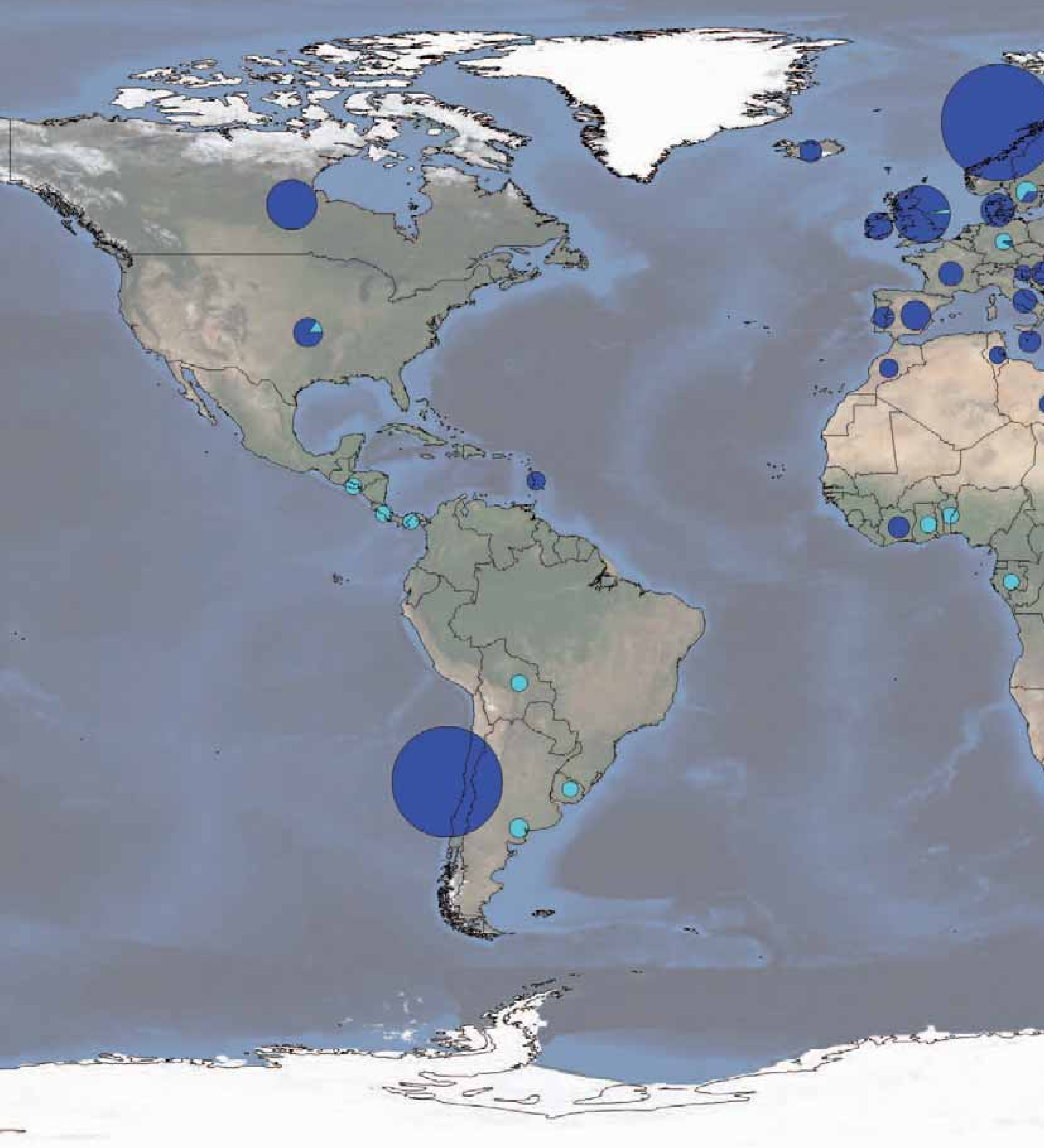
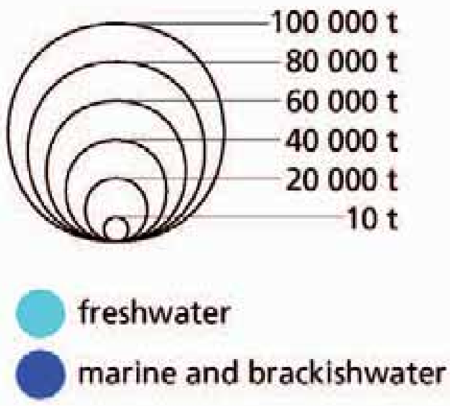
