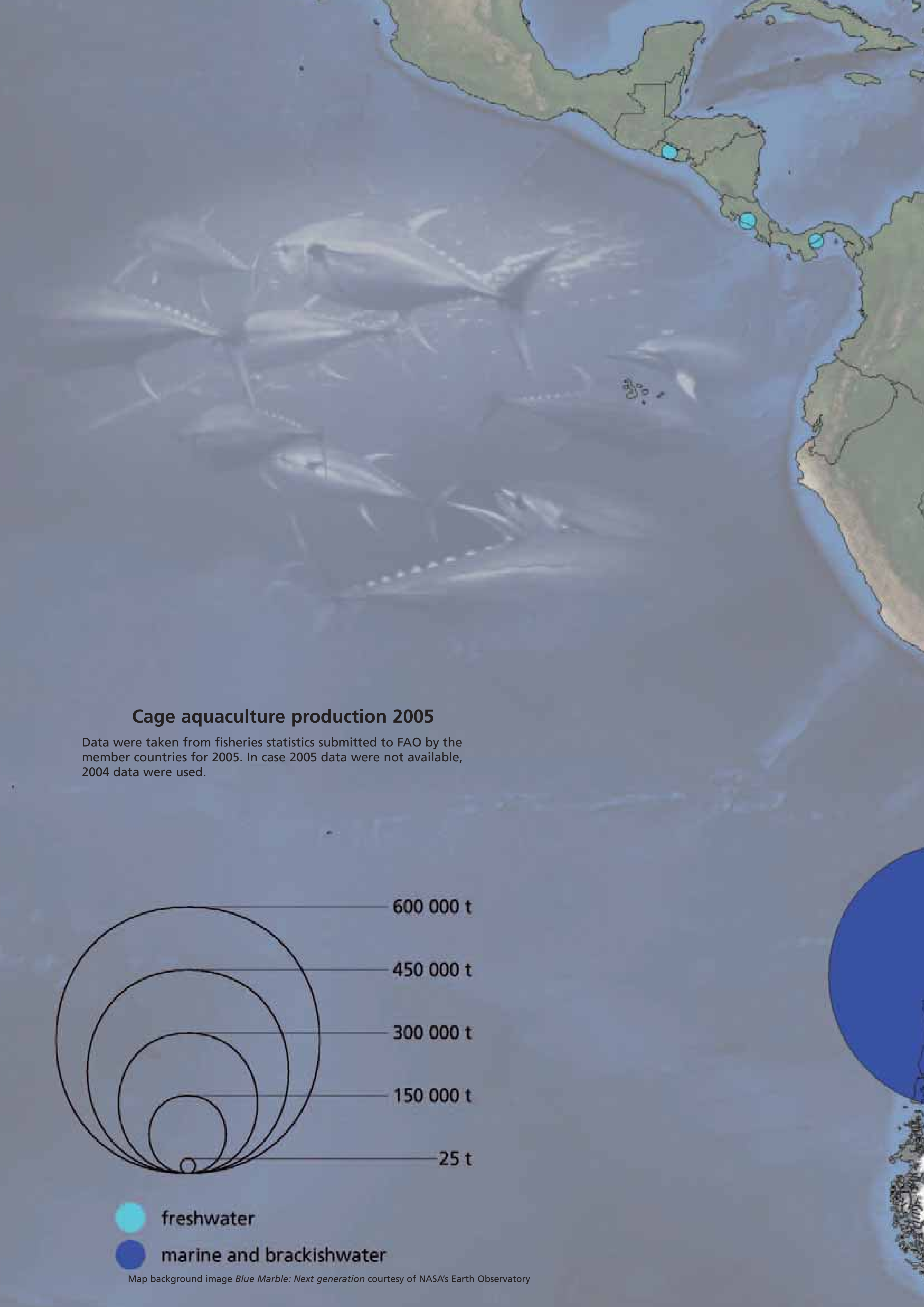
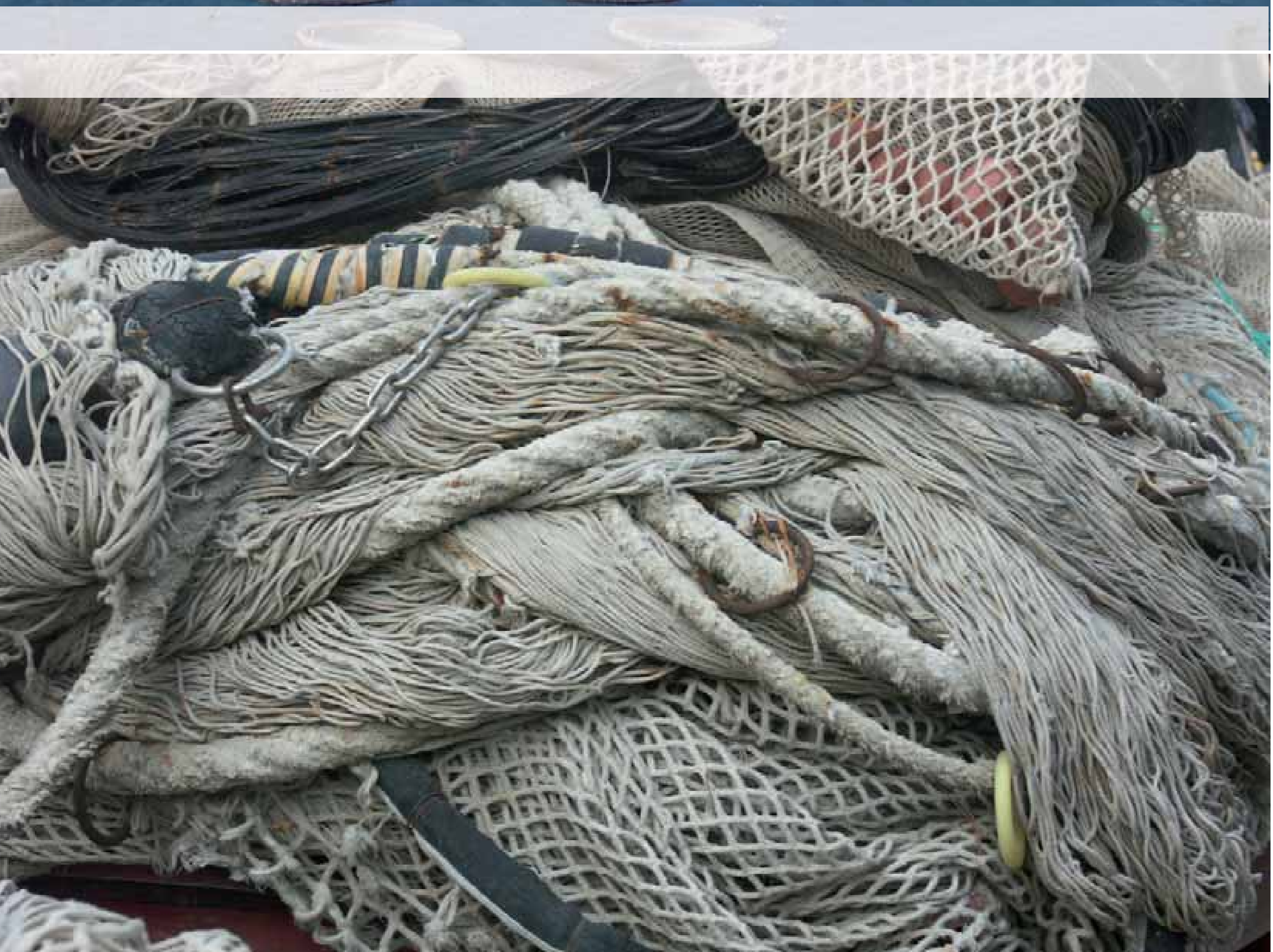
Cage aquaculture production 2005

