time is long and expensive. In Scotland nine companies were in operation in 2005 and production peaked at around 230 tonnes during the period 2003–2005 (FRS, 2005).

Today production is declining, and the volume in Scotland is expected to remain at only a few hundred tonnes per annum destined for niche markets. In Norway there are about 100 aquaculture licenses for halibut, and the annual volume was about 1 000 tonnes in 2005. Production is mainly land based.

Other species raised in cages in Europe are haddock (*Melanogrammus aeglefinus*) and charr (*Salvelinus alpinus alpinus*) (Table 1). Also, mullets (*Mugil* spp.) and tuna (*Thunnus* spp.) are farmed in cages (for details see chapter on cage culture in the Mediterranean region in this volume).

Locations and production

Not all of Europe is appropriate for aquaculture development, as many different factors affect the output and the viability of aquaculture operations (e.g. water quality, availability and cost of space, climatic conditions, etc.). When considering the location of aquaculture sites, it is critical to perform a systematic, integrated assessment of both the

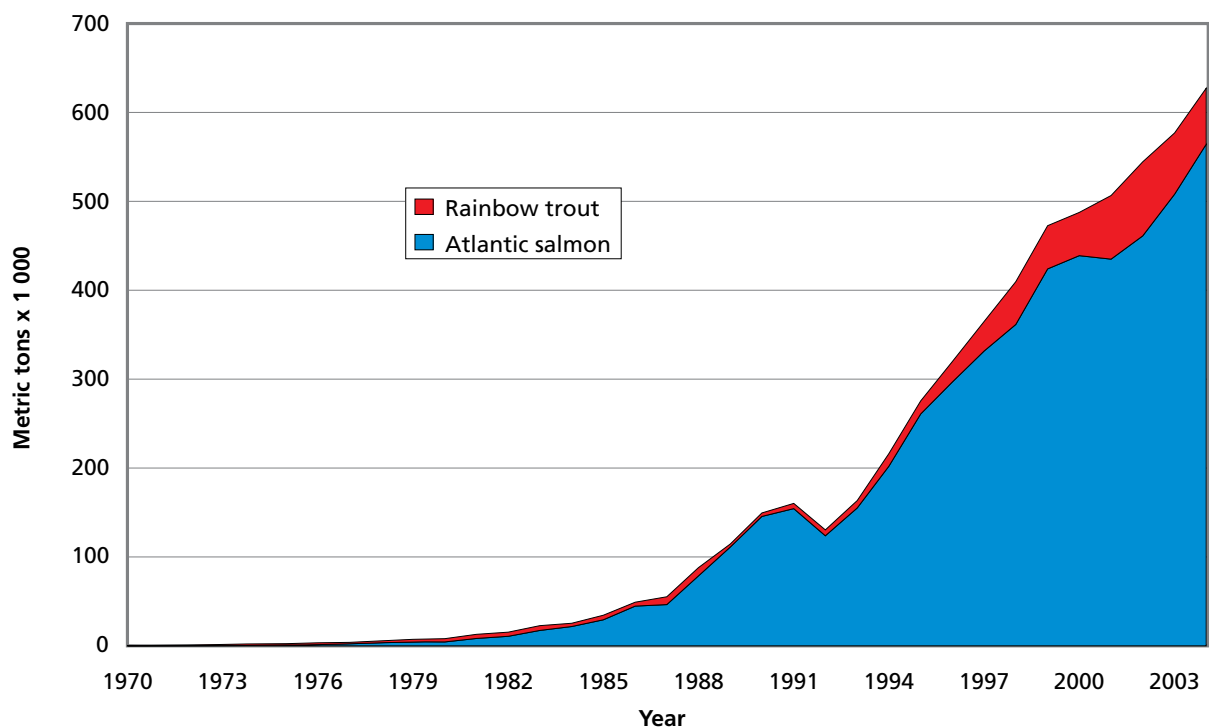
positive and negative impacts of new aquaculture developments (Commission of the European Communities, 2002).

There are of course huge differences among European countries in, for example, the degree of exposure at sites, ranging from rainbow trout production in rather sheltered locations in the Baltic Sea to the cultivation of Atlantic salmon in heavily exposed locations in the Faroe Islands. However, cage culture production in the different European countries is somewhat uniform in terms of use of technology (Beveridge, 2004).

During the establishment phase of cage sea farming in Europe, the organization of the industry was based on a large number of small companies, often family based.

With the development of the industry the company structure has become more diverse. The aquaculture sector includes today family operations, medium-scale fish-farm businesses and multinational mariculture enterprises, although it is increasingly dominated by the large multinationals (FAO, 2001). During this period the production volume at each site has become more adapted to the carrying capacity of the site. The level of exposure to organic load is continuously monitored, and the

FIGURE 7
Cage culture production in Norway from 1970 to 2004



Source: FAO, 2006

production volume is regulated according to what is acceptable for each site. There has also been a development towards using sites which provide better conditions for production.

Norway

Thanks to its extraordinary geographical characteristics (coastal waters warmed by the Gulf Stream, a lengthy coastline, rivers fed by melting snow for hatcheries), Norway became the first country to actively promote the development of salmon farming. Norwegian salmon farmers were able to sell their salmon easily to the European, American and Japanese markets because of their port infrastructure, processing facilities and highly developed transport and logistics networks.

While the first exploratory efforts were made in the late 1950s, the sector really developed in the 1970s once the major technical problems (nutrition, conditioning juvenile fish) were resolved. By the mid-1980s, salmon farming represented Norway's second most valuable seafood production after cod and by the turn of the millennium it had become the country's second most important export item after oil and gas. During the 1980s, the Norwegian industry started to export technology and

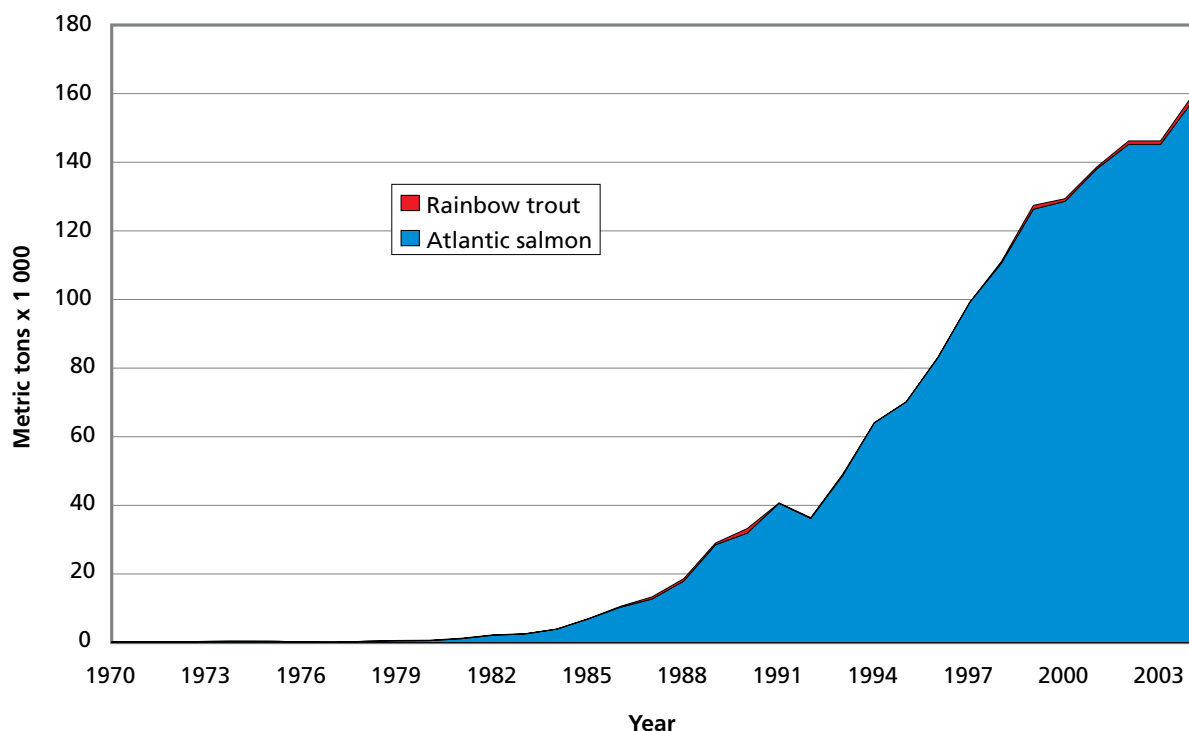
equipment to Canada, the United States of America and Chile. Extensive research support is provided by the Norwegian Research Council and by specialized institutions, and international expertise has been build up. Today, Norwegian interests play an important role in global salmon farming (FEAP, 2002). Cage culture production of Atlantic salmon and rainbow trout has expanded and intensified considerably over the years and in 2004 amounted to 566 000 tonnes and 63 000 tonnes, respectively (Figure 7).

Scotland

In 1969, the first commercial salmon farm was established at Loch Ailort on the West Coast. Today, Scottish salmon farms operate in the Highlands, the Western Isles, the Orkney Islands and the Shetland Islands (FRS, 2005).

Many of these areas have a history of high unemployment. This explains why government agencies in the United Kingdom of Great Britain and Northern Ireland and the European Community have provided assistance under a number of support mechanisms for investment loans, training, and technical support to encourage the growth of salmon farming as a viable economic industry.

FIGURE 8
Cage culture production of Atlantic salmon and rainbow trout in Scotland from 1970 to 2004



Source: FAO, 2006

The production of Atlantic salmon in Scotland has grown continuously (Figure 8), largely to supply the markets of the United Kingdom of Great Britain and Northern Ireland but also global markets. In the United Kingdom of Great Britain and Northern Ireland farmed salmon has now become the third most popular seafood after cod and haddock (FEAP, 2002).

Ireland

Irish history is renowned for its mythology and legends and the adventures of the famous seer-warrior Fionn Mac Cumhaill include how he gained his wisdom by tasting the “salmon of knowledge” – an instant measure of the esteem for salmon in this country .

Salmon farming takes place mainly on the west coast – often in very exposed sites – and has developed into an important component of the Irish aquaculture industry (Figure 9), which also includes shellfish and trout production.

Faroe Island

Lying about 300 miles northwest of the Shetland Islands, the Faroe Islands form a self-governing Region of the Kingdom of Denmark. With

the decline of fisheries and with little land for agriculture, the Faroese invested in salmon farming early in the 1980s and soon became one of the top salmon producing areas (Figure 10).

Most salmon are raised in very large floating fish farms located in the narrow straits between islands. These are quite vulnerable to storms and have to be well managed with a high degree of mechanization. Salmon farming rapidly became an important export activity for the Faroe Islands, channeling most of its products through Denmark to the European markets (FEAP, 2002).

The salmon production in Faroe Islands has gone through a difficult period in the last years because of the virus disease Infectious Salmon Anaemia (ISA).

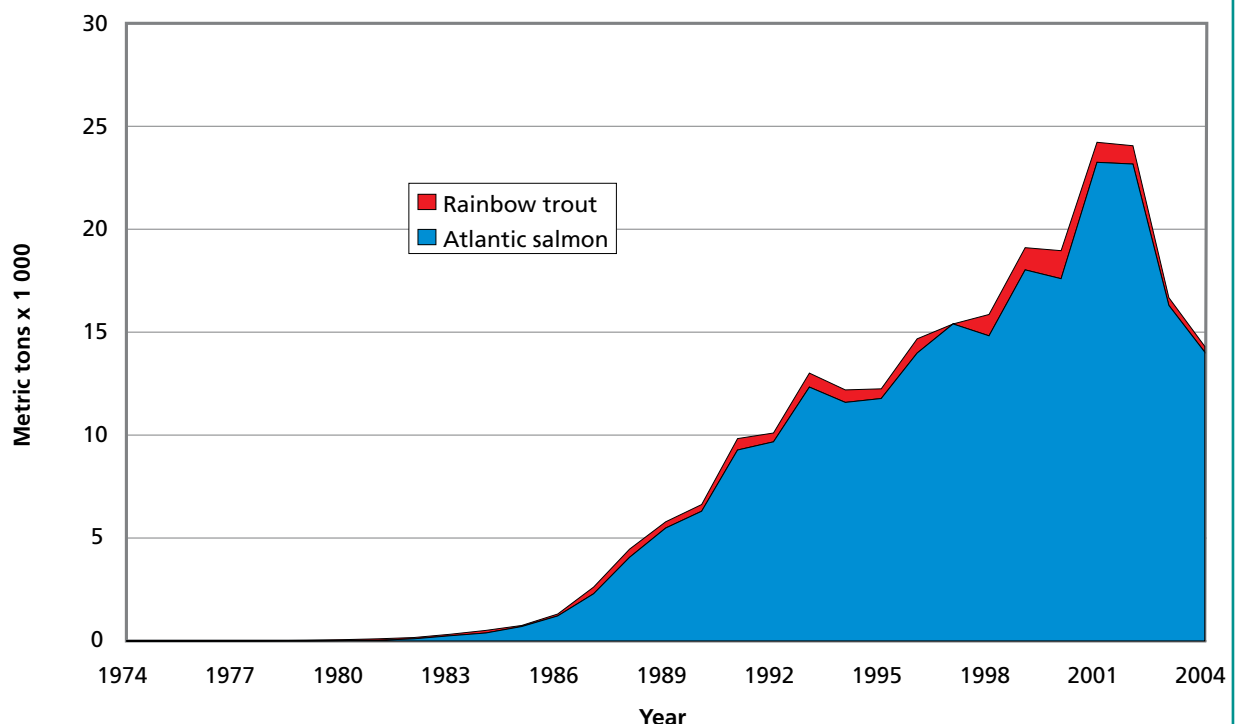
Other countries

Several other countries in northern Europe have cage culture industries. However, compared with the nations mentioned above the production volume is relatively low (Table 2).

Technology

The cage systems used in modern aquaculture have essentially changed little compared to the ones

FIGURE 9
Cage culture production of Atlantic salmon and rainbow trout in Ireland from 1974 to 2004



Source: FAO, 2006

first used. Cages are moored or floating, square, hexagonal or circular units, from which closed net bags are suspended. Fabrication materials have changed from wood to steel and plastic.

The cages consist of a floating collar with net enclosures suspended beneath. They can be described as ‘gravity cages’ because they depend on weights hanging from the nets to keep them open and have no underwater structural framework. Gravity cages are extremely successful and have supported the development of fish farming for the past 30 years. Steel collar cages are usually square in plan view (Figure 11) while plastic or rubber collar cages are usually circular in plan view (Figure 12)

and can be assembled in groups within a grid work of rope and chain moorings (Ryan, 2004).

Cage farming systems specially adapted for flatfish, as shown in Figure 13, have also been developed. These systems consist of several layers of shelves on which the fish can lie.

MAJOR REGIONAL CHALLENGES

Production method

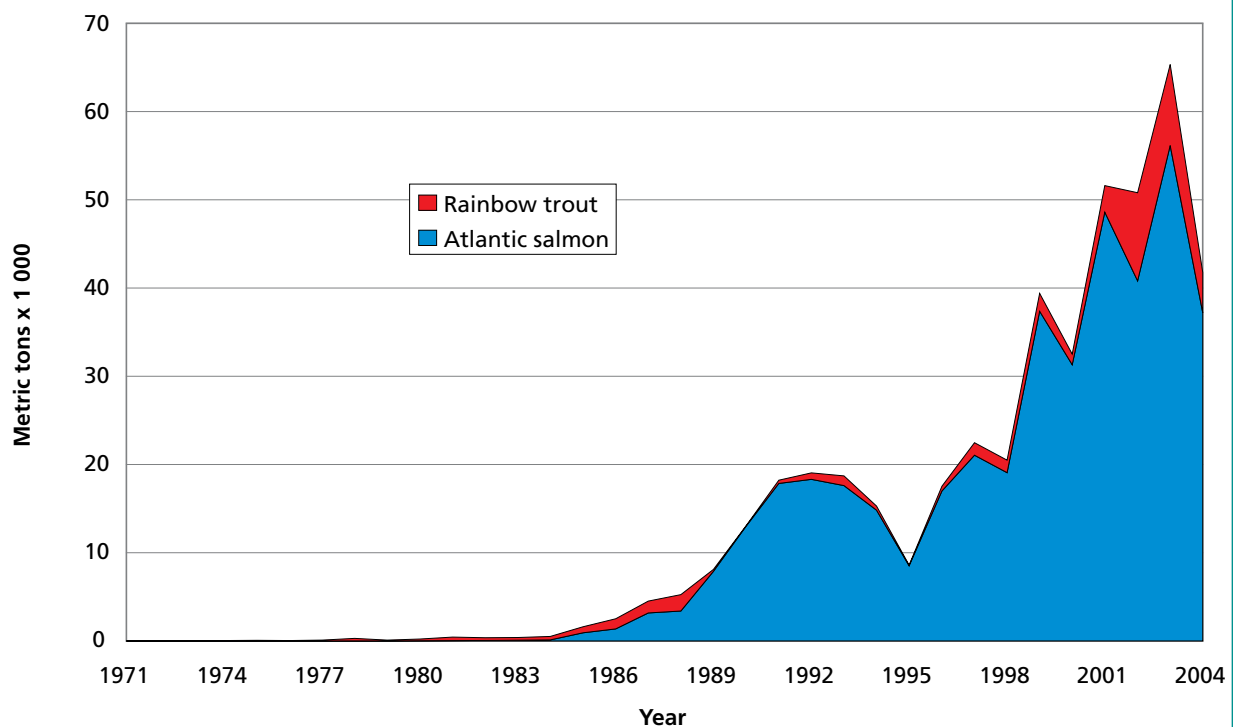
Aquaculture in Europe is still a young industry. The technology for cage culture farming was established some thirty years ago, and soon afterwards the production volume of fish started to increase (Figure 2). At this stage the production of small

TABLE 2
Cage culture production in selected European countries in 2004

	Haddock	Atlantic cod	Arctic char	Atlantic salmon	Rainbow trout	Total
Sweden					4 111	4 111
France				735	155	890
Iceland	72	636	1 025	6 624	137	8 494
Denmark				16	8 770	8 786
Finland					10 586	10 586
Total	72	636	1 025	7 375	23 759	32 867

Source: FAO, 2006

FIGURE 10
Cage culture production of Atlantic salmon and rainbow trout in the Faroe Islands from 1971 to 2004



Source: FAO, 2006

FIGURE 11
Example of a circular unit



COURTESY OF AQUALINE 2006

FIGURE 12
Example of steel collar cages



COURTESY OF SINTEF FISKERI OG HAVBRUK

quantities, combined with a very high demand for salmonids, led to a very high income per kg production.

Even with a high mortality rate, elevated feed consumption levels and the use of more or less self-made equipment, the aquaculture business was profitable. However, production during these first years disregarded the environment and was not always performed with animal welfare as a priority. Because of the problems during its establishment, the industry still has to contend with a poor reputation and most consumers are more resistant

to aquaculture than agriculture, although this may also be because most people do not have the same relation to aquaculture as to agriculture.

Technical issues

Seed supply

For salmonids the development of new knowledge and technology provided controlled spawning and high fertilization rates. Salmonid fish have a relatively large reproductive capacity combined with a high egg survival and sufficient egg production to service the salmon and trout farming industries can be carried out by a small number of producers. The vast majority of salmonid eggs are produced and transferred within countries.

There has been, and are, opposing forces to the international trade of eggs. International trade represents a health risk because of the possibility of transfers of pathological agents. Because of the genetic variation between salmonid stocks, there are also concerns about the possibility of genetic interaction between escapes and wild fish populations (McGinnity *et al.*, 2003; Walker *et al.*, 2006).

Genetic improvement by implementing selective breeding programmes has contributed significantly to increased performance and productivity of Atlantic salmon and rainbow trout.

However, as these breeding programmes are highly specialized and costly, they tend to become centralized in a very few countries and companies. Improved genetics at a reduced cost and a year-round egg availability represent an important motivation for international trade of salmonid eggs.

FIGURE 13
Example of cage adapted for flatfish



COURTESY OF AQUALINE 2006

Scotland imported about 14 million Atlantic salmon eggs in 2002, mainly from Iceland but also from Australia and the United States of America. The import of rainbow trout eggs represented more than 20 million and originated from South Africa, Denmark, Isle of Man and Ireland (FRS, 2005).

Trade of eggs between Norway and the European Economic Area (EEA) were prohibited for a time due to protective measures against ISA (Infectious Salmon Anaemia). However, these restrictions were lifted by 1 February 2003 (AquaGen, pers. comm. 2005).

Feeds and feeding

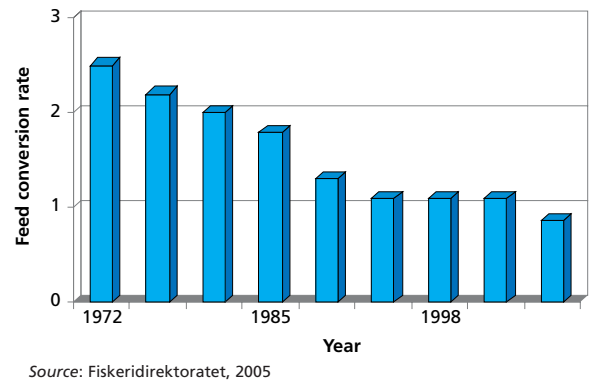
The changes in fishmeal/fish oil ratio in salmon feeds observed over the past two decades would not have been possible if it were not for the tremendous technological developments in feed manufacturing. Until the early 1980s salmon feeds consisted essentially of farm-made semi-moist pelleted feeds composed of minced sardines or other low-value fish mixed with wheat flour and a vitamin/mineral premix.

Although these feeds were usually readily consumed by the salmon, their manufacture was dependent upon a regular supply of fresh 'top quality' sardines or other low-value fish. In addition, the diets generally exhibited poor water stability and low feed conversion ratios.

Between the mid-1980s and the early 1990s, farm-made feeds were gradually replaced by dry commercially manufactured steam pelleted feeds, characterized by their high protein and low fat (<18–20 percent) content, and improved feed efficiency.

Since 1993, conventional steam pelleted feeds have been replaced by extruded salmon feeds. The extrusion has resulted in salmon feeds with improved durability (less fines and wastage), increased carbohydrate and nutrient digestibility (due to the increased starch gelatinization and/or destruction of heat-labile plant anti-nutrients), and with improved physical characteristics (including altered density and adjustable pellet buoyancy/sinking characteristics). Lower feed conversion ratios (FCRs) have been obtained through increasing dietary lipid levels, leading to an increase in dietary energy levels and a consequent improved protein and energy nutrient utilization. Extrusion became the main production method because of its many advantages. It is generally accepted that the major reasons for using extruded feeds in the salmon industry is their ability to expand the pellet, thereby

FIGURE 14
Development of the feed conversion rate in production of rainbow trout and atlantic salmon in Norway from 1972 to 1999



facilitating the inclusion of high dietary oil levels. Extruded pellets make an important contribution to the achievement of the present growth rates, a reduced impact on the ocean floor under the cages, stronger pellets that are usable in automatic feeders and the ability to incorporate a wider range of raw materials. The net result of these continuing improvements in feed formulation and feed manufacture, are increased fish growth, decreased feed conversion ratios (Figure 14), and hence lower fish production costs and environmental effects.

At present, over two thirds of salmon feeds by weight are composed of two marine ingredients, namely fishmeal and fish oil. Compared to other terrestrial animal and plant protein sources, fishmeal is unique as it is not only an excellent source of high quality animal protein and essential amino acids, but it also contains sufficient levels of digestible energy, of essential minerals and vitamins, and of lipids, including essential polyunsaturated fatty acids (<http://www.iffonet/default.asp?fname=1&WebIdiom=1&url=23>).

Salmonids are currently dependent upon fishmeal as their main source of dietary protein. A similar dependency also exists for fish oil as the main source of dietary lipids and essential fatty acids.

Between 1994 and 2003 the total amount of fishmeal and fish oil used within compound aquafeeds grew more than three-fold, from 963 000 to 2 936 000 tonnes and from 234 000 to 802 000 tonnes, respectively. The increase in usage is in line with the almost three-fold increase in total finfish and crustacean aquaculture production over this period, which increased from 10.9 to 29.8 million tonnes between 1992 and 2003.

On the basis of the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) used by FAO, the calculated consumption by global salmon aquaculture was:

- fishmeal: from 201 000 to 573 000 tonnes between 1992 and 2003
- fish oil: from 60 400 to 409 000 tonnes between 1992 and 2003
- total fishmeal and fish oil: from 261 400 to 982 000 tonnes
- Canada: mean fishmeal level 20–25 percent, mean fish oil level 15–20 percent;
- Chile: mean fishmeal level 30–35 percent, mean fish oil level 25–30 percent;
- Norway: mean fishmeal level 35–40 percent, mean fish oil level 27–32 percent; and
- United Kingdom of Great Britain and Northern Ireland: mean fishmeal level 35–40 percent, mean fish oil level 25–30 percent.

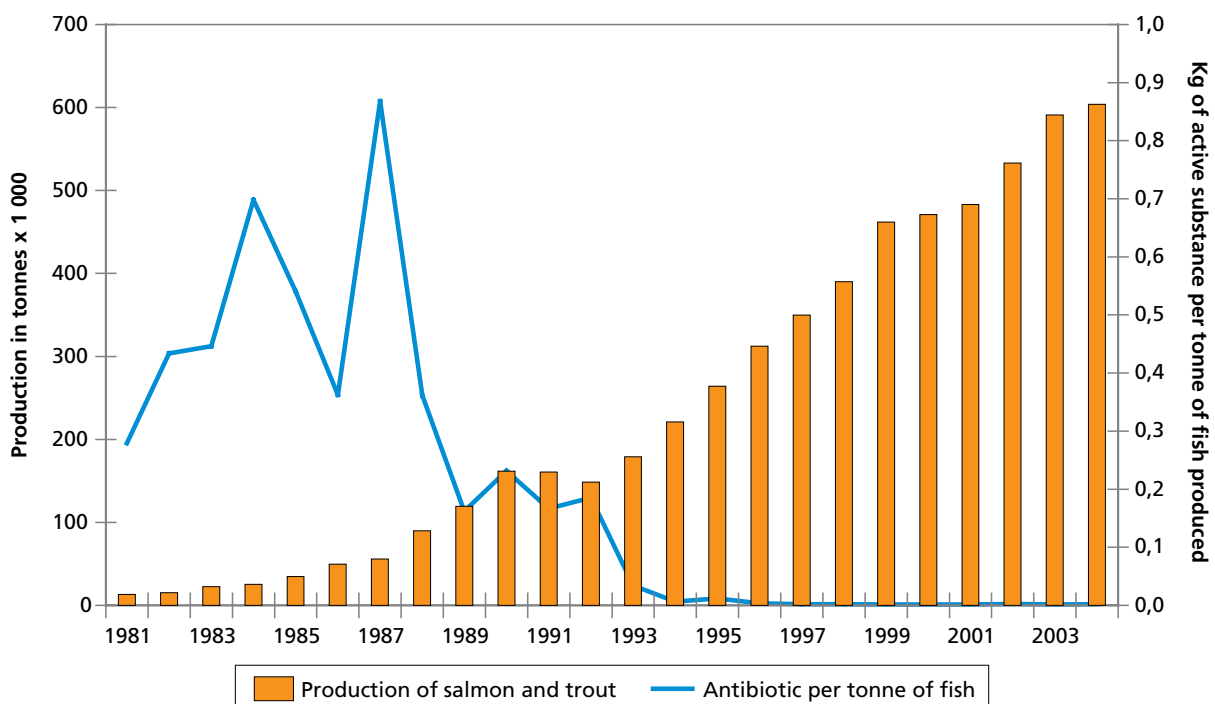
The percentage of dietary fishmeal and fish oil used in salmon feeds has changed dramatically over the past two decades, with fishmeal inclusion levels decreasing from an average level of 60 percent in 1985, to 50 percent in 1990, 45 percent in 1995, 40 percent in 2000 and to the present inclusion level of 35 percent. The decrease has been accompanied by an equivalent increase in dietary lipid levels, from as low as 10 percent in 1985, 15 percent in 1990, 25 percent in 1995, 30 percent in 2000, to as high as 35–40 percent in 2005.

Although on an industry basis the current average level of fishmeal and fish oil used in salmon feeds is approximately 35 percent and 25 percent, respectively, significant differences exist between the major producing countries:

Since between 50 and 75 percent of commercial salmon feeds are currently composed of fishmeal and fish oil any price increase of these finite commodities will have a significant effect on feed price and farm profitability. In general salmon feed represents about 50 percent of total farm production costs (Figure 17) (Tacon, 2005).

It has been questioned whether farming salmon is a proper use of resources, since the feed used can also be consumed by people directly. In this respect, there has been a special focus on the use of fishmeal and fish oil. Here it is important to note that these resources are largely used for animal feeds in any case. In this context, salmon farming is an efficient use of resources, since fish utilize the feed more efficiently than for example chicken or pigs (Holm and Dalen 2003).

FIGURE 15
Volume of antibiotics per kilogram of harvested salmon and rainbow trout compared to the volume harvested in the years 1981 to 2004



Source: FHL, 2005

Diseases

Intensification of any biological production such as aquaculture will inevitably result in problems, particularly in diseases of infectious origin. Outbreaks of virulent diseases may have serious consequences for aquaculture production, with significant economic impacts at a local, regional and even national level. The losses may be due to reduced production, but restrictions on trade are becoming increasingly important. Diseases in farmed aquatic animals may affect the environment in different ways, for instance by transmission of infectious disease to wild fish populations.

The food safety aspect of diseases in aquatic animals is less than in terrestrial animals as few of the fish diseases have a zoonotic potential. However, as microbial diseases in farmed fish sometimes are treated with antibiotics, both residues and microbial resistance against antibiotics may be undesired effects of fish diseases. Effective risk management is therefore crucial in order to reduce the economical, social and environmental costs due to severe diseases in aquaculture (Woo *et al.*, 2002; T. Håstein, pers. comm.).

Production of animal protein has to be sustainable, which means that preventive measures that are acceptable from a biological and environmental point of view should be used to keep disease problems in aquaculture at an acceptable level. Vaccination is now the single most important measure for prevention of bacterial diseases in farmed fish, especially in salmonid fish. The best indicator of the effect of vaccination as prophylactic measure is the reduction in use of antibiotics in fish farming. Currently, the entire population of Atlantic salmon and rainbow trout in Norway is vaccinated against at least three major bacterial diseases (vibriosis, cold-water vibriosis and furunculosis) prior to stocking into seawater. During a 10 year period the usage of antibiotics has been reduced to an absolute minimum, mainly due to the use of vaccines (Figure 15).

Although vaccines in general have proven to be effective in the protection against serious fish diseases, vaccination may be hampered by certain adverse effects. Mortality associated with the vaccination is in general low, but anaesthesia, handling and the intraperitoneal injection itself may cause occasional deaths.

When using injectable vaccines prepared with different types of adjuvants, reactions in the abdominal cavity are usually observed. These reactions may vary from rare to severe, in the form

of adhesions in the peritoneal cavity or other local reactions as common findings. Most often, such side effects are related to oil adjuvant injectable vaccines against furunculosis. The reason for this is that sufficient protection against this disease is only achieved with adjuvant vaccines.

In Atlantic salmon, the severity of the lesions is reduced if the size of the fish is at least 70 g and the water temperature is below 10°C. The timing of vaccination will also influence the development of side effects such as adherence, growth and spinal deformities (T. Håstein, pers. comm.).

With the development of vaccines, bacterial diseases are more or less mainly under control. The main challenges today related to fish health are viral diseases, and the one disease with the greatest economical impact is infectious salmon anaemia (ISA). This viral disease of Atlantic salmon was until 1996/1997 reported only to occur in Norway.

However, the disease condition called “haemorrhagic kidney syndrome” reported in Canada was subsequently found to be identical to ISA and ISA was also officially reported from Scotland in 1998 (66th OIE General Session). Atlantic salmon is the only species affected by ISA, but experiments have shown that both rainbow trout and sea trout (*Salmo trutta*) may act as asymptomatic carriers of the disease agent.

During the 1980s and the early 1990s, there was a dramatic increase in ISA outbreaks in Norway where some 90 farms were affected by the clinical disease. The mortality rates varied considerably from insignificant to moderate although a few farms suffered losses as great as 80 percent (Håstein *et al.*, 1999).

Other viral diseases which have had a significant influence on the cage culture industry in Europe are inter alia Infectious Pancreatic Necrosis (IPN) and Viral Haemorrhagic Septicaemia (VHS). In recent years viral Pancreas Disease (PD) has become an increasing problem, indicating that fish health is a constant concern, not least among new species which are now being introduced for cage farming.

Socio-economic issues – production costs, marketing, prices, employment

An increase in production and a greater availability of fish have converted cage-reared species from being an exclusive dish served in the best restaurants to a commodity product in the super- and hypermarkets. Quality has increased with quantity as a result of increased production knowledge and better technology. Even so, the increases in production

volume have reduced prices to consumers of cage-reared fish because of the competition between producers within and between countries. As a result each producer has been forced to reduce production costs dramatically. For example, the average price of Atlantic salmon and rainbow trout in Norway during the period 1986–2004 dropped from about €7 to about €2 per kg (2004 value).

There are differences in production costs among countries. However, other than for Norway, official figures of production costs for different European producer countries are not available.

In 1986 feed represented 31 percent of Atlantic salmon/rainbow trout production costs, while the purchase of smolt accounted for 26 percent and wages 15 percent. Almost twenty years later feed, smolt and wages represent 56 percent, 13 percent and 9 percent, respectively (Figure 17).

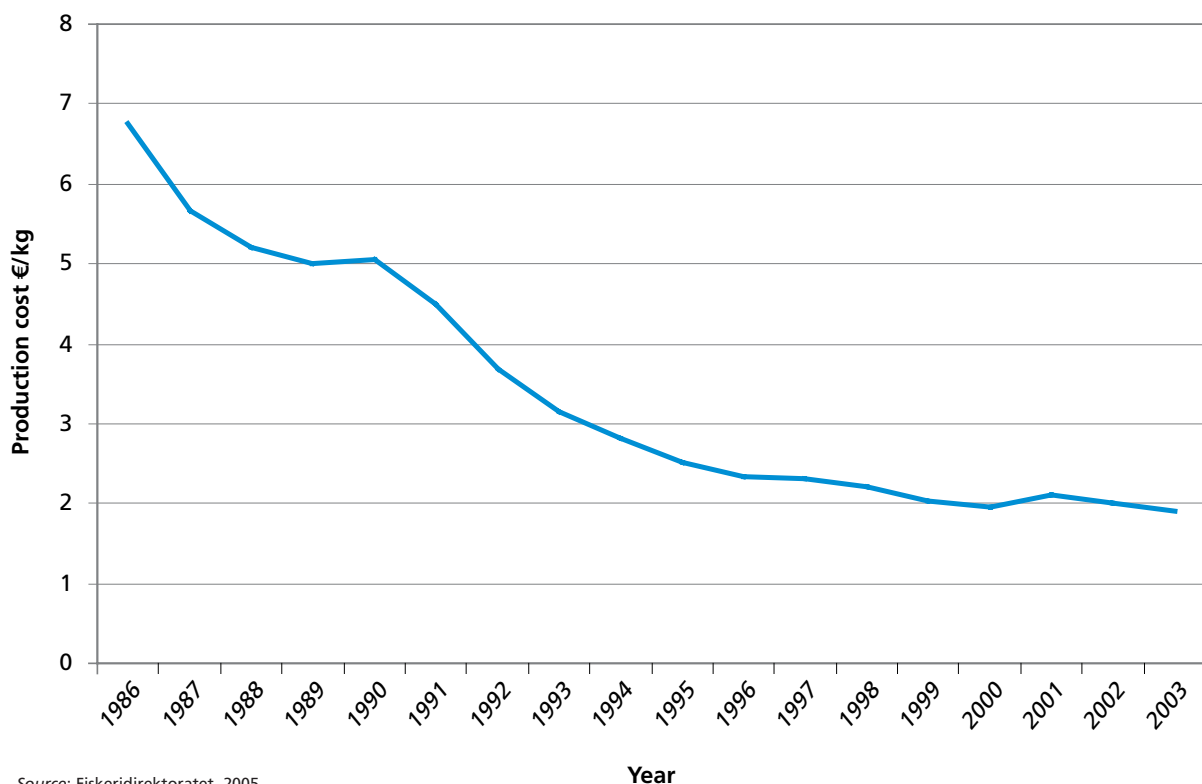
This may be explained by an increase in production efficiency by producing larger quantities per farm, which reduces the need for labour both in the smolt and the grow-out sector. The increase in productivity is a result of better logistics, better technology and improved biological characteristics of the fish.

Fish feed has taken an increasing share of the total production cost. This has resulted in a growing focus on the feed conversion rate, which the industry has managed to reduce considerably (Figure 14). This has not only reduced production costs, but also had an important role in minimizing the environmental impact of marine cage aquaculture on the environment.

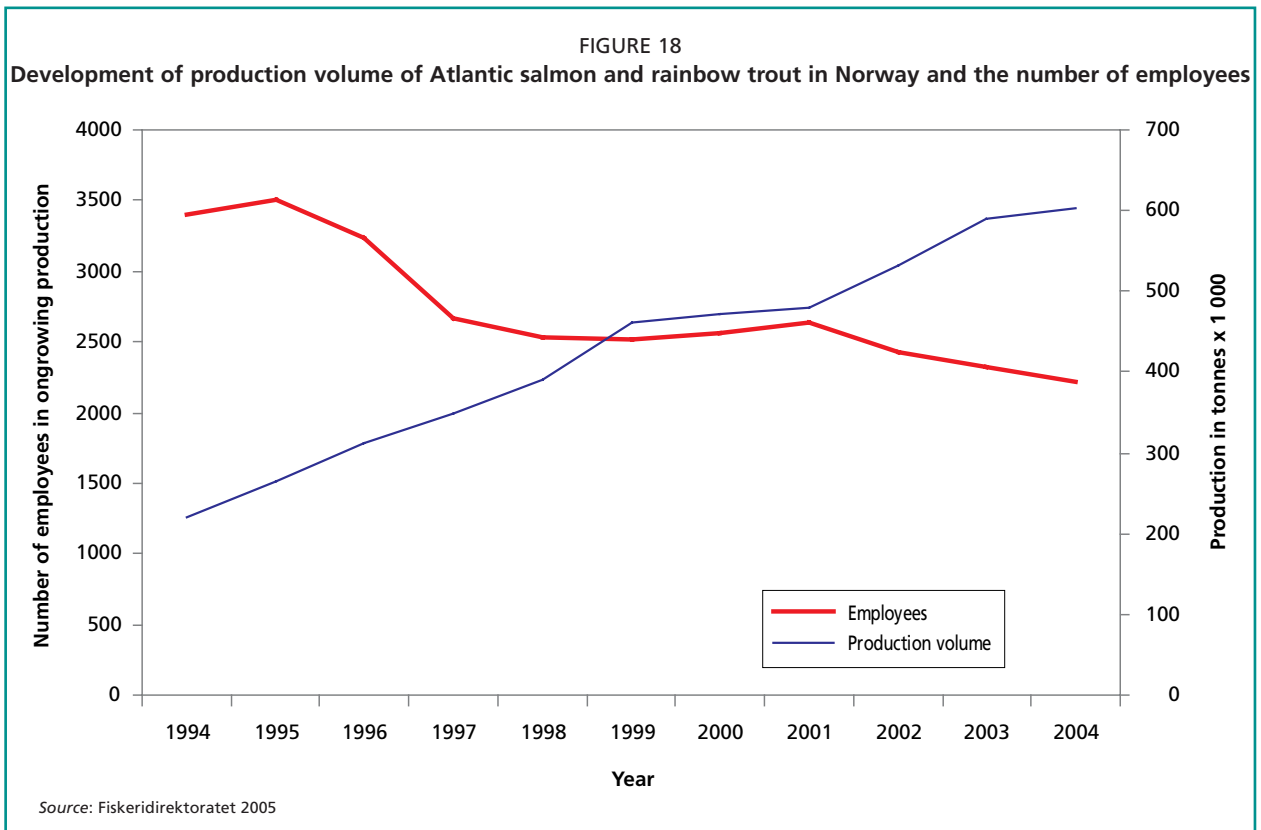
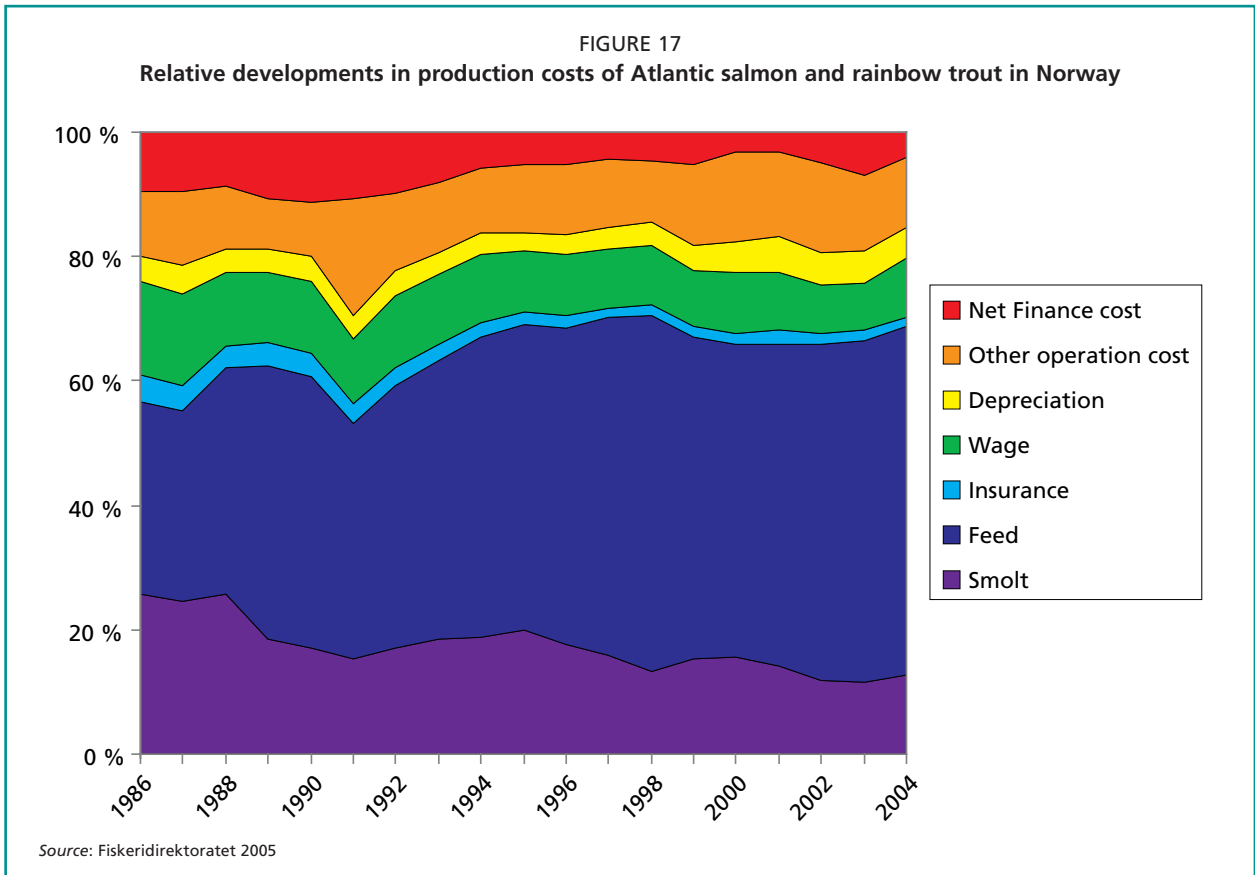
As seen in Figure 17 wages represent a decreasing share of total production costs, which as mentioned earlier, is the result of increasingly efficient production, where less people produce more fish (Figure 18). In 2004, 2 210 persons produced about 600 000 tonnes of fish in Norway. In other words, the average annual production per person was about 270 tonnes of fish!