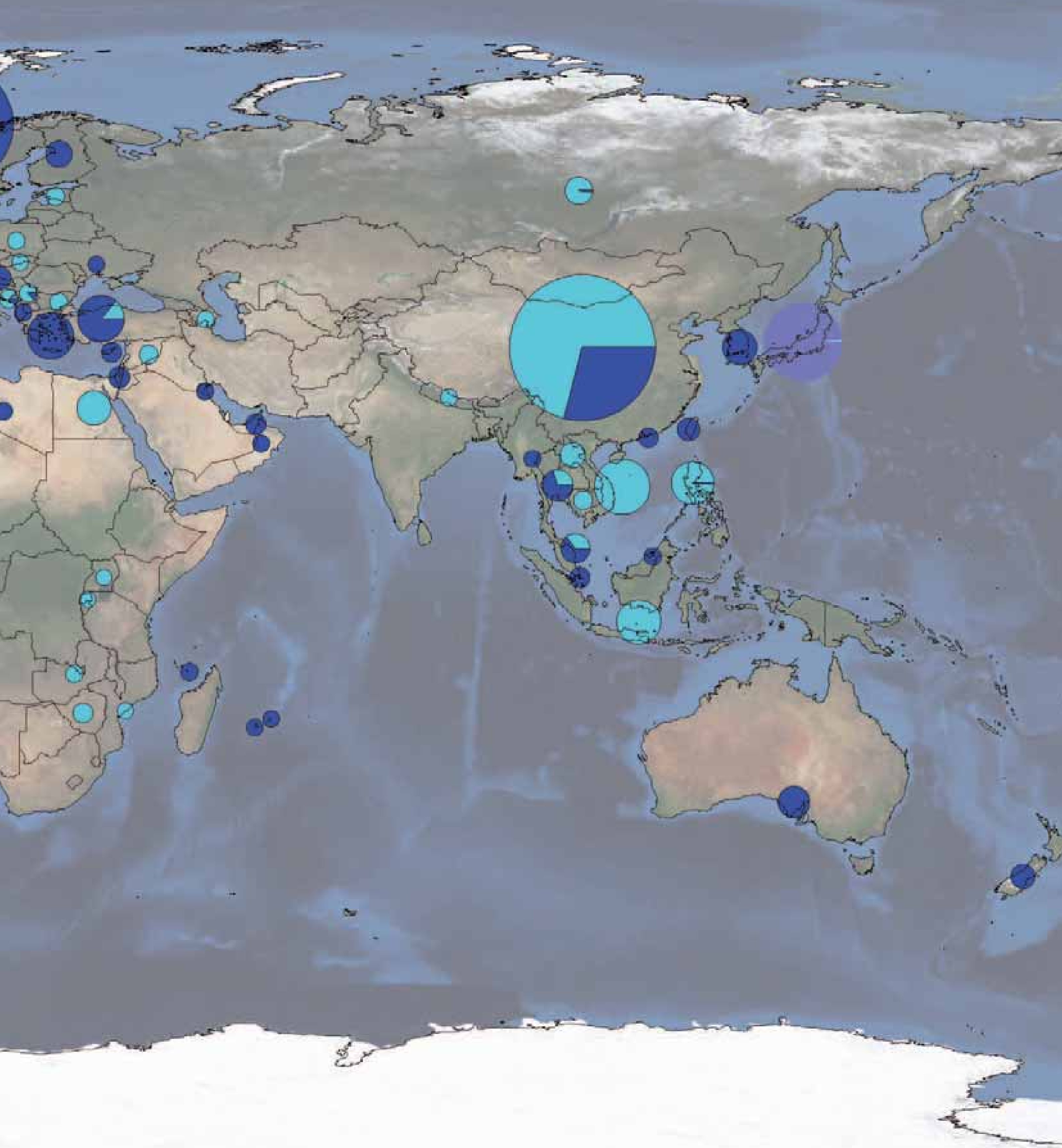


Cage aquaculture production 2005

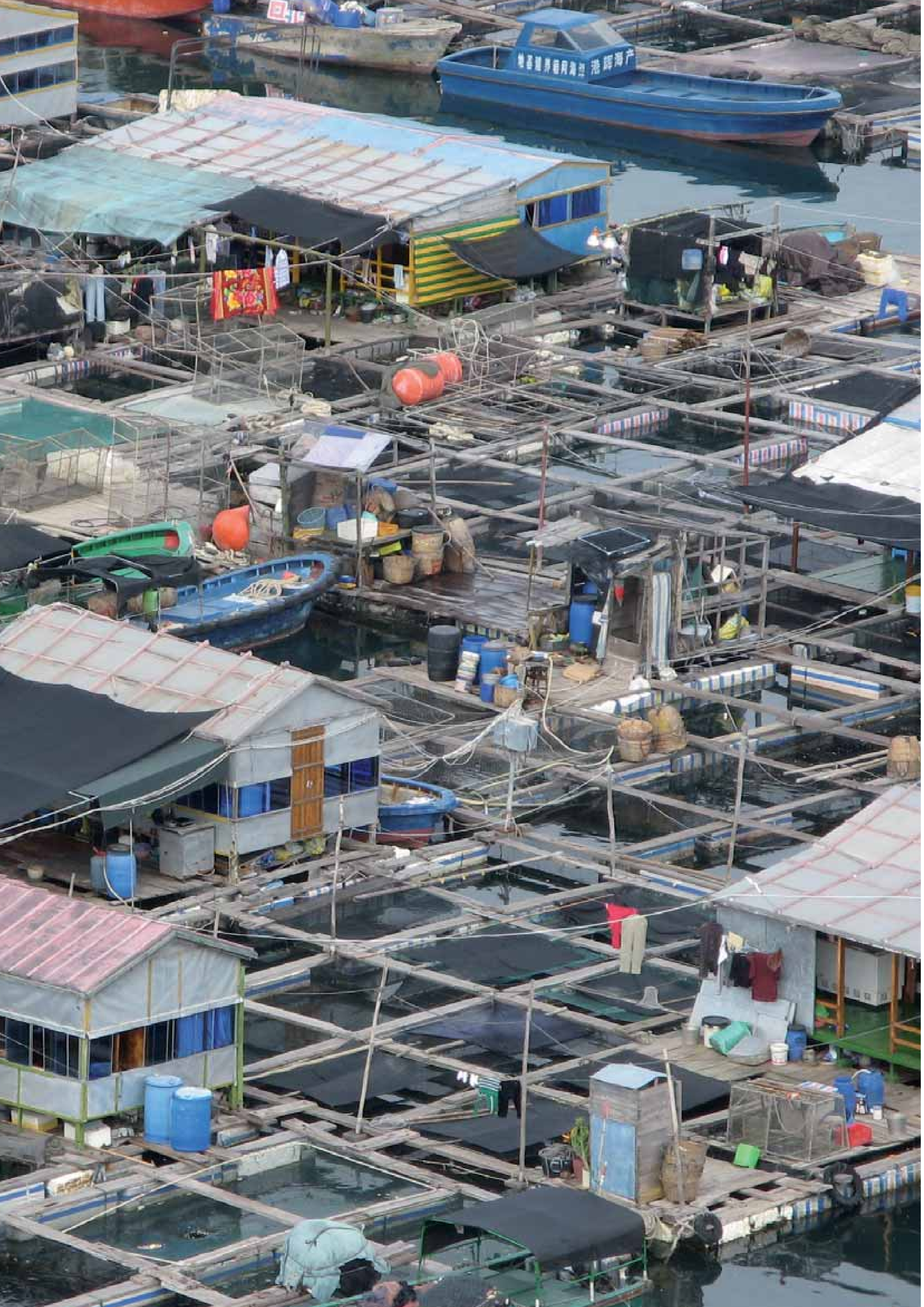
Data were taken from fisheries statistics submitted to FAO by the member countries for 2005. In case 2005 data were not available, 2004 data were used.