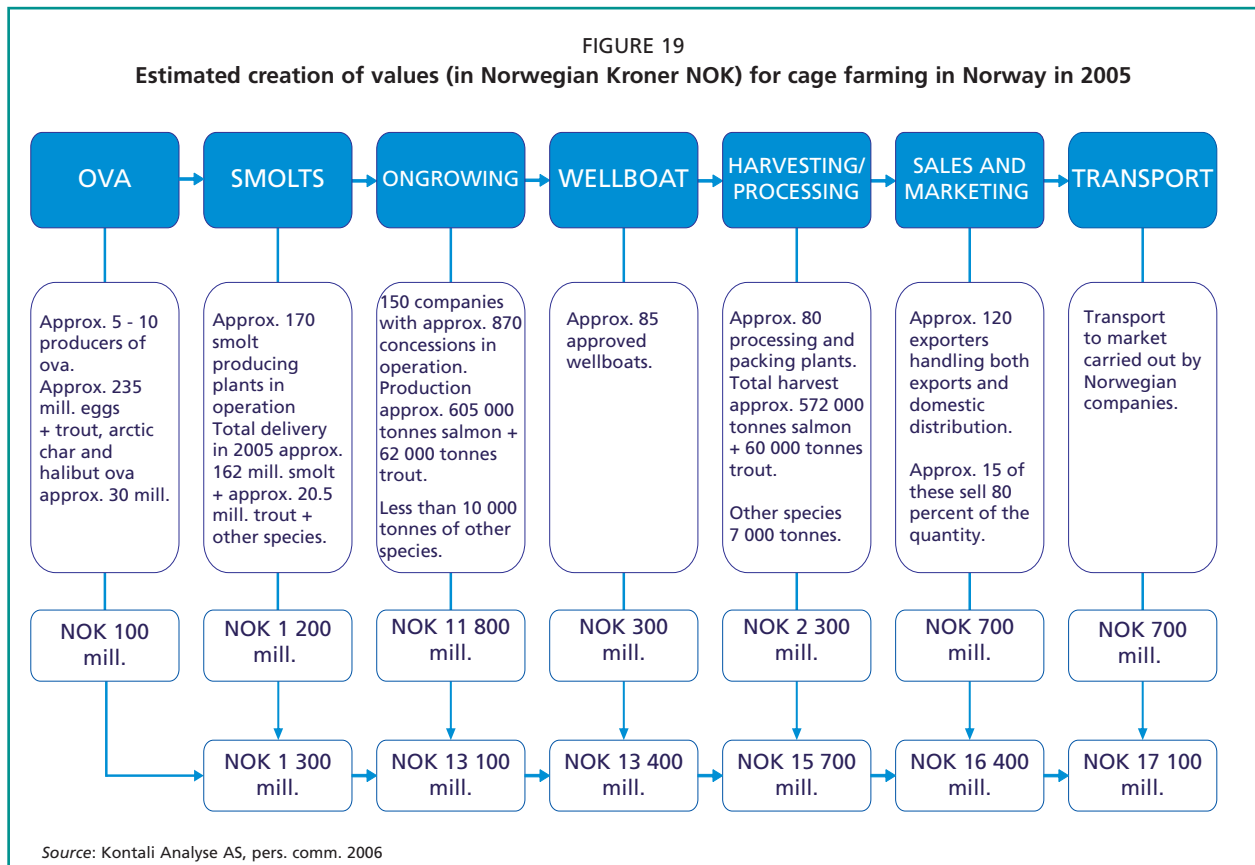
In addition to the people employed directly in the on-growing production in Norway, it is estimated that about 20 000 people are indirectly involved in the aquaculture industry as suppliers to the industry. In 2004 these people contributed to an added value of about €1.5 billion (Figure 19). The main contribution is derived from the on-growing units, but the slaughtering and processing industry also play important roles.

FIGURE 16
Development in production cost of Atlantic salmon and rainbow trout from 1986 to 2004 (in 2004 € / 1€ = 8 NOK)



Source: Fiskeridirektoratet, 2005





For Ireland and Scotland the great majority of fish is sold within the European Union market, to which they belong. Norway is not a member of the EU, and about 95 percent of fish cross the border to a foreign market.

Being the major producer of Atlantic salmon Norway has, over the last twenty years, experienced accusations of dumping from other salmon producing countries. Both the United States of America and the EU have claimed and continue to claim that Norway has been selling fish below production cost. The dumping cases can be argued to have had a negative impact on the development of a free salmon trade to the detriment of the interests of consumers. For the countries involved it has been difficult to develop long-term market development strategies with the intention of increasing the consumption of cage reared fish.

Environmental impact – escapes, pollution, ecological impacts

Healthy development of the fish farming industry not only requires fulfilling the needs of the farmed fish but also paying attention to the environment. Only a sustainable, environmentally sound aquaculture will gain social acceptance.

Ultimately, sustainability is also in the farmers' interest as healthy and clean waters are an essential prerequisite for first-rate fish products. Optimal results originate from good growth conditions for the fish and proper husbandry.

Even if there has been a significant decrease in the environmental impact from the cage culture industry in Europe, there are still some challenges: escapes, marine eutrophication, sea lice and access to sea areas.

Escapes

Every year fish escape from sea cages. This may be a result of incorrect use of the equipment, technical failure or external factors such as collisions, predators or propeller damages (Beveridge, 2004; Walker *et al.*, 2006). Loss of fish and damage to equipment not only represents an economical loss for the farmers, but also has negative environmental impacts.

How can the addition of more salmon to the rivers actually be harmful? The answer to this question may not be immediately obvious. Research on this problem is time consuming and the answers have not begun to emerge until recently. Escaped farmed salmon can affect wild salmon on several

levels, both ecologically and in terms of fitness and the sustainability of wild populations. Escaped fish mix with wild fish at sea as well as in rivers. They thus constitute a competitor to wild salmon for food and space and may spread parasites and disease. Escaped farmed salmon are also capable of breeding with wild stocks, thereby introducing novel genetic material to the wild population that can reduce the lifetime fitness of individuals, driving population numbers down (McGinnity *et al.*, 2003). Genetic changes may also result in changes in ecological and behavioural traits (Holm and Dalen, 2003).

Marine eutrophication

In areas with intensive aquaculture production the nitrogen and phosphorus load and accumulation of organic matter may be detrimental to the environment (Naylor *et al.*, 2000; Beveridge, 2004). Aquaculture production in Europe is mainly localized in rural areas with low population densities, and thus a low general nutrient load. In these regions there has been an increase in the aquaculture production. Even if the reduction in the feed conversion rate contributed significantly to decreasing impacts per unit fish production effect on the environment, the total nutrient load from the aquaculture industry has increased. As a result the European Commission has issued a number of directives in an effort to reduce impacts from the aquaculture industry. Council Directive 91/676/EEC27 aims to reduce water pollution caused or induced by nitrates from agricultural sources, including the spreading or discharge of livestock effluents. The Commission will study if the directive should be extended to include intensive fish farming (Commission of the European Communities, 2002). The newly issued Water Framework Directive is also likely to result in reductions in nutrient loadings to coastal water if fish farm wastes are identified as causing sites to fail to reach good ecological status.

Adverse impacts due to eutrophication of a location are reversible. Studies show that locations to which large quantities of organic material were added and which had highly anaerobic sediments can recover to an almost natural state after a rehabilitation period of between three and five years. The length of the rehabilitation period depends on local topographical conditions (Holm and Dalen, 2003).

Olsen *et al.* (2005) argue that nutrients should be regarded as resources rather than toxins for marine ecosystems where the aquaculture industry is located. It is also argued that it is acceptable

to use the mechanism of dilution to disperse waste products as long as they are free from toxic components. At a current speed of 15 cm/sec, the water at a site is exchanged about 100 times per day. An exchange rate of 2–3 times is typically needed to keep the levels of nutrients in the water column lower than the critical load. Farms located in dynamic sites will usually have volumetric inorganic nutrient loadings that are within the year to year variability of the natural background levels.

In Norway, a system has been developed for environmental monitoring of fish farms with regard to the accumulation of organic matter. The system is called MOM – a Norwegian abbreviation translated as Modeling – On-growing Fish Farm - Monitoring. The model includes a simulation and monitoring program. At locations where the utilization ratio is high, more frequent and more comprehensive studies have to be conducted. At lower utilization ratios the requirements of studies are less stringent. The new system for modeling and monitoring fish farms (MOM) has given the government and the industry a better basis for tailoring production and discharges to the carrying capacity of an individual location (Holm and Dalen, 2003).

Sea lice

The salmon lice (*Lepeophtheirus salmonis*) are ectoparasites that use salmonids as a host. Although they have always been present on wild salmonids in marine waters, the louse has gradually become a serious challenge to wild salmon stocks as the aquaculture industry has grown due to a multiplication of potential hosts on farmed fish and an overall increase in infection pressure.

Norwegian authorities require the maintenance of sustainable lice level with regard to salmon and sea trout stocks in individual fjord systems. Existing treatments for controlling the salmon lice can be roughly divided into biological methods, i.e. the use of wrasse (*Crenilabrus melops*, *Ctenolabrus rupestris*, *Centrolabrus exoletus*), and chemical treatment. Wrasse must be used continuously, while chemical treatment is used when the number of sea lice reaches a certain threshold. Regular monitoring of sea lice levels is therefore essential. In Norway fish farmers are obliged to regularly report the number of lice on each site and the information is made available through an internet site established by the industry itself (www.lusedata.no). In Scotland, integrated lice treatment methods are generally practiced by the salmon farming industry. Much of the salmon farming areas of

Scotland are now covered by Area Management Agreements, in which farms coordinate their intake of fish, fallowing and the use of medicines in order to minimize lice levels. Although there are few hard data, there is anecdotal evidence that wild salmon and sea trout numbers are recovering in such areas as a result.

Common to all pharmaceuticals intended to combat salmon lice is that they are toxic to a number of organisms, especially crustaceans, which are the subphylum that salmon lice belong to. However, the toxic effects of the substances are relatively local, in the sense that individuals located a distance from the fish farm are not exposed to toxic doses of the agents. The area of effect around a fish farm will vary with the type of substance and local environmental conditions, such as currents and aquatic chemistry.

Escaped salmon can contribute to an increase in lice exposure of the wild populations. Measures to reduce the escape of farmed salmon may therefore help to reduce the infection pressure on stocks of wild salmonids (Holm and Dalen, 2003; Walker *et al.*, 2006).

Copper impregnation of nets

Installations in the sea will always be subject to fouling by shellfish, algae, barnacles and hydroids (Corner *et al.*, 2007). Chemical impregnation is used to reduce fouling on nets but it also has other functions, such as making the net stiff, thereby helping it hold its shape in the water, it helps prevent UV radiation from weakening the net and it fills the gaps between net filaments, thereby reducing the area available to be fouled.

Leaching of copper from fish farm nets remains a cause for concern, Data on copper concentrations in water near fish farms and net cleaning facilities are difficult to find but copper concentrations of over 800 milligrams per kilogram of sediment have been found in sediments under fish farms in areas with low water exchange (Holm and Dalen, 2003; Beveridge, 2004). On-farm washing of copper anti-fouled nets is now prohibited in the UK and is carried out by licensed net manufacturers. There are as yet few viable, more environmentally friendly antifouling alternatives at present.

Access to suitable sea areas

Even if each cage culture production site does not produce a large footprint, there is a potential for conflicts of interest in coastal areas. The aquaculture industry is today well aware of the importance of

choosing sites that are optimal for raising fish. Therefore, large areas of the coastline are of no interest to the industry. Regulations require a minimum distance between sites, and a safety area around each production unit. In certain coastal areas there may be conflicts of interest between fisheries, navigation routes, harbours, conservation, recreation activities, the military, etc. In Norway, the Commission's Demonstration Programme on integrated coastal zone management has shown that the best response to such complex situations is an integrated territorial approach addressing the many different problems within an area, involving all stakeholders. Future aquaculture development should be based on Integrated Coastal Zone Strategies and Management Plans, that consider aquaculture in relation to other existing and potential future activities and that take into account their combined impact on the environment. (Commission of the European Communities, 2002)

Policies and legal frameworks

Aquaculture is a highly diverse industry involving a broad spectrum of species, systems and practices. It may create new economic niches, leading to increased employment, a more effective use of local resources, and opportunities for productive investments. The contribution of aquaculture to trade, both local and international, is also increasing (Commission of the European Communities, 2002). Most of the countries involved in aquaculture have developed strategies to promote the development of the aquaculture sector, as for example "The Code of Good Practice for Scottish Finfish Aquaculture" (Scottish Finfish Aquaculture Working Group, 2006).

In Europe the European Parliament is the most important supranational decision maker. The Commission recognized the importance of aquaculture in the same frame as the reform of the Common Fisheries Policy and the necessity to develop a strategy for the sustainable development of this sector (Commission of the European Communities, 2002).

The aquaculture industry in Europe is organized in a common federation, the Federation of European Aquaculture Producers (FEAP), established in 1968. The FEAP is currently composed of 31 National Aquaculture Producer Associations from 22 European countries. Its main role is to provide a forum for the member associations to promote the establishment of common policies on issues related to production and to the commercialization

of aquaculture species in Europe. The decisions or Resolutions are communicated to the appropriate authorities, at a European or national level. The FEAP has also developed a Code of Conduct. The Code is not mandatory but addresses those areas that the Federation considers to be of prime concern. Additionally, the role of the Code is to motivate and assist the development of the principles of best practices (FEAP, 2000).

There are several non-governmental organizations (NGOs) addressing the impact of aquaculture on the environment, related to pollution, food safety and the influence on wild fish populations. The NGOs vary in size, the level of seriousness and activity in the different countries.

THE WAY FORWARD

In an earlier section, this paper described the exponential growth in European cage culture farming since the introduction of modern cages in the early 1970s. During its short history, the industry has experienced a number of drawbacks related to e.g. health, economy and trade conflicts. Despite the many problems, the volume of production has increased. The development of biological skills and technology has resulted in the ability to deliver products throughout the year of a uniform quality and at a low price. Even if the cage culture industry has matured, however, there remain major challenges to be addressed.

The growth in the sector will lead to more competition for resources such as feed and space. Also, consumers have recently experienced several food scandals in Europe. Combined with a higher standard of living, this has resulted in a growing awareness of food safety issues. Consumers have also become more interested in ethical issues related to food production. Hence, the quality of food, production methods and the documentation of these are increasingly important.

The struggle for resources

A Norwegian study concluded that the four most important contributions to the development of the marine sector are competent labour, long-term availability of capital, area (space) and infrastructure. Being a decentralized industrial activity cage mariculture competes with other sectors for labour, capital and the development of infrastructure. It is important for the industry to contribute to the development of small rural communities, making them attractive for people to live. An economically sustainable industry attracts venture capital for

further development. In periods of economic depression, however, this has been a problem not least for the development of an industry based on new species.

Europe has the best intentions to take care of small remote communities. The main challenge has been to find industries that may have an interest in being located in decentralized areas. The aquaculture industry is such an activity, and it can be argued that there should be a political acceptance to use economic resources to establish the necessary infrastructure.

An increased occupancy of coastal areas has been more difficult to accept politically. The growing importance of well-performing sites excludes large areas. For areas with acceptable conditions there may often be conflicts with other interests of an environmental, economic, recreational or military nature. Further growth of cage aquaculture may be achieved by increasing production per site, by making more sites available or by moving production offshore.

The European Commission concluded that fish cages should be moved further from the coast, and that more research and development of offshore cage technology must be promoted to this end. Experiences from outside the aquaculture sector, e.g. in oil platform construction, may be exploited by the aquaculture equipment sector, allowing for savings in the development costs of new technologies (Commission of the European Communities, 2002). However, it is important to keep in mind that moving production offshore will significantly increase the need for investment. Increased investment must be compensated by an increase in efficiency in order not to incur higher production costs. Offshore cage culture production may also increase the risk of escapes, the need for a more complex infrastructure and may no longer be such a significant contributor to rural development.

Feed resources

Fishmeal and fish oils are essential constituents of fish feeds. In the last decade, the amount of fishmeal used to produce feed for aquaculture has increased considerably, but the annual world fishmeal production has remained static (Commission of the European Communities, 2002). Over the past 20 years fishmeal and fish oil production have ranged between 6.2 and 7.4 million tonnes and 1.0 and 1.7 million tonnes respectively, except during the more severe El Niño years. This picture of overall

stability of pelagic feed fish supply is against a background of changing use due to market forces. Fishmeal is used for both aquatic and land animals, but as aquaculture demand has increased, this has been met by diverting supplies away from land animals, with use now increasingly being confined to starter and breeder diets for poultry and pigs. Fish oil, previously used largely for hardening margarines/bakery products, is now mainly used in aquaculture. Small amounts now also go to human nutraceuticals; use for hardening has almost been phased out (Shepherd *et al.*, 2005).

Since fishmeal and fish oils are limited resources, it is extremely important to continue research efforts to find substitute protein sources in fish feed formulation (Commission of the European Communities, 2002).

One possible source of considerable quantities of fish raw materials is to be found among what is already fished, but for various reasons is thrown back into the sea. Today's fisheries are largely based on selective fishing where only certain species are fished. In addition to the desired species, large amounts of fish are caught as by-catch. Some by-catch is landed and recorded, while the rest often is dumped into the sea. The global discarding of fish has been estimated to be 27 million tonnes. Millions of tonnes of protein are thus dumped annually into the ocean. In Norway, the authorities have adopted a zero discard policy stating that it is illegal for commercial fishermen to throw back any of the catch to the sea. This is an incentive to fish more selectively by avoiding fishing during certain periods and areas where high by-catches can be expected. The prohibition is also a driving force behind the development of equipment that reduces by-catches. EU member states have a law that is almost the exact opposite of Norway's. EU member states have introduced a prohibition against the landing of fish where a "Total Allowable Catch" has been reached. In many cases, this leads to fishing vessels being forced to dump fish (Holm and Dalen, 2003).

Another possible solution to the challenge of reduced availability of marine resources is the production of feed based on raw materials from lower trophic levels. Current research explores the development of technology for harvesting zooplankton, such as *Calanus finmarchicus* and krill (Crustacea: Malacostraca). These animals are an important source of marine fats, are found in huge quantities in the North Atlantic and are an important food source for Antarctic fish, seabird

and cetacean populations. Again, however, such fisheries would have to be carefully managed to avoid unacceptable changes to ecosystem structure and function.

Commercially synthesized protein has been available for use in fish feed. For example, Pronin® is a high quality single cell protein source. It is derived from fermentation using natural gas as an energy and carbon source. Its high protein content (about 70 percent) combined with its nutritional and functional properties make Pronin® well suited as a protein ingredient in feedstuffs for fish and animals. Its use as a protein source for sea and freshwater farmed salmon has been extensively tested and documented. According to the producer up to 33 percent of the protein could be incorporated in the feed for salmon in seawater (<http://www.norferm.no>).

Plant-based raw materials have also been suggested as an alternative feed resource. Their use in aquaculture feed has increased and a 30 percent plant-based content is becoming common. With the right combination of plant and marine oil, a similar content of healthy omega-3 fatty acids is almost as achievable as with the use of 100 percent marine oil. The major fish feed manufacturers are consequently replacing an increasing share of fish oil in the feed with plant oils (Holm and Dalen, 2003).

Trends regarding the current dietary use of fishmeal and fish oil substitutions vary from country to country, depending upon feed ingredient availability and transportation/importation and processing costs, and the intended market where the salmon is to be sold. In Norway up to 55 percent and 50 percent of dietary protein and lipid, respectively, are of non-marine origin. The most important ingredients are soybean protein concentrate, soybean meal, corn gluten meal, wheat gluten, rapeseed oil, and the crystalline amino acids lysine and/or methionine. In the United Kingdom of Great Britain and Northern Ireland up to 45 percent of dietary proteins are replaced, whereas only a limited amount of fish oil is replaced (up to 10 percent) due to market demands. The protein sources used are maize gluten, soybean products (mostly extracted), wheat gluten, rapeseed oil, and crystalline amino acids (Tacon, 2005).

Consumer demand

In January 2004, a paper in the journal *Science* reported that the PCB levels in farmed salmon were six times higher than those in wild salmon (Hites *et al.*, 2004). Although the recorded PCB levels

were well within international food standards, the study received widespread coverage in the media (Chatterton, 2004).

The consumers reacted to the news by refusing to buy and eat salmon. The negative media stories failed to mention that the Science study was funded by the Pew Charitable Trusts – an organization which frequently raises critical issues related to aquaculture (Chatterton, 2004).

This story stresses two very important issues related to the market. Firstly, consumers do care about the quality, safety and production methods of the food. Secondly, there are interest groups that follow the aquaculture industry closely, and question the sustainability of farming fish. This means that the industry has to continuously focus on food safety and production methods, and be able to document a sustainable production of healthy food.

Food safety

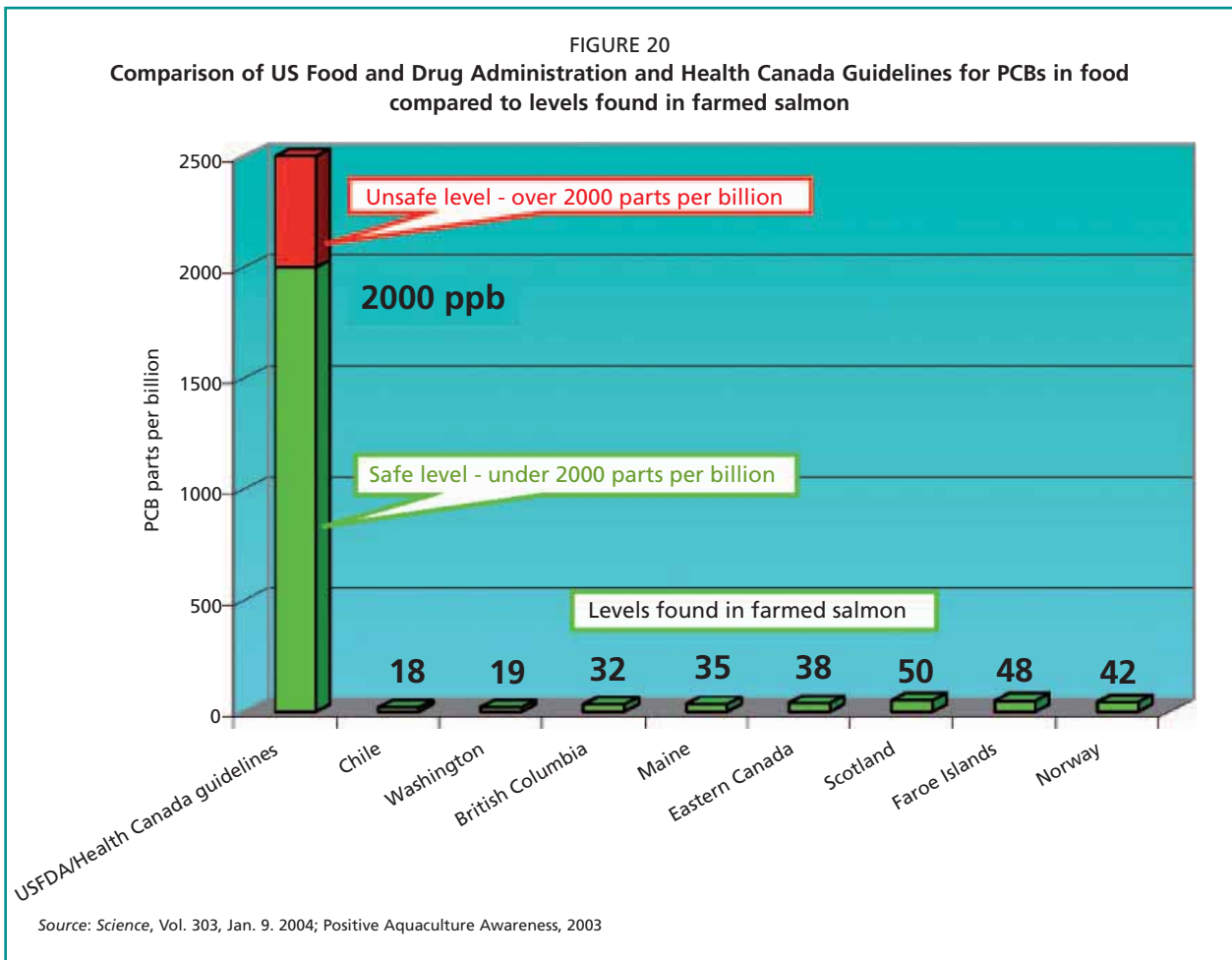
The prime goal of European fish farmers is to produce nutritious products of the highest quality.

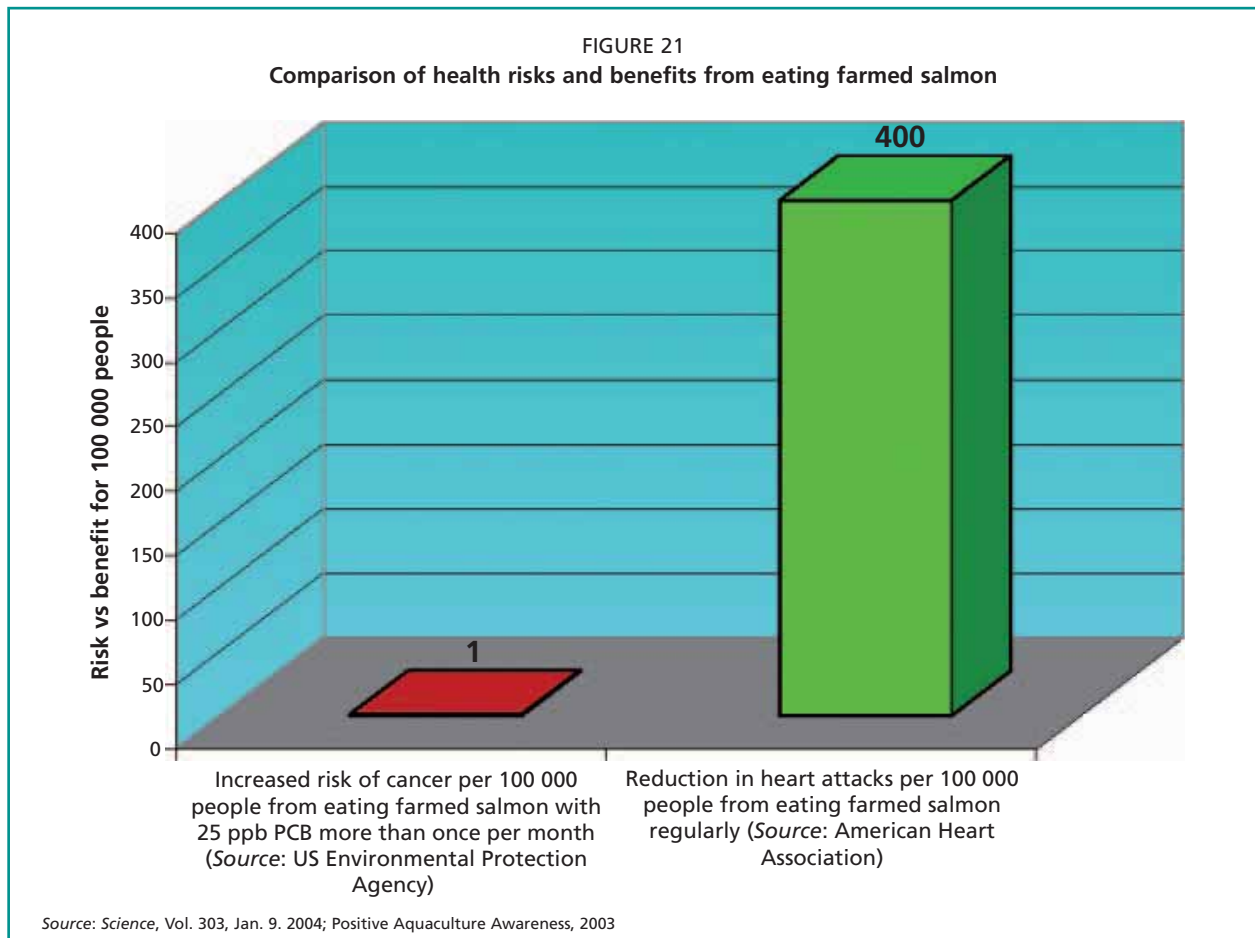
Aquaculture is a controlled process that allows the farmer to grow and harvest good quality fish, with the following characteristics:

- A healthy fish that has been reared in the best possible conditions
- A protein source of high dietetic quality
- A nutritious source of food
- Available continuously throughout the year
- A product that is consistently fresh
- Good taste and flavour

The FEAP Code of Conduct urges that fish farmers contribute actively towards the balanced and sustainable development of aquaculture and that they make their best efforts to assure the transparent development of the activity to the benefit of the consumer (FEAP, 2000).

The salmon farming industry is subjected to a host of allegations related to environmental sustainability and human health and nutrition. One of the most serious charges is that farmed salmon contain dangerous levels of PCBs (polychlorinated biphenyls), an industrial compound that is widespread in the environment (see also above).





Trace amounts of PCBs may be found in farmed salmon for the same reason they can occur in wild salmon, beef, chicken and many other foods: they accumulate in small amounts in the food chain. Farmed salmon are usually fed fishmeal derived from sustainable anchovy and mackerel fisheries. Anchovies and mackerel may ingest trace amounts of PCBs in their natural environment, which can then find their way into farmed salmon via the feed. However, the level measured is far below what is considered to be a health risk (Figure 20) (Positive Aquaculture Awareness, 2003).

Conscious consumers may be very demanding towards producers of food. If cage culture producers are able to produce first class and healthy products, the focus on food quality can become very positive for the industry. European citizens face an increasing problem related to malnutrition and excess weight. The positive health effects of eating fish are many, among the most important being their contribution to the prevention of heart diseases (Figure 21).

The industry is facing a major challenge in attempting to successfully rebut allegations related to the safety of eating fish. This can only be done

by providing sound scientific documentation of the positive health effects of consuming fish and by giving consumers the facts.

Traceability

Traceability will probably also be of great importance for food safety in the future. The TraceFish organization believes that with increasing information demands from consumers, it is no longer practical to physically transmit all the relevant data along with the product. A more sensible approach is to mark each package with a unique identifier, and then transmit or extract all the relevant information electronically (see <http://www.tracefish.org>).

Animal welfare

There has been increasing concern about the welfare of fish in general, but especially in aquaculture in recent years as a result of research suggesting that fish, like higher vertebrates, experience pain and suffering (Commission of the European Communities, 2004).

In order to improve welfare of farmed fish protocols and fish husbandry standards, e.g. for fish density and pre-slaughter handling, are to be defined. A set of rapid, inexpensive and non-invasive screening methods may be used as welfare indicators. Welfare is, however, individually based whereas the types of indicators being developed may only provide indicators of average conditions in e.g. sea cages.

Norway and the United Kingdom of Great Britain and Northern Ireland have established research groups dedicated to fish welfare issues and have provided welfare solutions by integrating information from various scientific disciplines such as behaviour, physiology and fish health (Damsgård, 2005).

Socio-economics and marketing

Sea-cage aquaculture is widely spread across Europe and often in rural or peripheral areas, where alternative employment opportunities are chronically lacking. The fundamental issue in the development of the sector is the maintenance of competitiveness, productivity and durability of the aquaculture sector (Commission of the European Communities, 2002).

In general, the total demand for any commodity is expected to grow with population growth, since the latter determines the overall size of the market. It is believed that there will be a decline in demand for high-priced aquatic products, although such demand may shift to lower priced fish products. Future demand for fish will basically be determined by the number of consumers, their eating habits and disposable incomes, as well as by the price of fish products. Many of the changes that will occur in the level and structure of fish consumption will reflect more complex demographic and attitudinal variables. Ageing populations, changing gender roles, smaller household sizes, dietary concerns, food safety issues and ethical concerns are influential factors that exist throughout Europe (FAO, 2001).

Competition between producers of different protein sources is continual. In order to strengthen its position the aquaculture industry has to strengthen the marketing of its products. There has been a generic marketing campaign for salmon in Europe, financed by Norway as a part of the so-called Salmon Agreement. In future, such types of campaign may also be used to stimulate the consumption of aquaculture-reared fish and hence increase the market share of cultivated marine products.

European producers will continue to experience increased competition from fish reared outside Europe. Species such as tilapia (*Oreochromis* spp.) may be produced at a very low price and cannot readily be cultured in cages in Europe. Increased competition should not be met by restrictive international trade practices but by focusing on quality and increased productivity without, of course, bringing it into conflict with obligations related to sustainable production.

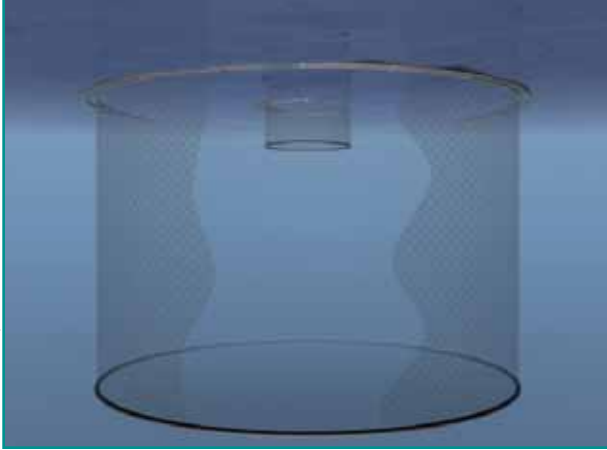
There has been a significant increase in the productivity of the industry (Figure 16), mainly due to improved fish health and growing production volumes. As seen in Figure 17 feed remains a major production cost and there is a major focus on reducing the economical feed conversion rate (ECR) (kilogram feed used per kilogram fish slaughtered). The industry has been successful in reducing the biological feed conversion rate (BFR) (kilogram feed used per kilogram fish produced). A further reduction in the ECR requires lower mortality rates. For the salmon industry, the average mortality in Norwegian sea cages is about 20 percent. Improved fish health management is essential to further reduce mortality rates.

Efficient health management requires measures to reduce the need for therapeutic treatments by avoiding disease outbreaks. This can be achieved by vaccines, where they exist. Strong biosecurity measures are important to avoid entry of pathogens and can be achieved by isolating farms and establishing control systems to all human entries, including veterinarians, clients and service providers. Fallowing is used to help disinfect sites between harvesting and stocking. Good health management should also include daily management targeted to reduce stress (manipulation, density, feeding regimes, etc). Stress is a very important factor, because it can combine with an appropriate pathogen to give rise to a disease outbreak.

There has been a significant increase in productivity per employee (Figure 18), reducing the share of wages in the total production. Nonetheless, because of the high salaries in Europe it is of major importance to further increase productivity per employee in order to compete with producer countries outside Europe. This may be achieved, for example, by increasing total production and production per site and per production unit.

New technology has made it possible to increase the size of each cage (Beveridge, 2004). Figure 22 shows a traditional cage used a few years ago, with a circumference of 40 metres and a depth of

FIGURE 13
Example of the development of using bigger units. Increase from circumference of 40 m and depth of 4 m to circumference of 157 m and depth of 30 m resulting in volumes of 510 m³ and 59 000 m³, respectively



COURTESY OF AQUALINE 2006

4 metres giving a total volume of 510 m³. Today some sites are using cages with a circumference of 157 metres and a depth of 30 metres, giving a total volume of 59 000 m³. Such cages can enclose biomasses of 1 100 tonnes. The advantages of using bigger units are among other things fewer units to handle and the possibility to invest more resources in monitoring fish and environmental variables. Positive effects on growth have also been reported. However, there are also considerations with regard to routine fish handling (grading, harvesting, disease treatment) and escapes.

There is an increased focus on the effect of the environment on the growth of fish, in particular in relation to dissolved oxygen levels within cages. Equipment has been developed that can add oxygen to sea cages (Beveridge, 2004).

However, more importantly the quality of the site is of vital importance. A good site has the necessary currents to maintain dissolved oxygen at acceptable levels and to provide the necessary dilution of organic matter preventing accumulation under the production units. The topography of the

sea bottom and the depth under the cages are also of great significance in optimizing production.

Many of the best and most suitable sites for aquaculture production in Europe already have aquaculture projects, meaning that there is high competition for the remaining suitable areas. This may result in a move towards more exposed sites offshore. This is likely to prove a great technical and logistical challenge; if solved, however, there is significant potential to increase production. It is reported that Ireland for example could increase its production ten-fold to 150 000 tonnes, generating more than 4500 extra jobs (Ryan, 2004).

CONCLUSIONS

Most food production systems have a negative impact on the environment. Thirty years after the first steps were taken by the pioneers of cage culture production in Europe, the industry has matured. Cage culture production of salmonids is increasingly becoming an environmentally sustainable way of producing high quality food. However, as the consumer becomes even more aware of sustainability and food safety issues, the industry has to continue to improve production methods. Growing demands for fish products also challenge the industry to raise the production without increasing the need for marine raw material. The industry also has to compete with other interests in the use of coastal marine areas.

There is a great interest to further develop this industry, providing essential profitable activities to sustain communities living at the margins of Europe. Development must not be at the expense of product quality, however, or of the environment. It must also be sufficiently efficient that it can compete with other food producers, both within and outside Europe.

ACKNOWLEDGEMENTS

Knut Hjelt, Alexandra Neyts (Norway) and Trevor Telfer (Scotland) have contributed significantly with facts, advice and improvements of the manuscript.

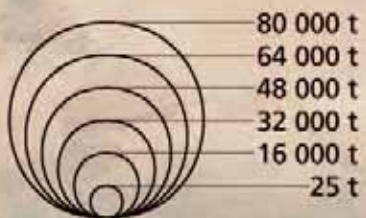
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Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.

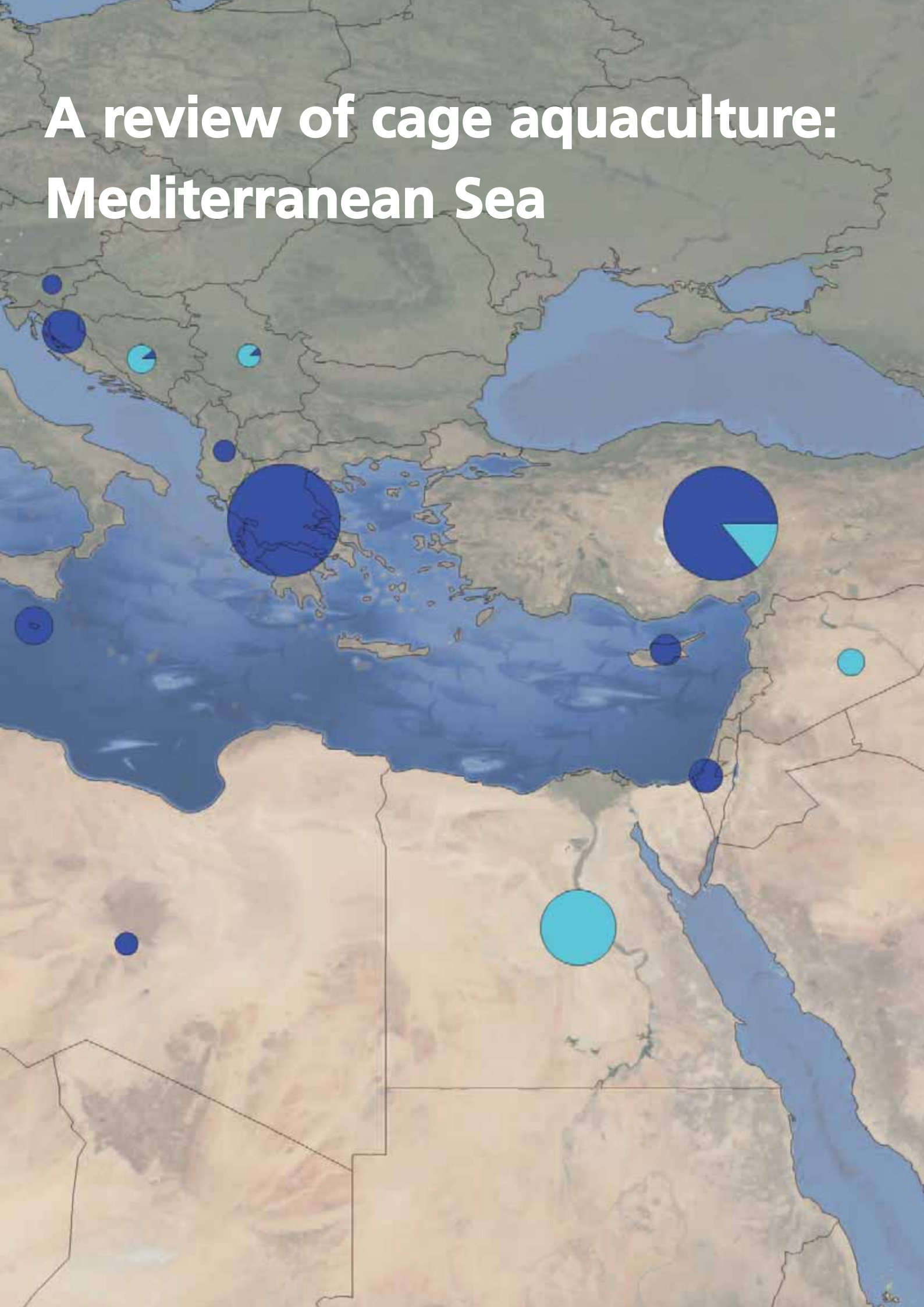


 freshwater

 marine and brackishwater

Map background image *Blue Marble: Next generation* courtesy of NASA's Earth Observatory

A review of cage aquaculture: Mediterranean Sea





A review of cage aquaculture: Mediterranean Sea

Francesco Cardia¹ and Alessandro Lovatelli²

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A review of cage aquaculture: Mediterranean Sea. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 156–187. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

The Mediterranean is an intercontinental sea surrounded by Europe to the north, the Near East to the east and Africa to the south. The following 19 sea-facing nations are taken into account in this review: Spain, France, Monaco, Italy, Malta, Slovenia, Croatia, Serbia and Montenegro, Albania, Greece, Turkey, Cyprus, Syrian Arab Republic, Lebanon, Israel, Egypt, Libyan Arab Jamahiriya, Tunisia, Algeria and Morocco.

Marine cage culture in the Mediterranean area expanded rapidly in the mid 1980s, mainly in Spain and Greece, when an increasing number of farms started producing the European seabass (*Dicentrarchus labrax*) and the gilthead seabream (*Sparus aurata*). Freshwater cage culture, although marginally practiced in several countries for rearing the rainbow trout (*Oncorhynchus mykiss*) (e.g. Italy, Turkey, Cyprus), is mostly developed in Egypt, along the Nile delta branches, where from the 1990s onwards the Nile tilapia (*Oreochromis niloticus*) and silver carp (*Hypophthalmichthys molitrix*) culture expanded. In 2003 the production was 32 000 tonnes (SIPAM, 2006).

The European seabass and the gilthead seabream are currently the most widely caged fish species in the Mediterranean. Production has progressively increased over the last ten years from 34 700 tonnes in 1995 to 137 000 tonnes in 2004, with an average annual growth rate of 17 percent. In 2004, the cage production of these two species accounted for approximately 85 percent of the total production.

The controlled reproduction of the European seabass was first achieved in France and Italy in the mid 1970s. In the early 1980s fingerlings of the gilthead seabream were successfully produced. In 2002, the total European seabass and gilthead seabream fingerling production in the Mediterranean was estimated to be in the region of 650 million (Stirling University, 2005). The most common market size range for both species is between 300–400 g. In cage farming this weight is achieved in 12–18 months for the gilthead seabream and 15–20 months for the European seabass, when the production cycle commences in the spring and fingerlings of 2–4 g are used.

The rapid expansion of cage culture in the 1990s, mainly in Greece and Turkey, brought about a market crisis in the late 1990s. From 2000 to 2002 the market prices dropped to their minimum values forcing several companies out of business.

All Mediterranean countries are producing European seabass and gilthead seabream in cages. The leading countries, sorted by production volume in 2004, were Greece, Turkey, Spain, Italy, Croatia and France. Altogether these countries accounted for more than 90 percent of the total cage production of these two species (SIPAM, 2006; FAO, 2006).