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



Cage aquaculture: a global overview



Cage aquaculture: a global overview

Albert G.J. Tacon[1] **and Matthias Halwart**[2]

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

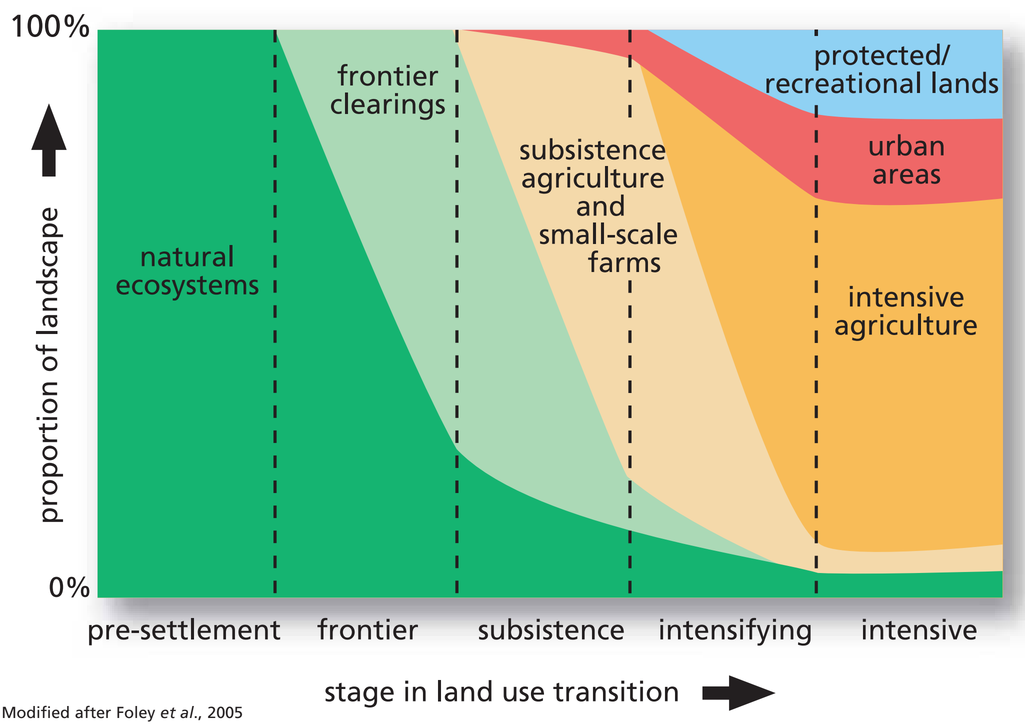
The on-growing and production of farmed aquatic organisms in caged enclosures has been a relatively recent aquaculture innovation. Although the origins of the use of cages for holding and transporting fish for short periods can be traced back almost two centuries ago to the Asian region (Pillay and Kutty, 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

FIGURE 1
Land-use transitions: will aquaculture follow a similar pathway?



Source: Modified after Foley *et al.*, 2005

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
Latin America and the Caribbean region	
Argentina, Bolivia, Chile, Costa Rica, El Salvador, Martinique (France), Panama, Uruguay	Brazil, Colombia, Guatemala, Honduras, Mexico, Nicaragua
North American region	
Canada, United States of America)	
Northern European region	
Bulgaria, Denmark, Estonia, Finland, Germany, Iceland, Ireland, Norway, Poland, Russian Federation, Slovakia, Sweden, United Kingdom	
Mediterranean region	
Albania, Bosnia and Herzogovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Libyan Arab Jamahiriya, Malta, Morocco, Portugal, Slovenia, Syrian Arab Republic, Tunisia, Turkey	Spain
Sub-Saharan African region	
Benin, Gabon, Ghana, Mauritius, Mayotte (France), Mozambique, Réunion (France), Zambia, Zimbabwe	Côte d'Ivoire, Kenya, Madagascar, Nigeria, Rwanda, South Africa, Uganda
Asia and Oceania	
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

FIGURE 2
Major cage aquaculture producing countries globally

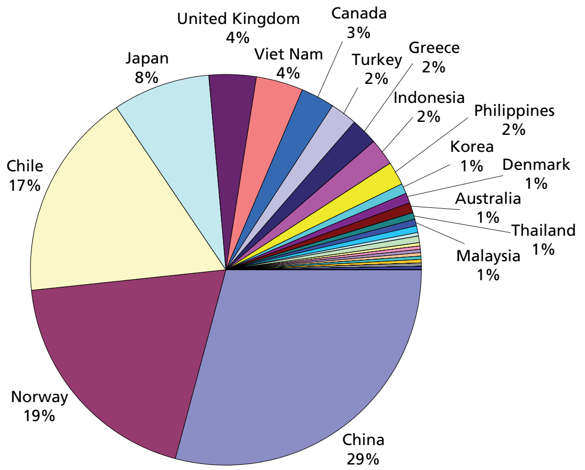
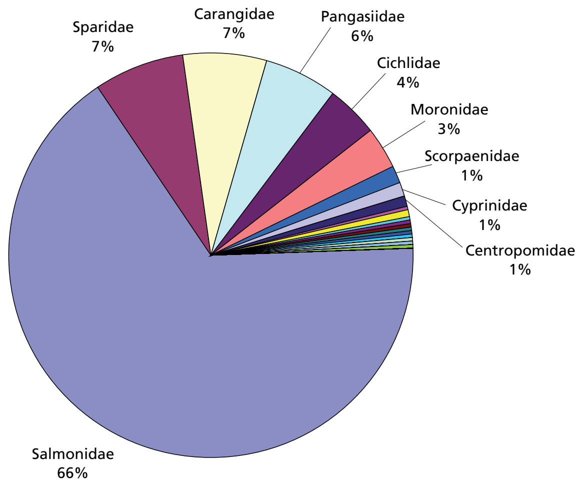


FIGURE 3
Worldwide cage aquaculture production by fish family



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

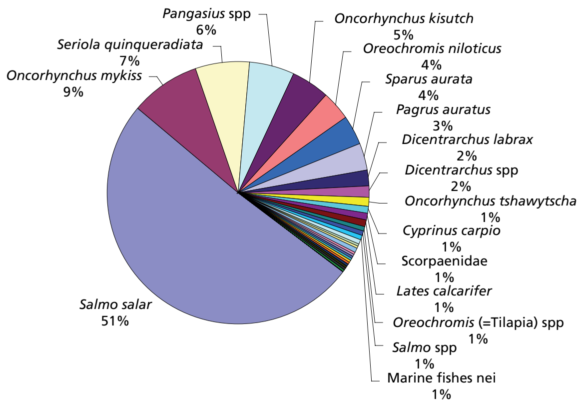
However, cage culture systems employed by farmers are currently as diverse as the number of species currently being raised, varying from traditional family-owned and operated cage farming operations (typical of most Asian countries; De Silva and Phillips, 2007; Pillay and Kutty, 2005) to commercial cages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

FIGURE 4
Worldwide cage aquaculture production by fish 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
Pangasius spp	133 594	41.1
Oreochromis niloticus	87 003	26.7
Cyprinus carpio	21 580	6.6
Oreochromis (=Tilapia) spp	16 714	5.1
Oncorhynchus mykiss	14 625	4.5
Salmo spp	12 071	3.7
Channa micropeltes	11 525	3.5
Salmo trutta	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
Salmo salar	1 219 362	58.9
Oncorhynchus mykiss	195 035	9.4
Seriola quinqueradiata	159 798	7.7
Oncorhynchus kisutch	116 737	5.6
Sparus aurata	85 043	4.1
Pagrus auratus	82 083	4.0
Dicentrarchus labrax	44 282	2.1
Dicentrarchus spp	37 290	1.8
Oncorhynchus tshawytscha	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.