Commercial activities on fattening captive Atlantic bluefin tuna (*Thunnus thynnus thynnus*) in large floating cages have been reported since the mid 1980s (Spain), but a significant expansion of this farming practice in the region started only in the mid 1990s. Atlantic bluefin tuna fattening should be viewed as a capture-based aquaculture practice considering that the fish are caught by purse seiners and stocked in cages usually from 3

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to 10 months. Harvested fish are mainly for the Japanese market. Currently the countries where this practice is carried out include Spain, Italy, Malta, Croatia, Greece, Turkey, Cyprus, the Libyan Arab Jamahiriya and Tunisia. The total recorded official production in the Mediterranean in 2003 was approximately 19 000 tonnes (FAO/GFCM/ICCAT, 2005).

Among the more important newly cultured marine finfish species are the sharp-snout seabream (*Diplodus puntazzo*) and the meagre (*Argyrosomus regius*). Several commercial trials have also been carried out with a variety of sparid species, such as the common dentex (*Dentex dentex*), common seabream (*Pagrus pagrus*), common two-banded seabream (*Diplodus vulgaris*) and some sparid hybrids.

Several constraints are currently limiting the expansion and development of marine species diversification in cages. Among others: specific tolerability to caged conditions of the candidate species, the development of suitable commercial feeds and a positive market response to the newly introduced farmed species.

The Mediterranean shoreline offers a wide choice of farming sites, both sheltered and exposed. For this reason, several cage models are used from very simple wooden frames and barrels structures to very modern and technologically sophisticated facilities, such as steel platforms or submersible steel cages with integrated feeding systems. However, the most widely used floating cages are the High Density Polyethylene (HDPE) ones as a result of their adaptability to different sea conditions.

This paper provides available information on the number of farms, reared species, cage production (quantity and values), trends of the sector in the past decade, and other issues on cage culture around the Mediterranean.

BACKGROUND AND AIM OF THE STUDY

This background technical document on Mediterranean cage aquaculture was prepared and presented at the “Second International Symposium on Cage Culture in Asia” held in Hangzhou, People’s Republic of China, from 3 to 8 July 2006. The aim of this report is to provide a general overview on the Mediterranean cage aquaculture sector by comparing available data from different sources. Worth mentioning is that official national aquaculture production statistics frequently do not distinguish between different fish farming methods. The main information sources used for this exercise have been the following:

- **SIPAM** (Information System for the Promotion of Aquaculture in the Mediterranean under the General Fisheries Commission for the Mediterranean - GFCM)

An ad hoc questionnaire was prepared and sent to all the SIPAM National Coordinators. Statistics regarding cage production have also been collected from the SIPAM Web site (www.faosipam.org);

- **NASO** (National Aquaculture Sector Overview)

These reports, most of them published on the FAO Web site, provide a general overview of the national aquaculture sectors and are available for all the countries considered in this paper;

- **FAO FishStat+**

Official FAO statistics have been used as main reference for values and national productions. In

the case of any discrepancy with data reported in the SIPAM Web site, the FishStat+ source has been considered valid;

- **ICCAT** (International Commission for the Conservation of Atlantic Tunas)

Atlantic bluefin tuna data has been displayed in accordance with those in the “Report of the third meeting of the ad hoc GFCM/ICCAT Working Group on Sustainable Bluefin Tuna Farming/Fattening Practice in the Mediterranean” and in the ICCAT website (www.iccat.es). When there was a lack of information, the NASOs and the SIPAM Web site were consulted;

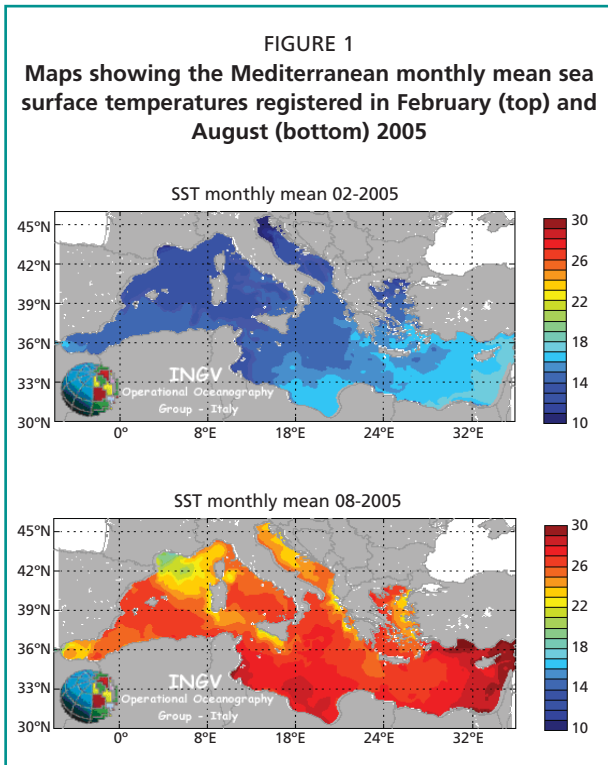
- **Personal contacts**

Some inputs have been provided through direct and personal contacts with BIOMAR and SKRETTING personnel and members of various producer/farmer associations.

THE MEDITERRANEAN SEA

The Mediterranean is an intercontinental sea enclosed between Europe to the north, Africa to the south, and the Near East to the east. It covers an area of approximately 2 512 000 square kilometres, including the Marmara Sea but not the Black Sea. It has an average depth of 1 500 m and a maximum depth of 5 150 m off the southern coast of Greece.

The Mediterranean is almost a completely closed water basin where the continuous inflow of surface water from the Atlantic Ocean is the sea’s major source of water. It is estimated that the entire water volume of the Mediterranean takes over a century



to be completely renewed through the 300 m deep Strait of Gibraltar.

The limited water inflow and high evaporation makes the Mediterranean saltier than the Atlantic Ocean. Sea surface temperatures vary from a minimum average of 10 °C in winter in the Adriatic Sea to a maximum of 28-30 °C around the south eastern shores. Within this temperature range consolidated finfish farming species such as salmon and turbot, cannot be farmed (Figure 1).

Towards the south east, the Suez Channel connects the Mediterranean with the Red Sea. Many living organisms, not endemic to the Mediterranean ecosystem, have invaded the Eastern Mediterranean basin since the opening of the channel.

A low concentration of phosphates and nitrates limits the availability of food thus the total quantity of marine life in the Mediterranean. In this context, over-exploitation of the marine resources is a serious problem.

On the other hand, however, some areas, such as the Corso-Ligurian Basin and the Gulf of Lion, are characterized by higher levels of primary productivity due to the up-welling of nutrients. The total length of the Mediterranean coasts is approximately 45 000 kilometres. It is highly populated region with numerous and varied activities, including tourism, which strongly compete for sea space with the aquaculture industry.

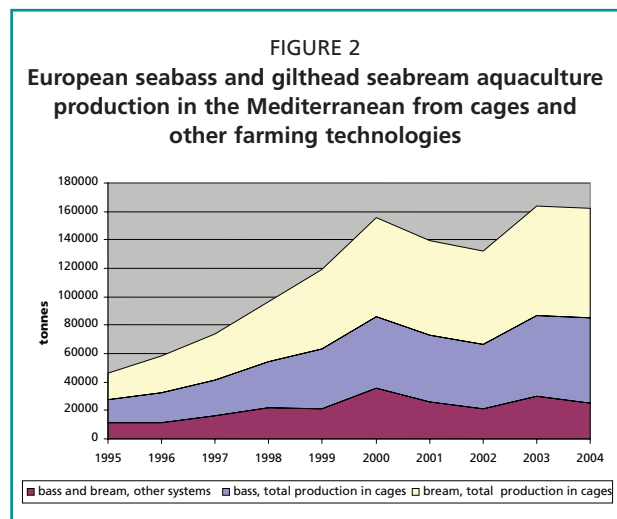
The states facing the Mediterranean Sea are: Europe: Spain, France, Monaco, Italy, Malta, Slovenia, Croatia, Serbia and Montenegro, Albania, Greece, Turkey, and Cyprus; Asia: Syrian Arab Republic, Lebanon, Israel; and Africa: Egypt, Libyan Arab Jamahiriya, Tunisia, Algeria and Morocco. From a political point of view Spain, France, Italy, Malta Slovenia, Cyprus and Greece are member of the European Community (EU) and hence, although independent countries, they are required to act upon EU decisions and directives regulating the aquaculture industry.

REARED SPECIES

European seabass and gilthead seabream

The most commonly farmed marine species in Mediterranean Sea are the European seabass (*Dicentrarchus labrax*) and the gilthead seabream (*Sparus aurata*). These species are produced using a large variety of aquaculture facilities and techniques. They are traditionally cultured in lagoons, where wild fingerlings are collected during the seasonal migration from the sea into lagoons, and then reared in closed basins using extensive or semi-extensive methods (e.g. *vallicoltura* in the Northern Adriatic lagoons). The European seabass and the gilthead seabream are now intensively reared in ponds, tanks, raceways and cages. In 2004, the Mediterranean production of these two species was 88 500 tonnes for the gilthead seabream and 73 800 tonnes for the European seabass (FAO/FIDI, 2006) with Greece as the leading producer with a combined production of approximately 63 000 tonnes for the two species.

Currently, most of the Mediterranean production comes from cages. This quantity has progressively



increased over the last ten years from 34 700 in 1995 to 137 000 tonnes in 2004, with an average annual growth of 17 percent (Figure 2). In 2004, the combined Mediterranean cage production of these two species accounted for approximately 85 percent of their total production.

Fry production

Both the European seabass and the gilthead seabream are euryhaline species. The controlled reproduction of the European seabass was achieved in the mid 1970s and in the early 1980s for the gilthead seabream.

In the case of the gilthead seabream the natural spawning season is from December to March and from January to February for the European seabass. Following hatching the larval stages are provided with live feed (rotifers and *Artemia*), an eventually weaned with extruded feed. Bigger hatcheries are equipped with photoperiod units where broodstock are kept in batches and the temperature and light duration are artificially controlled simulating the environmental conditions which are typical of the natural spawning period.

Different fingerling sizes are used to start a cage production cycle; commonly an average weight of 2-4 g (120-160 day old fish) is used. Fingerlings represent approximately 15–20 percent of the production costs. In 2002, around 290 million European seabass and 355 million gilthead seabream fingerlings were produced (Table 1).

The average price of a two grams fingerling varies depending on the producing country; an average estimate would be approximately of €0.22 for the gilthead seabream and €0.20 for the European seabass. In Turkey the cost of fingerlings is approximately 20 percent less compared to the average.

Production cycle

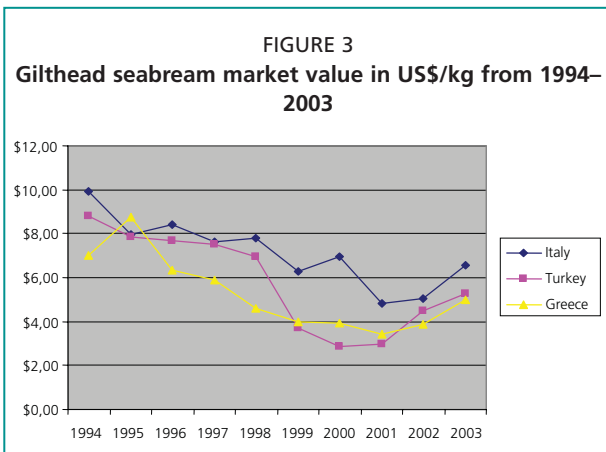
Cage production usually starts in spring and market size fish of 300-400 g are produced in about 14–16 months for gilthead seabream and 16-18 months for European seabass. In the case of pre-ongrown fish (mainly gilthead seabream of 40-60 g), the goal is to harvest market size fish (300 g) before the end of the year, i.e. reducing the production cycle, making the product available in December, and avoiding the risks related to winter stocking.

Nets with different mesh sizes are used during the whole production cycle: knotless, square or hexagonal shaped mesh, from 4 mm up to 25 mm or more depending on the size of the fish. If not treated with antifouling, nets are usually changed several times in each cycle (increasing mesh size), and the frequency varies depending on environmental conditions and the mesh size of the nets. Net washing machines to clean the cages are widely used. The fish are usually harvested when they reach an average weight of 300–400 g. The whole production is almost entirely sold fresh or iced in polystyrene boxes.

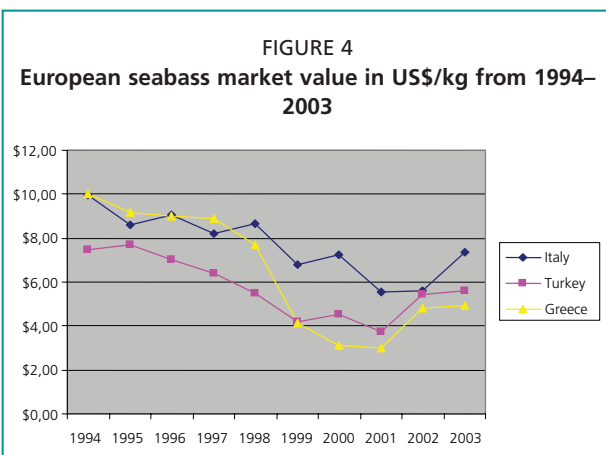
TABLE 1
European seabass and gilthead seabream fingerling production, trade and apparent use in selected Mediterranean countries

Year 2002	European seabass				Gilthead seabream			
	Production (million)	Imports (million)	Export (million)	Apparent use (million)	Production (million)	Imports (million)	Export (million)	Apparent use (million)
Greece	129.0	8.6	1.2	136.4	171.0	11.4	1.6	180.8
Turkey	53.7	0.0	6.0	47.7	30.8	0.0	0.0	30.8
Italy	50.0	0.0	20.0	30.0	45.0	0.0	7.0	38.0
Spain	8.0	4.7	0.0	12.7	53.0	0.0	7.2	45.8
France	23.0	0.0	10.8	12.2	20.0	0.0	15.0	5.0
Portugal	7.0	0.2	2.0	5.2	12.0	1.8	2.0	11.8
Croatia	5.0	3.3	0.0	8.3	0.4	3.8	0.0	4.2
Cyprus	4.6	0.0	2.6	2.0	15.2	0.0	9.9	5.3
Egypt	7.2	n.a.	n.a.	n.a.	7.2	n.a.	n.a.	n.a.
Tunisia	4.1	n.a.	n.a.	n.a.	4.0	n.a.	n.a.	n.a.
Total Production	291.6				358.6			

Source: Stirling University, 2005; SIPAM, 2006



Source: FAO/FIDI, 2006



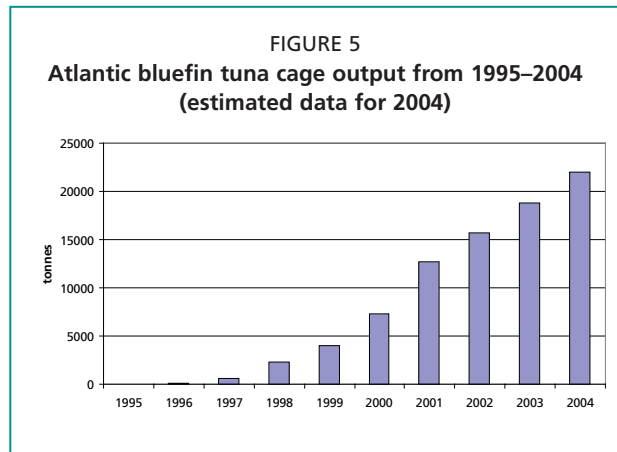
Source: FAO/FIDI, 2006

Market

Italy is the largest and most developed market; in order to satisfy the estimated consumption of more than 66 000 tonnes (Stirling University, 2004) in 2002, large amounts of fish were imported from all major Mediterranean producers (including Greece, Turkey and Spain).

The rapid and uncontrolled increase in bass and bream production registered throughout the 1990s brought about a severe market crisis. In 2000–2002 the market prices dropped to minimum values (Figures 2 and 3). This crisis was particularly felt by companies which had a high production cost (e.g. small Italian offshore cage farms and poorly performing land-based farms) and by new farms whose business plans were made with a higher value per kilogramme prevision. As a consequence of such events several producers went bankrupt.

Product availability and market prices are not stable throughout the year. Their fluctuation is related to several factors, such as the season (during and immediately after summer the cage farms reach their maximum load and there is a tendency to reduce the stocked biomass in autumn) or market demand.



Source: FAO, 2006; ICCAT, 2006

Atlantic bluefin tuna

Farming of the Atlantic bluefin tuna (BFT) is a capture-based aquaculture practice based entirely on the use of wild-caught “seed” material. This aquaculture practice is expanding and is still considered to be a highly profitable investment. The total official production registered in 2003 was approximately 19 000 tonnes and in 2004 the production estimate is 22 000 tonnes³ (Figure 5).

Schools of tuna are caught by purse seiners during April to July. The fish destined for farming are then transferred to the cages which are towed using tugboats to the fattening site. The diameter of the offshore cages varies from 30 to 90 metres and the volume can reach up to 230 000 m³. The input period is from May to August and the initial input size can vary from a few kilograms (e.g. Croatia stocks small tuna specimens of approximately 4–20 kg in size) to large adults of 300–400 kg (Table 2). The farming season can vary and normally has a duration of less than one year with the exception of Croatia as the farmers prefer to stock small tuna which foresees a fattening period of up to two years.

In order to increase the weight and fat content of the farmed fish, the tuna are fed with bait fish, stored frozen and defrosted prior to the distribution. Low value fish, such as mackerel, sardine, herring, squids and other small pelagic fish are used to feed tuna. The daily feeding ratio can reach up to 7–10 percent of live biomass in the summer months. The farms usually stock several hundreds tonnes of live tuna and therefore their daily consumption of bait fish is large. Tuna feeding is one of the issues that concern

³ The 2004 data are not complete for all the producing countries, only the production of Spain, Croatia, Cyprus and Tunisia is currently available for this year (SIPAM). The amount of 22 000 tonnes has been estimated taking into account the 2003 production data of the other BFT producing countries.

TABLE 2
Duration of the Atlantic bluefin tuna fattening/growing season (cells shaded in grey)

Country	Farming season	J	F	M	A	M	J	J	A	S	O	N	D
Croatia	04-20 months					»							
Cyprus	05-08 months					»							
Greece	07 months								»				
Italy	03-06 months					»	»						
Libya	05-06 months						»						
Malta	04-07 months						»						
Spain	06-09 months						»	»					
Turkey	04-09 months						»						

Symbols »: start of farming/fattening season.
Source: FAO/GFCM/ICCAT, 2005

primarily the environmental sustainability of the practice.

The harvest period is mainly concentrated during autumn/winter months, when the wild caught tuna often reaches its minimum and the selling price is higher (Table 3).

The Atlantic bluefin tuna production is almost entirely shipped to the Japanese market and, a very small amount, to the USA. Fish are killed, one by one, while they are still in the cages, and then shipped fresh and iced, gilled and gutted or dressed, by air. Tuna production is also sold in situ, on the cage, to ships that deliver the product by sea to the market. Fish are finally sold in the Japanese fish market auctions where prices can be substantially variable, depending on the type (e.g. fresh, frozen) and the quality of the product, in terms of fat contents, meat colour and appearance.

New species

Research and trials on “new species” are continuously carried out to satisfy the need of production and market differentiation driven by the apparent saturation of the European seabass and gilthead seabream markets. Several steps must

be achieved in order to close a profitable production cycle of a new species of potential interest to the consumers: i.e. broodstock management, controlled reproduction, larval culture and weaning, feed formulation, market receptivity, etc. Once such issues have been solved, the adaptability of the new species to cage farming needs to be considered and adequately dealt with.

Sharpsnout seabream (*Diplodus puntazzo*) is one of the most popular “new” species in cage culture. This sparid species is commonly produced in some of the large hatcheries and fed on a bass and bream diet. Farming is carried out in Greece, Italy, Turkey, Cyprus and several other countries, but always in small quantities compared to seabass and seabream. High stocking densities seem to be the cause of recurrent parasitic infections in caged conditions. In Greece outbreaks of *Enteromyxum leei* and consequent mortalities of cage reared fish has driven producers to reduce their production.

Other varieties of sparids, such as the common dentex (*Dentex dentex*), common seabream (*Pagrus pagrus*) and some sparid hybrids are also reared but currently only on a trial basis in order to test cage productivity and market response. An

TABLE 3
Duration of the Atlantic bluefin tuna harvesting season (cells shaded in grey)

Country	Harvesting season	J	F	M	A	M	J	J	A	S	O	N	D
Croatia	05 months									⇒	Ⓢ		
Cyprus	02-03 months										⇒	Ⓢ	
Italy	07 months							⇒		Ⓢ			Ⓢ
Malta	03 months									⇒	Ⓢ		
Spain	04-05 months								⇒			Ⓢ	Ⓢ
Turkey	06 months											⇒	Ⓢ

Symbols ⇒: start of harvesting Ⓢ: main harvesting months
Source: FAO/GFCM/ICCAT, 2005

interesting species with high potential is the meagre, *Argyrosomus regius*. In few years the production of this species has increased considerably, in particular in France but also to some extent in Italy, Spain and Morocco. Existing commercial hatcheries are in a position to reproduce massive quantities of this species and the response to cage rearing has given excellent results. Furthermore, meagre can be fed the same feed used for the European seabass and gilthead seabream; it also has a relatively high Specific Growth Rate as it can grow over a kilogram in one year. No significant pathological outbreaks have been registered even when farmed at high stocking densities.

The major constraint is still represented by the market which currently demands traditionally farmed species and remains rather suspicious of new farmed species.

MEDITERRANEAN CAGE AQUACULTURE General production overview

Mediterranean cage culture expanded significantly in the early 1980s following the salmon cage culture success and the introduction and adaptation of farming technologies and know-how from Norway and the United Kingdom (Scotland). A boost to this industry came with the success in the controlled reproduction of the European seabass (*Dicentrarchus labrax*) and the gilthead seabream (*Sparus aurata*) which resulted in a massive production and availability of fry. Atlantic bluefin tuna (BFT) farming/fattening commenced in the mid 1980s in the Andalusia Province of Spain. In the late 1990s the sector expanded dramatically reaching an estimated production of approximately 18 000 tonnes in 2003 with a number of Mediterranean countries engaged in the sector.

Landings from Mediterranean cage farms have expanded over the last decade, increasing from approximately 37 300 tonnes in 1995 to just under 187 000 tonnes in 2003 (Figure 6). The share of cage fish production, as a percentage of the entire Mediterranean aquaculture production (estimated at about 1.44 million tonnes in 2003), rose from 4.2 percent in 1995 to almost 13 percent in 2003 (Figure 7). During the last decade, marine finfish cage culture gained a predominant position in the sector. The production trend clearly demonstrates the success and spreading of this technology in the Mediterranean Sea (Figure 8). It may be noted that production rose from an estimated 35 000 tonnes in 1995 to 182 000 tonnes in 2004 with an average annual growth rate of 25 percent increasing the

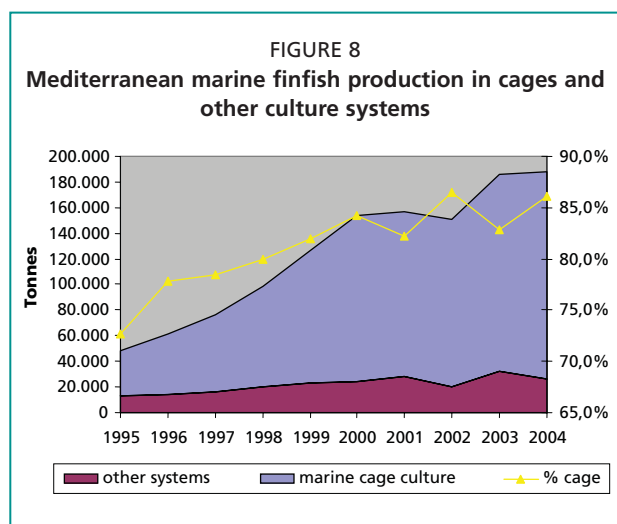
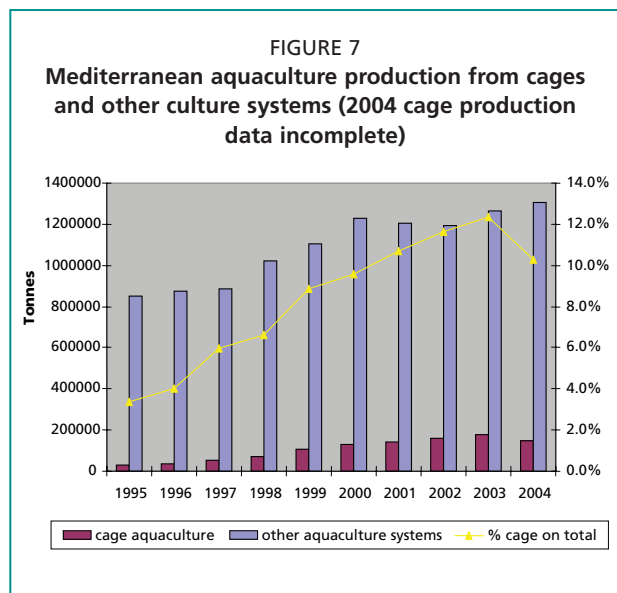
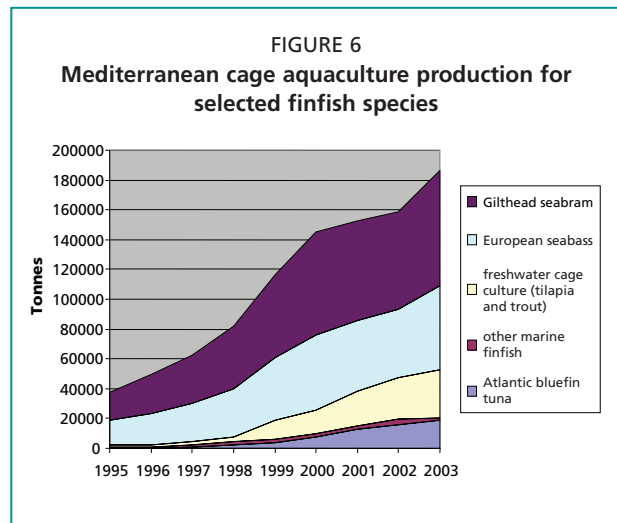


TABLE 4
Freshwater aquaculture production in 2004 (in tonnes) – species production by countries, share on total freshwater aquaculture

	Egypt	Cyprus	Italy	Serbia and Montenegro	Syrian Arab Republic	TOTAL
Nile tilapia and silver carp	32 062 ^a	--	--	--	--	32 062
Common carp		--	--	400	1 080	1 480
Rainbow trout		11	50	40	--	101
Total freshwater cage production in 2004						33 643
Total Mediterranean freshwater production in 2004						272 166
% of cage production on total						12,4%

^a Egypt production quantity data for 2004 not available, here reported is the 2003 data (Sources: FAO/NASO, 2006; FAO/FIDI, 2006).

share on total marine finfish production from 71 percent in 1996 to 86 percent in 2004.

Freshwater cage culture has developed mainly in Egypt, where the Nile tilapia (*Oreochromis niloticus*) and silver carp (*Hypophthalmichthys molitrix*) are produced in cages situated along the Nile delta branches. The cage production of these species steadily increased in the last decade from 1 977 tonnes in 1995 up to 32 062 tonnes in 2003.

Rainbow trout (*Oncorhynchus mykiss*) and common carp (*Cyprinus carpio*) are also marginally reared in freshwater cages in ponds or dams reservoirs in Italy, Turkey, Cyprus and in the Syrian Arab Republic. Table 4 provides data on freshwater cage production and its share compared to the total freshwater aquaculture production.

NATIONAL CAGE PRODUCTION OVERVIEW

Spain

Cage culture is widely practiced along the Mediterranean coast of Spain and around the Canary Islands. Due to the lack of suitably sheltered sites,

cage aquaculture is mainly developed offshore. Production volumes have increased almost ten fold during the period 1995-2004. Cage aquaculture began in the mid 1980s using the European seabass and gilthead seabream as the two main farmed species. Atlantic bluefin tuna fattening began in 1985 along the coast of the Andalusia Province and in 1997 in the province of Murcia. Spain was the first country in the Mediterranean to start farming this large pelagic species (FAO/GFCM/ICCAT, 2005). Cage culture is currently practiced in all the Mediterranean provinces and in the Canary Islands (Atlantic Ocean). Table 5 provides Spanish cage production by province for 2003.

Following Egypt, Spain is the second country in the Mediterranean in terms of aquaculture production levels. In 2004 the entire aquaculture output was estimated to be over 363 000 tonnes with 93 percent of this volume deriving from the marine environment; this amount includes 294 000 tonnes of blue mussel (*Mytilus edulis*) mainly produced along the Galician coast.

TABLE 5
Cage aquaculture in Spain in 2004 - Number of farms and quantities sorted by province

Administrative province	Number of seabream and seabass farms	Gilthead seabream (tonnes)	European seabass (tonnes)	Number of tuna farms	Atlantic bluefin tuna (tonnes)	Total production (tonnes)
Andalusía	8	1 218	1 015	2	13	2 248
Baleares	1	52	3			55
Canarias	25	1 319	690			2 009
Cataluña	7	0	417	1	52	470
Levante (Valencia)	14	3 913	375			4 289
Murcia	7	1 561	750	11	3 620.8	5 933
TOTAL	62	8 063	3 253	14	3 687	15 004

Source: FAO/NASO, 2006; ICCAT, 2006; Skretting, pers. comm.; Biomar, pers. comm.

TABLE 6
Cage production in Spain from 1995–2004 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Atlantic bluefin tuna	n.a.	77	173	1 879	3 347	3 682	4 447	4 751	3 687	6 423
European seabass	361	583	434	856	1 147	1 757	1 646	2 625	3 253	3 329
Gilthead seabream	1 624	2 418	2 569	3 533	5 000	8 042	4 728	7 607	8 063	9 669
Grand Total	1 986	3 079	3 179	6 268	9 494	13 481	10 821	14 983	15 003	19 421
Total aquaculture production	223 965	231 633	239 136	315 477	321 145	312 171	312 647	322 714	313 288	363 181
% cage	0.9%	1.3%	1.3%	2.0%	3.0%	4.3%	3.5%	4.6%	4.8%	5.3%

Source: SIPAM, 2006; FAO/GFCM/ICCAT, 2005; FAO/FIDI, 2006

TABLE 7
Total aquaculture and cage values in Spain from 1995–2004

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total aquaculture	250 015	250 131	247 943	307 611	344 357	377 800	392 112	374 696	361 547	431 990
Total cage	19 280	27 404	25 994	61 422	91 675	119 379	107 418	128 988	118 391	167 993
% cage	7.7%	11.0%	10.5%	20.0%	26.6%	31.6%	27.4%	34.4%	32.7%	38.9%

Source: SIPAM, 2006; FAO/FIDI, 2006

In 2004, the cage production quota, which progressively increased in the last decade, was in the region of 5.3 percent compared to the entire output of the Spanish aquaculture industry (Table 6). It is worth noting, however, that the quantity of seabass and seabream farmed in cages in the same year represented around 70 percent of the national production for these two species.

The economic contribution of cage aquaculture is reported in Table 7. In the past decade, the value of finfish produced in cages increased steadily and gained a considerable share of the industry. This is mostly thanks to the Atlantic bluefin tuna industry that reached the quota of 22 percent of the total aquaculture sector value in 2004.

Spain is the leading country in the Mediterranean with regard to Atlantic bluefin tuna aquaculture providing a reported total production of 6 423 tonnes in 2004. There are currently 14 farms of which 11 are located off the coast of Murcia. This powerful pelagic species is mainly farmed in large High Density Polyethylene (HDPE) cages. Most of the production is sold on the Japanese market (>96 percent), approximately 60 percent as frozen and the balance fresh. On the other hand, the production of seabass and seabream is mainly absorbed by the national market⁴ with a small

⁴ From 1998–2002 imports of seabass increased almost ten fold, from 1 175 to 11 058 tonnes with a negative export balance (2 980 tonnes in 2002); in the case of seabream 9 466 and 866 tonnes were imported and exported, respectively, in 2002.

amount exported mainly to Portugal, which absorbs approximately 70 percent of the total export. The remainder is exported to Italy and France.

Spanish hatcheries provide the total national demand of seabream fry, but only 60 percent of seabass fry. In 2002, the estimated total production of seabream fry amounted to 53 million, of which 7.2 million was exported. In the same year, 8 million seabass fry were produced and an additional 4.7 million imported⁵.

Spanish finfish netcage farms are mainly located in semi-offshore and offshore sites. The type of cages used for farming seabass and seabream are mainly circular floating cages made with HDPE pipes; their diameter varies from 15 to 25 metres. Some field trials, using cages with diameters of up to 50 metres, are currently in progress. These cages can stock up to 800 000 fingerlings/cage.

Also in use are four iron floating platforms produced by Marina System Iberica; these are large structures with an overall diameter of around 60 metres in diameter and fitted with 8–9 cages. These are moored near Tarragona (1 unit), Cadiz (1 unit) and the remaining two units are moored off the coast of Barcelona.

France

France is one of the leading European countries in terms of aquaculture production (approximately

⁵ In this paper, fry production data refer to the whole production, i.e. including fry used in land-based fish farms.

TABLE 8
Cage farms in France – location of production sites and most commonly reared species

Company name	Location	Species farmed
Cannes Aquaculture	Provence	seabass, seabream, meagre
Poissons du soleil	Provence	seabass and seabream
Marée Phocéenne	Provence	seabass and seabream
Lou Loubas	Provence	seabass and seabream
Provence Aquaculture	Provence	seabass and seabream
Cachalot SCEA	Provence	seabass and seabream
Aquapeche	Provence	seabass
Cannes Aquaculture	Corsica Island	seabass, seabream and meagre
Gloria Maris	Corsica Island	seabass and meagre
Campomoro	Corsica Island	seabass
Santa Manza	Corsica Island	seabass

Source: Biomar, pers. comm.

244 000 tonnes in 2004). The sector is dominated by the Pacific cupped oyster (*Crassostea gigas*) with approximately 114 000 tonnes, the blue mussel (*Mytilus edulis*) with 55 600 tonnes and the freshwater rainbow trout (*Oncorhynchus mykiss*) with approximately 35 300 tonnes. Cage aquaculture still represents a niche sector in the industry since it has developed at a slower pace compared to other neighbouring Mediterranean countries.

Cage aquaculture began in France in 1988, with bass and bream farms mainly located along the western Mediterranean coast and Corsica. The main farm sites in the Mediterranean are located in Provence, which provides 65 percent of the country's production. The balance is produced in Corsica (Table 8).

The top farmed species are the European seabass and the gilthead seabream. In 2004, production was 2 290 tonnes, representing 47 percent of the total

production (4 817 tonnes) of these two species (Table 9).

It is worth noting the increasing production of the meagre (*Argyrosomus regius*) in numerous Mediterranean farms. In addition to the Mediterranean farms, two cage operations are also located in the Atlantic coast farming rainbow trout. The share of cage production, as a percentage of the total aquaculture production, has fluctuated from 0.8 percent in 1995 to 1.2 percent in 2004.

The share of cage production value compared to the total aquaculture value remained rather stable in the last decade. A negative trend (apart from the 1997 value which excludes trout production) in 2001 and 2002, as a result of the market price drop for the European seabass and gilthead seabream, resulted in a lower income (Table 10).

The majority of the production is sold on the national market. France is also a net exporter of finfish fingerlings. In 2002, approximately

TABLE 9
Cage production in France from 1995–2004 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Meagre	0	0	0	0	30	101	200	275	345	385
European seabass	1 440	1 224	1 135	1 300	1 625	1 100	950	1 080	1 190	1 190
Gilthead seabream	470	500	597	750	600	1 040	1 340	980	1 140	1 300
Rainbow trout	424	375	n.a.	200	279	160	114	190	150	150
Total caged	2 334	2 099	1 732	2 250	2 534	2 401	2 604	2 525	2 825	3 025
Total aquaculture production	280 786	285 526	287 243	267 850	264 857	266 802	251 655	252 008	239 851	243 907
% cage	0.8%	0.7%	0.6%	0.8%	1.0%	0.9%	1.0%	1.0%	1.2%	1.2%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 10
Total aquaculture and cage values in France from 1995–2004

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total aquaculture	663 176	600 133	626 884	560 326	487 921	425 054	453 763	501 051	580 424	655 123
Total cage	21 036	18 698	15 246	17 000	17 573	14 223	13 233	13 286	17 988	24 237
% cage	3.2%	3.1%	2.4%	3.0%	3.6%	3.3%	2.9%	2.7%	3.1%	3.7%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 11
Number of cage farms in Italy in 2004 sorted by environment and by province

Administrative Regions	Number of marine cage farms	Number of brackish water cage farms	Number of freshwater cage farms
Calabria	9	-	-
Campania	2	-	-
Friuli-Venezia Giulia	1	-	-
Lazio	3	-	-
Liguria	3	-	-
Lombardia	-	-	3
Puglia	6	-	-
Sardegna	8	4	1
Sicilia	15	-	-
Toscana	2	1	-
Veneto	1	1	-
Total	50	6	4

Source: Italian Ministry of Agriculture, 2005

43 million seabass and seabream fry were produced of which approximately 26 million were exported. Cage farms in France are commonly located in sheltered sites and are mainly of the square floating type (Jet Float units or wooden framed cages). A few circular HDPE cages are also in use.

Italy

The first commercial experience in intensive cage farming in Italy started in the late 1980s early 1990s. In 1989 the Sicily Fish Farm company began its offshore cage culture activity off the coast of Sciacca, southern Sicily. A year later a new company (Spezzina Acquacoltura) commenced a marine farm in the vicinity of the port of Genoa. In 1991 Aqua Azzurra, a company that was operating a fish hatchery and an inland rearing facility began a cage operation off the coast of Pachino, southern Sicily.

In 2004, an aquaculture survey conducted by the Italian authorities showed that 50 marine cage farming companies⁶ had been registered along with

six companies with cages in brackish water lagoons⁷ and four operating freshwater cages (Table 11).

The Italian marine cage farms are located mainly in the southern province (e.g. Campania, Puglia, Calabria, Sicilia and Sardegna) where approximately 80 percent of the registered companies are operational. This has been the outcome of the distribution criteria of the subsidy programme (both national and EU) which mainly allocates investment funds to depressed areas of the country.

There are four freshwater cage farms producing rainbow trout. Three farms are located in Lombardia using old and abandoned marble quarries and one in Sardinia with cages positioned in an artificial dam. Their combined annual production is currently estimated to be slightly below 50 tonnes.

The most importantly farmed species are the European seabass and gilthead seabream. More recently a number of Atlantic bluefin tuna fattening farms have been established mainly in southern Italy. Occasionally, some of these farms culture a

⁶ The survey includes companies that have a license but not currently in operation.

⁷ These companies have small cages or small net enclosures where wild fingerlings caught in the "lavorieri" are stocked, some of them carry on a pre-growing phase before release fish in the lagoon where are extensively reared.

TABLE 12

Cage production quantities in Italy from 1995–2003 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003
Atlantic bluefin tuna	0	0	0	0	0	0	800	1 800	1 700
Gilthead seabream	330	550	700	1 350	1 500	1 850	2 600	2 850	2 950
European seabass	850	1 150	1 200	1 600	1 650	1 600	1 800	2 000	2 100
Total caged	1 180	1 700	1 900	2 950	3 150	3 450	5 200	6 650	6 750
Total aquaculture production	214 725	189 373	195 719	208 625	210 368	216 525	219 069	185 762	193 362
% cage	0.5%	0.9%	1.0%	1.4%	1.5%	1.6%	2.4%	3.6%	3.5%

Source: FAO/GFCM/ICCAT, 2005; API, pers. comm., FAO/FIDI, 2006

TABLE 13

Total aquaculture and cage values in Italy from 1995–2003 (Atlantic bluefin tuna values not available)

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total aquaculture (excl. tuna)	419 288	394 937	397 984	449 366	365 101	455 774	415 318	337 107	519 419
Total cage (excl. tuna)	9 941	15 066	15 229	24 322	20 618	24 510	22 563	25 708	34 796
% cage	2.4%	3.8%	3.8%	5.4%	5.6%	5.4%	5.4%	7.6%	6.7%

Source: FAO/GFCM/ICCAT, 2005; API, pers. comm., FAO/FIDI, 2006

variety of “new species” (mainly Sparids), but their production is estimated to be less than 1 percent of the entire caged production.

In 2003 (2004 data not currently available) the total seabass and seabream cage production was estimated to be approximately 5 050 tonnes (Associazione Produttori Italiani - API, pers. comm.). In addition to this production a further 1 700 tonnes of Atlantic bluefin tuna were also produced (Table 12). The 2003 cage production (6 750 tonnes) represented 3.5 percent of the total Italian aquaculture production⁸ which is dominated by mussel, rainbow trout and clams. Cage output share has nevertheless steadily increased since 1995 although a number of factors are limiting its growth (mainly coastal use conflicts and limited availability of sheltered sites). From 1995 to 2003 the share of the cage production on total aquaculture value (excl. BFT) increased from 2.4 to 6.7 percent (Table 13).

In Italy two major hatcheries are in operation (Valle Ca' Zuliani in Veneto and Panittica Pugliese in Apulia) which produce approximately 65 percent of the national fingerling supply. In 2002 almost 95 million juveniles were produced, out of which 50 million were European seabass. Currently, fingerling production exceeds the national demand.

⁸ Seabass and seabream are not exclusively farmed in cages, but also in inland facilities. The total official national production of these species is 18 000 tonnes in 2003 and the caged quota can be estimated at approximately 28 percent.

Approximately 5 and 20 million gilthead seabream and European seabass were exported in 2002, respectively.

The Italian shoreline has limited sheltered sites and this represents a constraint to the expansion of the sector. Furthermore, tourism (a major economic sector) often competes for the use of sea and shore resources. Approximately 60 percent of marine cage farms are currently located in semi-offshore or offshore sites entailing higher production costs and the adoption of different technological solutions in terms of cage models and mooring systems. Compared to other countries in the Mediterranean, Italy operates a large number of cages specifically designed for offshore sites (i.e. REFA Tension Legs, Sadco Shelf steel cage, Farmocean and several submersible models).

Seabass and seabream production is almost entirely channelled to the national market. Italy is the most important market in Europe and the Mediterranean for these two finfish species.

In 2004, the ICCAT list of authorized Atlantic bluefin tuna farms reports six Italian companies. They are all located in southern Italy, i.e. three in Sicily, two in Calabria and one in Campania. In 2003, the harvest of Atlantic bluefin tuna was estimated to be approximately 1 700 tonnes.

Malta

In Malta aquaculture production is carried out entirely in marine cages. Cage aquaculture started

TABLE 14
Active cage farms in Malta, reared species and estimated production capacity in 2003

Company	Species	Production capacity (tonnes)
Pisciculture marine de Malte	seabass and seabream	1 100
Fish and Fish Ltd	seabass and seabream	300
Malta Fish Farming Ltd	seabass and seabream	150
ADJ Tuna Ltd (Sikka l-badja)	Atlantic bluefin tuna	1 500
Melita Tuna Ltd	Atlantic bluefin tuna	1 500
Malta Tuna trading Ltd	Atlantic bluefin tuna	1 200
ADJ Tuna Ltd (Comino Channel)	Atlantic bluefin tuna	800

Source: FAO/NASO, 2006

TABLE 15
Cage production in Malta from 1995–2004 sorted by species

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Atlantic bluefin tuna	0	0	0	0	0	330	1 108	1 855	3 550	n.a.
European seabass	500	396	300	80	80	234	206	53	98	131
Gilthead seabream	800	1 156	1 500	1 870	1 922	1 512	1 091	1 122	835	782
Grand Total	1 300	1 552	1 800	1 950	2 002	2 076	2 405	3 030	4 483	913

Source: SIPAM, 2006; FAO/NASO, 2006

in the early 1990s initially farming the European seabass and gilthead seabream. Only recently a number of Maltese companies shifted their interest towards the more profitable fattening of Atlantic bluefin tuna⁹. Six companies were operational in 2003, three producing seabass and seabream and three engaged in the tuna fattening. The estimated national production capacity is 1 550 tonnes for seabass/seabream and 5 000 tonnes for Atlantic bluefin tuna (Table 14).

Seabass and seabream production reached a maximum output in 1999 with approximately 2 000 tonnes produced. Subsequently, the negative production trend of these two species has been compensated by the growth of the tuna industry. In 2003 the total cage production was estimated to be 4 500 tonnes. The 2003 production values reported by the Ministry of Rural Affairs for seabass and seabream was approximately US\$7 million and US\$65 million for Atlantic bluefin tuna.

There are no commercial hatcheries on the island and all fingerlings are imported. In 2004, approximately 1.9 million European seabass and gilthead seabream fingerlings were supplied by France, but also from Spain and Italy. The market size European seabass and gilthead seabream are

mainly exported to Italy while the BFT is almost entirely for the Japanese market and exported either chilled or frozen.

Cage aquaculture employs around 300 persons. In the seabass and seabream sector the work force consists of approximately 70 full-time employees. Tuna farming employs 130 full-time workers and 100 part-time workers.

Malta uses floating cages of different models, materials and dimensions. Seabass and seabream on-growing is carried out in Dunlop rubber and Corelsa HDPE cages with a diameter of 18 to 22 metres. Any pre-growing is carried out in square cages 5x5 metres (Jet-float) or in Floatex HDPE cages. The BFT industry uses larger HDPE cages with a diameter of 50-60 metres (in 2003 two 90 metre diameter cages were installed) usually moored in deep waters (60 metres) fitted with 30 metres deep.

Slovenia

The Slovenia shoreline is approximately 30 kilometres long and there are only two marine cage companies located in the Bay of Piran. In 2004, a total of 40 cages (total rearing volume of approximately 17 000 m³) were operational, producing both the European seabass and the gilthead seabream. The total official production in 2004 was approximately 78 tonnes for seabass and

⁹ New sites have recently been licensed for tuna fattening. Sites where seabass and seabream are farmed are also used.

TABLE 16
Cage production in Croatia from 1995–2004 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Atlantic bluefin tuna	0	0	390	400	672	1 200	2 500	3 971	4 679	3 777
European seabass	247	172	394	1 152	1 300	1 300	1 520	1 800	1 813	3 000
Gilthead seabream	90	80	40	595	450	800	940	700	610	700
Total caged	337	252	824	2 147	2 422	3 300	4 960	6 471	7 102	7 477
Total aquaculture	4 007	2 889	3 900	6 358	6 900	7 874	12 666	12 387	12 284	13 924
% cage	8.4%	8.7%	21.1%	33.8%	35.1%	41.9%	39.2%	52.2%	57.8%	53.7%

Source: FAO/FIDI, 2006; FAO/NASO, 2006

31 tonnes for seabream (FAO/FIDI, 2006). Cage production accounted for 40 percent of marine production consisting of 5.9 percent of the total aquaculture production. In terms of commercial value, the cage production share was approximately 20 percent of the whole aquaculture value. All seabass and seabream fingerlings are imported from France, Spain and Italy. The cages used are the floating type, rectangular (8 x 5 m) or circular of different diameters (8, 12 and 16 metres).

Croatia

Marine finfish aquaculture in Croatia is entirely carried out in floating cages. The first experience of intensive farming started in 1980. The Croatian shoreline provides numerous sheltered sites and this has, particularly in recent years, favoured and encouraged the development of cage farming. Nevertheless, there has been a tendency to switch from inshore to semi-offshore farm sites using more sophisticated and advanced facilities and cage technologies.

As indicated in Table 16, cage aquaculture production increased dramatically (more than 20-fold) with an annual average growth rate of 56.4 percent. The share of cage aquaculture in relation to the total aquaculture production grew from 8.4 percent in 1995 to 53.7 percent in 1994.

The commercial value of cage production compared with the entire aquaculture sector clearly indicates the importance of the cage farming sector even though available data does not include income from BFT sector (Table 17).

If a value of US\$15/kg of tuna produced in 2004 is assumed (same as reported by Spain; FAO/FIDI, 2006), the cage production value share would have increased to 87.7 percent, further indicating the importance of cage farming in the Croatian aquaculture sector.

Croatia has a small production of fingerlings. Of the two marine species, it is estimated that in 2002 the country produced 5 and 0.4 million European seabass and gilthead seabream, respectively, and imported 3.3 and 3.8 million, respectively. National supply only provides for approximately 40 percent of the total fry demand. The fattening of Atlantic bluefin tuna started in 1996 and by the year 2002, in the counties of Zadar, Sibenik and Split, 10 farms were fully operational and a total of 65 floating cages were in operation. In Croatia BFT farming uses relative small juvenile specimens captured in May and June, when they weigh only a few kilograms. The fattening period to the commercial size can take up two or three years. In 2003, the export of tuna accounted for more than 74 percent of total fish exports.

TABLE 17
Total aquaculture and cage values in Croatia from 1995–2004 (Atlantic bluefin tuna values not available)

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total aquaculture (excl. bluefin tuna)	12 472	8 963	11 303	23 037	23 481	26 488	32 597	29 245	24 096	33 295
Total cage (excl. bluefin tuna)	3 280	2 440	3 902	13 976	14 000	16 800	18 450	18 750	14 538	22 200
% cage	26.3%	27.2%	34.5%	60.7%	59.6%	63.4%	56.6%	64.1%	60.3%	66.7%

Source: FAO/FIDI, 2006; FAO/NASO, 2006

TABLE 18
Reared species, number of farms and production in Serbia and Montenegro in 2004 sorted by location

Location	Species	Number of farms	Production (tonnes/year)
Serbia	Common carp	18	400
Serbia	Rainbow trout	1	30
Montenegro	Rainbow trout	1	10
Montenegro (Adriatic Sea)	European seabass and gilthead seabream	1	20
Montenegro (Adriatic Sea)	Mussel	n.a.	40
Total cage production			500

Source: FAO/NASO, 2006

In the 1980s, the cages used for seabass and seabream farming were locally made with a wooden frame fitted with floats and nets. Although these home-made cages are still used by some farmers in sheltered sites, most operators tend now to use circular or square floating HDPE cages.

Serbia and Montenegro

Cage aquaculture in Serbia and Montenegro is dominated by freshwater production of common carp and rainbow trout (Table 18).

Freshwater cage aquaculture of these species is carried out mainly in Serbia. There are currently 20 active farms half of which produce less than 10 tonnes/year. Total annual cage production is in the region of 440 tonnes. Approximately 90 percent of the production is carp. The existing two trout cage farms are located in lakes and the maximum stocking density is around 15 kg/m³. Carp cage farms are located mainly along rivers, channels or artificial water bodies. The stocking density varies from 20 to 60 kg/m³.

The shoreline on the Adriatic Sea is only a few kilometres wide. In 1998 a seabass/seabream cage farm was established in Ljuta (Kotor Bay). To date, the annual marine finfish production is approximately 20 tonnes. Furthermore, in the Bay of Boka Kotorska, there are several small cage producing mussel (total annual production is approximately 40 tonnes).

According to the FAO National Aquaculture Sector Overview¹⁰ for Serbia and Montenegro the total production of market-size fish was 7 951 tonnes in 2004, representing a value of approximately US\$1.4 million. The share of the cage aquaculture is approximately 6.3 percent in terms of production (500 tonnes) and 7.2 percent in terms of value.

¹⁰ The official statistics data are not complete with all the reared species.

Albania

In Albania cage aquaculture is carried out exclusively along the Ionian coastline. Both the European seabass and the gilthead seabream are reared in floating cages. Marine finfish cage production commenced at the beginning of this decade, with a reported production in 2001 of approximately 20 tonnes. During 2004 there were seven licensed companies and a total of 63 cages which produced approximately 350 tonnes of seabass and seabream.

Although there are no reported negative interactions with the tourism sector, cage culture is yet to develop as the industry is still afflicted by several constraints such as the lack of local hatcheries and reliable feed suppliers. Furthermore, imports of fingerlings and feed from the EU has a considerable impact on the production costs.

Greece

Greece is the most developed Mediterranean country in terms of cage aquaculture with 310 licensed production sites (Table 19). It is currently the largest producer of seabass and seabream¹¹ in the region. This development has been favoured by several factors amongst which:

- (i) coastline provides a large number of sheltered sites;
- (ii) proximity to largest regional market (i.e. Italy);
- (iii) encouraging European and national subsidizing policies.

The first commercial companies were established in the early 1980s: Leros Aquaculture (in Leros Island) in 1982; Selonda SA (in Korintos) in 1984; Nireus SA in 1988; and Fishfarm Sami in 1989. In the 1990s the sector expanded considerably. Seabass and seabream production from 1995-2001 increased from approximately 19 000 tonnes to more than

¹¹ New species such as *Diplodus* spp., *Pagrus* spp., etc. are also reared in cages and their production is estimated to be around the 1 percent of the seabass and seabream production.

TABLE 19
Number of cage farms per administrative province in Greece in 2004

Province	Number of cage farms
Central Greece	78
Attiki	22
West Greece	28
Peloponissos	46
Ionian Islands	30
Epirus	36
South Aegean	36
North Aegean	23
Kriti	3
East Macedonia	2
Central Macedonia	4
Thessalia	2
Total	310

Source: Greek Ministry of Agriculture, pers. comm.

66 000 with a growth of almost 350 percent over this six-year period and an average annual growth rate of 24 percent.

However, the production has not been strategically planned in terms of promoting the final product, both internally and abroad. High fish surplus caused a sector crisis and prices dropped considerably below production costs (Table 21). Several companies in Greece, as well as in other seabass and seabream producer countries, went bankrupt¹². In 2002, production dropped for the first time in the decade (Table 20).

Approximately 60 percent of the farms produce annually between 50 to 200 tonnes and the remaining 40 percent between 200 to 500 tonnes. Small farms are often merged into larger companies. In 2002, there were 25 companies which produced around 50 percent of the total production. The top three companies (Selonda Aquaculture SA, Hellenic Aquaculture SA and Nireus SA) produced a third of the total national output.

In 2004, the total value of cage production was estimated to be in the region of US\$329 million and represented 90 percent of the total aquaculture income. The trend over the last 10 years has been positive, with the exception of the year 2002 when the seabass and seabream crisis effects were more marked.

¹² The Stirling Report on seabass and seabream market reports that in 2001, 377 sites were licensed and operated by 167 companies. In 2004 the official licensed sites reported by the Ministry of Rural Development (pers. com.) dropped to 310.

Due to the fact that Greek aquaculture is almost entirely represented by cage aquaculture the share of the cage production value over the total value of the sector has been steady, i.e. around 90 percent during the last ten years (Table 22).

The sector employs around 4 500 people (full-time and part-time) and most of the farms have from 5 to 20 employees.

The Greek shoreline allow establishing fish farms in sheltered onshore sites where the risk from adverse weather conditions is limited. This has allowed the use of low technology cage systems resulting in contained investment and maintenance costs. The majority of the farming structures are circular, double piped HDPE floating cages. Floating square shaped modular cages (pontoon-like) are also commonly used.

At present, there is only one Atlantic bluefin tuna farm which is operational in Greece (Bluefin Tuna Hellas SA), which was established in 2003 in the Echinades Islands, Prefecture of Kefallonia-Ithaki Islands through a joint-venture of the two largest Greek seabass and seabream companies, i.e. Selonda SA and Nireus SA. At present, no official production data are available.

Turkey

Cage farming started in 1985 with the production of European seabass and gilthead seabream. Cage culture for these two species increased dramatically and by 2003 production was approximately 37 700 tonnes from 345 farms. A small share of Turkish trout production (or 2.9 percent of the total trout production of 40 868 tonnes in 2003) was and continues to be reared in marine floating cages along the Black Sea coast¹³.

The Turkish shoreline, particularly along the Aegean Sea, is similar to the Greek coast with numerous sheltered sites where cage farming can be safely practiced using conventional floating cages and mooring systems. Most marine cage farms are located in the southern Aegean coast. The production from this region is approximately 95 percent of the whole seabass and seabream production. During the period 1995-2004, cage production increased from 7 600 tonnes to 48 300 tonnes with a growth of 634 percent and an average annual growth of approximately 25 percent (Table 23). In 2003, the production share of cage aquaculture, in terms of

¹³ There are also few examples of freshwater trout cage farms, whose production is not quantified but presumably not relevant in terms of production share.

TABLE 20
Cage production in Greece from 1995–2004 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
European seabass	9 539	11 662	15 193	18 469	24 413	26 653	25 342	23 860	27 324	25 691
Gilthead seabream	9 387	13 799	18 035	21 951	32 837	38 587	40 694	37 944	44 118	37 394
Other finfish	1	122	2	38	107	86	75	83	161	316
Total caged	18 927	25 583	33 230	40 458	57 357	65 326	66 111	61 887	71 603	63 401
Total aquaculture production	32 644	39 852	48 838	59 926	84 274	95 418	97 512	87 928	101 434	97 068
% cage	58%	64%	68%	68%	68%	68%	68%	70%	71%	65%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 21
Price trends in Greece from 1995–2004 for the European seabass and gilthead seabream

Value (US\$/kg)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
European seabass	7.50	7.67	7.03	6.42	5.48	4.18	4.55	3.76	5.43	5.59
Gilthead seabream	7.00	8.77	6.33	5.90	4.62	3.99	3.95	3.41	3.85	4.97

Source: FAO/FIDI, 2006

TABLE 22
Total aquaculture and cage values in Greece from 1995–2004

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total aquaculture	157 307	235 864	246 589	274 997	330 408	291 318	307 364	243 891	348 193	365 561
Total cage	137 252	210 426	220 894	248 046	285 619	265 450	276 045	219 103	318 044	329 706
% cage	87%	89%	90%	90%	86%	91%	90%	90%	91%	90%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 23
Cage production (in tonnes) in Turkey from 1995–2004 sorted by species, total aquaculture production and share of cage on total production

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Atlantic bluefin tuna	0	0	0	0	0	260	3800	3 300	4 100 ^a	n.a.
European seabass	2 773	5 210	6 300	8 660	12 000	17 877	15 546	14 339	20 982	26 297
Gilthead seabream	4 847	6 320	7 500	10 150	11 000	15 460	12 939	11 681	16 735	20 435
Rainbow trout	n.a.	n.a.	2 000	2 290	1 700	1 961	1 240	846	1 194	1 650
Total caged	7 620	11 530	15 800	21 100	24 700	37 358	33 525	30 166	43 011	48 382
Total aquaculture prod	21 607	33 201	45 450	56 700	63 000	81 091	71 044	64 465	84 043	94 010
% caged	35.3%	34.7%	34.8%	37.2%	39.2%	46.1%	47.2%	46.8%	51.2%	51.5% ^b

^a Estimate.

^b Figure not inclusive of BFT.

Source: SIPAM, 2006; FAO/FIDI, 2006; FAO/GFCM/ICCAT, 2005

TABLE 24
Total aquaculture and cage values in Turkey from 1995–2004

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total aquaculture (excl. bluefin tuna)	127 197	182 569	227 960	280 745	306 408	219 775	142 315	130 482	278 614	396 144
Total cage (excl. bluefin tuna)	70 467	97 429	121 450	160 756	174 989	134 703	87 189	79 329	179 409	241 865
% cage	55%	53%	53%	57%	57%	61%	61%	61%	64%	61%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 25

Cage production in Cyprus from 1995–2004 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Atlantic bluefin tuna	0	0	0	0	0	0	0	0	0	1 370
European seabass	99	100	57	205	299	299	383	421	448	698
Gilthead seabream	223	527	769	828	986	1385	1 278	1 267	1 182	1 356
Other marine finfish	26	36	15	22	28	53	64	12	1	0
Rainbow trout	29	38	41	48	12	19	23	12	20	11
Total caged	377	701	882	1 103	1 325	1 756	1 748	1 712	1 651	3 435
Total aquaculture	452	787	969	1 178	1 422	1 878	1 883	1 862	1 821	3 545
% caged	83.4%	89.1%	91.0%	93.6%	93.2%	93.5%	92.8%	91.9%	90.7%	96.9%

Source: SIPAM, 2006; FAO/FIDI, 2006; FAO/NASO, 2006

quantity, was approximately 51 percent of the total national production.

Around 75 percent of seabass and seabream production is exported to EU countries. In 2004, the value of the cage production was estimated at US\$242 million and represented almost two thirds (61 percent) of the entire Turkish aquaculture income (Table 24). During the period 2000–2002 the market crisis for seabass and seabream also affected Turkish producers. Cage production value decreased from approximately US\$175 million in 1999 to approximately US\$79 million in 2002; this was due both to a reduction in production and to a considerable drop in the market prices (Seabass: from US\$7.72/kg in 1999 to US\$3.00/kg in 2002; Seabream: from US\$6.95/kg in 1999 to US\$3.00/kg in 2002).

Factors that have promoted Turkish cage culture development include suitable and abundant shoreline sites along the Aegean coast and a favourable national subsidizing policy developed to support the sector. A premium payment is available for fingerling production and marketed fish. This subsidy is expected to continue up to 2010. European seabass and gilthead seabream producers estimated that the 2006 will amount to approximately 55 000 tonnes. A second seabass

and seabream crisis is foreseen by the operators over the next few years. The Turkish producers nevertheless feel that the increased production will be almost entirely absorbed by the internal market and supported by the growing tourism industry (API, pers. comm.).

The most popular cage models in use are the HDPE floating type of different shapes and sizes. Some experienced companies have started using large circular cages with a diameter of 50 metres (i.e. Fjord Marine Turkey). Due to the constraints with the tourism sector most cage farms have left the protected inshore shallower water and relocated in more exposed offshore sites. It has, therefore, been necessary to adopt improved cage technologies and small wooden framed square cages have been replaced by HDPE circular cages.

The Atlantic bluefin tuna fattening activity commenced in 1999 and is currently carried out in six licensed sites; two off the coast of Izmir and four along the southern coast of Anatolia. The total potential production is estimated at 6 300 tonnes. In 2004, the reported production was 4 100 tonnes.

Cyprus

In Cyprus the aquaculture sector consists almost entirely of offshore marine cages. The most

TABLE 26

Total aquaculture and cage values in Cyprus from 1995–2004

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total aquaculture	4 467	7 512	8 173	9 013	9 574	10 304	9 527	10 487	11 709	34 149
Total cage	3 334	6 107	7 174	8 098	8 297	8 776	7 868	8 905	9 731	33 098
% cage	74.6%	81.3%	87.8%	89.9%	86.7%	85.2%	82.6%	84.9%	83.1%	96.9%

Source: SIPAM, 2006; FAO/FIDI, 2006; FAO/NASO, 2006

TABLE 27
 Estimate rearing volumes, farmed species and total production in the Syrian Arab Republic in 2004, sorted by production site

Area	Cubic metres	Farmed species	Production (tonnes)
Latakia	11 056	Common carp	325
Al-Raqqah	36 126	Common carp	755
Total	47 182	--	1 080

Source: FAO/NASO, 2006

important farmed species are the European seabass, gilthead seabream and Atlantic bluefin tuna. All the farms are situated along the southern coast of the Island. Cage farming started in the mid 1980s with small cages moored in the harbours of Paphos and Larnaca. The first commercial offshore cage farm was established in 1986. In 2004, six offshore bass and bream farms were operational (five near Limassol and one near Larnaca). One of these farms also operates Atlantic bluefin tuna cages (Kimagro Fish Farming Ltd). Different models of cages are used, suitable to the offshore characteristics of the farm sites, such as Dunlop, Bridgestone, PolarCircle and Farmoccean. HDPE cages with a 50 metre diameter are used for tuna fattening.

In 2004, the share of cage culture production was 97 percent of the total aquaculture production (Table 25). A small seasonal production of rainbow trout is reported from cages moored in dams and reservoirs. The overall value of cage production in 2004 was estimated at US\$34.1 million of which almost 60 percent was Atlantic bluefin tuna (Table 26).

Seabass and seabream produced in Cyprus are mainly sold in the local market. Approximately 30 percent of the fish are exported to Israel, Russia and the USA. Tuna on the other hand is exported to Japan and USA, mainly as a frozen product. A small part (<1 percent) is sold fresh. There are four hatcheries producing seabass and seabream¹⁴ that supply the national demand for fingerling. Production currently exceeds the internal demand and in 2004 an estimated 7.5 million fingerlings were shipped to Greece, Turkey and Israel.

Syrian Arab Republic

In the Syrian Arab Republic only freshwater aquaculture is carried out. The most prominent species reared are the common carp and the Nile tilapia. Small

amounts of grass carp, African catfish and silver carp are also produced. Cage aquaculture started in the mid 1970s by exploiting artificial water bodies. Currently there are two main cage production sites (i) Lake Assad-Eufrates (Governorate of Al-Raqqah) and (ii) Lake Tishreen (Governorate of Latakia). The available farmed volume and production outputs for 2004 are reported in Table 27.

In 2004 approximately 1 080 tonnes were produced, representing 24.4 percent of the overall carp production and 12.4 percent of the entire aquaculture output. In the same year the estimated aquaculture value was in the region of US\$15 500 and the share of caged carps (US\$1 620 thousand) was 10 percent. The cages used in this area are floating, mainly consisting of wooden, square shaped frames and empty barrels. The volume of the nets varies from 30 to 300 cubic metres.

Lebanon

In Lebanon aquaculture is still at an early state of development and only freshwater aquaculture is currently practiced. The most important farmed specie is the rainbow trout. In 2004, an estimated 700 tonnes were produced for a value of US\$2.1 million. At present there are no operational cage farms.

Israel

Cage culture started in the early 1990s in Israel with the establishment of a commercial cage farm and a hatchery in the Gulf of Eilat. Currently four companies are operational and are located in three separate sites: two in the Gulf of Aqaba (Ardag and Dag Suf) with a combined annual production of approximately 2 000 tonnes; one inside the Ashdod Harbour breakwater, which, in 2003 produced approximately 500 tonnes; and one near Michmoret. The most commonly reared species are the gilthead seabream, accounting for 90 percent of the total cage production and the European seabass, red drum and stripped bass with a combined production of 10 percent.

¹⁴ Also a small production of "new species" is reported including the red porgy, sharpsnout seabream, shi drum and the Japanese seabream.

TABLE 28
Number of cages, farmed species and total production in Egypt in 2003 sorted by production sites

Area	Number of cages	Species	Production (tonnes)
El Behira	920	Silver carp	8 400
Kafr El Sheikh	1 834	Silver carp and tilapia	10 500
Damietta	1 620	Nile tilapia	12 774
Faiyum	50	Nile tilapia	260

Source: FAO/NASO, 2006

Various attempts have been made to carry out offshore cage culture; however, the severe sea conditions of the Mediterranean coast have represented a serious constraint towards the development of this industry. An estimated 10 million fingerlings were produced in 2000. The internal demand however remains high and an additional 2 million fingerlings were imported from Cyprus.

Egypt

Egypt, with a production exceeding 440 000 tonnes, is one of the most productive countries in Africa. Cage culture is common especially in the Nile and particularly in the most northern branches of the Delta where over 4 428 cages are operational and provide a total rearing volume of 1.3 million cubic metres (Table 28). The recorded fish production from these cages in 2003 was approximately 32 000 tonnes. The most commonly reared species is the Nile tilapia (*Oreochromis niloticus*), but also the silver carp (*Hypophthalmichthys molitrix*) is reported as a caged species. In 2003, the entire Egyptian cage production represented 7.2 percent of the total aquaculture production and 6.0 percent of the total value (Tables 29 and 30). From 1995 to 2003 the total aquaculture production increased by 519 percent, while the cage production growth reached as far as 1 521 percent, providing an average annual growth rate of 63 percent.

The cage culture sector has benefited immensely from the development that has occurred in the support services sector, for example, the availability of hatcheries and feed mills, etc. Cage aquaculture has also flourished rapidly supported by the

increasing availability of consultants, experts and technicians with the required knowledge to develop this activity. Furthermore, the General Authority for Fish Resources Development (GAFRD) also provided support to the development of cage aquaculture.

A pilot project in marine cage culture was carried out in the Marsa Matrouh Lagoon where ten cages were utilized to rear mainly wild fingerlings of mullet and black bream caught in the lagoon (Megapesca, 2001). The most frequently used cage models are home-made square cages built using barrels as floating devices and assembled under wooden frames where the fish nets are fixed.

Libyan Arab Jamahiriya

Various experimental cage farming trials were carried out in the early 1990s in the Lagoon of Ein Elgazala. Cages were installed to farm wild-caught fingerlings of gilthead seabream, European seabass and Mugil spp. fished in the lagoon. A number of open sea cages are currently in use and have been installed in three sites along the Libyan coasts: Al-Garabouli and Al-Koms north-west of Tripoli, and Ras Al-Hilal on the north-eastern coast.

In Al-Koms there are currently six HDPE circular floating cages (Farmocean Power-rings) rearing European seabass and gilthead seabream. One Atlantic bluefin tuna farm is operational off the coast of Al-Garabouli while a new one-cage system (50 m diameter) has been established in Ras El-Hilal. Seabream and seabass are also farmed in Ras El-Hilal one of the few sheltered sites along the Libyan coastline. At present, four PolarCircle submersible cages are in place (16 m diameter) and

TABLE 29
Cage production in Egypt from 1995–2003 and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total caged	1 977	1 720	2 103	2 855	12 885	16 069	23 716	28 166	32 059
Total aquaculture production	71 815	91 137	85 704	139 389	226 276	340 093	342 864	376 296	445 181
% cage	2.8%	1.9%	2.5%	2.0%	5.7%	4.7%	6.9%	7.5%	7.2%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 30
Total aquaculture and cage values in Egypt from 1995–2004

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total aquaculture	115 194	167 902	183 879	327 263	447 146	815 046	756 980	655 565	615 011
Total cage	3 361	3 034	4 328	6 043	22 011	27 783	41 029	43 191	37 065
% cage	2.9%	1.8%	2.4%	1.8%	4.9%	3.4%	5.4%	6.6%	6.0%

Source: SIPAM, 2006; FAO/FIDI, 2006

four floating cages (22 m diameter) supplied by Fusion Marine.

In 2004, the official production data reported for seabass and seabream was 170 and 61 tonnes, respectively, although it is not clear whether or not this amount results entirely from cage culture. In 2003, Atlantic bluefin tuna farming produced 420 tonnes (for a value of approximately US\$2.5 million) and 154 tonnes (for a value of approximately US\$900 000) in 2004.

Tunisia

In Tunisia cage culture was first practiced in the Lagoon of Boughrara (Medenine Province) where several small cages were installed for seabass and seabream culture in the late 1980s. This activity was interrupted in 1991 and 1994 due to the occurrence of a series of algal bloom outbreak causing the loss of the entire stock of 400 and 300 tonnes, respectively. Some of these cages have now been moved to a new site near the Zarzis Harbour area. A second company (Tunipeche) is now operating in Ajim (near Jrba).

In 2004, seabass and seabream cage production accounted for approximately 14 percent of the whole national production of both species (678 tonnes of seabream and 466 tonnes of seabass). The cage share, in comparison to the total aquaculture production, has increased from 1.2 percent in 2001 to 6.5 percent in 2004, with a substantial production boost in 2002–2003 due to tuna farming

(Table 31). The value of cage aquaculture (excl. BFT) in 2004 was US\$1.2 million. This accounted for around 10 percent of the total aquaculture value (Table 32).

There are currently two hatcheries in operation and in 2004 the combined production of European seabass and gilthead seabream fingerlings was 4.8 and 3.1 million, respectively (SIPAM, 2006). Furthermore, Atlantic bluefin tuna aquaculture has grown rapidly during the last few years. At present four tuna cage farms are operational; two near Hergla (Sousse Governorate) and two near Chebba (Madhia Governorate). The total production capacity of these farms is 2 400 tonnes.

Algeria

Cage aquaculture is not currently practiced in Algeria although reports indicate that some projects are likely to be established in the near future. The Ministry of Fishery Resources has included cage culture activities in its National Development of Fishery and Aquaculture Plan for 2003–2007 for which potential sites have already been identified. Two projects are currently in the final phase and they are expected to be operational towards the end of 2006 (Delphine Pêche near Oran and Azzefoune Aquaculture near Tizi-Ouzou).

The planned annual production of the aforementioned farms is around 1 000 tonnes of both seabass and seabream. The production should be sold on the internal market.

TABLE 31
Cage production in Tunisia from 2000–2004 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	2000	2001	2002	2003	2004
Atlantic bluefin tuna	0	0	0	678	1 485
European seabass	0	88	132	96	70
Gilthead seabream	0	20	22	29	80
Total caged	0	108	154	803	1 635
Total aquaculture production	1 553	1 868	1 975	2 612	3 749
% caged	0.0%	1.2%	1.8%	5.5%	6.5%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 32
Total aquaculture and cage values in Tunisia from 2000–2004

Value (US\$1 000)	2000	2001	2002	2003	2004
Total aquaculture (excl. bluefin tuna)	7 107	9 196	8 746	8 418	11 947
Total cage (excl. bluefin tuna)	0	884	1 084	862	1 261
% cage	0.0%	9.6%	12.4%	10.2%	10.6%

Source: SIPAM, 2006; FAO/FIDI, 2006

Morocco

In Morocco, European seabass and gilthead seabream have been mainly reared in floating cages located in the Lagoon of Nador where a company known as MAROST was established in 1985, but ceased operating in 2005 due to marketing constraints. In the open sea on the Mediterranean coast, in Mdiq (near Tetouan), a company named Aqua Mdiq also produces seabream and seabass.

The production in 2004 was estimated to be approximately 120 tonnes. In 2004, Morocco's production of seabass and seabream was approximately 720 tonnes divided equally between the two species (Table 33).

Over the last ten years cage production value decreased from US\$9 584 000 to US\$2 838 000 (see Table 34) due to the reduction of production as a consequence of declining seabass and seabream prices. The average price in 1995 for both species was US\$8.5/kg, which dropped to US\$4.4/kg for seabass and US\$3.5/kg for seabream in 2004 (FAO/FIDI, 2006). Seabass and seabream are exported primarily to Spain, and minor volumes to France and Italy. In Morocco there are two marine hatcheries one in Nador (MAROST) and one in Mdiq (Centre Aquacole de Mdiq). These hatcheries provide the great majority of seabass and seabream fries requested by the industry while the remainder are imported from Spain.

There is one Atlantic bluefin tuna cage farm (Marcomar SARL), located in the southern Atlantic

coast, but no data regarding the production is currently available.

CAGE MODELS

As described above, various cage types and systems are being used by the Mediterranean finfish farms, the choice of which is usually determined by the following main factors:

- Site - The most important aspect to be considered is the site on which the cages will be set up and their suitability with regard to (i) exposure to potential sea storms, (ii) seabed characteristics and depth, (iii) prevailing sea conditions, and (iv) visual impact. An exposed site and an increased risk of heavy storms will require cages, nets and mooring systems designed to resist the maximum registered storm strength. If the site is somewhat sheltered, a simplified mooring system and lighter rearing structure will reduce the cost of the initial investment. Should negative interactions be encountered with the coastal tourism submerged or low visual impact models are often considered and/or possibly recommended by the authorities responsible for the issuance of the farming license.
- Cost of cages - The initial cost of the investment usually represents a limiting factor particularly for those investors with a fixed budget. However, the cheapest option may not take into consideration the suitability of the structures for the site.

TABLE 33
Cage production in Morocco from 1995–2004 sorted by species, total aquaculture production and share of cage on total production

Quantities (tonnes)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
European seabass	533	400	568	563	275	n.a.	374	325	389	370
Gilthead seabream	590	658	254	161	466	n.a.	304	378	378	350
Total caged	1 123	1 058	822	724	741	n.a.	678	703	767	720
Total aquaculture production	2 072	2 084	2 329	2 161	2 793	1 889	1 403	1 670	1 538	1 718
% cage	54%	51%	35%	34%	27%	n.a.	48%	42%	50%	42%

Source: SIPAM, 2006; FAO/FIDI, 2006

TABLE 34
Total aquaculture and cage values in Morocco from 1995–2004

Value (US\$1 000)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total aquaculture	12 254	11 970	8 907	8 036	8 610	5 054	3 375	4 478	4 726	5 887
Total cage	9 584	9 113	5 324	4 642	3 683	n.a.	2 692	2 740	3 019	2 838
% cage	78.2%	76.1%	59.8%	57.8%	42.8%	n.a.	79.7%	61.2%	63.9%	48.2%

Source: SIPAM, 2006; FAO/FIDI, 2006

- Production plans - The size of the farm and cage model may vary depending on the target pursued by the investors. For instance, farmers aiming to produce a niche product, or attempting to diversify production with fish of various sizes, may prefer a large number of small cages rather than a few large ones so that only a reduced percentage of volume can be engaged in a selected production.

High density polyethylene cages

High density polyethylene (HDPE) cages are the most popular ones used in Mediterranean fish farm (Figures 9, 10 and 11). The HDPE pipes can be assembled in various ways in order to produce collars of different sizes and shapes. There are many HDPE cage supplier companies (Floatex, Corelsa, PolarCircle, Fusion Marine, etc.), however home made cages are also commonly used (Figure 12). These cages are often composed of two (sometimes three) rings of HDPE pipe 15-35 cm diameter, and held together by the base of several stanchions disposed throughout the entire circumference. The rings can be floating (filled with polystyrene) or sinkable (i.e. provided with flooding water/air hoses). The net is fixed at the base of each stanchion and is completely closed with a cap. The bottom of a submersible cage has weights and sometime a sinker tube. Collars are available, in various diameters, onto which nets, as deep as the site allows, are fixed. The mooring system can be quite complicated and the most commonly used is a square shaped grid of ropes, iron plates and buoys. The cages are moored onto the plates. The grid is moored with anchors through several orthogonal mooring lines.

Advantages: versatility of the materials; net changing simple; frequent visual check of the fish; relatively cost effective (especially for bigger cages).

Disadvantage: complicated mooring system requiring frequent checking and maintenance. Time is required to submerge the submersible models and constant weather forecast checks are required.

FIGURE 9
Square Dunlop floating cages and smaller circular HDPE cages used for pre-ongrowing in Cyprus



FIGURE 10
A 50-m diameter HDPE floating cages for Atlantic bluefin tuna fattening in Vibo Valentia, Italy



FIGURE 11
Fish harvesting in an 18-m diameter HDPE floating cage in Rossano Calabro, Italy



FIGURE 12
**HDPE self-built floating cages measuring 7x14
 equipped with automatic feeder system
 (pipes are visible)**



Farmocean

These cages are defined as semi-submersible rigid cages designed with a rigid steel framework developed in the 1980s as a result of an offshore farming system researched in Sweden. The net is fixed inside the main floating hexagonal frame and its shape is maintained by a sinker tube attached to the bottom. The volume of the cage can range from 2 500 to 5 000 m³ and each cage is moored through three main radial lines. A feed system is usually placed on the top of the floating frame storing up to 3 000 kg of feed; energy is supplied by solar panels. A winch on the top of the steel frame lifts the sinker tube together with the bottom of the net to simplify the harvesting process.

Advantages: cages have been tested over almost 20 years in a variety of sea conditions; suitable also for exposed sites; integrated feeding system; stable holding volume.

Disadvantage: high initial capital costs; complicated access when harvesting; net changing difficult; high maintenance costs; high visual impact.

Farmocean International also produces HDPE circular floating cages (two or three pipes) equipped with iron stanchions (Power-rings cages).

REFA tension legs

These cages are made of a net kept in shape by submerged buoys and an inferior rigid frame. The mooring system is composed of six bottom concrete blocks located vertically under each cage (Figure 14). The top of the cage is fitted with a circular HDPE collar to ensure access and feeding. During adverse weather conditions the cage will

submerge entirely causing a loss in the rearing volume. The nets are fitted with a zip which allows the removal of the top portion of the cage during fish harvesting and to allow positioning of the net on a larger HDPE floating collar.

Advantage: simple design and automatic response to adverse sea conditions; cost effective; small bottom area occupied by the mooring system; easy to repair; few components requiring maintenance; very low visual impact.

Disadvantage: closed cage and poor visual check of the fish; small surface for feeding; difficult to change the nets.

Floating platforms

These structures have been installed in Spain and in Italy (Figures 14 and 15). The first were built in Spain by Marina System Iberica (MSI). Two such structures are moored near Barcelona, one near Cadiz and one near Tarragona. These structures are square or hexagonal in shape and hold 7-8 net cages. The mooring system is composed by several mooring lines (rope-chain-dead body) fixed at the corners. The platforms are provided with sinking systems that permits buoyancy control.

In the 1990s a pilot project was developed in Italy and a platform built which included facilities such as a packaging room and staff lodgings. This structure became operational in 2000 and consists of a 60 metre wide circular iron collar where six nets of 5 500 m³ each are fixed. The platform has a 10x20 m building divided in two floors (ground floor: packaging area, cold store and ice room; 1st floor: staff lodgings, kitchen/canteen, meeting room). It is currently moored in deep waters (80 m) and moored by a single line of 300 meters which allows the structure to freely rotate over a

FIGURE 13
**A REFA tension legs cage farm. Only some floats and
 the floating collars are visible (Sardinia, Italy)**



FIGURE 14
Cultimar floating fish farming platform from Marina System Iberica near Barcelona (Spain)



FIGURE 15
A floating fish farm platform fitted with six large cages and a central 2-story work building (Naples, Italy).



COURTESY OF ITTICA OFFSHORE DEL TIRRENO

large water surface to better disperse fish waste. The power is supplied by two generators and a sinking system allows raising the floating level of the structure during the storms.

Advantage: excellent logistic; possibility of feeding with any sea condition; constant visual check of the fish; supposedly a highly durable structure.

Disadvantage: high initial investment cost; high maintenance costs; net changing difficult; extremely high visual impact.

Bridgestone and Dunlop

These types of floating cages are designed for severe offshore conditions (Figure 9). Bridgestone and Dunlop provide cages made by assembling rubber oil hoses with junctions placed “face to face”. Iron stanchions are clamped on the hoses to allow the net to hang.

The cages have a square, hexagonal or octagonal shape. Square cages can be assembled in multiple cage modules. Different volumes are available up to (theoretically) 60 000 m³. Such cages are used in Spain, Italy, France and Cyprus.

Advantages: modular nature of the components permits a variety of configuration; extremely resistant; suitable for exposed sites; long durability.

Disadvantage: limited external walkway; expensive at lower volumes.

Jetfloat system

This is a modular component system: plastic cubes can be assembled to create a floating structure where nets are fixed (Figure 16). Originally projected for harbour and piers use, this system can be used in sheltered sites where square cages can be built thanks to several accessories made exclusively for aquaculture purpose (i.e. stanchions and mooring devices). This specific technology is used mainly in France, Greece and Malta. As mentioned these structures are used mainly in sheltered sites and are also used as pre-ongrowing units.

Advantage: versatility of the system (any size and side ratio cages can be assembled); easy replacement of the damaged module; easily dismantling and storage.

Disadvantage: not suitable for very exposed sites; more expensive compared with traditional HDPE cages; relatively expensive at lower volumes.

Sadco Shelf

This Russian company produces and distributes two types of steel cages both of which are submersible. The Sadco series (1200, 2000 and 4000) have been evolving since the early 1980s (Figure 17). A tubular structure holds a completely closed net kept in shape by a sinker tube connected to the

FIGURE 16
Cannes Aquaculture (France) using floating cages built with Jetfloat components



FIGURE 17

A Sardo-Shelf cage in a submerged position. The waterproof automatic feeding system is visible (Italy)



main structure through steel cables. On the top of the cage a waterproof integrated feeding system is installed and equipped with an underwater video system remotely controlled. This type of cage is available in various models and sizes from 1 200 to 4 000 m³. A new type of underwater cage (Sadco-SG) has been developed over the past few years. This cage is made of a polygonal steel tubular frame, a sinker tube and a submerged tank for buoyancy control. The cage can be submerged through the inflow of water inside the tank. It does not have a self-contained feeder but can work with a manual feeding pipe or centralized feeding system. These cages are designed for exposed sites in offshore conditions. Sadco cages are installed mainly in Italy.

Advantage: suitable for all site (also very exposed); resistant and durable; low visual impact; no reduction in the culture volume also in strong current conditions.

Disadvantage: difficult to change nets (in the Sadco series); expensive at low volumes; automatic feeder still being properly tested.

MAIN ISSUES

Cages are open systems with a continuous exchange of the water body. The risk of pollution to the environment represents a major concern for this sub-sector of the aquaculture industry. Furthermore, conflicts with other coastal areas users are often reported, mainly with the tourism sector.

All Mediterranean countries where cage culture is more widely developed require an Environmental Impact Assessment (EIA) which is an important tool used by the authorities when approving a project proposal. In most Mediterranean countries

an EIA is mandatory, but there are also exceptions in which the EIA is required only if the production estimate exceeds a certain limit (e.g. >20 tonnes in France). The Environmental Monitoring Programme (EMP), as part of licence conditions, also represents an important tool to supervise the potential polluting effects of any given fish farm. However, an EMP is not always required.

The main impacts that must be taken into account within an EIA are:

- Modification of natural currents - a project will have to take into account this aspect, analysing the available historical data and assessing potential risks related with the farm location.
- Chemical pollution - this risk is related to several factors such as (i) estimated production and soluble wastes; (ii) use of copper-zinc based antifouling on net and moorings; (iii) antibiotic treatment; and (iv) chemical baths to treat parasitic infections.
- Organic matter discharge - this may represent a hazard for the benthic population under and around the cages, as well as a source of self-pollution for the reared fish.
- Visual alteration of scenic places - a serious problem if the farm site is near a coast stretch with a particularly scenic landscape and/or a well developed tourist industry.
- Farmed fish escapes and interaction with local species - escapees represent a risk for the environment as the fish could have a predatory behaviour. In the case of massive break outs the prey/predator ratio of the surrounding ecosystems may be critically altered. Furthermore, escapees may induce "genetic pollution", i.e. interbreeding with indigenous specimens as well as compete for specific ecological niches.

The Commission of European Communities defines Integrated Coastal Zone Management (ICZM) as "...a dynamic, multi-disciplinary and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information collection, planning (in its broadest sense), decision making, management and monitoring of implementation. ICZM uses the informed participation and co-operation of all stakeholders to assess the societal goals in a given coastal area, and to take actions towards meeting these objectives. ICZM seeks, over the long-term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics" (CEC Communication 2000/547). This strategy, with the support of

the EIA and EMP tools, could well represent a valid technical approach for the development of a sustainable aquaculture management system. Several Mediterranean countries, including non-EU members (e.g. Croatia), have embraced the idea and are in the early stages in applying the system.

Disease control and health management

Evidence exists that pathogenic exchanges may occur in cage culture systems and therefore particular attention is required to minimize these exchanges in both directions (i.e. between farmed and wild fish and vice versa). This is aggravated by the evidence that certain pathogens (mainly monogenean parasites) can easily switch their host from a wild one to a farmed one therefore increasing their pathogenic action.

To minimize the risk of wild fish stock contamination, high quality and certified fingerlings are essential. Large commercial hatcheries are almost pathogen-free producing fingerlings which are strictly monitored for known pathogens. Veterinary certificates are usually release for each fry batch. There are, however, a large number of smaller hatcheries that may not reach satisfactory standards and may represent a risk in spreading diseases.

Pathogen contamination between wild specimens and reared fish is more difficult to control. Disease outbreaks depend on several factors including rearing conditions, animal welfare and fish stress (due to stocking density, water quality, diet, oxygen availability, handling, etc.). In cage farms the use of antibiotics should be minimized and this can be partly achieved by vaccinating fingerlings against the most common pathogens. In case of the European seabass the two most important pathogens are the *Vibrio anguillarum* (causing vibriosis) and *Photobacterium damsela* (causing pasteurellosis). For both these disease vaccines are available. Vaccination against vibriosis is often administered to the early stage fingerlings while treatment against pasteurellosis is usually carried out upon specific request.

Furthermore, it is important to mention that the current legislation dealing with health management issues are not homogeneous throughout the Mediterranean countries, especially with regards to the licensing of chemicals and health products.

Technology

The use of automation and mechanization in the production process has been increasing in order to

reduce production costs. Efforts are being made to install and enhance the use of automatic feeding systems, sometimes with sensors which provide a feedback on feed consumption. These tools can reduce considerably labour costs as well as reduce feed dispersion which has a positive impact on both environment and production costs. Feeding systems must nevertheless be frequently monitored and properly tuned. Grading machines and harvesting pumps are increasingly used.

Tuna aquaculture

Atlantic bluefin tuna farming is an activity that clearly overlaps with fisheries. The risks and issues that should be considered to define the sustainability of this recent activity are strictly related with both sectors. The tuna fattening industry has expanded over the last few years and the value output has increased considerably. The sector is based on the use of “wild-seed”. The amount of tuna which can be annually harvested is fixed by ICCAT and quotas assigned to the signatory parties. Although a strict control is practiced throughout the production cycle, several gaps may still facilitate the exploitation of the resource beyond the allowable quota.