Not withstanding 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.

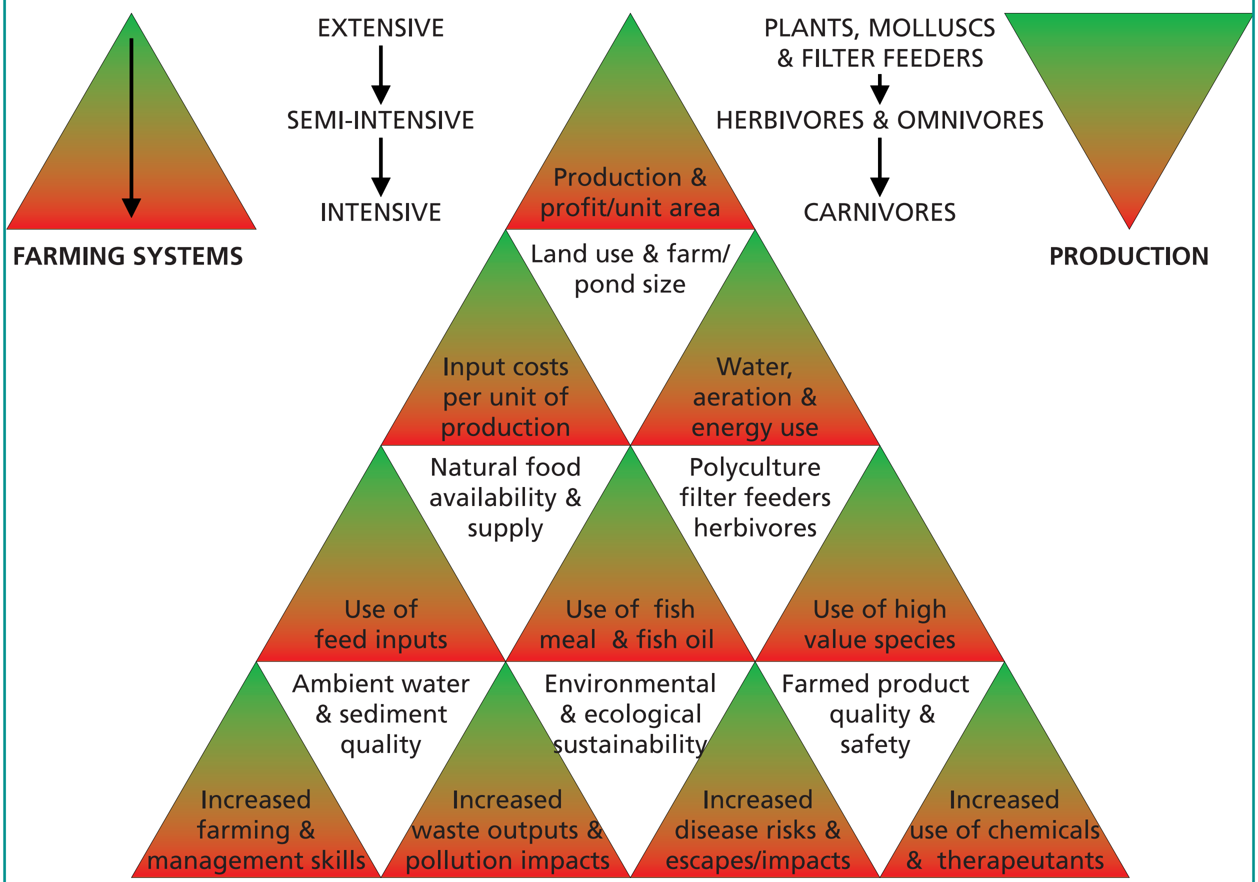
There needs to be more strategic environmental assessment and management which takes account of all the economic activities affecting the aquatic environment and the capacity of the environment to assimilate wastes (Halwart and Moehl, 2006). On the other hand cage culture offers one of the few solutions 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

FIGURE 5

Major differences between conventional extensive, semi-intensive and intensive farming systems in terms of production, resource use and potential/perceived environmental risks



Source: adapted from Tacon *et al*. 1995 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).