One of the main aquaculture challenges in the coming years will be the domestication of the BFT. Although research results have been promising, more work is required preferably through international collaboration arrangements.

Market and product differentiation

In the beginning of the 1990s the consolidation of rearing techniques and the availability of new technologies pushed an increasing number of entrepreneurs to produce the European seabass and gilthead seabream using marine cages (Note: In 1990 production cost in Italy for these two species ranged between US\$19-21/kg).

Ten years later, due to the availability of EU Structural Funds, the lack of a sector growth strategy and poor market planning and promotion, brought about a market crisis of the sector. The current low prices and narrow profit margins are unsuited for a “high risk” activity such as marine cage culture. For these reasons many producers are focusing on (i) promoting their products on new or poorly exploited markets (such as Russia, Germany, United Kingdom, USA); (ii) considering new culture candidates from both technical and marketing points of view; (iii) adding value to their products (now sold mainly as whole fresh fish) and supporting marketing campaigns.

Offshore “migration”

Sheltered sites have always been preferred for installing a cage farm. These are the easiest places to practice cage aquaculture, both for the initial lower investment cost and for managing of the farm. A sheltered site allows the use of light cages that require a simple mooring system. As farms are generally close to the shoreline, powerful and fast boats are not needed and routine farm activities can be done carried out without to many difficulties. However, a sheltered site is usually in shallow waters with low currents and with a carrying capacity which may be insufficient for supporting an intense farming activity. Furthermore such sites are often in the vicinity of beaches, bays or areas highly frequented by tourists.

The aspects highlighted above along with the ever improving cage technologies are driving producers, licensing authorities and regulators to move fish farms further offshore. Such sites have however a number of inherent disadvantages, among which:

- cages, mooring systems and nets must be suitable for exposed sites and are consequently more expensive;
- deeper operational working routine for divers;
- difficulty in approaching the cages during severe weather conditions
- reduced number of feeding days during adverse sea conditions in the absence of an automatic feeding system;
- higher transportation costs;
- strong currents may increase feed loss; and
- higher risks of fish escaping.

The constraints listed certainly contribute to an increase in capital and operational costs however they are counterbalanced by a series of advantages. Cages moored in deeper waters (>35 m) and exposed to stronger currents will certainly reduce bottom sedimentation and accumulation of organic matter, thus promoting waste dispersal and minimizing the risk of pollution and self-pollution. Moreover, a higher water quality and renewal implies better rearing conditions and animal welfare with (i) lower risk of disease outbreak and use of chemicals; (ii) potential higher stocking density;

(iii) higher oxygen saturation resulting in better growth and lower feed conversion rates; (iv) lower visual impacts and reduction of conflicts with other resource users; and (v) higher fish quality with a lower fat/meat ratio.

THE WAY FORWARD

The development of cage aquaculture in Mediterranean is generally based on the principles of biodiversity conservation and sustainable use of the natural resources. Cage aquaculture is expanding rapidly throughout the region requiring more than ever planning and regulatory frameworks for the strategic and controlled development of the sector. Furthermore, additional scientific research is required to address the biological and technological constraints currently limiting the performance of the sector. Some of the major actions that require further attention are summarized as follows:

- strengthen the EIA and EMP tools and promote their application;
- promote an Integrated Coastal Zone Management (ICZM) approach in support of a developing mariculture industry;
- reduce the use of antibiotics;
- promote Mediterranean products in poorly and unexploited markets;
- strengthen research on species diversification for aquaculture;
- further develop value-added products using traditionally farmed species;
- work on the domestication of the BFT and develop an adequate commercial feed;
- strengthen the collection of reliable information on cage culture activities; and
- support offshore “migration” of cage farms.

ACKNOWLEDGEMENTS

The authors are grateful to all those persons who collected, made available or shared information. Particular thanks goes to Nadia Moussi, Anna Giannotaki, Carla Iandoli, Enrico Ingle, Gaspare Barbera, Alessandro Ciattaglia, Fabrizio Di Pol, François Loubere, Roberto Agonigi, Darko Lisack and Angelo Colorni.

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Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.

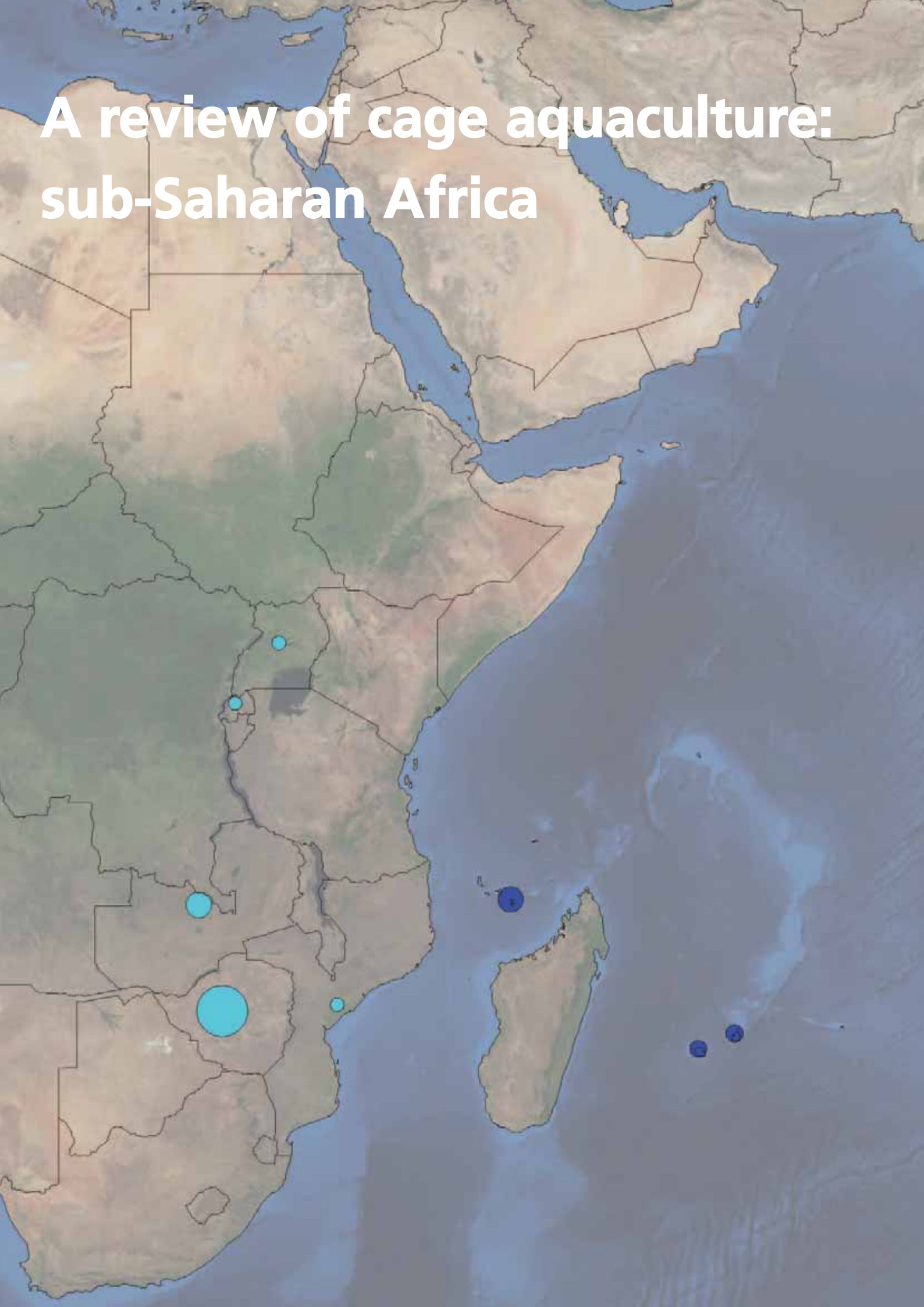


3750 t
3000 t
2250 t
1500 t
750 t
10 t

 freshwater

 marine and brackishwater

A review of cage aquaculture: sub-Saharan Africa





A review of cage aquaculture: sub-Saharan Africa

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A review of cage aquaculture: sub-Saharan Africa. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 188–207. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

Cage culture is an emerging activity in sub-Saharan Africa, and there are only a handful of successful examples. However, the region offers considerable scope for the industrial-scale development of freshwater cage culture, especially in the great lakes region and in tropical West Africa. There is also potential for brackish and marine cage culture, but as yet there has been no sustained commercial development of this subsector.

Working examples of cage culture in the region are tilapia farms in Ghana, Kenya, Malawi, Uganda, Zambia and Zimbabwe. All farms grow Nile tilapia (*Oreochromis niloticus*) with the exception of those in Malawi, which use the local species *O. shiranus* and *O. karongae*, both known as “chambo”. The growth performances of tilapias other than *O. niloticus* and of wild strains of *O. niloticus* are unlikely to be globally competitive. Therefore, the use of improved strains of Nile tilapia across sub-Saharan Africa should be reviewed and restrictions relaxed. Breeding centres in conjunction with practical hands-on training need to be established.

However, the main constraint to the development of competitive cage culture in the region is the unavailability of locally produced, high-quality extruded feeds at competitive prices. Local raw materials should be used. This issue, as well as a current lack of economies of scale, are key drivers behind high production costs in African cage aquaculture.

Other constraints include a lack of training in cage culture, a lack of processing and routes to developed markets in some countries, traditionally low prices and quality of wild-caught fish in the region, a lack of potential investors willing to take a long-term investment risk in sub-Saharan Africa, a lack of understanding and commitment by governments to the development of aquaculture in some countries and a lack of expertise in disease identification and management.

Countries will need to address these issues and should create an enabling environment for cage culture with due recognition of environmental and social aspects. National strategies and plans, the development of aquaculture zones, and public awareness campaigns, including for capital providers, will play an important role.

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INTRODUCTION

This review is part of a study commissioned by the Food and Agriculture Organization of the United Nations (FAO) on the global status of cage culture in 2006. The report reviews the history of freshwater cage culture in sub-Saharan Africa³, highlights working examples in the region (specifically in Ghana, Kenya, Malawi, Uganda, Zambia and Zimbabwe), identifies problems facing the development of the industry and makes recommendations as to the way forward.

Aquaculture has a checkered history in Africa, and since the 1950s its development has focused on subsistence-level pond-based systems. Commercial aquaculture has not been well promoted in the region and has thus been slow to develop. Cage culture in Africa probably started as a means for fishermen to hold a suitable quantity of caught fish alive until market (Masser, 1988). Initially, cages were fabricated with wood or foliage material, and fish were fed food scraps and possibly trash or by-catch fish. More advanced cage culture started in the 1950s, and synthetic materials were used in cage construction and mooring. Research on cage culture started only in the 1960s, as before then pond culture seemed to be economically viable and was more popular, and therefore was the focus of research in academic institutions.

Cage culture was introduced on a test basis in sub-Saharan Africa in the 1980s when momentum for aquaculture development grew and the need for aquaculture research received government recognition as part of national development plans (Masser 1988). Multilateral and bilateral donors increased technical assistance, and aquaculture started to develop more solidly. Recently the general development policies of several African countries have been changed to recognize aquaculture as its own independent sector (FAO, 2001).

Cages have since been piloted in Côte d'Ivoire, Ghana, Kenya, Malawi, Rwanda, South Africa, Uganda, Zambia and Zimbabwe, and commercial cage culture is currently developing in Ghana, Kenya, Malawi, Uganda, Zambia and Zimbabwe (the authors could not ascertain the status of cage culture in Côte d'Ivoire).

³ The sub-Saharan Africa region covers Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Côte d'Ivoire, Congo, Ethiopia, Gabon, Gambia, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Uganda, Zaire, Zambia and Zimbabwe.

There are no major examples of pen culture or marine or brackish-water cage culture in the region. A few small-scale pilot projects of pen culture for oysters and abalone are noted in Namibia and South Africa. The main focus of this paper is thus freshwater cage culture in inland water bodies.

Tilapias are the only fish that have been farmed in cages in the region (mainly Nile tilapia (*Oreochromis niloticus*), and “chambo” (*O. shiranus* and *O. karongae*)). There have been one or two small trials with North African catfish (*Clarias gariepinus*) but as no data are available these are not mentioned further in this review

THE CURRENT SITUATION

Cage culture is currently practiced in Ghana, Kenya, Malawi, Uganda, Zambia and Zimbabwe.

Ghana

There are two cage-farming companies in Ghana: Crystal Lake Fish Ltd. and Tropo Farms Ltd. Both are situated in Lake Volta, one of the world's largest man-made lakes.

Established in the late 1990s in the Asuogyaman District of Ghana's Eastern Region, Crystal Lake Fish Ltd. grows indigenous tilapia (*O. niloticus*) in ponds and concrete tanks (breeding and juveniles) and cages (grow-out to market size). The farm has 24 circular (8 m diameter each) tanks for hatchery (8) and nursing (16) purposes. When fingerlings



Cage aquaculture sites in Africa

reach an individual weight of 5–8 g, they are transferred to one of the nine cages (32 m diameter and 5 m depth) that are located about 1 km from the shore in 25 m deep water. Stocking density is up to 100 000 fish per cage or 0.5 to 1.0 kg/m³. Fish are fed a powdered feed during the first two months to a size of 40–50 g, then they are moved to another cage at a density of 50 000 to 60 000 fish per cage for three months to reach an individual selling weight of 250 g. The total production cycle is five months. Annual production in 2006 was around 340 tonnes of whole fish, although the company wants to expand production to 1 000 tonnes per annum. Crystal Lake has an agreement with a local distribution company. All the fish are gutted and transferred to the Capital for onward distribution.

Tropo Farms has been pond farming for six years and in 2005 developed a pilot-scale cage site on Lake Volta near Akosombo Dam. Tropo grows indigenous *O. niloticus* in ponds (breeding and juveniles) and cages (grow-out to market size). Current production from cages is around 10 tonnes of whole tilapia per annum, although Tropo plans to expand its cage-culture operations. Tropo sells its fish fresh at the farm gate into the Ghana market.



COURTESY OF M. HALWART

Feeding time at Crystal Lake Fish Ltd., Lake Volta, Ghana

Species-specific information

Oreochromis niloticus is indigenous in Ghana but the local strain is considered by some fish farmers not to perform well because of slow growth rates. Selective breeding of the local strain is underway in an attempt to improve performance. Introduced strains such as GIFT (Genetically Improved farmed Tilapia) are currently not allowed to be farmed in cages in Ghana.

Cage/pen type and size and number of cages

Crystal Lake has plastic circle cages that were purchased from Europe. There are about 8 cages installed in circa 25 m deep water at Crystal Lake, each with a diameter of 15 m and a depth of 4 m. Each cage is stocked with 50 000 fingerlings of *O. niloticus* at 30 g that are cultured for six months.

Tropo has a pilot-scale cage site with eight cages of 40 m³ each. Production nets are locally made. Juveniles of 10 g are transferred to the cage site from Tropo's pond site, which is one hour by good road, and are currently being grown to a market size of around 350 g. Water exchange rates are good at Tropo's cage site and the water depth is around 20 m.

Stocking density

Stocking density at harvest is expected to be around 40 kg/m³ at both farms.

Production per cage per unit time

Crystal Lake Fish Ltd.'s annual production is around 340 tonnes of whole fish, while Tropo's current annual production from cages is around 10 tonnes of whole tilapia.



COURTESY OF M. HALWART

Start up activities for a new aquaculture enterprise, Lake Volta, Ghana

Market size and price

Tropo's market size is around 350 g, while at Crystal Lake, the fish are grown to market size of around 250 g.

Technical issues

Seed supply

Both fish farms produce their own fry. Crystal Lake has its own hatchery with concrete tanks and grows fingerlings in larger lined earthen ponds before they are transferred to floating cages on the lake.

Feeds and feeding

Obtaining high quality locally manufactured feed is the most serious constraint to commercial cage farming in Ghana. Local extruded feeds are not available. Tropo makes its own moist sinking feed on site and is working on obtaining a locally manufactured pellet. Meanwhile it is also importing high-quality extruded feed from Europe on a trial basis. The price of locally produced feed exceeds US\$400/tonne due to the relatively high price of imported raw materials. Feed conversion ratios (FCRs) using their own feed have been reported as 1.7 to 2.2 by Tropo, but these results are from ponds.

Diseases

No serious disease problems have been encountered, although external bacterial infections (*Columnaris*) and fish lice (*Argulus*) have been reported.

Socio-economic issues

The overall contribution of aquaculture to the economy of Ghana has not been separated from the contribution of fisheries. Livelihood opportunities identified are usually those related to marine and inland capture fisheries. Ten percent of the population is involved in the fishing industry from both urban and rural areas (IMM, 2004a; 2004b). In the case of Crystal Lake, the farm recruits labourers from a nearby village and about 15 workers live on the farm itself.

Production costs

Production costs should be below US\$1 per kg of whole fish for a large tilapia cage farm in Ghana. However, feed price is high at over US\$400/tonne and the local strain of *O. niloticus* is slow growing, according to some producers. With improved economies of scale, better growth performance and the availability of a quality extruded feed at a reasonable price, tilapia cage culture could become a major industry in Ghana.



Tropo Farms cages in Lake Volta, Ghana

Marketing and prices

Demand for tilapia is strong and growing in Ghana and its neighbour Nigeria, and farm-gate prices are reported as around US\$2.20/kg. The existing cage farms sell fresh whole or fresh gutted fish at the farm gate, but processing and marketing are expected to become more sophisticated as production volumes increase. Fish makes up around half of the country's animal protein consumption. Most fish products in Ghana are marketed locally and are fresh, making up for dwindling supplies from traditional capture fisheries. In the future, Crystal Lake plans to export fillets to the European Union (EU).

Employment

Tropo employs 40 staff in its pond and cage operations, while in 2005 Crystal Lake Fish was said to employ about 50 workers from the local village. Crystal Lake has demonstrated how aquaculture can help Africans fight poverty by creating employment and improve living standards

Lake Volta supports the livelihoods of 300 000 people, of whom nearly 80 000 are fishermen and 20 000 are fish processors or traders. There are 1 000 people involved in the aquaculture sub-sector, working mainly in pond culture (Mensah *et al.*, 2006).

Environmental issues

Lake Volta is a large freshwater hydroelectric reservoir fed by the Volta River. Water quality is good for tilapia culture, with consistent year-round warm temperatures. Environmental impact assessments (EIAs) are required before any cage culture is allowed in Ghana.

Pollution

Lake Volta is free of pollution and the water quality is exceptionally suitable for aquaculture

Escapes

There have been no reported escapes.

Ecological impacts

At Crystal Lake, effluent water from the fish hatchery is used to produce vegetables in a one-hectare plot that are distributed at no cost to local people.

*Institutional issues**Policies and legal frameworks*

Aquaculture is regulated by the Directorate of Fisheries (DoF), the Environmental Protection Agency, the Water Resources Commission and Local Assemblies. DoF is the lead agency vested with the administrative control of aquaculture. It is also the main institution responsible for planning and development in the aquaculture subsector. The Council for Scientific and Industrial Research (CSIR), an umbrella organization that supervises all research organizations, is mandated to carry out aquaculture research. Both agencies are funded by the government. Crystal Lake is privately owned and has obtained assistance from the International Finance Corporation (Africa Project Development Facility).

Training

There are several governmental institutions associated with aquaculture research and training. These include the Directorate of Fisheries, Kwame Nkrumah University of Science and Technology, the University of Ghana, the University of Cape Coast and Kwadaso Agricultural College. Part-time consultants are hired to train local supervisors and workers on fish-farm operations.

Non-governmental organizations (NGOs)

Several NGOs are involved in aquaculture but none are specifically promoting cage culture in Ghana.

Others

The World Bank has recently been involved in funding various aquaculture and fisheries projects.

Kenya

Commercial cage culture commenced in Kenya in 2005. There was a pilot cage site in the 1980s that is now defunct. The only existing fish cages are for tilapia (*Oreochromis niloticus*) and are operated by Dominion Farms Ltd. at Yala, near Lake Victoria in western Kenya.

Species-specific information

Nile tilapia is not indigenous to much of Kenya, but it is allowed for aquaculture in Lake Victoria because it was introduced there in the 1970s and has flourished. No further introductions of improved genetic material have been made. A selective breeding programme is currently underway at Yala aimed at improving the performance of the local stocks under farmed conditions.

Cage/pen type, size and number of cages

The existing cages are small (4 m³), intensively stocked, hapa-type wooden-frame cages placed in dammed areas and irrigation canals on Dominion's large new arable farm development in Yala. There are currently 30 such cages. Production nets are made locally in Kenya.

Stocking density

Harvest stocking density is expected to reach 200 kg/m³.

*Technical issues**Seed supply*

Tilapia fry are produced by Dominion Farms and juveniles are stocked into the cages from Dominion's own tilapia hatchery. The Fisheries Department has also been producing fingerlings of various species (mainly tilapia) in its fingerling production centres (Lake Basin Fry Production Centres).

Feeds and feeding

Obtaining good quality locally made feed is the most difficult constraint for commercial cage culture in Kenya. Raw materials are available locally at reasonable prices (Radull, 2005) but extrusion is currently not possible. Dominion plans to put in its own extruder. Feed cost is currently around US\$350/tonne in Kenya for a tilapia grower feed.



Pilot cages in Kenya, 1980s

Diseases

No disease problems have been reported.

Socio-economic issues

Aquaculture has recently become a source of healthy animal protein in many parts of Kenya. A number of subsistence-level fish farmers have turned into small-scale commercial fish farmers. Some of the commercial farmers who are starting production want to produce for both the local and export markets; hence in the next few years aquaculture is likely to make a significant contribution to both food security and foreign exchange earnings in Kenya.

Production costs

Production costs should be below US\$1 per kg of whole fish for a large tilapia farm in Kenya. However, the current poor economies of scale and poor feed quality raise the production costs.

Marketing and prices

Wild-caught tilapia and Nile perch (*Lates niloticus*) are available in Kenya at relatively low prices. However availability is declining because of over fishing and prices are rising steadily. Currently cage culture is targeting the local market for fresh and frozen whole fish and fillets.

Employment

Cage culture currently employs less than 10 people in Kenya.

Environmental issues

Lakes Victoria and Turkana offer great potential for cage culture. Water quality is good and water temperatures are warm all year round, but Kenya's eastern basin of Lake Victoria is relatively shallow and Lake Turkana is remote. These factors conspire to slow the development of cage culture.

Pollution

EIAs are required before any cage culture activities are allowed in Kenya.

Escapes

There have been no reported escapes.

Ecological impacts

The lakes have important capture fisheries that are communally owned and fished and, as in Uganda, there is some resistance to the idea of cage culture probably because this activity is either not known

or not well understood. This situation is likely to change within five years in Kenya.

*Institutional issues**Policies and legal frameworks*

Aquaculture is controlled by the Department of Fisheries in the Ministry of Agriculture and Rural Development. The department is responsible for the administration and development of fisheries and aquaculture, enforcement of fisheries regulations including licensing, collection and reporting of fishery statistics, market surveys, fish quality assurance and control of import and export of fish and fishery products (FAO, 2004a).

Training

Aquaculture training is available in Kenya on an occasional course basis. The Department of Fisheries, in collaboration with Moi University also undertakes aquaculture extension programmes. The Fisheries Department at Moi University has developed an aquaculture facility that will be used for training, research, demonstration and extension services in the region (FAO, 2004a). However, this is basically pond culture and the authors do not have direct information on cage culture training.

Non-governmental organizations

There are several NGOs involved in aquaculture in Kenya, although none are specifically promoting cage culture. The United States Agency for International Development (USAID) has been active in rural aquaculture development since the 1990s.

Malawi

Maldeco Ltd, an old and well established fishing and fish processing company that branched into cage culture in 2004 on Lake Malawi, has the only cage culture in Malawi. It grows *Oreochromis shiranus* (locally known as "chambo") in ponds (breeding and juveniles) and cages (grow-out to market size). Annual production is currently around 100 tonnes of whole fish, but Maldeco plans to produce 3 000 tonnes per annum within five years. It processes the fish on site near Mangochi and markets its products in Malawi as frozen whole fish and fillets.

Species-specific information

Oreochromis shiranus, *O. karongae* and red-breast tilapia (*Tilapia rendalli*) are indigenous in Lake Malawi. *Oreochromis niloticus* is not indigenous in

Malawi and current policy prohibits its introduction, as well as that of other exotic species.

Screening for suitable indigenous species for aquaculture has been an ongoing activity at Malawi National Aquaculture Centre since 1960, supported by various projects. The genetic improvement of indigenous species is also encouraged. Selective breeding of *O. shiranus* and *T. rendalli* with respect to their genetic performance is ongoing at Malawi National Aquaculture Centre (Chimatiro and Chirwa, 2005).

Cage/pen type and size and number of cages

Maldeco Ltd. is located in the Mangochi District, in the southern region of the country. It has square steel cages that are 6 m deep and imported from Europe. The cage site is about 200 m offshore and in deep water, with good currents caused by the start of flow from the lake into the Shire River. Production nets are nylon and imported from Europe.

Currently Maldeco has only one cage site containing 10 cages. Juveniles are transferred from ponds and grown up to 300 g or more, which is the size for whole tilapia most in demand in Africa.

Production level

Maldeco targets to produce about 3 000 tonnes per annum from both ponds and cages.

Market

There is high demand for farmed fish in the upland areas away from the lakes and in the urban centres (Chimatiro and Chirwa, 2005).

Technical issues

Seed supply

Maldeco breeds its own fry in earthen ponds at a site about 13 km from the cage site.

Feeds and feeding

Obtaining high quality locally manufactured feed is the most serious constraint for commercial cage farming in Malawi. Extruded feed is not available locally.

Diseases

No disease problems have been encountered.

Socio-economic issues

Aquaculture in Malawi contributes to food security in terms of increased access to food, increased food production, improved household capacity to acquire food and improved utilization of farmland for food

production (Jamu and Chimatiro, 2004). Fisheries resources contribute 4 percent to the nation's gross domestic product (GDP). Aquaculture accounts for about 2 percent of the nation's fish production (Chimatiro and Chirwa, 2005).

Production costs

Production costs should be below US\$1 per kg of whole tilapia for a large cage farm in Malawi. However, feed quality constraints, poor economies of scale and the research and development costs attached to developing new tilapias for cage culture all increase production costs. Actual production cost data were not available.

Marketing and prices

Maldeco markets its own fish as frozen whole fish and fillets to local supermarket chains and other outlets across Malawi. Prices are strong for whole tilapia in Malawi at over US\$2/kg.

Environmental issues

Lake Malawi is one of the great African lakes. Water quality is good for cage culture although, like Zimbabwe, Malawi has a three-month cold season (June through August) that slows fish growth rates. From time to time, fish kills are reported due to overturn in Lake Malawi.

Pollution

Maldeco carried out an EIA before commencing its cage culture operations.

Institutional issues

Policies and legal frameworks

Fisheries and aquaculture are controlled by the Department of Fisheries. Fisheries is an important sector of Malawi's economy despite dwindling of the natural fishery resources of the lake over the past 20 years. Aquaculture is a target development sector in Malawi for food security reasons, because fish is the preferred source of protein and because Lake Malawi offers great scope for cage culture. Also Malawi is targeting export of farmed fish once an industry is established.

The Malawi Department of Fisheries, in the Ministry of Mines, Natural Resources and Environmental Affairs, is responsible for the management and development of the aquaculture sector.

Maldeco leases areas of Lake Malawi from the government for mooring and operating cages.

Training

Aquaculture training is available in Malawi from the National Aquaculture Centre and Bundu College. The Malawi Gold Standard Aquaculture Production System is both a model for profitable small-scale commercial fish farming and a set of extension training materials for disseminating the model to fish farmers in suitable areas of Malawi. This was developed by a 10-person team of technical experts from the World Fish Centre (WFC), Chancellor College and the Department of Fisheries, with support from USAID/Malawi – see also <http://www.usaid.gov/mw/pressandinfo/aquaculture.htm>.

Non-governmental organizations

There are several NGOs involved in aquaculture in Malawi, but none are specifically promoting cage culture. WFC is working with Malawi's Fisheries Department to help farmers get much more out of their land, although this is generally subsistence or rural aquaculture. USAID has been supporting the fisheries sector in Malawi.

Uganda

Cage culture is a new activity in Uganda, having commenced in early 2006, that is being encouraged by the government as a development priority. This is because revenues from the dwindling wild capture fishery are a major source of foreign currency for Uganda and the government believes that aquaculture will supplement these revenues. There are currently only three pilot-scale cage sites on Lake Victoria, in the Entebbe and Jinja areas. Son Fish Farm Ltd, United Fish Packers Ltd and one other manage these, and form part of a three-year (to 2008) USAID-funded aquaculture development programme. Cage performance results are not yet known.

Species-specific information

Oreochromis niloticus is indigenous in many parts of Uganda, although it was introduced to Lake Victoria in the 1970s, where it has flourished. No further introductions of imported genetic material have been made. A selective breeding programme is currently underway in Uganda aimed at improving the performance of the local stocks under farmed conditions. Although available data suggest that growth rates are satisfactory, the introduction of improved strains from abroad is being considered because Uganda wishes to fast-track aquaculture development.

Cage/pen type and size and number of cages

The pilot-scale cage sites all have small intensively stocked cages of no more than 5 m³ each. There are about 15 such cages in Uganda at present. The sites are all inshore and in shallow (<5 m deep) areas. The cage frames are constructed locally using polystyrene floats and wooden walkways. Production nets are nylon and made in Uganda. Predator nets are being used as a precautionary measure, although the predation risk has not yet been determined.

Juveniles (10 g) are transferred from a government hatchery, which is to be supplemented by Son Fish Farm's commercial hatchery in Jinja. The fish are being on-grown to an export-oriented market size of 700 g and will be processed for export in any of Uganda's 17 EU-approved fish plants.

Stocking density

Stocking densities are 200 fish per m³ in the trial cages. Harvest stocking density is expected to reach 100 kg/m³.

Technical issues

Seed supply

Tilapia fry are produced by a government hatchery at Kajjansi (near Kampala) and are later expected to be produced by Son Fish Farm Ltd in Jinja.

Feeds and feeding

Obtaining good quality locally made feed is the most difficult constraint for commercial cage culture in Uganda. Raw materials are available locally at reasonable prices but extrusion is currently not available.

Diseases

No disease problems have been reported.

Socio-economic issues

Production costs

Production costs should be below US\$1 per kg of whole fish for a large tilapia farm in Uganda but this has not yet been demonstrated.

Marketing and prices

Wild-caught tilapia and Nile perch are available in Uganda at relatively low prices. However, availability is declining due to overfishing and prices are rising steadily. Currently cage culture is targeting the European market for fresh fillets, although the regional market, especially the Democratic Republic of Congo (DRC), Kenya and

Uganda itself, is likely to become important within five years.

Employment

Cage culture currently employs less than 20 people in Uganda but is expected to become a major activity within five to ten years.

Others

The lakes have important capture fisheries that are communally owned and fished, and there is some resistance to the idea of cage culture probably because this activity is new and not well understood. This situation is likely to change within five years in Uganda.

Environmental issues

Lakes Victoria, Kyoga and Albert, and the Nile River offer enormous potential for cage culture. Water quality is good and water temperatures are warm all year round because Uganda lies on the equator.

Pollution

EIAs are required before any cage culture activities are allowed in Uganda.

Escapes

There have been no reports of escapes to date.

Institutional issues

Aquaculture is controlled by the Department of Fisheries' Aquaculture Unit. Fisheries exports are Uganda's most important source of foreign currency. Wild catch has reached maximum sustainable yield and aquaculture is being vigorously promoted for food security reasons as well as to supplement volumes and secure future export revenues. The Competent Authority responsible for managing fish quality for export is the Department of Fisheries.

Training

Aquaculture training is available in Uganda in the form of occasional courses. The National Agriculture Research System Act has resulted in aquaculture research being opened up to other public or private institutions and individuals such as universities, consultancies and training institutions with the capability to carry out the required research. The Kajjansi Aquaculture Research and Development Centre remains, however, the core institute for strategic research in the country. On-farm trials and "farmer participatory research" have been

the norm. Aquaculture research has been funded by other organizations and individuals, including NGOs, universities, donor agencies and local governments, with students and farmers interested in understanding and solving issues of commercial aquaculture. The Fisheries Training Institute in Entebbe offers opportunities for research and diplomas and certificate training (Mwanja, 2005).

Non-governmental organizations

There are several NGOs involved in aquaculture in Uganda although none are specifically promoting cage culture.

Zambia

There are three small cage farms in Zambia operating on Lake Kariba in the Siavonga area that were established in the 1990s. None produces more than 10 tonnes per annum of whole fish. All farm *Oreochromis niloticus* and all produce their own fry and juveniles⁴.

Lake Harvest Aquaculture in Zimbabwe is currently investigating the establishment of a satellite cage farm in Zambia.

Species specific information

Oreochromis niloticus is not indigenous in Zambia, having been introduced in the 1980s for fish farming along the banks of the Zambezi. No further introductions of improved strains have been made since then and it is likely that there is a high level of inbreeding among farmed stocks. The introduction of improved strains is being considered.

Cage/pen type and size and number of cages

All three farms have square cages of around 40 m³, with wooden walkways. Production nets are nylon and are made in Zimbabwe or imported. No predator nets are used. The three cage sites are located in shallow (<5 m deep) inshore areas and are close enough to land to have walkways out to the sites. The total number of cages is around 30. Juveniles are transferred to the cages from pond sites, where they are on-grown to market size of around 350 g.

Stocking density

Stocking density at harvest is around 20 kg/m³.

⁴ Editor's note: According to Maguswi (2003) there were 4 commercial enterprises practicing cage culture on Lake Kariba. They each used 44 cages 6 m x 6 m x 6 m (216 m³) and 10 pens to grow *Oreochromis niloticus* and used pellet feed.

Production per cage per unit time

Average production for bigger cages (216 m³) volume is 3.5 tonnes (Maguswi, 2003).

*Technical issues**Seed supply*

The three cage farms each produce their own fry.

Feeds and feeding

A reasonably good quality locally manufactured extruded feed is available in Zambia but the price is high at over US\$400/tonne and not all the cage farmers use it.

Tiger Animal Feeds is the largest specialized animal feed producer in Zambia. While poultry, pig and dairy feeds constitute the bulk of its production, the company is also involved in formulating and making fish and crocodile feeds. The company benefits from highly qualified staff, feed-mill equipment and agreements with a European company for fish feed. Production levels vary with demand, with poultry feeds topping the list. The company has focused on developing formulas for various feeds to ensure constant product quality and consistency. All feeds are formulated with 95 percent of high quality and laboratory-checked local raw ingredients (i.e. wheat flour, maize meal, cooking oil) (FAO, 2004b; Bentley and Bentley, 2005).

Diseases

No disease problems have been reported.

Socio-economic issues

Fish production is important to the national economy and contributes significantly to employment, income and food production. It is estimated that up to 55 percent of the national average protein intake is from fish. The importance of fish in Zambian household food expenditure increases in proportion with increasing levels of poverty. The contribution of fish to gross domestic product (GDP) is estimated to be 3.8 percent. This estimate is based largely on the contribution from capture fisheries, because production from fish culture is not regularly reported (Maguswi, 2003).

Production costs

Production costs should be below US\$1 per kg of whole fish for a large tilapia farm in Zambia. However the relatively high cost of feed, as well as poor existing economies of scale make profitability marginal.

Marketing and prices

The three existing cage farms sell their fish at the farm gate in fresh form into the Zambia market. There are supply outlets in the major cities. Demand and prices are strong in Zambia.

Employment

No figures are available.

Environmental issues

Lake Kariba is a 5 000 km² freshwater hydroelectric dam-lake fed by the Zambezi River. Water quality is good for cage culture, although a three-month colder season (June through August) retards fish growth.

Pollution

An EIA is required before any cage farm operation may commence in Zambia.

Escapes

There have been no reports of escapes.

*Institutional issues**Policies and legal frameworks*

Aquaculture in Zambia is controlled by the Department of Fisheries under the Ministry of Agriculture and Cooperatives. In order to obtain a clear picture of the aquaculture development objectives, a National Aquaculture Development Strategy (NADS) was prepared in 2004. Zambia is a fish-eating nation and cage and pond culture is being promoted. Lake Kariba offers great industrial expansion opportunities.

Training and research

There is little formal training in aquaculture in Zambia. There are five aquaculture research centres in the country that are administered by the



One of three cage farms in Lake Kariba, Zambia



Wooden cages in Lake Kariba, Zambia

Department of Fisheries. These are the only centres in the country where aquaculture research is carried out. Programmes are drawn up in close collaboration with extension officers and farmers. The centres are supported through government grants and donor agencies. Monthly, quarterly and annual reports are submitted for follow-up actions, review of activities and verification of results. The Natural Resources Development College (NRDC) in Lusaka Province offers a three-year diploma course in fisheries that includes aquaculture. The Kasaka Fisheries Training Institute in Kafue (Lusaka Province) offers a two-year certificate course in fisheries and aquaculture for technicians who expect to be in regular contact with fish farmers (Maguswi, 2003).

Others

The Rural Aquaculture Promotion project (RAP) is primarily the fruit of a collaborative effort between the Zambian Department of Fisheries (DOF) and the United States Peace Corps since around 1996. As part of efforts to develop aquaculture, the Government of the Republic of Zambia requested the Japanese government to support service training for fisheries officers via the Japan International Cooperation Agency (JICA).

Zimbabwe

Zimbabwe's only cage culture operation is Lake Harvest Aquaculture (Pvt) Ltd (Lake Harvest). Established in 1997 at Lake Kariba in northern Zimbabwe, Lake Harvest is a modern, vertically integrated farm that grows *Oreochromis niloticus* in ponds (breeding and juveniles) and cages (grow-out from 10 g to market size). Annual production is around 3 500 tonnes of whole fish. Lake Harvest processes its fish on site and markets its products in Europe, mainly as fresh fillets, and in the region as frozen fillets and whole fish. Factory by-products

are sold locally for human consumption and used by Lake Harvest's own crocodile farm.

Species-specific information

Oreochromis niloticus is not indigenous in Zimbabwe and was introduced in the 1980s by the government for fish farming along the banks of the Zambezi. No further introductions of fresh genetic material have been made since then and there is considered to be a high level of inbreeding among farmed stocks, although this has not been verified. The introduction of improved strains from abroad is being considered and selective breeding is, meanwhile, in progress.

Cage/pen type and size and number of cages

Lake Harvest uses plastic circle cages modified from the European design for Atlantic salmon. It makes its own cages, which are 1 000 m³, although trials with smaller cages are underway. Production nets are nylon and made on site from imported net panels. Each cage has a predator net made from polyethylene trawl net that is required because Lake Kariba is home to predatory tiger fish (*Hydrocynus* spp.) and crocodiles. Lake Harvest has trained an in-house dive team that dives on the nets to check for holes, escapes and net and mooring integrity.

Each cage site consists of 14 cages. There are six sites, spaced at least 1 km apart, and a total of 84 cages. Water depth at the cage sites varies between 20 and 50 m. Juveniles weighing 10 g are transferred from Lake Harvest's ponds to "juvenile cages" where they are on-grown to 80 g. They are then transferred to "production cages" and grown to a market size of around 600 g, an average body weight providing a good blend of fish for filleting and the whole fish trade.

Stocking densities

Stocking densities are 250 juveniles per m³ and 80 growers per m³. Harvest stocking density is up to 45 kg/m³.

Technical issues

Seed supply

Lake Harvest produces its own fry (up to 5 million per month) and has developed a selective breeding programme to improve growth performance. The company overproduces fry and selects out slower growers at 3 g. New genetic material is being sought. Lake Harvest also sells fry to third parties for dam-lake stocking programmes, although demand is low in Zimbabwe at present.

Feeds and feeding

Obtaining high quality locally manufactured feed is the most difficult constraint for commercial cage farming in Zimbabwe. Problems with local availability of raw material, high price and product quality have been experienced since Lake Harvest's start-up. Extrusion is available but of poor quality. Price varies between US\$275/tonne and US\$400/tonne delivered for a tilapia finisher. FCRs of 2.1 to 2.4 have been reported.

Diseases

No serious disease problems have been encountered, although some fish show skin lesions from time to time that are infected with *Aeromonas hydrophila*. This problem is being managed.

Socio-economic issues

Production costs

Production costs should be below US\$1 per kg of whole fish for a large tilapia farm in Zimbabwe. However hyperinflation and a difficult economic environment have raised production costs, making profitability marginal.

Marketing and prices

Lake Harvest has its own sales and marketing office in Luxembourg that sells mainly fresh fillets to major distributors across northern Europe. The main outlets are fresh fish counters and pre-packs in supermarket chains. Lake Harvest also sells about 45 percent of its production as frozen fillets and whole fish in Zambia, Zimbabwe, Botswana, Malawi and South Africa. Demand is growing in these markets and prices are firming.

Employment

Lake Harvest employs about 200 people in its fish farm operations; 90 employees are in cage operations while the remainder is involved in pond operations, net making and mending, maintenance and administration.

Environmental issues

Lake Kariba is a 5 000 km² freshwater hydroelectric dam-lake fed by the Zambezi River. Water quality is good for cage culture, although a three month colder season (June through August) slows fish growth.

Pollution

Lake Harvest's operation has not resulted in any adverse impact on the lake environment, which the

independently managed Environmental Monitoring Program can confirm.

Escapes

Lake Harvest uses a double netting system on its cages to reduce the chance of fish escaping directly into the lake.

Ecological impacts

Lake Harvest carried out a detailed EIA before installing cages. It now has biannual environmental audits done by the University of Zimbabwe, the results of which are submitted to the relevant authorities. Lake Kariba is in a national park operated by Zimbabwe's Parks and Wildlife Authority. No significant environmental change has been identified by the audits over the nine years that cages have been operated.

An increase in the wild fishery catches around the cages has been noted in recent years, as well as an increase in the relative abundance of *Oreochromis niloticus* in the eastern basin of the lake where the cages are located. This could be due to natural stocks of *O. niloticus* being attracted to the fish feed in the area.

Institutional issues

Policies and legal framework

Aquaculture is ultimately controlled by the Parks and Wildlife Authority, although public health issues in fish processing are managed by the Department of Livestock and Veterinary Services. Aquaculture is an emerging sector in the Zimbabwean economy but is not well known by the institutions despite its high potential for expansion on Lake Kariba and in the Zambezi Valley. Lake Harvest leases areas of Lake Kariba from the Parks and Wildlife Authority for mooring and operating cages.

Training

There is no training in aquaculture in Zimbabwe besides on-the-job training at Lake Harvest.

Non-governmental organizations

There are no NGOs involved in cage culture in Zimbabwe.

THE WAY FORWARD

Socio-economics and marketing

National plans and targets

A recent technical workshop concluded that cage aquaculture represents an important development opportunity for many African countries, but will

require an effective policy framework to ensure that structural constraints to development are overcome and that development is equitable and sustainable. Successful development of cage aquaculture will depend on many factors. The challenge for both government and the private sector is to work together to address these issues comprehensively at the farm, local, national and regional levels (Halwart and Moehl, 2006).

Commercial aquaculture is developing at a very slow pace in all the countries listed. There is growing interest in cage culture but support from investors is needed. There is a need to improve the development and application of policies, strategies, and legal and regulatory frameworks to enable not only cage culture but all types of commercial aquaculture in sub-Saharan Africa.

During the last five years, there has been a marked emergence of commercial aquaculture and this appears to be related to increasing fish price (Hecht, 2006). The FAO National Aquaculture Sector Overviews from sub-Saharan Africa reveal that the commercial sector contributes approximately 65 percent to the total fresh and brackish-water fish production, while nearly 100 percent of mariculture production is from the commercial sector (Awity, 2005; Chimatiro and Chirwa, 2005; Maguswi, 2003; Mwanja, 2005). The potential for cage culture in inland waters such as Lake Kariba, Lake Malawi and Lake Victoria has been proven and production is set to grow.

Mariculture of prawns in Mozambique, oysters in South Africa and Namibia and abalone in Namibia has been established and has laid a foundation for increased production and the commercialization of other species.

In Zimbabwe, hyperinflation and a difficult economic environment has raised production costs, making profitability and expansion of its cage culture operations difficult.

In order to provide a sound platform for commercial aquaculture, public-sector support is required for manpower training, research and development, technology development and transfer, zoning of aquaculture areas, regulatory and product certification frameworks, facilitating environmental assessment processes for key projects, species screening and selection, access to long-term credit and coordinated public sector decision making.

Production for domestic consumption or export

Due to the high cost of production in most cage-culture systems, most commercial farms would like

to export their products to international markets such as the European Union (EU) where they are likely to obtain better profit margins. For example, Lake Harvest exports fillets to the EU and Namibian oyster farmers export to the Far East. Because of their low volumes and intensity of production, small-scale cage farmers usually target domestic markets.

Existing fillet processing plants as in Uganda, Ghana, Tanzania and Malawi act as an exporting advantage.

There is also growing interest in aquaculture products within the region and demand is said to have surpassed supply. Countries with better or growing economies (e.g. South Africa, Nigeria and the DRC) are slowly becoming major markets for aquaculture products within the region.

Pricing and value addition for aquaculture products

Tilapia has recently been introduced on world markets, mainly as an alternative to marine whitefish and has become a popular food fish, not only in developing countries but also in the developed world. The global tilapia market is expanding rapidly, with the United States being the most important market. Because of tilapia's ability to adapt to the environment and the relatively simple way it can be farmed, many newcomers are entering the industry and international competition is growing.

Processed product forms are usually marketed as fresh fillets, super-chilled fillets, frozen fillets and whole/round/gutted fish.

Employment and gender issues

Since cage culture is still an emerging activity in sub-Saharan Africa, employment is still very low, but has a great potential for growth.

Women are increasingly involved in technical light-weight production jobs such as net mending and are also very active as processing hands in many processing plants and in land-based hatchery operations. However, offshore duties are still dominated by men.

Technical and environmental issues

Site and choice of water body

Inland water bodies in all the mentioned countries are ideal for cage culture, as they have suitable water quality and temperatures.

The EIA should address issues on the physical environment and identify the desirable places to

locate the cages within the lakes and reservoirs. Lake Harvest Aquaculture has its own practical and robust environmental monitoring programme. All farmers need to develop routines for adjusting the environmental impact to the local carrying capacity.

Some of the cage sites studied in this paper conducted an EIA prior to setting up the cage farms, which shows that environmental issues are taken seriously from the beginning. The cages have been set up in areas free from aquatic vegetation and with good current flow, as currents help to remove sediments and replenish oxygen.

Special care should be taken when planning for cage culture in inland water bodies that are also resources for other users. Lake Victoria is home to commercially viable stocks of Nile perch that provide a source of livelihood for many artisanal fishermen. Lake Kariba and Lake Malawi contain tourist attractions; hence cage culture should be in harmony with these other operations.

Cage-culture projects should be designed to work in close harmony with the local environment and need to follow the stipulated operational regulations in order to be a sustainable business. They should comply with all applicable environmental laws and regulations, strive to attain international standards and always maintain a constructive dialogue with legislative authorities.

Waste control and effluent management

Cage-farm wastes are usually in the form of uneaten feed and fish faeces. Feed is usually the major input to the cage-farm operations. Feed suppliers should aim to meet rigorous quality standards to ensure that feed wastage is kept to a minimum. Many operators now use extruded fish feed diets of improved digestibility to maximize assimilation and minimize loss to the environment. Use of floating feed is vital for cage-farm operations.

Mooring cages in deep waters and where good currents flow results in cage wastes being easily flushed away, thereby avoiding organic build up under the cages.

Species selection and aquatic animal movements

Lucas and Southgate (2003) define the choice of aquaculture species as the balance between the biological knowledge and economics of the species. It is interesting to note most cage sites visited grow Nile tilapia (*O. niloticus*), which has become one of the most commercially important species of cultured

freshwater fishes. In 2004 global production of Nile tilapia constituted some 82 percent of the total production of all tilapias.

Nile tilapia is a good fish for warm-water aquaculture, as it is easily spawned, uses a wide variety of natural foods as well as artificial feeds, tolerates poor water quality and grows rapidly at warm temperatures. These attributes, along with relatively low input costs, have made tilapia the most widely cultured freshwater fish in tropical and subtropical countries today.

Consumers like tilapia because of its firm flesh and mild flavour, hence markets have expanded rapidly in the United States, the EU and Asia during the last 10 years, mostly based on foreign imports.

Feeds and feed management

Availability of a quality feed at a competitive cost is one of the biggest problems in commercial aquaculture in sub-Saharan Africa. In southern Africa there are very few dedicated aquaculture feed manufacturing companies. AquaNutro in South Africa is the only dedicated aquaculture feed manufacturer providing 80 percent of South African aquaculture feeds. Tiger Animal Feeds in Zambia is the largest specialized aquafeed producer that is also capable of producing floating feeds (Bentley and Bentley, 2005).

Cage farmers need to be trained or well informed in feed management practices, feed formulations, and feed manufacturing and distribution trends. They need a better understanding of daily feed rates and feed tables, practical feeding methods (use of hand feeding and demand feeders) and the fish feed response.

Fish disease and health management

Fish diseases were not a major threat at any of the cage sites visited. Most fish diseases are caused by overcrowding, malnutrition, unfavourable water quality or poor handling techniques. Thus good husbandry practices should be adopted to avoid occurrences of disease (e.g. use of known broodfish stocks for initial fry production). Furthermore a consistent fish health monitoring programme that includes preventive, regulatory and disease control measures is needed. Coordination with international and national aquatic animal health organizations is also vital should there be outbreak of serious fish disease.

CONCLUSIONS

Although aquaculture is not a traditional activity in Africa, sub-Saharan Africa offers enormous potential for cage culture in fresh, brackish and marine waters. Some countries offer more potential than others, especially those with large, warm (>25 °C) freshwater resources (e.g. the great lakes region and West Africa). Freshwater cage culture has begun to develop in some countries over the past 20 years but there are only a handful of successful operations (e.g. farms in Ghana, Kenya, Malawi, Uganda, Zambia, and Zimbabwe) and the scale is still small except in the case of Zimbabwe. Marine and brackishwater cage culture has not yet developed at all in the region.

General aquaculture development issues

The technical problems facing cage culture in sub-Saharan Africa are, in order of importance, lack of good sites with potential for industrial-scale expansion and year-round warm (>25 °C) water temperatures; lack of good quality, fast-growing tilapia and catfish fry; lack of good quality extruded feed at an affordable price (i.e. US\$350/tonne and below for tilapia); and lack of access to export and higher value markets, which is currently limited due to poor logistics, poor infrastructure and/or institutional barriers (e.g. many countries are not approved to export fish into the EU).

A key problem for cage culture in sub-Saharan Africa is that *Oreochromis niloticus* is not allowed for introduction in many countries where it is not indigenous and, even where it is indigenous, better performing strains are often not allowed to be imported. This is usually because of concerns about escapes and their effect on genetic biodiversity. The problem with this restriction is that *O. niloticus* (especially the GIFT strains developed over twenty years or so in Asia) is well known to be the best performing tilapia for aquaculture, making it difficult to be cost efficient with other species and lesser performing strains. Other tilapia species also present a marketing hurdle for exports outside Africa because *O. niloticus* is now the best known of the tilapias in Asian, EU and United States markets.

Socio-economic issues

Socio-economic problems constraining the development of cage culture in sub-Saharan Africa include relatively high production costs (often >US\$1 per kg of whole tilapia at the farm gate) due to poor economies of scale and expensive feed,

and the traditionally low price and quality of fish in many countries. This has led to difficulty in penetrating local and regional markets with higher price/higher quality cage-farmed fish, particularly given the poor cold chain distribution in many countries, which leads to the rapid loss of fish quality in local retail outlets. Drying and salting tends not to add value to higher quality farmed fish and so is not appropriate for cage-farmed fish.

Lack of capital, especially working capital.

In many countries cage-culture operations need to be vertically integrated from fry production through marketing, because of a lack of reliable suppliers, fish hatcheries, fish processors and other links in the value chain. This requires individual company investments to be large (often more than US\$8 million if processing is also included), in order to achieve economies of scale. There are very few investors willing to invest such sums in aquaculture in African countries because aquaculture is considered a technically risky activity offering medium to long-term returns.

Training

Few countries in sub-Saharan Africa offer training in aquaculture at a practical hands-on level. Farms have to do their own on-the-job training, which is time consuming and a significant cost for investors, who can choose to invest in other continents. There is too much “re-inventing of the wheel” by fish farmers in Africa because of a lack of technical training in aquaculture as well as a lack of exposure of fish farmers in the region to successful cage operations.

Institutional issues

The main institutional problem facing cage culture in sub-Saharan Africa is that aquaculture is usually controlled by fisheries departments and sometimes there is no dedicated aquaculture unit within those departments. The problem is that aquaculture is an entirely different activity to fisheries, requiring different disciplines that are more akin to intensive agriculture such as poultry farming than to capture fisheries. There is often a lack of understanding of aquaculture by fisheries personnel in some countries and this can lead to aquaculture not getting the promotion and support it needs at the policy-making levels.

There are few successful demonstrations of cage aquaculture in sub-Saharan Africa, and this leads to a lack of understanding of the sector at the policy-

making levels in some countries. Consequently some governments find it difficult to promote aquaculture successfully.

Few countries in sub-Saharan Africa have identified aquaculture development zones and even fewer have the necessary legal frameworks to accommodate investments in cage culture readily (e.g. leases for cage sites).

RECOMMENDATIONS

The following recommendations are made towards the promotion and development of freshwater cage culture in sub-Saharan Africa:

Technical recommendations

- The use of *Oreochromis niloticus* and its improved strains (especially GIFT) needs to be reviewed across sub-Saharan Africa. Unless restrictions on the use of this species are relaxed, Africa may find it difficult to be competitive in cage tilapia culture. There are already examples of tilapia farmed in Asia entering inland African markets at prices lower than local production costs. Those countries that continue to ban the use of *O. niloticus* should consider investing properly in the selective breeding and husbandry of local strains.
- Breeding centres need to be established in East, West and Central/Southern Africa. Selective breeding should not be left to individual farms, as good breeding requires a higher degree of expertise than individual farms can afford. The centres should focus on the selective breeding of tilapia and catfish, and sell or make available their improved strains to multiplier hatcheries.
- An aquaculture training centre(s) should be established in the region that offers practical hands-on training at the supervisory and management levels.
- The sector needs support for the development of locally made, high quality extruded feeds. Local raw materials should be used whenever possible

in order to avoid the high road transportation costs seen in most African countries.

- The sector needs support in the form of expertise in nutrition, husbandry, and disease identification and management.

Socio-economic recommendations

- There is a need to encourage larger and more experienced aquaculture investors to participate in the sector, as these would provide solid foundations for the growth of industrial-scale cage-aquaculture development in sub-Saharan Africa. Big investors will bring with them, among other things, new hatcheries, technical expertise, improved growth performance, feed quality improvements, economies of scale, routes to market, processing, etc.

Environmental recommendations

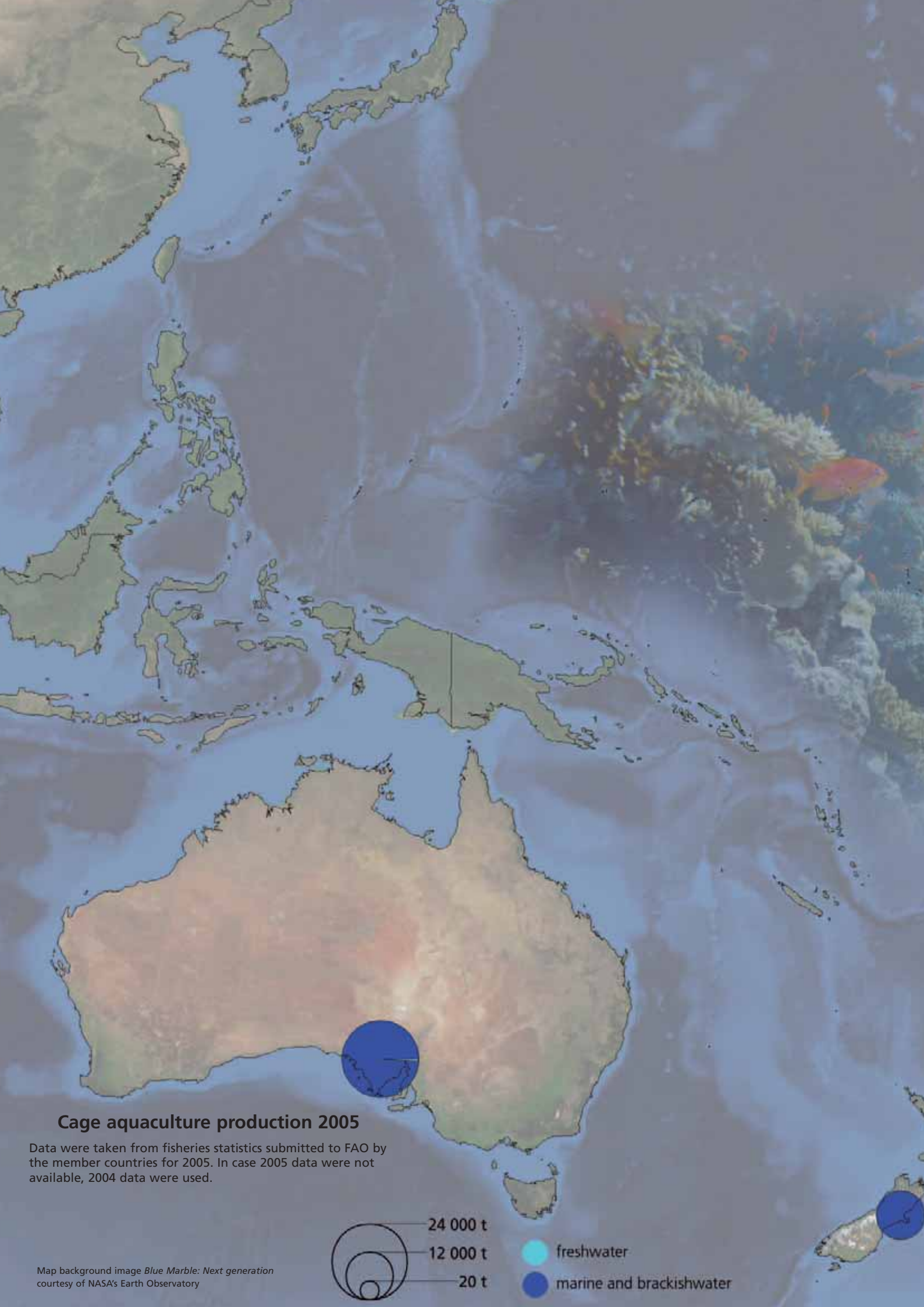
- Aquaculture zones should be established. This will simplify the investment process, as sites will already have been identified within such zones, EIAs already carried out, leases simplified, etc.
- Environmental monitoring and advice should be provided as a service to cage farmers by the relevant authorities.

Institutional Recommendations

- An enabling environment needs to be created that is investor friendly. Aquaculture departments should be created that provide one-stop shops for possible cage culture investors.
- Local and international banks should be educated in aquaculture investment.
- Restructuring of government support should be considered; duties and tariffs on imported aquaculture equipment and feed should be reviewed so as to encourage investment in cage culture.
- In some countries, public awareness campaigns should be carried out so that the way is eased for the introduction of cages in certain water bodies (e.g. Lake Victoria).

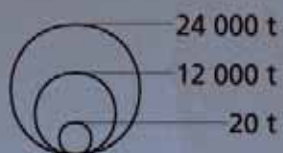
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Cage aquaculture production 2005

Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.



freshwater

marine and brackishwater

A review of cage aquaculture: Oceania





A review of cage aquaculture: Oceania

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A review of cage aquaculture: Oceania. In M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 208–231. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

ABSTRACT

Cage aquaculture is little practised in the Oceania region, compared with other regions. Total production for the Oceania region was only about 24 000 tonnes for 2003 (based on FAO production statistics which likely underestimate regional production). Most of this production is from Australia and New Zealand.

Major commodities for cage aquaculture production in the Oceania region are:

- Southern bluefin tuna (*Thunnus maccoyii*) which is farmed exclusively in South Australia.
- Salmonids, principally Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) in Australia (Tasmania and South Australia) and Chinook salmon (*Oncorhynchus tshawytscha*) in New Zealand.
- Barramundi (*Lates calcarifer*) which is farmed in sea cages and in cages in freshwater and brackishwater ponds in Australia (Queensland, Northern Territory, Western Australia), Papua New Guinea and French Polynesia.
- Yellowtail kingfish (*Seriola lalandi*) in Australia (South Australia).

In addition, there is some production of snapper (*Pagrus auratus*) and mullet (*Argyrosomus hololepidotus*) in Australia and of tilapia (*Oreochromis niloticus*) and carp (*Cyprinus carpio*) in Papua New Guinea.

Some of the reasons for the limited development of cage aquaculture in the region are:

- In Australia, there is considerable community concern regarding the impacts of large-scale aquaculture. This concern has in some cases been exacerbated by effective lobbying by conservation groups, to the detriment of the reputation of aquaculture.
- In New Zealand, a moratorium on further development of marine aquaculture since 1991 has effectively halted industry growth.
- Many Pacific Island countries have low population bases and relatively poor infrastructure to support anything but basic cage aquaculture. In addition, transport links to targeted export markets are relatively poorly developed and transport costs are high.

A major feature of cage aquaculture development in Australia and New Zealand, compared with many other regions, is the strong emphasis on environmental management and reduction of environmental impacts. This in turn reflects the strong emphasis on maintaining high environmental quality in both Australia and New Zealand, if necessary at the expense of industry development.

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BACKGROUND AND AIM OF STUDY

This study was commissioned by the Food and Agriculture Organization of the United Nations (FAO) as one of a series of reports on the global status of cage aquaculture to be presented at the Second International Symposium on Cage Aquaculture in Asia held in Hangzhou, China, 3–8 July 2006.

This paper reviews the current status of cage aquaculture in the Oceania region, identifies a number of issues that impact on cage aquaculture development in that region, and summarises the needs to sustainably develop cage aquaculture in the region.

HISTORY AND ORIGIN OF CAGE CULTURE IN THE REGION

Cage aquaculture is little practised in the Oceania region, compared with other regions. Total production for the region was only around 24 000 tonnes for 2003, based on FAO data (FAO, 2006), although these data appear to underestimate total production. The bulk of production is from Australia and New Zealand.

Cage aquaculture commenced in the region in the 1980s with the development of Atlantic salmon (*Salmo salar*) aquaculture in Tasmania. Atlantic salmon were first introduced into Tasmania by Acclimatization Societies in the 1800s, these introductions were unsuccessful (Love and Langenkamp, 2003). More recently, Atlantic salmon were introduced from Canada to New South Wales in the mid-1960s for stocking purposes. In the late 1960s the Commonwealth government banned all imports of salmonid genetic material in order to prevent exotic diseases entering Australia. Tasmania acquired eggs from the New South Wales hatchery in the early 1980s and commercial production in Tasmania commenced in the mid-1980s (Love and Langenkamp, 2003).

In New Zealand, chinook salmon (*Oncorhynchus tshawytscha*) were successfully introduced by the Marine Department in the hope of starting a commercial rod fishing and canning industry. An initial attempt to introduce chinook salmon was made for a recreational fishery by the Hawkes Bay Acclimatisation Society in 1875 but this and several other attempts in various parts of New Zealand were unsuccessful. Chinook salmon were eventually introduced via a hatchery on the Hakataramea River, between 1901 and 1907 which sourced fish from the Baird Fish Station on the McLeod River, a tributary of the Sacramento River in California.

Subsequently Chinook salmon became established with self-sustaining returns to rivers on the east coast of the South Island and to a minor extent on the west coast of the South Island. Further imports of live salmon into New Zealand have not been permitted for over 50 years.

Interest in salmon farming in New Zealand grew steadily during the 1970s as part of a worldwide trend towards commercial aquaculture. New Zealand's first commercial salmon farm was established in 1976 as an ocean ranching venture at Waikoropupu Springs in Golden Bay, and made its first sales of freshwater-reared salmon in 1978. Other early ocean ranching farms included an ICI/Wattie joint venture on the lower Clutha River, and larger-scale hatcheries on the Rakaia River and the nearby Tentburn coastal site. The first sea-cage salmon farm was established in 1983 in Stewart Island's Big Glory Bay by BP New Zealand Ltd. This was soon followed by the development of farms in the Marlborough Sounds.

Southern bluefin tuna (*Thunnus maccoyii*) aquaculture began in Australia in 1990 and by 2002 had developed into the largest farmed seafood sector in Australia (Ottolenghi *et al.*, 2004). The development of southern bluefin tuna aquaculture was driven by declining catches and a desire by fishers to value-add the limited volume of product available by growing the fish in pens. In the early 1960s the annual global catch of southern bluefin tuna reached 80 000 tonnes. However, by the mid-1980s, with catches falling and numbers of mature fish declining, it was apparent that stock management and conservation was needed. From the mid-1980s Australia, Japan and New Zealand, the main nations fishing the species at the time, began to apply quotas as a management and conservation measure to enable stocks to rebuild (Love and Langenkamp, 2003). Individual transferable quotas were introduced into the Australian tuna industry in 1984 and by 1987 South Australian quota holders had bought up most of the Australian quota. In 1988 the initial Australian quota of 14 500 tonnes was cut to 6 250 tonnes, and then in 1989 to its current level of 5 265 tonnes (Love and Langenkamp, 2003).

This large reduction in tuna supply prompted a move away from canning to value-adding through farming with a focus on the Japanese sashimi market. The first experimental farm was established at Port Lincoln in 1991 under a tripartite agreement between the Australian Tuna Boat Owners' Association of Australia, the Japanese Overseas

Fisheries Cooperation Foundation, and the South Australian government. Over the past decade the farmed sector has grown to the point where around 98 percent of the Australian southern bluefin tuna quota is now farmed (Love and Langenkamp, 2003; Ottolenghi *et al.* 2004).

Because of Australia and New Zealand's traditional linkages with Europe and the United Kingdom, much of the development of cage aquaculture has utilized technology adoption from European aquaculture. This also reflects the high labour costs in these countries, and hence a need to mechanize as much as operationally possible to reduce the labour component of production costs.

THE CURRENT SITUATION

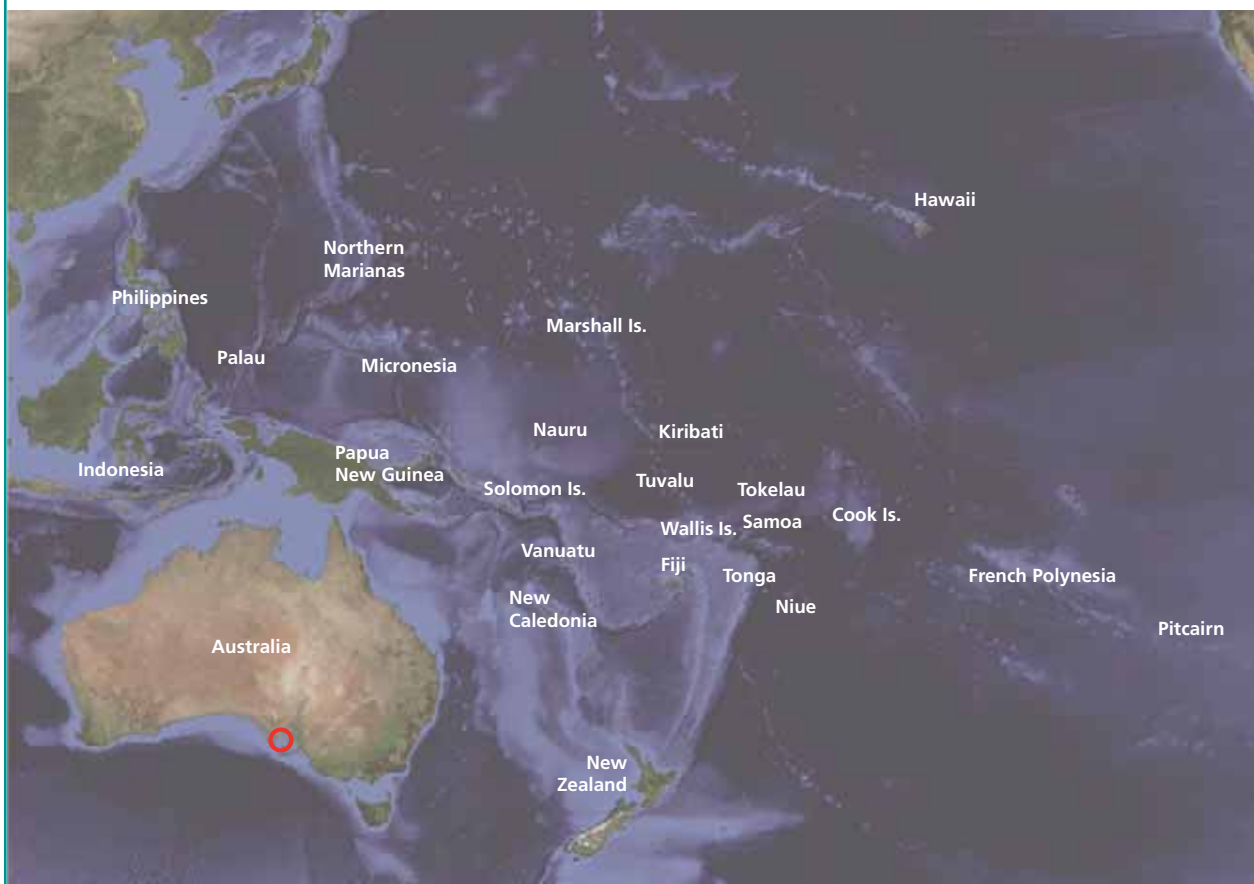
Southern Bluefin Tuna

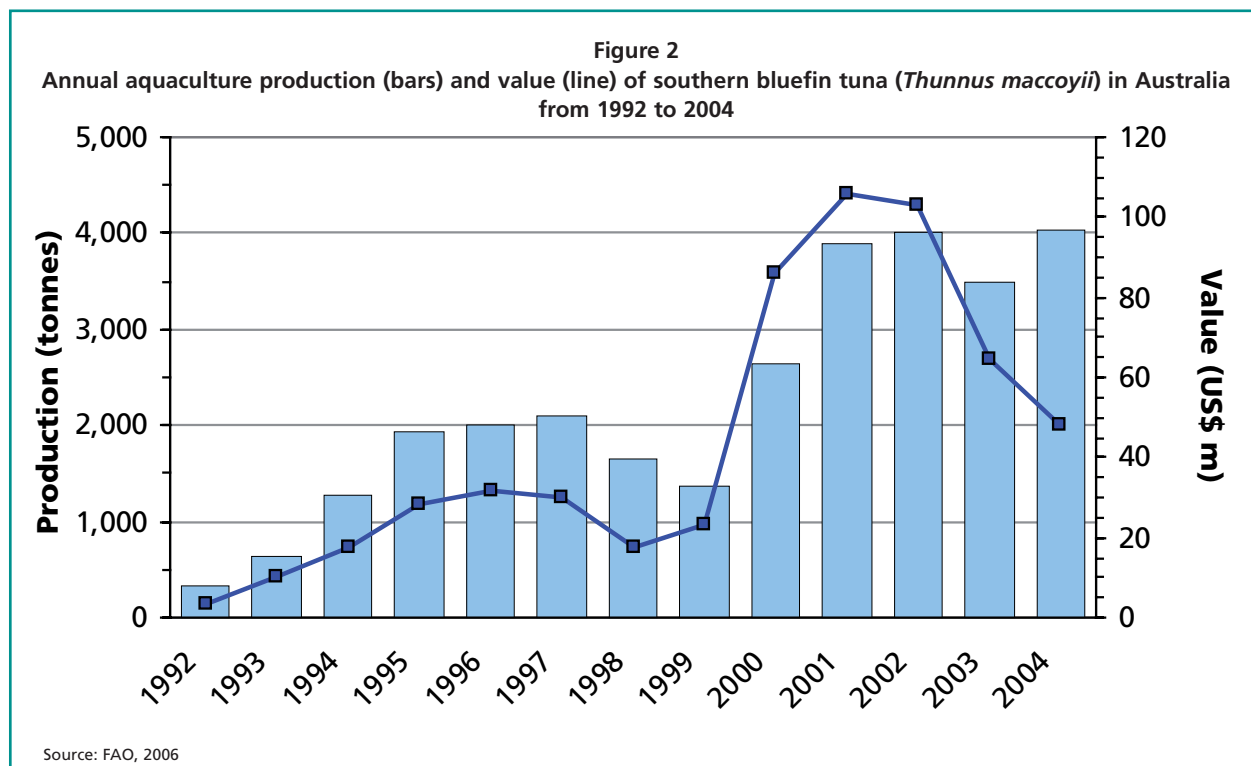
Southern bluefin tuna (*Thunnus maccoyii*) aquaculture is limited in geographical extent to South Australia, specifically the Port Lincoln area of the Eyre Peninsula. Although one company proposed to build a sea cage farm in Western Australia, this has not yet gone ahead (O'Sullivan *et al.*, 2005) (Figure 1).

Initially, the sea cage sites were located relatively close inshore, within Boston Harbour at Port Lincoln. However, a mass mortality event in 1996 resulted in the loss of around 1 700 tonnes of tuna valued at AUD 40 m (US\$30 million). Possible causes for the mortality event include: asphyxiation due to fine sediments that were stirred up during a storm, and the impacts of toxic micro-algae. Subsequently, the tuna cages were moved further offshore into deeper water where potential sediment impacts would be lessened (Ottolenghi *et al.*, 2004; O'Sullivan *et al.*, 2005).

FAO data record production of 3 500–4 000 tonnes for 2002–2004 (Figure 2). EconSearch (2004) provide figures of 5 300 and 5 400 tonnes for 2001–02 and 2002–03 respectively (Table 1), while O'Sullivan *et al.* (2005) note that 'recently production has stabilised to slightly over 9 000 tonnes'. The value of production has recently been around AUD 250 m (US\$190 million) per annum, making this the most valuable aquaculture sector in Australia. However, in 2003–04 farm gate prices fell from over AUD 28 (US\$21)/kg to around AUD 16 (US\$12)/kg due to a strong

FIGURE 1
Map of Oceania showing location of southern bluefin tuna cage culture sites





Australian dollar and increased competition from overseas product, reducing the value of production to AUD 151 m (O'Sullivan *et al.*, 2005).

TABLE 1
Production and value of farmed southern bluefin tuna from South Australia, 1996–97 to 2002–03 (EconSearch, 2004). The low output in 1995–96 was due to a large-scale mortality during 1996.

	Into farms		Farm output
	Whole Weight	Processed Weight	Farm Gate Value
	'000 kg	'000 kg	AUD m
1995-96	3,362	1,170	29.3
1996-97	2,498	4,069	91.5
1997-98	3,610	4,927	120.7
1998-99	4,991	6,805	166.7
1999-00	5,133	7,750	240.0
2000-01	5,282	9,051	263.8
2001-02	5,296	9,245	260.5
2002-03	5,409	9,102	266.9

Southern bluefin tuna are caught in the Great Australian Bight (Southern Ocean) under a strict international quota system. The juvenile tuna are around 120 cm total length and weigh 15–20 kg (PIRSA, 2000). The fish are caught in purse seine nets and transferred to a 'towing cage'. The towing cage is towed slowly (1–2 knots) by vessel back to the grow-out cages – a journey of up to 500 km.

The tuna are then transferred to the grow-out cages.

Tuna net cages range from 30 to 50 metres diameter and 12 to 20 metres depth. The inner nets are generally 60–90 cm mesh size. If an outer predator-exclusion net is used, it is generally 150–200 cm mesh size. Tuna are stocked at around 4 kg per cubic metre, or around 2 000 fish per cage (PIRSA, 2000; Ottolenghi *et al.*, 2004).

Southern bluefin tuna are fed pilchards and mackerel once or twice daily, six or seven days per week (PIRSA, 2000). Food conversion ratios are high: around 10–15:1 (Ottolenghi *et al.*, 2004). Attempts to develop cost-effective pellet diets for southern bluefin tuna are continuing but have had limited success to date (Ottolenghi *et al.*, 2004). Tuna are cultured for 3–6 months until they reach the target harvest weight of 30 kg (PIRSA, 2000).

Australian farmed tuna is sold almost exclusively to the Japanese sashimi markets. All frozen product, representing around 75 percent of sales, and around half of fresh chilled product, is now sold direct rather than auctioned (Love and Langenkamp, 2003). Despite the recent declines in the Japanese economy, the demand for bluefin tuna remains high. However, it has become apparent to many producers that relying on a single market (Japan) is a risky strategy (Ottolenghi *et al.*, 2004). Although demand in Japan remains high, the prices that

Japanese consumers are willing to pay is declining and there is an increasing trend towards the purchase of less expensive products (Ottolenghi *et al.*, 2004). Southern bluefin tuna must compete with other, lower-priced tuna species such as big-eye (*Thunnus obesus*) and yellow-fin (*Thunnus albacares*) (Ottolenghi *et al.*, 2004).

There is a substantial research effort into improving the sustainability of southern bluefin tuna aquaculture, much of it through the Cooperative Research Centre for Sustainable Aquaculture of Finfish (AquaFin CRC). The main research programmes deal with developing cost-effective feeds for southern bluefin tuna, and quantifying and reducing environmental impacts associated with sea cage aquaculture. Only one company has expressed an interest in developing hatchery production technology for southern bluefin tuna, with the bulk of the industry opposed to the high level of investment essential to address such a long-term and technically demanding aim.

Salmonids

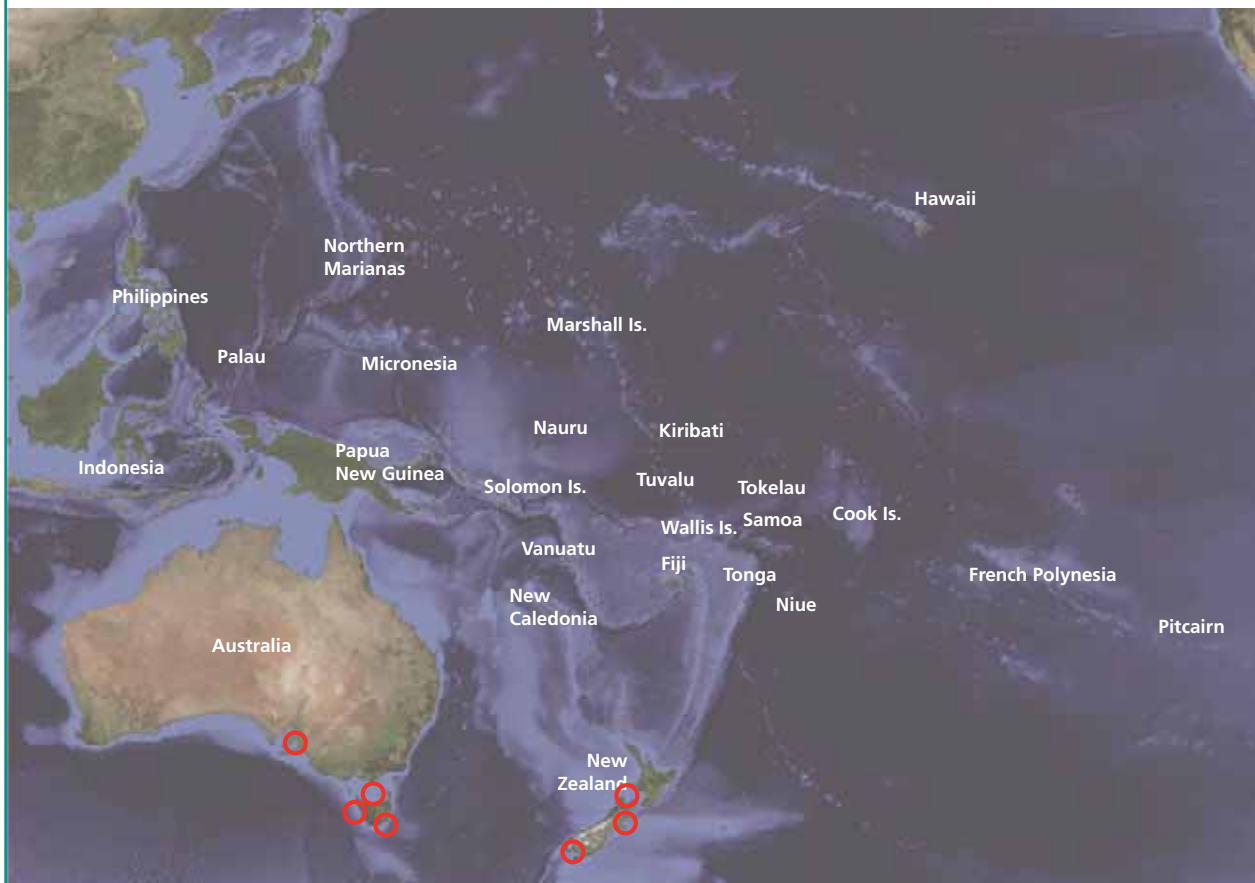
Australia

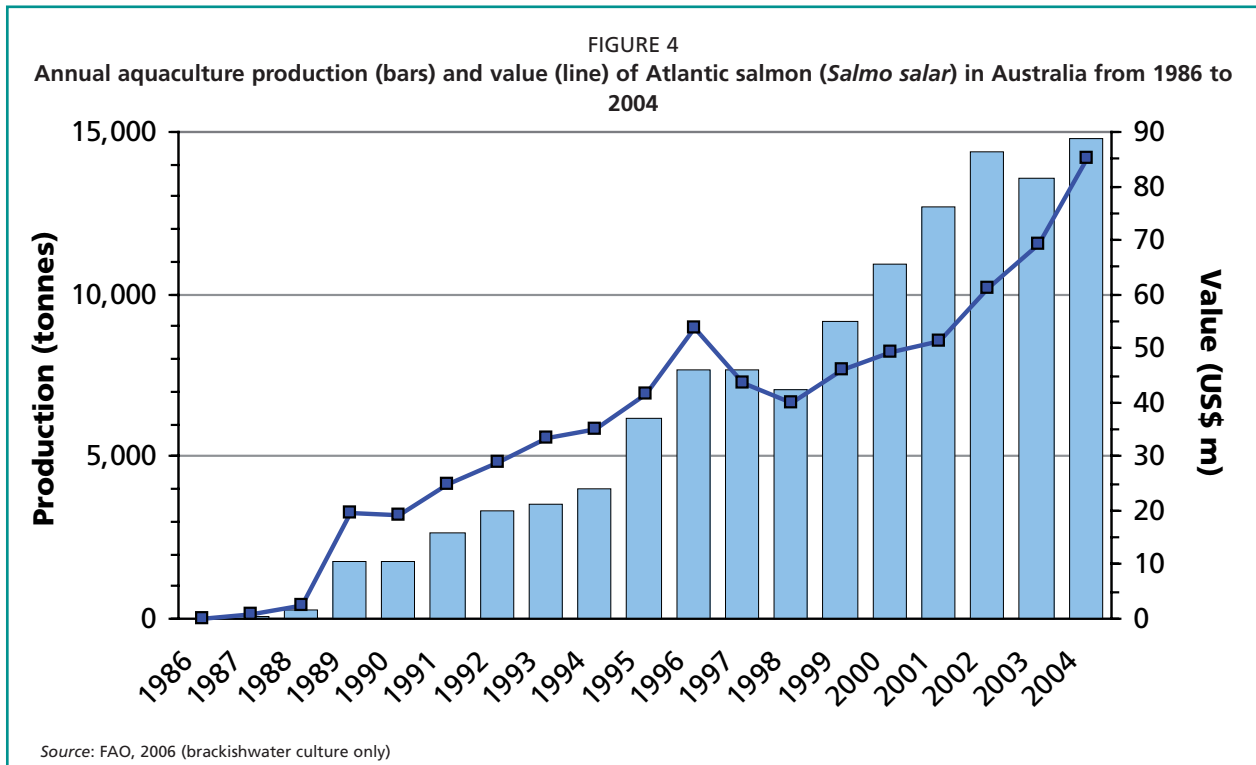
In Australia, Atlantic salmon (*Salmo salar*) makes up the bulk of salmonid cage aquaculture production, though there is also some production of rainbow trout (*Oncorhynchus mykiss*) in sea cages. Some trials have also been undertaken with brown trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*) (O'Sullivan *et al.*, 2005). Most salmonid farming is in Tasmania, and there is one salmonid sea cage farm in South Australia (Figure 3).

FAO data indicate that production is generally increasing and reached 14 800 tonnes in 2004, valued at US\$85 million (Figure 4). The Tasmanian Atlantic salmon industry has seen further mergers of aquaculture operations, leading to a reduced number of large and vertically integrated operations (O'Sullivan *et al.*, 2005).

Salmon fingerlings are produced in freshwater hatcheries, then transferred to freshwater ponds when they reach about 40 mm total length (TL).

FIGURE 3
Map of Oceania showing location of salmonid cage farm sites





They remain in the ponds for about one year, then the 'smolts' are transferred to sea cages for grow-out. Market preference is for 3–4 kg (2–3 years old) fish (PIRSA, 2002a).

As Tasmanian salmonid production has risen, an increasing proportion of production has been sold on the domestic market (Love and Langenkamp, 2003). In the mid-1990s around three-quarters of farmed salmon production was sold on the domestic market, and a quarter exported to Asian markets. More recently, the proportion sold on the domestic market is estimated to have increased to around 85 percent in 2000/01 (Love and Langenkamp, 2003). There are a range of product types available, including whole salmon, fillets and cutlets, as well as value-added products such as smoked salmon. A new product is salmon roe 'caviar', of which several tonnes have been sold to both domestic and export markets (O'Sullivan *et al.*, 2005).

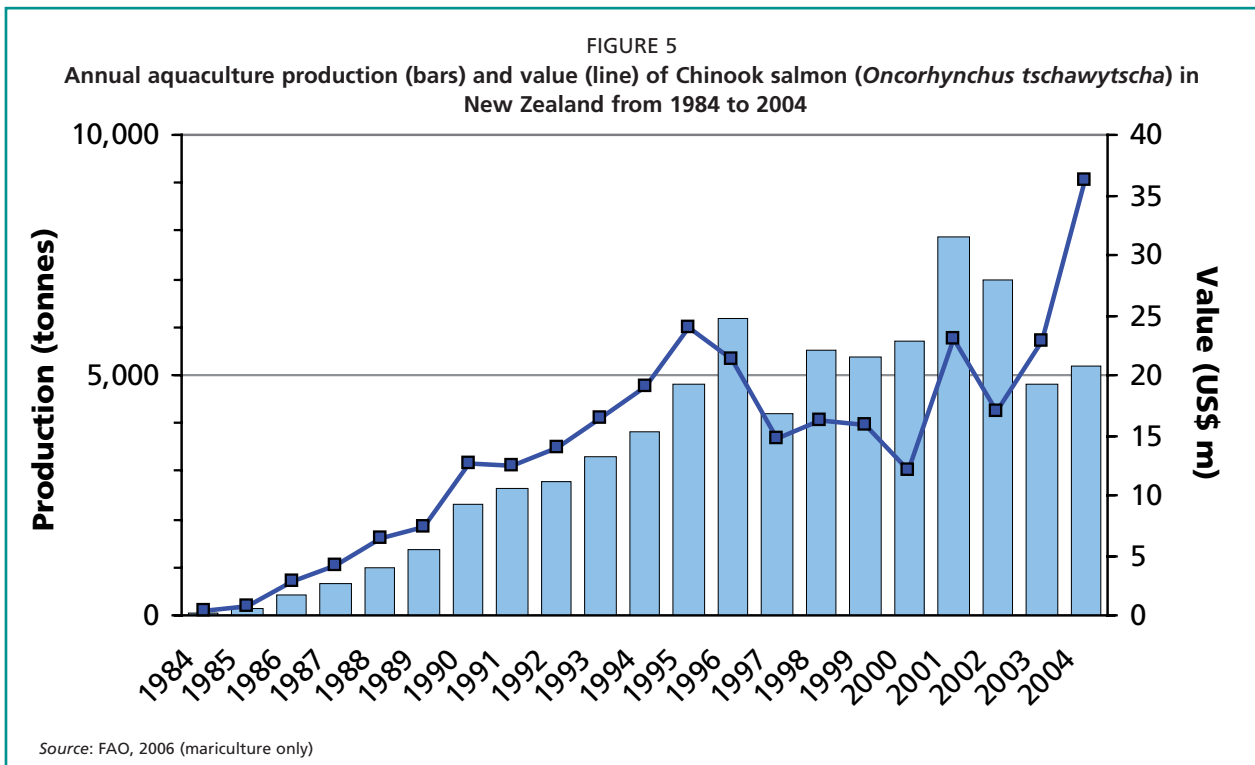
Despite the opening of the once protected Australian market for fresh salmonid products to overseas producers, domestic prices for Atlantic salmon have remained relatively steady. For sea cage product, farm gate prices for 'head-on gilled and gutted' product were around AUD 7.35 (US\$5.50) to AUD 13.20 (US\$9.90)/kg in 2003/04 (O'Sullivan *et al.*, 2005). However, increasing competition in the global export market for salmon reduced demand for Australian product (O'Sullivan *et al.*, 2005).