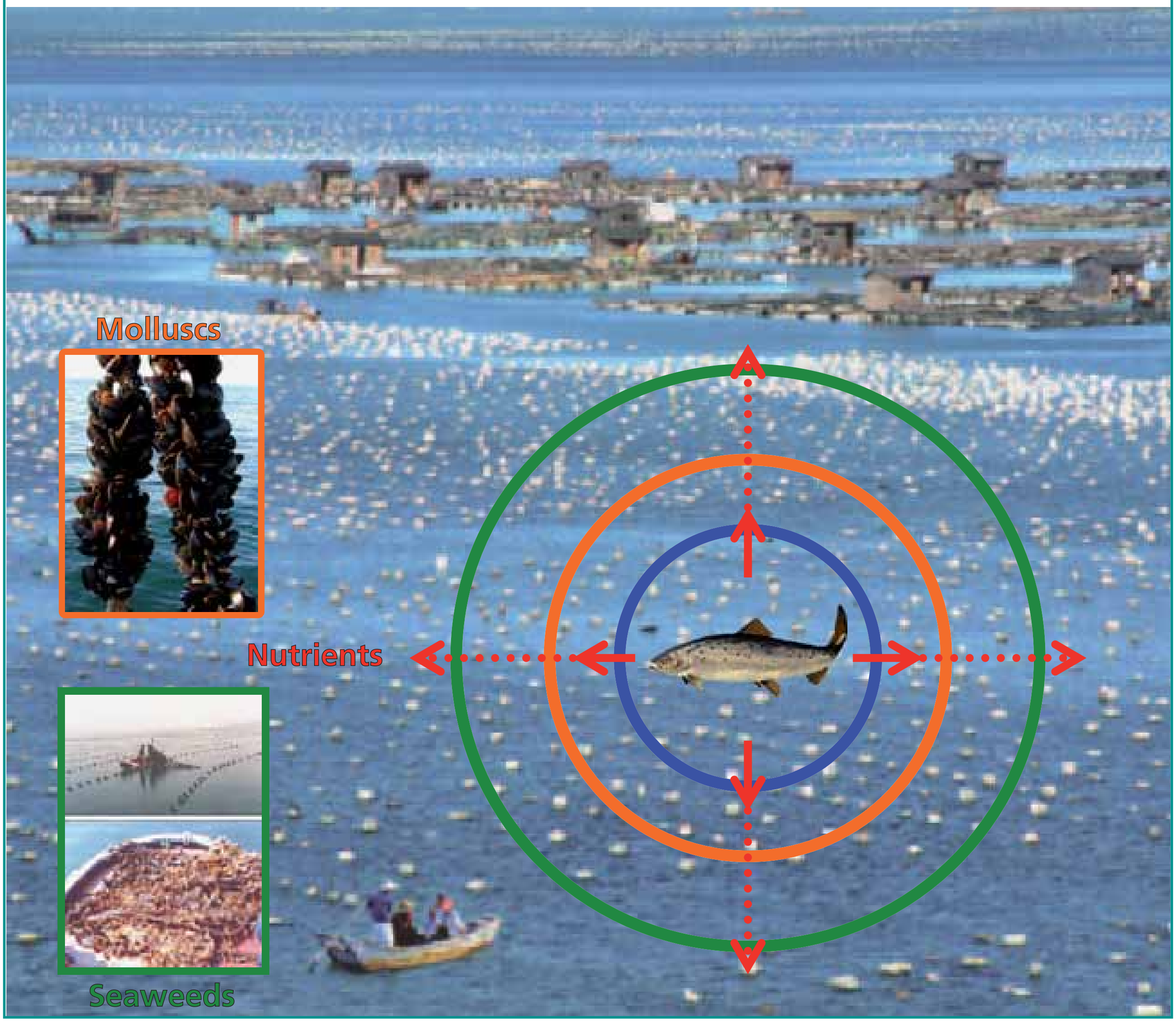
Integrating the system: a multi-trophic approach to cage culture

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 environmentably 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.

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