New Zealand

Effectively all production of salmon in New Zealand is of the Chinook salmon (*Oncorhynchus tshawytscha*). Two major production techniques are used: freshwater culture and sea cage culture. Seedstock are cultured using conventional methods: eggs and milt are collected from from captive broodstock, the fertilized eggs are incubated in a freshwater hatchery (usually at 10–12 °C), and the newly hatched fry are reared for a further 6–12 months before being transferred to larger sea cages or freshwater ponds for grow-out. The fish are cultured for two to three years, and are typically harvested at 2–4 kg.

Ocean ranching was trialled but is no longer undertaken commercially in New Zealand. Ocean ranching required large numbers of smolts to be released to the sea to fend for themselves before reaching adulthood, then relying on their homing ability to guide them back to their point of release to be harvested. Several companies attempted this potentially efficient style of farming during the 1980s, but abandoned it when marine survival rates proved too low and inconsistent to sustain a commercially viable return (Gillard and Boustead, 2005).

Production of farmed salmon in New Zealand in 2004 was about 7 450 tonnes worth approximately NZD 73 million (US\$44 million), from less than 10 hectares of surface structures of sea farms plus



freshwater farms. In comparison, FAO data list 5 200 tonnes valued at US\$36 m (FAO, 2006). A time series of FAO production data suggests that production has remained relatively stable (though with significant annual fluctuations) since 1996, but that there has been an increase in relative product value in recent years (Figure 5). Most production originates from sea cage farms located in the Marlborough Sounds and Stewart Island. Individual farm sites produce up to approximately 1 500 tonnes of salmon (Gillard and Boustead, 2005) (Figure 3).

The existing production capacity of the New Zealand salmon farming industry is approximately 10 000 tonnes with an estimated capacity for expansion to at least 14 000 tonnes. Currently there are 14 ongrowing sites and 12 hatcheries/freshwater sites, with an estimated juvenile fish production capacity of 10 million smolts (Gillard and Boustead, 2005).

About 50 percent of salmon produced in New Zealand is exported. Japan is the major market, but other regional markets, including Australia, are targeted. Most product for the Japanese market is in the form of gilled and gutted, or headed and gutted. There is also some export of value-added products, such as smoked salmon. The local market demands value-added products such as steaks, fillets, smoked salmon, gravlax and kebabs.

Barramundi

Australia

Barramundi (*Lates calcarifer*) farming is carried out in all mainland states of Australia, but most production is from Queensland (mostly from freshwater ponds), the Northern Territory (sea cages and brackishwater ponds) and South Australia (freshwater tanks). Two types of cage farming are practised: sea cage farming, and cages in freshwater or brackishwater ponds. There are only three sea cage farms in Australia: one each in Queensland, the Northern Territory and Western Australia (Figure 6). Most freshwater pond production is from northeastern Queensland (Figure 6).

FAO data record 2004 production as 1 600 tonnes valued at US\$9.9 million (Figure 7)). O'Sullivan *et al.* (2005) report 2003/04 production at 2 800 tonnes valued at AUD 23.6 m (US\$17.7 million).

Barramundi seedstock is sourced entirely from hatchery production. There are two main techniques for seedstock production: intensive and extensive culture. Intensive culture generally has higher production costs than extensive culture, and fingerling quality may vary considerably. However, intensive culture can be carried out during the cooler time of the year (July to September) to provide fingerlings for grow-out during the warmer summer months. In contrast, extensive larval rearing has lower production costs but

FIGURE 6
Map of Oceania showing location of barramundi cage culture sites

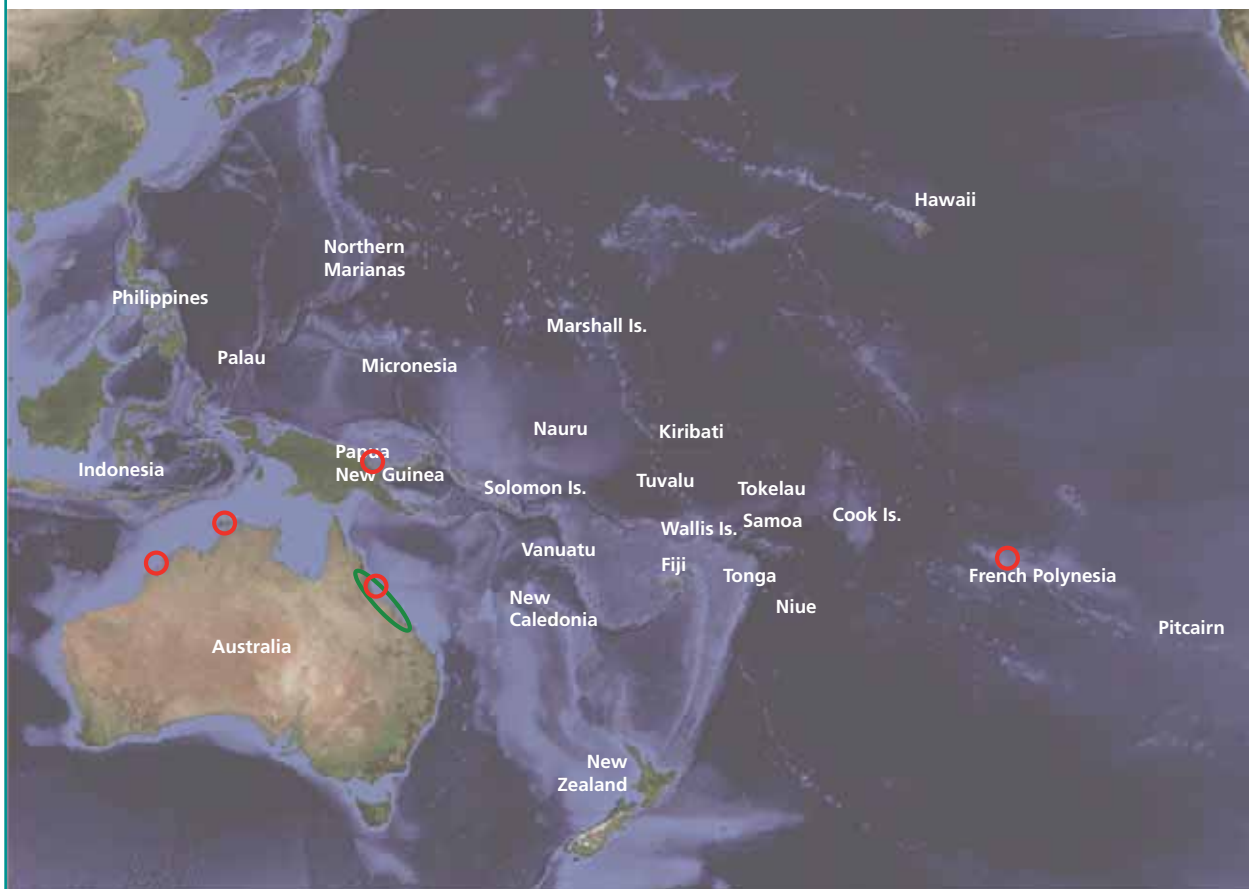
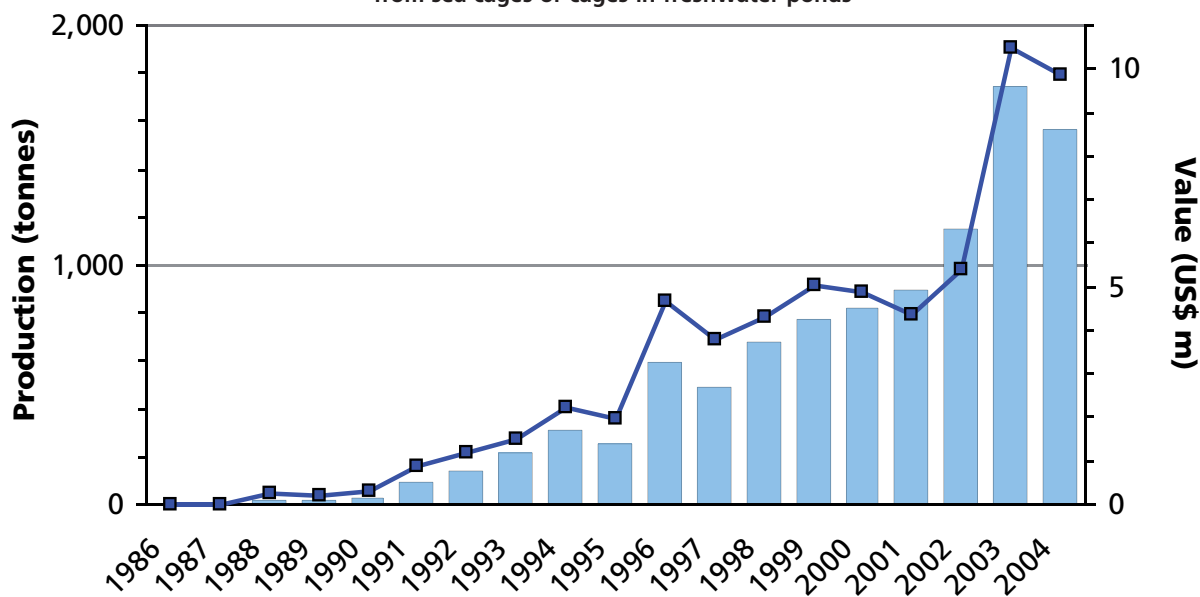


FIGURE 7
Annual aquaculture production (bars) and value (line) of barramundi (*Lates calcarifer*) in Australia from 1986 to 2004. These data are not disaggregated by production type, but a major proportion of this production is from sea cages or cages in freshwater ponds



Source: FAO, 2006

less certainty of production and is limited to warmer summer months (October – March). Some hatcheries use a combination of both techniques: intensive production early in the season, followed by extensive production during the summer (Rimmer, 2003; Tucker *et al.*, 2005).

After larval rearing, barramundi are transferred to a nursery at between 1 cm and 4 cm TL. The role of the nursery is twofold: to allow regular grading to reduce mortality due to cannibalism, and to allow efficient weaning of the juvenile barramundi to inert diets. Nursery facilities usually comprise aboveground swimming pools, or fibreglass or concrete tanks, ranging from about 10 000 to 30 000 litres capacity. Small cages (about 1 m³) made from insect mesh are floated in the tank and the fish are retained in the cages. Alternatively, the fish may be released into the tanks, but this makes grading difficult (Rimmer, 1995).

Barramundi can be weaned to artificial diets at a relatively small size, although the ease and success with which weaning can be accomplished depends primarily on the size of the fish. Larger fish are generally easier to wean than smaller fish, and fish smaller than about 16 mm TL are difficult to wean. Barramundi fingerlings may start feeding on inert diets within a few hours of harvesting from the larval rearing ponds, and most fish start feeding within a few days.

Cannibalism can be a major cause of mortalities during the nursery phase and during early grow-out. Barramundi will eat fish up to approximately 67 percent of their own length. Cannibalism is most pronounced in fish smaller than about 150 mm TL; in larger fish, it is responsible for relatively few losses. Cannibalism is reduced by grading the fish at regular intervals (as frequently as every 2–3 days) to ensure that the fish in each cage are similar in size (Rimmer, 1995).

Most barramundi culture is undertaken in net cages in freshwater or brackishwater ponds. Cages are square, rectangular or circular in shape, and range in size from 8 m³ up to 150 m³. Traditional cages for barramundi culture in ponds are constructed from a bag of knotless netting within which is placed a weighted square formed from PVC pipe and a floating square of the same material. Other designs, for larger cages, utilize more rigid structures.

Early barramundi sea cage farms in Australia used European-style circular cages, based on salmon farming technology. Gradually, these have been replaced with purpose-designed square or rectangular cages. A particular issue that has

affected barramundi sea cage design in Australia is their location in high energy environments. There are only three barramundi sea cage farms in Australia and two of these are located in high-energy environments: the Northern Territory farm is subject to tidal movements up to 8 m, while the Queensland farm is situated in an estuary with lesser tidal amplitude (up to 3.5 m) but with high velocity currents during strong tides. The strong currents that the farms are exposed to have resulted in both farms moving away from traditional mesh cages to more rigid designs utilizing steel or plastic mesh cages.

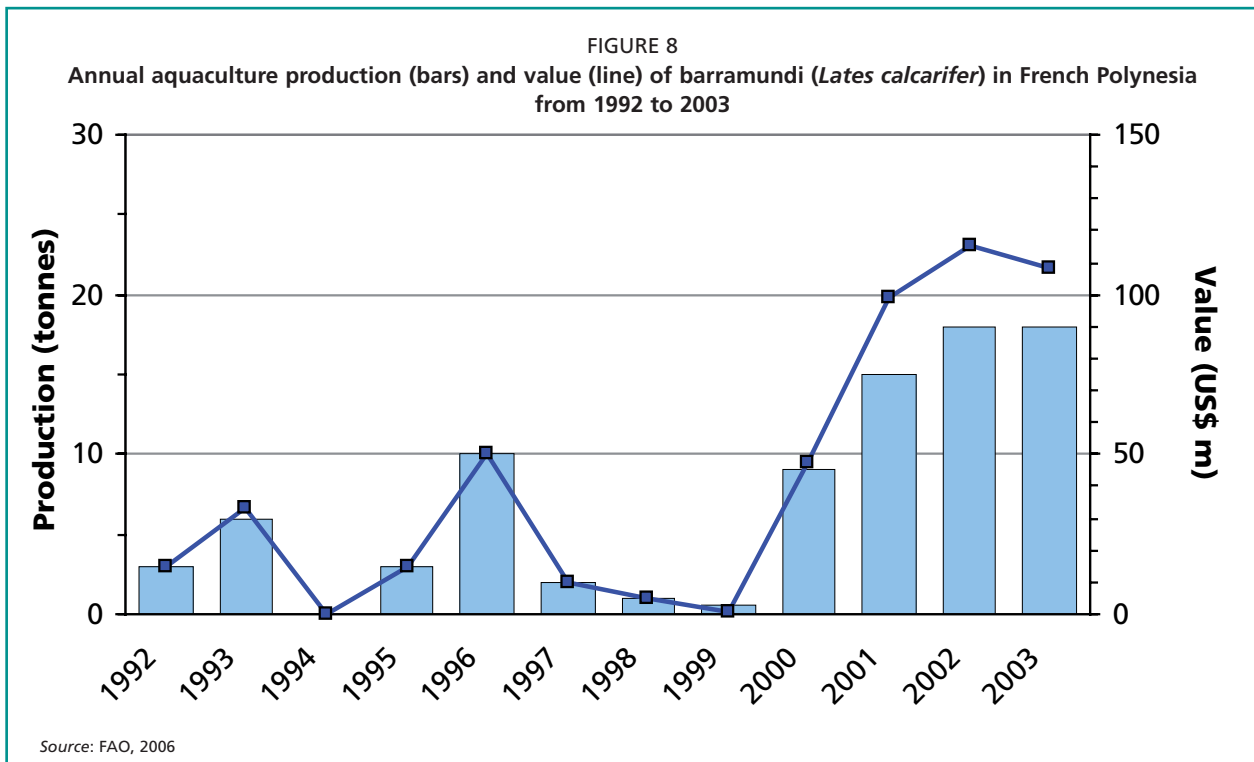
Stocking densities used for cage culture of barramundi generally range from 15 to 40 kg/m³, although densities may be as high as 60 kg/m³. Generally, increased density results in decreased growth rates, but this effect is relatively minor at densities under about 25 kg/m³ (Rimmer, 1995).

Barramundi are fed pellet diets, and there has been much research done on developing cost-effective diets, including high-energy diets. Although automated feeding systems have been used on the large-scale sea cage farms, most barramundi farmers feed manually. Juveniles are fed up to 6 times per day, and this is reduced gradually to two feeds (morning and evening) when the fish reach 40 g (Rimmer, 1995). Food conversion ratios for cage culture of barramundi vary widely, ranging from 1.3:1 to 2.0:1 during the warmer months, and increasing during winter.

Much farmed barramundi is marketed at 'plate size', i.e. 300–500 g weight. Although growth is highly variable, particularly in response to temperature, in general barramundi grow from fingerling to 'plate' size in 6–12 months. Larger farms are also producing larger fish (1.5 – 2 kg) for the fillet market; these take from 18 months to 2 years to reach market size (Rimmer, 1995; Love and Langenkamp, 2003; O'Sullivan *et al.*, 2005). In 2003/04, farm gate prices for Australian barramundi ranged from AUD 7 (US\$5.25) to AUD 10.60 (US \$8)/kg (O'Sullivan *et al.*, 2005). Most product is sold on the domestic market – in 2001/02 less than 2 percent of Queensland production was exported (Love and Langenkamp, 2003).

French Polynesia

Barramundi was introduced to French Polynesia from Singapore by IFREMER in the late 1980s (AQUACOP *et al.*, 1990). Initial trials indicated that barramundi adapted easily and performed well, so IFREMER undertook a programme of



research and development in hatchery production, nursery and grow-out to support the commercial development of barramundi aquaculture in French Polynesia (AQUACOP *et al.*, 1990) (Figure 6).

There are currently only two barramundi farms in French Polynesia, and each operates their own hatchery. Barramundi are grown at a relatively low density (20 kg/m³) and consequently growth is rapid, reaching 400 g 'plate size' in six months. Annual production is around 15–20 tonnes per annum (Fig. 8). Most production is sold domestically, but one farm has attempted exports to Europe.

Papua New Guinea

Sea cage culture of barramundi commenced in Papua New Guinea in 1999, when a private company began production. By 2004, production reached 100 000 fish per annum (Middleton, 2004). Fingerling production techniques were similar to those used in Australia, and the fish were fed commercial pellet diets imported from Australia. A notable feature of the production programme was that the seed and feed was provided by the company to local family-scale grow-out farms along the north coast of Madang (Figure 6). The family groups cared for the fish, then the company bought back the fish for sale on domestic and export (Australia) markets.

Yellowtail kingfish

Australia

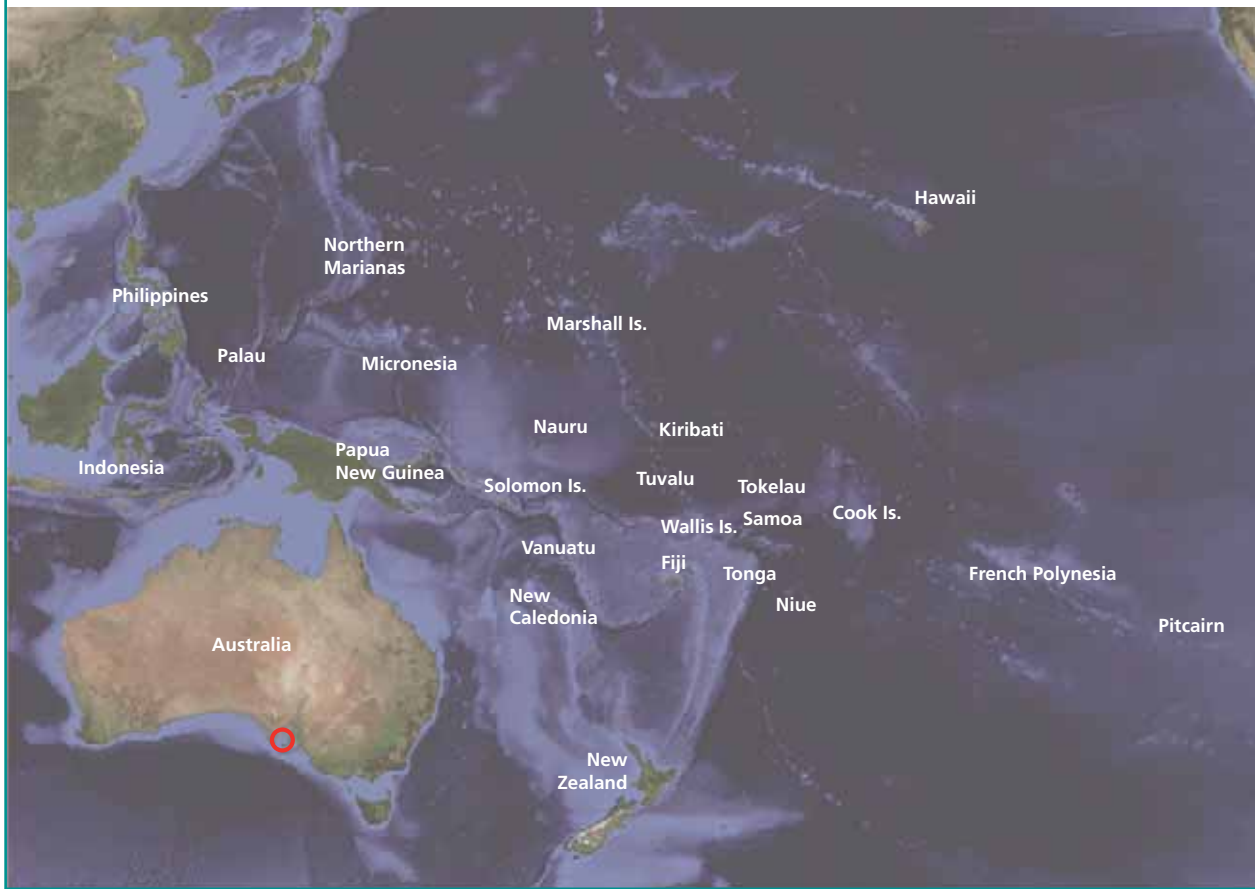
Yellowtail kingfish (*Seriola lalandi*) is a new species currently being developed for aquaculture in Australia. Yellowtail kingfish aquaculture developed from a desire for southern bluefin tuna aquaculture operations to diversify their production base and consequently is concentrated in the Eyre Peninsula region of South Australia at Fitzgerald Bay, Cowell and Port Lincoln (Figure 9).

Yellowtail kingfish production is not disaggregated in the FAO data, but Australian production in 2003/04 was estimated at 1 000 tonnes value at around AUD 8 m (O'Sullivan *et al.*, 2005). In comparison, global production of *Seriola* species is around 140 000 tonnes (Ottolenghi *et al.*, 2004).

Although culture of related species, such as *S. quinqueradiata* in Japan, is highly reliant on capture of wild fingerlings (Ottolenghi *et al.*, 2004), yellowtail kingfish aquaculture in Australia is based on hatchery-produced seed. There are currently two commercial hatcheries in South Australia producing seed of this species (PIRSA, 2002b; Love and Langenkamp, 2003).

Broodstock (usually 10–40 kg) are netted from the wild and are maintained in large indoor tanks of at least 90 m³ volume and 2 m depth at densities below 20 kg/m³ (PIRSA, 2002b; Benetti *et al.*, 2005). Broodstock were previously fed wet feed,

FIGURE 9
Map of Oceania showing location of yellowtail kingfish cage culture sites



including chopped fish and squid and vitamin and mineral supplements (PIRSA, 2002b), but concerns regarding vitamin deficiencies in the broodstock has led to the use of a vitamin-fortified semi-moist compounded feed for broodstock (Benetti *et al.*, 2005). Yellowtail kingfish spawn naturally in the tanks, without need for hormonal induction (PIRSA, 2002b). Some facilities use photothermal control to influence the reproduction and spawning of the captive broodstock (Benetti *et al.*, 2005). Spawning is variable, but generally occurs every 4–5 days (Benetti *et al.*, 2005).

Yellowtail kingfish larvae are reared using standard intensive techniques. Larval rearing tanks range in size from 2.5 to 10 m³ and are cylindroconical in shape (Benetti *et al.*, 2005). Larvae are stocked at around 100 larvae/l (Benetti *et al.*, 2005) and are initially fed rotifers, then enriched *Artemia metanauplii* from day 12 to day 28. Weaning onto inert diets begins at day 20 and is usually complete by day 40 (PIRSA, 2002b; Benetti *et al.*, 2005). Larval growth is rapid with larvae reaching 4–20 mm fork length by day 16,

and up to 35 mm by day 25 (PIRSA, 2002b). Fish can be transferred to cages from 5 grams in weight (PIRSA, 2002b). Previously, many hatchery-reared juvenile yellowtail kingfish had significant skeletal deformities about the head region. This problem has been ascribed to vitamin deficiencies and has been largely resolved by improving broodstock nutrition (Benetti *et al.*, 2005).

Sea cages used for yellowtail kingfish culture are generally 25 metres diameter and 8 metres deep. Smaller nursery net cages (12 metres diameter, 4 metres deep) are used for smaller fish. South Australia limits culture density to a maximum of 10 kg / m³ (PIRSA, 2002b). Fish are fed formulated pellet diets and food conversion ratios (FCRs) of 1.0 – 1.5:1 have been achieved using a pellet diet originally developed for barramundi (Benetti *et al.*, 2005).

Growth of yellowtail kingfish is temperature dependent with best growth under tropical or sub-tropical conditions. Yellowtail kingfish can grow to 1.5–3 kg in 12–14 months, and may reach 1.5 kg in 6–8 months if growing conditions are ideal (PIRSA,

2002b; Love and Langenkamp, 2003; Ottolenghi *et al.*, 2004; Benetti *et al.*, 2005). Alternately, they can be grown out to 4–5 kilograms at eighteen months for sashimi (Love and Langenkamp, 2003; Benetti *et al.*, 2005).

Yellowtail kingfish are generally harvested as whole fish. Some products is sold domestically in fillet or cutlet form, and better quality fish may be sold for sashimi. In Japan it has been marketed under the Japanese name of the fish: hiramasa (Love and Langenkamp, 2003; Ottolenghi *et al.*, 2004). There is demand from export markets (Japan, other parts of Asia, the United States and the United Kingdom) particularly for sashimi product (PIRSA, 2002b, Ottolenghi *et al.*, 2004). Currently, demand for yellowtail kingfish sashimi product exceeds supply (Ottolenghi *et al.*, 2004).

New Zealand

Yellowtail kingfish aquaculture is currently at the research and development and pilot study phase in New Zealand (Benetti *et al.*, 2005). The National Institute for Water and Atmospheric Research

has carried out substantial research into yellowtail kingfish aquaculture since 1998. Results of this work are summarized in Benetti *et al.* (2005).

Tilapia and carp

There has been some cage culture of tilapia (*Oreochromis niloticus*) and carp (*Cyprinus carpio*) in Yonki Lake, Eastern Highlands Province, promoted by the provincial government and the National Fisheries Authority (Figure 10). Yonki Lake is a hydroelectric impoundment about 50 km wide and holds 33 million cubic metres of water. In 2004, the cages in Yonki Lake were producing 500 kg of fish each month, and up to several thousands of fingerlings were being sold at the local markets. Local estimates of production potential are that the lake has potential to generate PGK 5 million (US\$1.7 million) annually with 1 000 farmers producing 1 000 tonnes of freshwater fish per month. There is currently a small-scale research programme to support the development of cage aquaculture for tilapia at Yonki Lake, and to promote the use of locally-made fish feeds.

FIGURE 10
Map of Oceania showing location of tilapia and carp cage culture sites



Other species

Australia

In Australia, there has been some development of other marine finfish species for aquaculture, including snapper (*Pagrus auratus*) and mullet (*Argyrosomus hololepidotus*). While there has been some limited production of snapper, difficulties with product quality and growth rates have led to decreasing production – in 2003-04 production was valued at just over AUD 200 000 (US\$150 000) (O’Sullivan *et al.*, 2005).

Mullet culture is showing more promise with production in 2003/04 of over 500 tonnes value at AUD 4 m (US\$3 million) (O’Sullivan *et al.*, 2005).

Other species that have been trialled or are currently under development for marine aquaculture include: whiting (*Sillago* spp.), striped trumpeter (*Latris lineata*), black bream (*Acanthopagrus butcheri*), silver bream or tarwhine (*Rhabdosargus sarba*), greenback flounder (*Rhombosolea tapirina*), mangrove jack (*Lutjanus argentimaculatus*), fingermark (*Lutjanus johnii*), Australian salmon (*Arripis trutta*), Australian herring or tommy rough (*Arripis georgianus*), and snubnose garfish (*Arrhamphus sclerolepis*) (O’Sullivan *et al.*, 2005).

While there has been considerable interest in developing an aquaculture industry based on the high-value groupers in demand in Hong Kong and China, the development of this sector has been constrained by lack of effective government support to develop grow-out options, restrictive environmental legislation affecting potential sea cage grow-out sites, and antagonistic community attitudes to aquaculture development in coastal areas. Small numbers of barramundi cod (*Cromileptes altivelis*), estuary cod (*Epinephelus coioides*) and flowery cod (*E. fuscoguttatus*) fingerlings have been produced but to date there has only been limited commercial production of these species.

French Polynesia

FAO data for marine finfish species other than barramundi produced in French Polynesia range from 1 to 4 tonnes per annum (FAO, 2006). These are lagoon species which are being trialled to evaluate their aquaculture potential.

Species being trialled in French Polynesia include: moi or sixfinger threadfin (*Polydactylus sexfilis*), brassy trevally (*Caranx regularis*), golden trevally (*Gnathodon speciosus*), and batfish (*Platax orbicularis*).

Federated States of Micronesia

A company from the Republic of Korea has established a grow-out operation for wide-banded seaperch in the Federated States of Micronesia (Henry, 2005). Seed are imported from the Republic of Korea, but there is little other information available on this operation.

New Caledonia

There is currently no aquaculture production of marine finfish in New Caledonia. However, the New Caledonian Economic Development Agency, ADECAL, has a project in place to develop aquaculture of high-value marine finfish species, including groupers and snappers (A. Rivaton, pers. comm.).

MAJOR REGIONAL / COUNTRY ISSUES

Major issues with regard to cage aquaculture in Oceania differ between Australia and New Zealand, and the broader Pacific Islands region. Consequently, they are discussed separately in this section.

Technical

Seed supply

Seed supply for most forms of aquaculture in Oceania is from hatchery production. In Australia and New Zealand, fisheries management generally restricts the collection of juvenile fish for aquaculture. There are several notable exceptions to this, including southern bluefin tuna and eel (*Anguilla* spp.) aquaculture. This provides a significant constraint to aquaculture development in Australia and New Zealand, because any new aquaculture development is reliant on developing hatchery production technology as a first step. This can be a lengthy and costly process, and adds significantly to the costs of developing any given industry sector. In comparison, in Asia many aquaculture commodities are first investigated through the collection and grow-out of wild-caught seed. This enables farmers to evaluate the performance of the species concerned, and decide whether it will be cost-effective to produce them in hatcheries. It also enables the development of grow-out technology in parallel with, rather than in series with, hatchery production technology.

In the Pacific Islands, there are few traditional collection fisheries for juvenile fish to support grow-out operations. The exception is collection

of milkfish (*Chanos chanos*) for pond grow-out in several Pacific Island countries, including Kirabati and Nauru.

Some recent developments in the Pacific and in the Caribbean have used light traps and crest nets to harvest pre-settlement juvenile or late larval fish and invertebrates for subsequent grow-out (Dufour, 2002; Hair *et al.*, 2002; Watson *et al.*, 2002). This mode of harvesting exploits the rationale that most fish and invertebrate species with pelagic larval stages are subject to extremely high mortality prior to and at settlement and that harvesting a proportion of these will have negligible impacts on recruitment (Doherty, 1991; Sadovy and Pet, 1998). In comparison, natural mortality of settled fingerlings may be relatively low and the fisheries for these larger fingerlings may be subject to the same harvesting constraints as fisheries for adult fish (Sadovy and Pet, 1998). To date, these capture techniques have shown promise for the collection of aquarium fish species, but may capture only small numbers of fish species in demand for grow-out for food fish (Hair *et al.*, 2002).

Feeds and feeding

Feeds and feeding are a major issue in cage aquaculture in the Pacific. In Australia and New Zealand, formulated feeds are used almost exclusively for cage production of finfish. The notable exception to this is southern bluefin tuna aquaculture, which is still completely dependent on the use of wet fish as a feed.

There has been much research into the development of compounded feeds in Australia, particularly for finfish. In Australia, much of this research and development has been supported by the Fisheries Research and Development Corporation through its Aquaculture Nutrition Subprogram and by the Australian Centre for International Agricultural Research (ACIAR). Several commercial feed suppliers now produce a range of different feeds for finfish aquaculture.

As noted above, there is a major research and development programme underway to develop compounded feeds for southern bluefin tuna. Much of the wet fish used to feed bluefin tuna is imported into Australia, and biosecurity concerns have been raised regarding the potential introduction of new pathogens. An incident of mass mortalities of wild stocks of pilchards in Australia was ascribed to a virus that may have been introduced in pilchards imported into Australia to feed southern bluefin tuna (Gaughan *et al.*, 2000).

In the Pacific Islands region, the lack of availability of compounded feeds has been one constraint to the development of sustainable aquaculture. High transport costs increase the cost of imported feeds, while small population and production bases restrict the development of locally-produced compounded feeds. On-going research, particularly funded by ACIAR, is building capacity and providing information for development of farm-made feeds for commodities such as tilapia.

Social and economic issues

Community perceptions of aquaculture

An important, but much ignored, facet of aquaculture development in the Oceania region is community perceptions of aquaculture. In Australia, much of the population is clustered along the coast, particularly the east coast, and there is considerable conflict regarding resource use in some areas. Community perception of the negative impacts of aquaculture has been instrumental in limiting many aquaculture developments in Australia, including a proposal for a sea cage farm in Queensland.

A recent study evaluated community perceptions to aquaculture in two districts: the Eyre Peninsula, South Australia, and Port Phillip Bay, Victoria (Mazur *et al.*, 2005). The survey found important differences in responses between the two case study areas that suggested that particular features of regions are likely to have some influence on perceptions of and responses to aquaculture. These may include: population densities, economic diversity, competing uses of marine/coastal environments, the size and structure of the aquaculture industries, and the existence of aquaculture-related conflicts.

Findings from the interviews indicate that aquaculture is highly valued for its contribution to economic growth in rural areas, especially where there has been historic economic decline. Respondents identified a number of issues associated with aquaculture: the need to improve environmental and business practices; knowledge and frameworks to mitigate negative social and environmental impacts; strategic investment in aquaculture research and development; resource security; and community support (Mazur *et al.*, 2005). Analysis of the South Australian mail survey data suggested that people recognise the economic benefits of aquaculture and feel the industry is concerned about environmental management. However, respondents were less trusting of and more concerned about the environmental risks of sea cage aquaculture. Respondents also felt that the

aquaculture industry needs to listen more closely to community concerns (Mazur *et al.*, 2005).

Based on these findings, Mazur *et al.* (2005) propose the use of more innovative participatory strategies and forums to complement existing community consultation activities. They also point out the need for more credible information to build public trust in aquaculture.

An extreme example of public antagonism toward cage aquaculture was the proposal to develop a sea cage farm in southern Queensland. The farm was proposed by a group with experience in the Tasmanian salmon aquaculture industry, who established a private company ('SunAqua') to farm marine finfish (snapper and yellowtail kingfish) in a sea cage facility to be sited in Moreton Bay, near Brisbane, Queensland. The company proposed to utilize off-the-shelf production systems similar to those used in salmonid farming.

Because parts of Moreton Bay are regarded as environmentally sensitive (the bay includes areas of Marine Park and RAMSAR listed sites) there was considerable opposition to the proposal by local conservation groups. By utilizing and adapting some of the more emotive arguments developed by anti-salmonid campaigners in the United Kingdom and Europe, the conservation bodies developed an effective campaign to prevent the SunAqua proposal going ahead. This included effectively utilizing local media, and holding mass rallies in Brisbane suburbs adjacent to Moreton Bay. Despite the SunAqua proposal being classified by the Queensland Government as a 'project of state significance', the conservation groups generated so much public concern regarding the proposal that it was eventually rejected.

Economic impacts of aquaculture

Most Australian states and territories collect production data which includes the gross value of production and some input data, particularly labour equivalents. However, there have been relatively few published studies on the socio-economic impacts of aquaculture in the broader community.

EconSearch (2004) evaluated the economic impacts of the South Australian aquaculture industry along the market chain in 2002/03, including:

- the farm gate value of production;
- the net value of local (SA) processing;
- the net value of local retail and food service trade; and
- the value of local transport services at all stages of the marketing chain.

The study found that the total value added value of aquaculture was AUD 331 m (US\$250 million) representing 0.70 percent of Gross State Product. Direct employment was estimated to be 1 614 jobs in 2002/03 with 1 355 flow-on jobs, giving total employment of almost 2 970. Approximately 90 percent of these jobs were in regional South Australia. Direct household income was estimated to be around AUD 48 m (US\$36 million) in 2002/03 and flow-on income approximately AUD 59 m (US\$44 million), giving total household income of over AUD 107 m (US\$80 million). In regional areas, the impact of the aquaculture industry in 2002/03 was concentrated in the Eyre Peninsula region, reflecting the dominance of tuna farming (EconSearch, 2004).

Marketing

A major disadvantage for aquaculture in the Oceania region is the low population base, and hence limited markets, in the region. Consequently, some commodities have been developed with a strong focus on export markets. An example of this is southern bluefin tuna, which is almost exclusively sold to the Japanese market. However, the distance to the lucrative large export markets of Europe, the United States and China and the poorly developed transport infrastructure in many parts of Oceania limit the ability of farmers to access these larger markets.

In many Pacific Island countries, such as French Polynesia, aquaculture product suffers from competition from cheap, good quality fish caught in the lagoon. However, there is potential for developing targeted markets such as restaurants and hotels which require a constant supply and guaranteed absence of ciguatera in their seafood products.

The largest local or domestic market in Oceania is Australia, and producers in Australia and other regional nations target the Australian seafood market. Like most seafood markets, aquaculture product competes with wild-caught seafood as well as imported products. Love and Langenkamp (2002) concluded that for aquaculture product (live and plate-sized fish) to be competitive against the wild caught product, aquaculture producers would need to work toward a price benchmark price of around AUD 9–10 (US\$6.75–7.50)/kg.

A key issue for Oceania aquaculture producers is competition from imported product. Of relevance for salmon operations, for example, is the recent sharp fall in world salmon prices as a

result of rapidly expanding world farmed salmon production, particularly in Chile. Barramundi currently faces competition from imported product from southeast Asia, and in the fillet market, from low priced imported Nile perch (Love and Langenkamp 2002). Many Asian producers do not face the stringent environmental and food safety requirements that are a significant cost to Australian and New Zealand producers, and are able to produce similar products at lower prices. The issue of import competition, in a global environment of reducing import protection and open markets, will be a major factor in the future development of cage aquaculture in the Oceania region.

Environmental

Environmental issues are a major feature of aquaculture development in Australia and New Zealand, particularly with regard to cage aquaculture.

In Australia, the focus is on development of Environmental Management Systems (EMS). An EMS puts in place a continual process of planning, implementing, reviewing and improving the actions that an organization undertakes to manage its risks and opportunities relating to: the environment, food safety and quality, occupational health and safety, profitability, public relations, and other aspects of the organization. EMS can be developed at the individual business level, for a group of businesses with a common interest, such as members of an industry association, or for all businesses in an aquaculture sector. EMS can be relatively simple, such as a code of best practice, or more comprehensive, such as ISO 14000 or other certification schemes.

EMS for the aquaculture industry in Australia is managed through the Aquaculture Industry Action Agenda, and takes into consideration the 'EMS Pathways' programme being undertaken by Seafood Services Australia seafood industry. Through the Action Agenda initiative, Codes of Practice and Customised Environmental Management Systems have been developed for several key aquaculture businesses that will champion the implementation of EMS for the Australian aquaculture industry.

The AquaFin CRC has a number of major research and development programmes to improve environmental management associated with sea cage farming (<http://www.aquafincrc.com.au/>).

Institutional

Australia

In Australia, the states are responsible for most management aspects of aquaculture. This includes:

- aquaculture farm licensing;
- appropriate environmental licensing;
- support for aquaculture technology development through research, development and extension activities;
- coordination and support for grower associations.

Federal responsibility for aquaculture is limited to broader areas such as national plans and, in particular, biosecurity. The National Aquaculture Development Committee has developed an Aquaculture Industry Action Agenda to promote aquaculture development in Australia. The ten key strategic initiatives of the Action Agenda are:

1. Making a National Aquaculture Policy Statement
2. Promoting a regulatory and business environment that supports aquaculture
3. Implementing an industry driven action agenda
4. Growing the industry within an ecologically sustainable framework
5. Protecting the industry from aquatic diseases and pests
6. Investing for growth
7. Promoting aquaculture products in Australia and globally
8. Tackling the research and innovation challenges
9. Making the most of education, training and workplace opportunities
10. Creating an industry for all Australian.

Key elements of the Aquaculture Industry Action Agenda are being implemented by the National Aquaculture Council, which is the peak body for aquaculture producer associations in Australia (<http://www.australian-aquacultureportal.com/>).

In conjunction with the Aquaculture Industry Action Agency, the Department of Agriculture, Fisheries and Forestry (DAFF) has developed 'AquaPlan' – a strategy to develop a national approach to emergency preparedness and response as well as to the overall management of aquatic animal health in Australia. AquaPlan was jointly developed by Government and private industry sectors, and links into existing State / Territory Government and industry health management arrangements.

A key feature of AquaPlan is the AquaVetPlan component, which provides a series of manuals and operational instruments which outline methods and protocols to manage emergency aquatic disease outbreaks in Australia. AquaVetPlan is based on the similar terrestrial model: AusVetPlan.

New Zealand

In New Zealand, a moratorium on the development of new marine farms was instituted in 1991. The Resource Management Act 1991 revoked the provisions in the Marine Farming Act 1971 relating to the issuing of new leases and licences.

The New Zealand Government has identified the need to update the legislative framework for aquaculture 'to provide more certainty for all participants, while at the same time not allowing adverse effects on the environment or undermining the rights of existing fishers'. The Ministry for the Environment, the Ministry of Fisheries, and the Department of Conservation are the main government departments involved in the development of the proposed new aquaculture legislation.

The ongoing impacts of the New Zealand Aquaculture Reform process have led to substantial frustration within the New Zealand aquaculture industry.

Pacific Island countries

The Secretariat for the Pacific Community (SPC) is an inter-governmental body with 22 member countries from the Pacific Islands region that works in collaboration with its member countries to develop work programmes to provide: technical assistance; professional, scientific and research support; and capability building for planning and management. SPC provides this support to the aquaculture industry in Pacific Island countries through their Aquaculture Programme.

The Pacific Islands region has a chequered history of aquaculture development, with relatively few successful ventures. To assist in developing aquaculture sustainably in the Pacific Islands region, SPC has developed an Aquaculture Action Plan (<http://www.spc.int/aquaculture/site/publications/documents/spc-aquaplan.pdf>). The Action Plan was the result of intensive consultation among some sixty regional and international specialists during the 1st SPC Aquaculture Meeting held in Suva, Fiji Islands, 11–15 March 2002.

The meeting reviewed seventeen commodities of interest to the region to identify a shortlist of priority commodities. Commodities were assessed on two criteria: potential impact and feasibility. From this process, the meeting agreed that the priority commodities for the region are: coral, giant clam, freshwater prawn, milkfish, pearl, sea cucumber, seaweed, and tilapia. In addition to focussing on a priority list of commodities, the plan identifies important cross-cutting issues for aquaculture development in the Pacific:

- Prior commitment needs to be made at country/institution/enterprise before sending people on training courses to actually put the training into practice on their return.
- There is a need for entrepreneurial skills and business training.
- It is critical that market and financial analysis is carried out for each priority commodity to determine the potential scale of production, cost of production and product specifications before actions are taken to establish each of the priority commodities.
- All development strategies need to include actions to minimise the threat of disease introduction and undertake preparations for control and management in the event of disease incursion outbreaks.
- There is an urgent requirement across the region to address policy and legislative frameworks for the successful introduction and management of the priority commodities.
- Country strategies, consistent with regional strategies, need to be developed focusing on policy, legislation, and development plans. It will be important that countries assemble as much objective information as possible in the process of addressing their own priorities.
- Sharing and updating information about aquaculture in the Pacific at regular intervals should be an important part of an ongoing regional effort.

A review of aquaculture legislation and policy in Pacific Island countries (Evans *et al.*, 2003) indicated that there was a notable absence of specific aquaculture policies both at the regional and national levels. Commonly, plans for aquaculture were often incorporated into general fisheries plans/policies and had mainly an economic objective, such as increasing employment and economic returns. The review concluded that national aquaculture

policies are needed in order to address and direct issues not only concerning industry development, but also encompassing the needs for subsistence and community-based aquaculture development, environmental integrity and food security (Evans *et al.*, 2003).

The review found that legislation tended to be inadequate despite various levels of development in Pacific Island countries. While laws in the region are similar, several important issues addressed in some countries were absent from other national legislation. Moreover, no generalised relationship could be drawn between the nature of regulation and level of aquaculture development (Evans *et al.*, 2003).

THE WAY FORWARD

The way forward for cage aquaculture in Oceania is by no means clear. Environmental sustainability and market competition are two major issues that need to be addressed if cage aquaculture is to expand from its current base. It is likely that cage aquaculture in Oceania will remain a relatively small industry by global standards because of the constraints discussed in this review.

To further develop cage aquaculture in Oceania will require a broad range of approaches to all aspects of aquaculture development and associated supply chains. Most agencies that support aquaculture development in the Oceania region have a strong focus on production issues, and put relatively little effort into post-harvest value-adding or development of supply chains.

Little effort has gone into community education regarding aquaculture, and social research impacting perceptions of aquaculture. Yet, these remain major constraints to the expansion of aquaculture in Oceania.

In Australia and New Zealand in particular, there is a need for cage aquaculture to establish its environmental credentials with the broader community. There are widespread community concerns regarding the environmental sustainability of aquaculture, including:

- the use of fisheries products (including fishmeal) to produce fish protein;
- impacts of nutrients from cage aquaculture on the local environment;
- impacts of escapees on local fish populations, including genetic impacts;
- potential disease translocation and epizootics.

As the work on community perceptions of aquaculture has demonstrated, an important

component of aquaculture industry development is communicating the benefits as well as the negative aspects of aquaculture to the community (Mazur *et al.*, 2005). Consequently, public information systems need to be an integral part of cage aquaculture development strategies.

Cage aquaculture in Oceania has significant competitive disadvantages compared with other regions. Labour costs in Australia and New Zealand are high, and are generally significant components of the production cost of most aquacultured commodities. In addition, economies of scale remain relatively low in Oceania because of low population density, limited availability of sites, and stringent licensing and environmental legislation. Consequently, cage aquaculture in Oceania needs to be developed taking into account competitive advantages compared with other regions, particularly Asia.

One aspect of comparative advantage that has been suggested for Oceania aquaculture results from the high level of biosecurity that is, or can be, instituted in Oceania countries. This provides opportunities for countries to exclude some of the more virulent diseases and to develop specific-pathogen-free (SPF) seedstock supplies. Under this model, Oceania could become an important provider of SPF seedstock to other regions, particularly Asia.

CONCLUSIONS

Cage culture in Oceania is likely to remain small by global standards. Its continued development, albeit at a relatively slow pace, depends on a range of social, economic and environmental issues being actively addressed by government and research and development agencies:

Economic issues

- Develop hatchery production technologies that reduce the cost of fingerling production while maintaining quality.
- Developing more cost-effective feeds to reduce production costs.
- Increase mechanization of production to offset high labour costs in Australia and New Zealand.
- Provide improved market intelligence, particularly of export markets for high value / low volume commodities.
- Develop value-added products for domestic markets.
- In Pacific Island countries, support the development of cage culture of commodities that

provide opportunities for income generation as well as food security.

- Develop advanced technologies for the control of disease.

Social issues

- Provide relevant and accurate information to the community in regard to the benefits and costs of aquaculture.
- Facilitate community participation in aquaculture planning and development at local, state and government levels.
- Develop production and harvest processes that meet consumer expectations of product quality and product safety.

Environmental issues

- Develop improved production technologies that reduce the environmental impacts of cage aquaculture.
- Develop or adapt production technologies for off-shore cage culture.

- Adequately quantify and report the environmental impacts of cage aquaculture.

Overall, the greatest need is for cage aquaculture in Oceania to look forward and to position itself with regard to other regions. Significant challenges lie ahead, particularly from competition with burgeoning cage aquaculture production in Asia, as well as the rest of the world. Oceania has significant disadvantages as a production base for cage aquaculture, and aquaculture managers and planners need to develop strategies to address the issues discussed in this review.

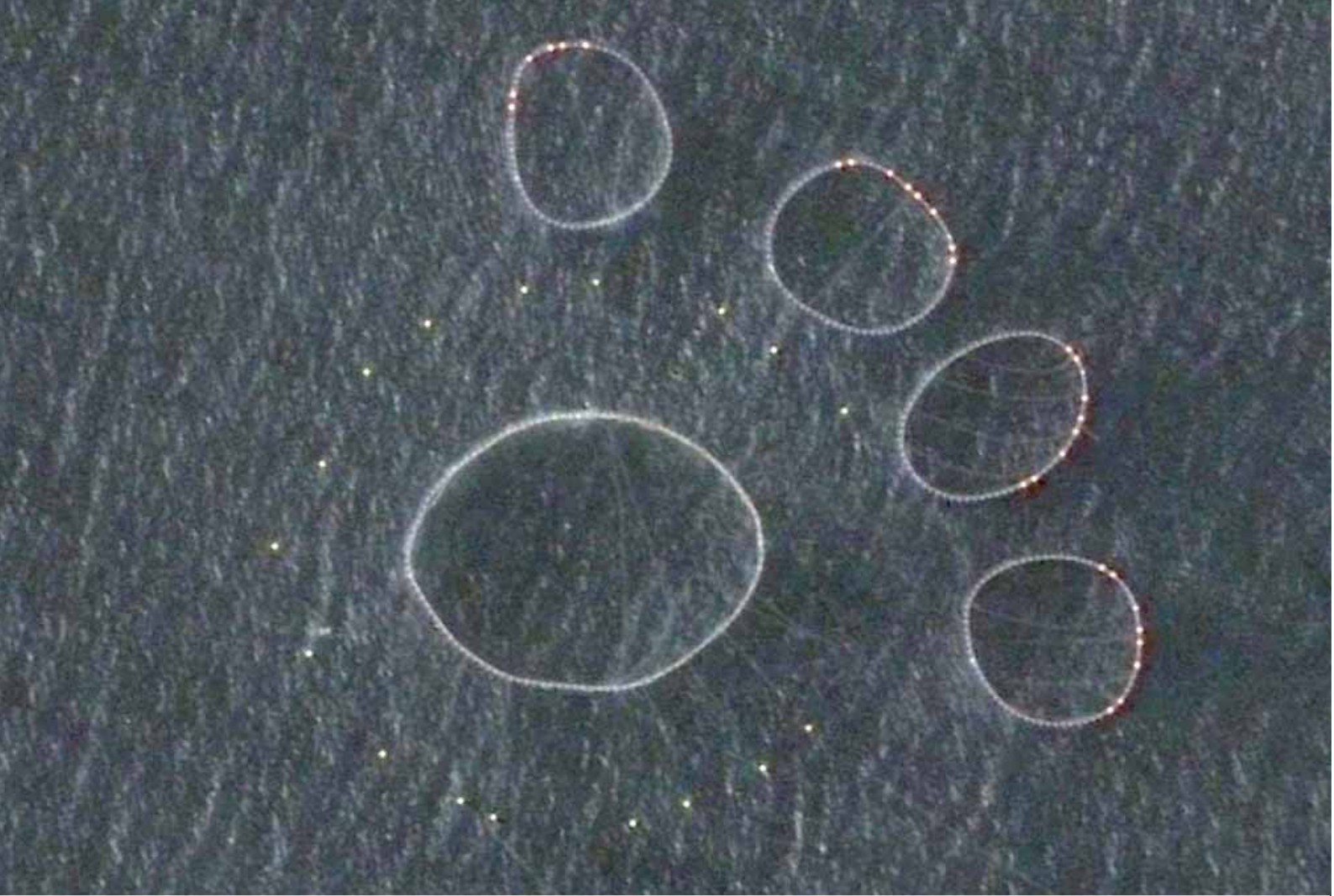
ACKNOWLEDGEMENTS

We acknowledge the support and assistance of FAO's Inland Water Resources and Aquaculture Service, particularly Dr Matthias Halwart. Dr Tim Pickering (University of the South Pacific, Fiji) and Tim Paice, Marine Farming Branch, Marine Resources, DPIWE, Tasmania kindly provided information for this review.

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Annexes

Annex 1 – The 2nd International Symposium on Cage Aquaculture in Asia (CAA2)

The 2nd International Symposium on Cage Aquaculture in Asia (CAA2) was held in Hangzhou, China from 3–8 July 2006. The symposium was organized by the Asian Fisheries Society (AFS) with support from Zhejiang University, the China Society of Fisheries and several other organizations. Approximately 300 people (including 150 from overseas) from over 25 countries attended the event. Many organizations, institutions and individuals supported and contributed to the success of CAA2, which was organized under the chairpersonship of Dr Chan-Lui Lee, President of AFS, Professor Wu Xinzhong, Mr Chen Jian, Dr Xu Haisheng and other staff of the Secretariat and the Organizing Committee of CAA2.

The proceedings of CAA2 are being managed by the AFS editorial board, namely Prof Zhou Yingqi, Dr Yang Yi and Dr Sena de Silva. The proceedings will include the special lectures and keynote presentations given by Dr Meryl Williams, Prof Xu Junzhou, Prof Yngvar Olsen, Dr Zilong Tan, Dr Arne Fredheim, Dr Ulf Erikson and Prof Ho Ju-Shey, together with many papers presented in the technical sessions on freshwater cage culture; marine cage culture; nutrition, feed and feeding; environmental impacts and management; disease prevention and health management; policy, management, economics and marketing.

The FAO Special Session documented here will become an integral part of the AFS Proceedings once these are finalized.

FAO Special Session: a Global Overview of Cage Aquaculture

The FAO Special Session was composed of a total of nine papers which were presented to the plenary over three consecutive days (Annex 1). The list of FAO-sponsored participants/presenters is attached as Annex 2.¹

In the global overview, A. Tacon highlighted that the production of farmed aquatic organisms in caged enclosures is relatively recent aquaculture innovation; commercial marine cage culture was pioneered in Norway in the 1970s with the development of salmon farming. The development and use of intensive cage-farming systems was driven by a combination of factors, including the increasing competition faced by the aquaculture sector for available water resources and space.

While there is little statistical information on the total global production of farmed aquatic species within cage culture, there is some information on the number of cage-rearing units, and production statistics are being reported to FAO by some member countries. These data have been complemented, to the extent possible, by expert information. To date, cage culture has been largely restricted to the culture of higher value (in marketing terms) feed-fed omnivorous and carnivorous fish species. The shift towards intensive cage-culture systems has also brought its share of problems and constraints. Despite these, cage aquaculture is currently one of the fastest growing segments of global aquaculture production and is predicted to have great development potential, particularly if it promotes using an integrated multi-trophic approach to cage culture in near-shore areas as well as making use of the expansion possibilities of siting cages far from the coasts. This development needs to be supported by appropriate policy and planning, and legal and management frameworks.

S. de Silva reported that cage culture in Asia is very diverse, in particular with regard to the intensity and size of operations. Asia has the lowest per caput availability of freshwater among all the continents. Consequently, cage culture is now often seen as a very effective way of secondarily utilizing this relatively scarce primary resource for foodfish production. The great bulk of inland cage-farming operations tend to be subsistence farming. Marine and brackish water cage farming in Asia is a relatively recent development, and increasingly gaining popularity. Most marine cage farming depends on trash fish as the primary feed, which is a factor that will impact on long-term sustainability.

In China, J.X. Chen noted that the beginning of modern intensive cage culture for food production and ornamental purposes dates back to the 1970s. It was first adopted in freshwater, afterwards in brackish and marine environments. Due to its advantages, cage and pen culture quickly expanded countrywide. In some sites, the balance of the ecosystem has been affected due to an overload of cages and pens with consequent problems. The fishery policies of the Chinese government require local authorities to limit the number of cage and pen-fish operations to a reasonable level in order to keep the ecological balance in a harmonious environment.

¹ Note that the full list of participants will be made available in the AFS Proceedings of CAA2.

A. Rojas reported that aquaculture is currently a significant commercial activity throughout Latin America and the Caribbean. While there are 33 Latin American and Caribbean countries involved in aquaculture, Chile and Brazil account for the bulk of production. In his presentation, Dr Rojas paid special attention to the case of Chile, as the majority of the cages used for fish production in Latin America and the Caribbean is located there.

An overview of the status and future prospects of cage and net-pen culture of marine and freshwater finfish in North America was provided by C. Bridger. After four decades of evolution and growth, North American cage-culture production and diversity are growing and the potential for future development and sustainability appears bright. A great deal of public research and private innovation in cage-culture technology, development of new species and advancement of management techniques has taken place in North America. However, much more technological development will have to take place if open ocean aquaculture is to meet its projected potential.

J.A. Grøttum reflected that since its beginnings 30 years ago, the aquaculture industry in Northern Europe has matured. The majority of production is in Norway, Scotland, Ireland and Faeroe Islands. However, countries such as Finland, Iceland, Sweden and Denmark also have cage-culture industries. All relevant aquaculture production using cage technology in Northern Europe is carried out in marine waters. Over the years, there has been a significant decrease in the environmental impact from the cage aquaculture industry in Europe. Despite the problems, there has been a more or less continuous growth in production, and the industry has become an important economic contributor to some of the remote rural regions of Europe.

F. Cardia noted that for the Mediterranean countries, marine cage culture started to develop

widely in the mid-1980s, mainly in Spain and Greece. The rapid development of cage culture in the 1990s, mainly in Turkey and Greece, culminated in a market crisis in the late 1990s and even more during the period 2000-2002, with a drop of market prices to minimal values. Several constraints currently limit the expansion and the development of marine cage culture in the Mediterranean. These include the need for species diversification, the development of suitable commercial feeds and a positive market response to newly introduced farmed species.

S. Leonard observed that cage aquaculture was an emerging activity in the countries of Sub-Saharan Africa. Presently only a handful of successful examples exist - the tilapia farms in Zimbabwe, Zambia, Malawi, Kenya, Ghana and Uganda. There is also potential for brackish and marine water cage culture, but as yet there has been little development in this subsector in the region.

The main constraint to the development of competitive cage culture in the region is the unavailability of locally produced, high quality feeds at competitive prices. If this and some other constraints are addressed, it is estimated that the region offers enormous scope for the commercial development of aquaculture of small, medium and industrial scales.

From the Oceania region, M. Halwart on behalf of M. Rimmer and his co-authors informed that cage aquaculture is little practiced in the region; most of the limited production is from Australia and New Zealand. Among the reasons for the limited development of cage aquaculture in the region are the considerable community concern regarding the impacts of large-scale aquaculture, the moratorium on further development of marine aquaculture in New Zealand and the low population bases and relatively poor infrastructure in many of the Pacific Island countries.

Annex 2 – Agenda

Monday, 3 July, 2006

Day 0: Pre-Symposium Activities		
1000 – 2000	Symposium and Exhibition Registration	1000 – 2000
1000 – 2000	Exhibition Set-up	1000 – 2000
1000 – 2000	Poster Set-up	1000 – 2000

Tuesday, 4 July, 2006

Day 1: Opening Ceremony, Special Lectures, Keynote Address and Trade Exhibition		
0830 – 0925	Opening Ceremony: Leader of ZJU <i>"Welcome to Zhejiang University and Caa2"</i> Dr Chan-Lui Lee, Chair CAA2 and President Asian Fisheries Society <i>"Welcome address and CAA2"</i> Leader of Chinese Fisheries Bureau <i>"address for CAA2"</i>	Chair: Prof. Y.Q.Zhou
0925 – 1000	Special Lectures 1 – Dr Meryl Williams <i>"Who will Supply World Demands for Fish"</i>	
1000 – 1030	Morning Tea	1000 – 1030
1030 – 1105	Special Lectures 2 - Prof. Xu Junzhou <i>"Cage Culture in China"</i>	Chair: Prof. Y.Q.Zhou
1105 – 1330	Trade Exhibition and Poster Viewing - Lunch	1105 – 1330
1330 – 1410	Keynote1 - Prof. Yngvar Olsen <i>"Environmental Interaction between Cage Culture and the Surrounding Water Masses"</i>	Chair: Dr. Ulf Erikson
1410 – 1450	Keynote 2 - Dr. Zilong Tan <i>"Health management practices for cage aquaculture in Asia - a key component for sustainability"</i>	
1450 – 1530	Keynote 3 - Dr. Arne Fredheim <i>"Technological trends and challenges in global open ocean fish farming"</i>	
1530 – 1600	Afternoon Tea	1600 – 1625
1600 – 1640	Keynote 4 - Dr. Ulf Erikson <i>"A review of harvesting and post-harvesting procedures of marine fish in cage culture with specific reference to cobia compared with Atlantic salmon"</i>	Chair: Prof. Yngvar Olsen
1640 – 1720	Keynote5 - Prof. Ju-Shey Ho <i>"Pest management: a challenge of cage aquaculture extension in Asia"</i>	
0900 – 1800	Trade Exhibition (Open to Public)	0900 – 1800
1830– 2100	Welcome Address, Cultural Performance and Symposium dinner	1830– 2100

Wednesday, 5 July, 2006

Day 2: FAO reviews, concurrent Scientific Sessions and Trade Exhibition						
0800 – 0840	FAO review 1 - Dr. Albert G.J. Tacon <i>"A review of cage culture: Global overview"</i>					Chair: Dr Chan-Lui Lee
0840 – 0920	FAO review 2 – Prof. Sena De Silva <i>"A review of cage culture: Asia-Pacific"</i>					
0920 – 0945	Morning Tea					0920 – 0945
	Room 139 Freshwater cage culture (Chair: SiFa Li Nguyen Thanh Phuong)	Room 225 Marine cage culture (Chair: Arne Fredheim Ketut Sugama)	Room 138 Nutrition, feed and feeding (Chair: Sena De Silva Shi-Yen Shiau)	Room 140 Environmental impacts and management (Chair: Chang Kwei Lin Yngvar Olsen)	Room 223 Disease prevention and health management (Chair: Zilong Tan Phan Thi Van)	

0920 – 1005	CAGE CULTURE OF RAINBOW TROUT IN WEST AZERBAIJAN, IRAN Armin Eskandari, Naser Agh	IMPROVEMENT ON AQUACULTURE CAGE NET VOLUME DEFORMATION Chai-Cheng Huang, Hung-Jie Tang, Jen-Ya Pan	A RAPID APPRAISAL APPROACH TO IDENTIFY LOCALLY AVAILABLE FEED INGREDIENTS FOR SMALL-SCALE CAGE AQUACULTURE Mohiuddin A. Kabir Chowdhury, Bureau D. P., Ponniah A. G.	ENVIRONMENTAL IMPACT ON CAGE CULTURE IN RESERVOIR Jiazhang Chen, Bing Xuwen	A GLOBAL SUCCESS STORY OF CAGE-BASED AQUACULTURE – SALMON FARMING AND THE TECHNOLOGY OF VACCINATION, KEY TO SUSTAINABILITY Alistair Brown, William J. Enright	0920 – 1005
1005 – 1025	GROWTH POTENTIAL OF TRIPLOID FISH <i>Nandus nandus</i> IN CAGES IN RELATION TO CLIMATE CHANGE S Banik, Nandita Ray, Abir Shib, Sankar Banik, Surajit Debnath	COMMERCIAL SCALE PRODUCTION OF POMPANO <i>Trachinotus ovatus</i> IN OFFSHORE OCEAN CAGES: RESULTS OF 2004 AND 2005 PRODUCTION TESTS IN HAINAN, CHINA, BY ASA-IM / USB Michael C. Creme, Hsiang Pin Lan, H.R. Schmittou, Zhang Jian	Nitrogen, Phosphorus, And Energy Waste Outputs Of Four Marine Cage Cultivation Fish Fed By Trash Fish Zhongneng Xu, Xiaotao Lin	INTEGRATED CAGE-CUM-POND AQUACULTURE SYSTEMS: A CONCEPTUAL MODEL James S. Diana, Yang Yi and C. Kwei Lin	IMPACT OF INFECTION WITH CAPSALID MONOGENEANS IN MARINE FISH CULTURED IN ASIA Leong Tak Seng, Anxing Li, Zilong Tan	1005 – 1025
1025 – 1045	CAGE CULTURE AS A SOURCE OF SEED PRODUCTION FOR ENHANCEMENT OF CULTURE-BASED FISHERIES IN SMALL RESERVOIRS OF SRI LANKA. Soma Ariyaratne	HUMPBACK GROUPE <i>Cromileptes altivelis</i> CULTURE WITH DRY PELLET AND TRASH FISH IN FLOATING NET CAGE IN EKAS BAY LOMBOK WEST NUSATENGARA Bejo Slamet, Titiek Aslianti, Anak Agung Alit	EFFECTS OF REPLACEMENT OF WHITE Fishmeal BY SOYBEAN MEAL AND BROWN Fishmeal ON GROWTH PERFORMANCE AND BODY COMPOSITION OF LARGE YELLOW CROAKER <i>Pseudosciaena crocea</i> Qingyuan Duan	DNA DAMAGE AS BIOMARKER FOR ASSESSING THE EFFECTS OF SUSPENDED SOLIDS TO FISH Chong-Kim Wong	HISTOPATHOLOGICAL AND ULTRASTRUCTURAL STUDY ON Nocardiosis IN LARGE YELLOW CROAKER, <i>Larimichthys crocea</i> Guoliang Wang, Shan Jin, Hong Yu, Yijun Xu, Siping Yuan	1025 – 1045
1045 – 1105	ASSESSMENT OF SUBMERGED TILAPIA FISH CAGE FARMING IN LAKE BUHI Plutomeo M. Nieves, Grace B. Brizuela, Ronnel R. Dioneda Sr., Allan B. de Lima	OPTIMISING FISH FARMING THROUGH ANALYSIS AND MODELLING OF PRODUCTION DATA: A CASE STUDY OF JAPANESE YELLOWTAIL (<i>Seriola dumerilii</i>) Clive Talbot	THE EFFECT OF RED KWAO KREUA (<i>BUTEA SUPERBA</i>) AND 17-A-METHYL TESTOSTERONE (MT) ON SOME GROWTH Kriangsak Meng-Umpfan, Rogelio Carandang Jr.	AN OVERVIEW OF POTENTIAL USE OF GENETIC STUDIES IN RELATION TO CULTURED MARINE FISH SPECIES IN SINGAPORE Genhua Yue, Wang C. M., Lo L.C., Zhu Z.Y., Lin G., Feng F., Li J., Yang W.T., Chou R., Lim H.S., Orban L.	DISEASE SURVEILLANCE IN MARINE FISH FARMED IN GUANGDONG, CHINA Anxing Li, S. Weng, L. Labrie, W. Chen, J. He, E. Ho, L. Grisez, Z. Tan	1045 – 1105
1105 – 1125	AQUACULTURE PRACTICE IN NON-FEEDING CAGES IN RESERVOIR Jian Zhu, Yan Xiaomei	RECENT DEVELOPMENTS OF GROUPE AQUACULTURE IN INDONESIA Ketut Sugama	TECHNICAL AND ECONOMICAL EVALUATION OF SMALL SCALE SILVER CARP (HYPOTHALMICHTHYS MOLITRIX) CAGE CULTURE FOR YOUTH IN THE RIVER NILE OF EGYPT EFFECT OF CAGE SIZE Nour A.M., Essa M.A., Omar Eglala, Zaki M.A. and Mabrouk H.A.	ENVIRONMENTAL CARRYING CAPACITY OF CAGE AQUACULTURE BASED ON DRY MATTER CONVERSION RATE IN XIANGSHAN HARBOR Huiwen Cai, Sun Yinglan	EXPERIMENTAL VERTICAL TRANSMISSION OF NODAVIRUS IN <i>Epinephelus coioides</i> , <i>Rachycentron canadum</i> AND DISEASE PREVENTION BY EGGS DISINFECTATION WITH CHEMICAL IN HATCHERIES Phan Thi Van, Pham Van Thu, Vo Anh Tu, Le Thi May, Pham Duc Phuong	1105 – 1125
1125 – 1145	TRIAL OF MONOSEX GIFT TILAPIA CAGE CULTURE IN MEKONG DELTA, VIET NAM Nguyen Van Hao, Nguyen Nhut	DEVELOPMENT AND EXPERIMENT ON THE GRADING DEVICE WITH FRUSTUM OF PYRAMID VOLUME WITH THE INSTANCE OF GRADING FOR RED SEA BREAM CULTURED IN OPEN OCEAN CAGES Guofu Zheng, TANG Yan-li, SHAO Qing, DING Lan, ZHU Jian-kang, WEI Guan-yuan, HUANG Gui-fang	FEED INGREDIENTS AND PROCESSING FOR INTENSIVE FARMING OF CARNIVOROUS FISH Trond Storebakken	DEVELOPMENT OF MARICULTURE AND BIOREMEDIATION OF SEAWEEDES IN CHINESE COASTAL WATERS Yufeng Yang, Fei Xiugeng	STUDIES ON PATHOGEN OF GREAT YELLOW CROAKER IN OFF-SHORE CAGE CULTURE Jinyu Shen,	1125 – 1145

1145 – 1205		LARVE FISH OF EPINEPHELUS COIODES PREDATION SUCCESS ON THE PSEUDODIAPTOMUS ANNANDALEI OF COPEPODA: CALANOIDA UNDER CALM AND TURBULENT HYDRODYNAMIC CONDITIONS Jiang-Shiou Hwang, Chien-Huei Lee, Shin-Hong Chen	EFFECTS OF FISHMEAL REPLACEMENT BY PLANT PROTEINS ON GROWTH AND BODY COMPOSITION OF JUVENILE JAPANESE SEABASS <i>Lateolabrax japonicus</i> Jinyun Ye	IMPACT OF CAGE FISH FARMING ON SEDIMENT ENVIRONMENT IN DAYA BAY Honghui Huang, Lin Qing, Li Chunhou, Gan Juli, Jia Xiaoping	IMPACT OF FISH VACCINATION AND CHALLENGES FOR DEVELOPMENT OF VACCINES Kjersti Gravningen	1145 – 1205
1205 – 1400	Trade Exhibition and Poster Viewing - Lunch					1200 – 1400
1400 – 1440	FAO review 3 - Mr. Jiixin Chen "A review of cage culture: China"					1400 – 1440
1440 – 1520	FAO review 4 - Dr. Alejandro Rojas "A review of cage culture: Latin America and the Caribbean"					1440 – 1520
1520 – 1545	Afternoon Tea					1520 – 1545
	Room 139 Freshwater cage culture Chair: Ida Siason Fatima Yusoff	Room 225 Marine cage culture (Chair: Chai-Cheng Huang Clive Talbot)	Room 138 Nutrition, feed and feeding (Chair: Trond Storebakken Roshada Hashim K.S. Mai)	Room 140 Policy, management, Economic and market (Chair: Matthias Halwart Marilou G. Directo)		
1545 – 1605	VERIFICATION STUDY ON THE FISH CAGE FEEDING AND STOCK MANIPULATION SCHEME IN LAKE BATO Plutomeo M. Nieves, Grace B. Brizuela, Victor S. Soliman, Salve G. Borbe	OVERVIEW OF STUDIES ON MARINE FINFISH REPRODUCTION AND LARVICULTURE IN THE UNITED STATES Zhijua Lin	REPLACEMENT OF Fishmeal BY POULTRY BY-PRODUCT MEAL AND MEAT AND BONE MEAL IN AQUAFEEDS –AN UPDATE (2004-2006) Yu Yu	STATUS OF FISH PENS AND FISH CAGES IN THE LAGUNA DE BAY, PHILIPPINES Marilou G. Directo, Jacqueline N. Davo	1545 – 1605	
1605 – 1625	USING OF FINE MESS CAGES IN CLOSED CIRCULATORY SALINE WATER SYSTEM AQUARIUM IN GIANT FRESHWATER PRAWN LARVAL (<i>MACROBRACHIUM ROSENBERGII</i>) REARING Krasindh Hangsapreurke, Boonyarath Pratoomchat and Prasert Prasongphol	A NEW PRACTICE OF OYSTER RAFT CULTURE IN HONG KONG Kwok Cheong Chung	EFFECT OF LYOPHILISED WHOLE YEAST <i>Saccharomyces cerevisiae</i> AS PROBIOTIC SUPPLEMENT IN THE FORMULATED DIETS ON GROWTH, NUTRITIONAL QUALITY AND IMMUNITY OF <i>Labeo rohita</i> (HAM.) Arvind Kumar, Partha Bandyopadhyay	AN ECONOMIC ANALYSIS ON MARINE CAGE AQUACULTURE IN ZHEJIANG PROVINCE, P.R.China Haiyang Zhu	1605 – 1625	
1625 – 1645	CAGE AQUACULTURE: A ECOFRIENDLY TECHNOLOGY FOR ENHANCEMENT OF RESERVOIR FISH PRODUCTION Praveen Tamot	NUMERICAL 3D MODELING OF NETTING-----CONCERNING WITY FISH CAGE Junting Yuan, Yingqi Zhou, Bo Zhao	EFFECTS OF DIFFERENT DIETARY FATTY ACID SOURCES AND THEIR PROPORTIONS ON GROWTH AND BODY COMPOSITIONS OF JUVENILE YELLOW CATFISH <i>Pelteobagrus fulvidraco</i> Jiqiao Wang, Wenhui Wang, Guize Liu, Xin Cheng, Wenkuan Li, Xiaonian Luo, Jingwei Li	STATUS AND IMPACTS OF TILAPIA FISH CAGE FARMING IN LAKE BATO: SOME POLICY AND MANAGEMENT OPTIONS FOR SUSTAINABLE DEVELOPMENT Plutomeo M. Nieves	1625 – 1645	
1645 – 1705	FISH CULTURE IN FLOATING CAGES CAN ENHANCE RESERVOIR FISH PRODUCTION Ankush Saxena	GROWTH-OUT TRIALS OF <i>COBIA RACHYCENTRON</i> CANADUM IN SEA CAGES USING EWOS PELLETT FEED AND TRASH FISH Nguyen Quang Huy, Bui Van Hung, Le Anh Tuan, Nhu Van Can, Tran Mai Thien, Niels Svennevig	EFFECTS OF DIETARY PHOSPHORUS LEVELS ON GROWTH PERFORMANCE AND BODY COMPOSITION OF JUVENILES BLACK SEA BREAM <i>SPARUS</i> Wanglong Hu, Shao Qing-Jun Xu ZiRong Liu JianXin Xu JunZhao, YE JinYun	SUSTAINING FISH PRODUCTION AND LIVELIHOODS IN THE RESERVOIR'S FISHERIES IN INDONESIAN: A SOCIOECONOMIC UPDATE Sonny Koeshendrajana, Fatryandi Nur Priyatna1, Sena S. De Silva	1645 – 1705	
1705 – 1725	THE CAGE AQUACULTURE OF <i>Perca fluviatilis</i> IN ZHEJIANG PROVINCE Binguan Zhu, YanJie Wang, JiaYing Wang, ZhongQi Jiang and HaiSheng Xu	MARINE FISH CAGE CULTURE IN CHINA Yongquan Su	EFFECTS OF Fishmeal PARTIAL REPLACEMENT BY SOYBEAN MEAL ON GROWTH, BODY COMPOSITION OF FINGERLINGS BLACK SEA BREAM <i>Acanthopagrus schlegelii</i> Jinyun Ye	OPEN-SEA FARMING: OPERATIONAL CONSTRAINTS Darko Lisac, Refa Med srl	1705 – 1725	

1725 – 1745	CAGE CULTURE OF CATFISH IN THE MEKONG DELTA; VIET NAM Nguyen Thanh Phuong, C. Kwei Lin and Yang Yi	BURNT MUSCLE PHENOMENA IN CULTURED YELLOWTAIL <i>Seriola quinqueradiata</i> Daisy Cristina Arroyo Mora	A STUDY ON FEEDING FORMULATION AND STOCKING DENSITY FOR NURSING SEX-REVERSAL TILAPIA (<i>Oreochromis niloticus</i>) FRY IN NET CAGE HAPA Thepparath Ungsethaphand, Boonyarath Pratoomchat and Prasert Prasongphol	THE THEORETICAL MODLE OF SOCIAL COST-BENEFIT ANALYSIS ON CASE AQUACULTURE Chen Sun	1725 – 1745
1745 – 1805				AN INQUIRY INTO EXTERNALITY OF CAGE CULTURE AND THE GOVERNMENTS MACRO-CONTROL OF CHINA Wei Yang	1745 – 1805
0900 – 1700	Trade Exhibition (Open to Public)				0900 – 1700

Thursday, 6 July, 2006

Day 3: FAO reviews, concurrent Scientific Sessions and Trade Exhibition						
0800 – 0840	FAO review 5 – Dr. Christopher J. Bridger “A review of cage culture: Northern America”					0800 – 0840
0840 – 0920	FAO review 6 – Dr. Jon A. Grøttum “A review of cage culture: northern Europe”					0840 – 0920
0920 – 1000	FAO review 7-Dr. Francesco Cardia “A review of cage culture: The Mediterranean”					0920 – 1000
1000 – 1025	Morning Tea					1000 – 1025
	Room 139 Freshwater cage culture (Chair: Jo Jae-Yoon Weimin Wang)	Room 225 Cage culture related topics (Chair: Pichai Sonchaeng Ye Jinyun)	Room 138 Policy, management, Economic and market (Chair: Albert G.J. Tacon Matthias Halwart, Chen Sun)	Room 140 Environmental impacts and management Chair: Niels Svennevig James S. Diana)	Room 223 Disease prevention and health management Chair: Jushey Ho Jennifer L. Watts)	
1025 – 1045	PEN CULTURE TECHNOLOGIES IN LAKE GAOBAO, YANGZHOU, CHINA Min Kuanhong	PROTECTION OF <i>Procambarus clarkii</i> AGAINST WHITE SPOT SYNDROME VIRUS USING RECOMBINANT ORAL VACCINE EXPRESSED IN <i>Pichia pastoris</i> Rajeev Kumar Jha, Zirong Xu, Shijuan Bai, Jianyu Sun, Weifen Li, Jian Shen	NECESSARY OF BUILDING CAGE AQUICULTURE ASSOCIATION FROM A PERSPECTIVE OF PUBLIC CHOICE Ning Cao, Gao Jian	THE REVIEW OF MARINE ENVIRONMENT ON CARRYING CAPACITY OF CAGE CULTURE Hao Zhang, Duqi Fang Minjie	A NON-HAEMOLYTIC GROUP B <i>Streptococcus</i> sp. FROM HYBRID TILAPIA (<i>Oreochromis niloticus</i> x <i>Oreochromis aureus</i>) Ahmed H. Al-Harbi	1025 – 1045
1045 – 1105	CULTURE SINCE THE INTRODUCTION OF NYLON NET CAGE IN SOUTH OF VIET NAM Boun-Teng Lyi	STUDIES ON THE SODIUM PUMP, AQUAPORIN 3 AND CFTR IN SEA BREAM: IMPLICATIONS FOR CULTURE AT ISO-OSMOTIC SALINITY Norman Y.S. Woo	CAGE FISH CULTURE AND SMALL SCALE FISHERY BASED LIVELIHOOD OF FISHERS COMMUNITY IN POKHARA VALLEY, NEPAL Suresh Kumar Wagle	INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS WITH HIGH-VALUED STINGING Md. Abdul Wahab	CHARACTERIZATION OF A REL/NF B HOMOLOGUE IN A GASTROPOD ABALONE <i>Haliotis diversicolor supertexta</i> Yusheng Jiang, Xinzhong Wu	1045 – 1105
1105 – 1125	INTEGRATED CAGE-CUM-PEN CULTURE SYSTEM WITH <i>Clarias garlepinus</i> IN CAGES AND CARPS IN OPEN PONDS Madhav K. Shrestha, Narayan P. Pandit, Yang Yi, C. Kwei lin, James S. Diana	ISOLATION, CHARACTERIZATION AND IDENTIFICATION OF POTENTIAL PROBIOTIC BACTERIA FROM THE INDIAN MAJOR CARPS <i>Catla catla</i> (HAM.), <i>Labeo rohita</i> (HAM.) AND <i>Cirrhinus mrigala</i> (HAM.) Partha Bandyopadhyay	AN ALTERNATIVE CAGE CULTURE MANAGEMENT BASED ON PROPERTY RIGHT SYSTEM AT INDONESIAN RESERVOIR CASE STUDY AT JATILUHUR, CIRATA AND SAGULING RESERVOIR Fatriyandi Nur Priyatna, Sonny Koeshendrajana, Sena S. De Silva	SUTABLE SITE SELECTION FOR RED TILAPIA CAGE CULTURE IN PING RIVER, CHIANGMAI AND LUMPHUN REGION, THAILAND USING GEOGRAPHIC INFORMATION SYSTEM(GIS) Prachaub Chaibu, Buncha Chawanchai, and Damgurng Chamnankha	EXPRESSION IN LIPO POLYSACCHARIDE-STIMULATED <i>Epinephelus awoara</i> SPLEEN BY SUPPRESSION SUBSTRACTIVE HYBRIDIZATION Li Wang, Xinzhong Wu	1105 – 1125

1125 – 1145	TECHNICAL AND ECONOMICAL EVALUATION OF SMALL SCALE FISH CAGE CULTURE FOR YOUTH IN THE RIVER NILE OF EGYPT 1-EFFECT OF STOCKING DENSITY OF NILE TILAPIA (<i>Oreochromis niloticus</i>), MONOSEX FINGERLINGS Omar E.A., Nour A.M. Essa M.A., and Zaki M.A.	ANALYSIS ON MUSSEL MARKET OF CHINA Xiang Gao	RESOURCE PRODUCTIVITY AND PROFITABILITY OF MILKFISH (<i>Chanos chanos</i> , Forsskal) CAGE AQUACULTURE IN THE COSTAL AREAS OF LINGAYEN GULF, PHILIPPINES Rosie S. Abalos, Ruben C. Sevilleja	CARRYING CAPACITY ASSESSMENT FOR GROUPEL CULTURE DEVELOPMENT IN FLOATING NET CAGES, PEGAMETAN BAY, BALI INDONESIA. Bambang Priyono, Tri Heru Prihadi, Murniyati	CLONING AND EXPRESSION OF FUR GENE FROM <i>Vibrio alginolyticus</i> Ronghua Qian	1125 – 1145
1145 – 1205	PRODUCTIVITY ENHANCEMENT OF CAGE FISH CULTURE BY IMPROVING LOCATION SPECIFIC FARMING METHODS IN LAKES AND RESERVOIR OF MID HILLS, NEPAL Jay Dev Bista	RESPONSE OF THE OYSTER <i>Crassostrea ariakensis</i> TO RICKETTSIA-LIKE ORGANISM (RLO) INFECTION AND ENVIRONMENTAL STRESS UNDER EXPERIMENTAL CONDITIONS Yang Zhang, Xinzhong Wu, Yusheng Jiang and Jian Chen	TCDC Consultant (Fisheries and Aquaculture Extension), Integrated Management of Lagoon Activities, Hanoi Agricultural University (HAU) Campus Kibria M.G., Ario Pieter Van Duijn and Runia Mowia	MANAGEMENT OF SUSTAINABLE FLOATING NET CAGE AQUACULTURE ON RESERVOIR Murniyati		1145 – 1205
1205 – 1315	Trade Exhibition and Poster Viewing - Lunch					1205 – 1315
1315 – 1355	FAO review 8 -Mr. Patrick Blow "A review of cage culture: Sub-Saharan Africa"					1315 – 1355
1355 – 1435	FAO review 9 - Dr. Michael Rimmer "A review of cage culture: Oceania"					1355 – 1435
1435 – 1500	Afternoon Tea					1435 – 1500
	Room 225 Open Forum	Room 138 Industry Session	Room D Environmental impacts and management (Chair: Yongquan Su, Genhua Yue)			
1500 – 1520	Members of Expert Panel: Dr. Ulf Erikson Prof Yngvar Olsen Dr Francesco Cardia Alistair Brown Dr Zilong Tan Dr Albert Tacon Dr Chang Kwei Ling Dr Arne Fredheim Dr Matthias Halwart Dr. Jon Grottum Prof Xiaoping Jia Prof Sena De Silva Prof Wu Changwen	Industry Session sponsored by National Renderers Association Inc.	INTEGRATING SEAWEEDES INTO FISH CAGE MARINE CULTURE SYSTEMS: A KEY TOWARD SUSTAINABILITY Shannan Xu	1500 – 1520		
1520 – 1540			DECISION SUPPORT SYSTEM FOR SUSTAINABLE ENVIRONMENTAL MANAGEMENT OF MARINE FISH FARMS R. Mayerle, W. Windupranata and K-J. Hesse	1520 – 1540		
1540 – 1600			TSUNAMI IMPACT AND RELIEF EFFORTS IN THAILAND Chang Kwei Lin, Pradit Sripatprasit	1540 – 1600		
1600 – 1620			IMPACT OF HEAVY METAL TO FISH AQUACULTURE IN FLOATING NET CAGE IN CIRATA RESERVOIR, INDONESIA Tri Heru Prihadi, Murniyati, Idil Ardi	1600 – 1620		
1620 – 1640			USE OF SIMULATION MODELING TO DESCRIBE NITROGEN RETENTION EFFICIENCY IN A FISH/BIVALVE INTEGRATED CULTURE SYSTEM Jennifer L. Watts	1620 – 1640		
1640 – 1700			THE CONTROL OF EUTROPHIC WATER IN CAGE WATER BY FLOATING-BED SOILLESS CULTURE OF PLANTS Bing Xuwen, Chen Jiachang	1640 – 1700		
1700 – 1730						1700 – 1730
0900 – 1700	Trade Exhibition (Open to Public)					0900 – 1700
1800 – 1930	Closing Ceremony and Happy Hour – Foyer of Exhibition Area					1800 - 1930

Friday and Saturday, 7 and 8 July, 2006

Day 4-5: Post-Symposium Tours	
Tour 1	2-day tour on off-shore cage culture in Zhujiajian
Tour 2	Day tour on fisheries/aquaculture in Lake Taihu, Zhejiang Institute of Freshwater Fisheries and pear culture sites
Tour 3	West Lake tour and city tour in Hangzhou

Annex 3 – List of FAO-sponsored participants/presenters

RESOURCE PERSONS

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This document contains nine papers on cage aquaculture including a global overview, one country review for China, and seven regional reviews for Asia (excluding China), northern Europe, the Mediterranean, sub-Saharan Africa, Latin America and the Caribbean, North America and Oceania, all of which were presented during the FAO Special Session on Cage Aquaculture – Regional Reviews and Global Overview at the Asian Fisheries Society Second International Symposium on Cage Aquaculture in Asia (CAA2), held in Hangzhou, China, from 3 to 8 July 2006. Each review, by geographic region, gives information about the history and origin of cage aquaculture; provides detailed information on the current situation; outlines the major regional issues and challenges; and highlights specific technical, environmental, socio-economic and marketing issues that cage aquaculture faces and/or needs to address in the future. The review recognizes the tremendous importance of cage aquaculture today and its key role for the future growth of the aquaculture sector. The global overview discusses the available data on cage aquaculture received by FAO from member countries; summarizes the information on cultured species, culture systems and culture environments; and explores the way forward for cage aquaculture, which offers especially promising options for multitrophic integration of current coastal aquaculture systems as well as expansion and further intensification at increasingly offshore sites.