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

A review of cage aquaculture: Latin America and the Caribbean



A review of cage aquaculture: Latin America and the Caribbean

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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 region[3]

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.

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.

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.

TABLE 1
World aquaculture production for the year 2004

	Volume		Value		
Region	**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

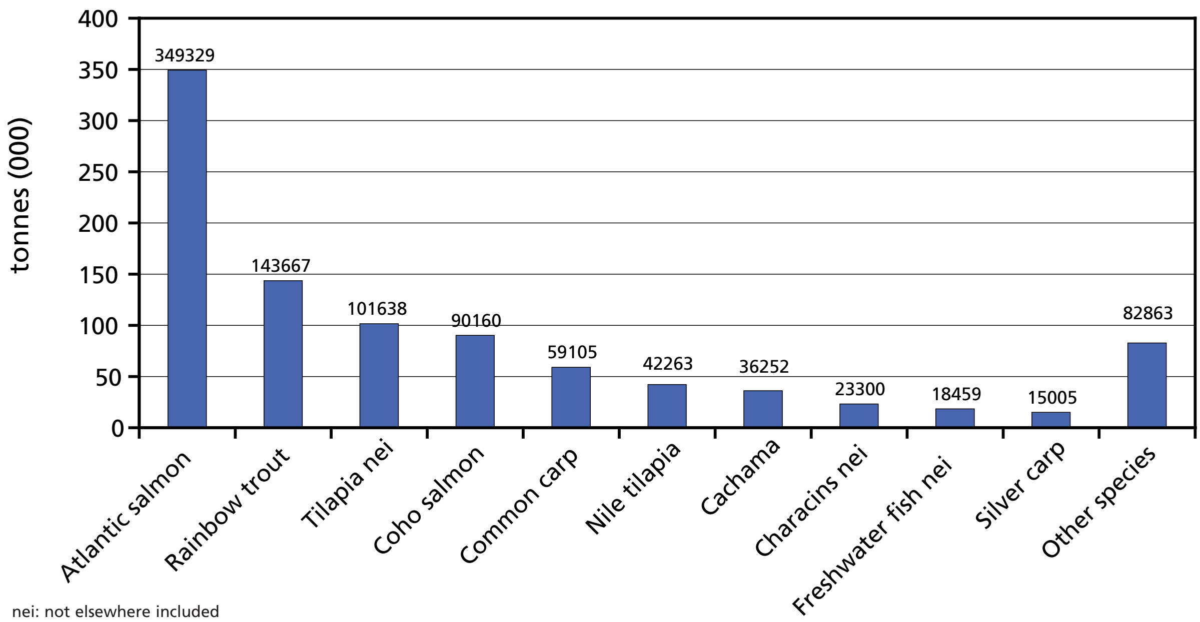
Source: FAO, 2005a,b

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.

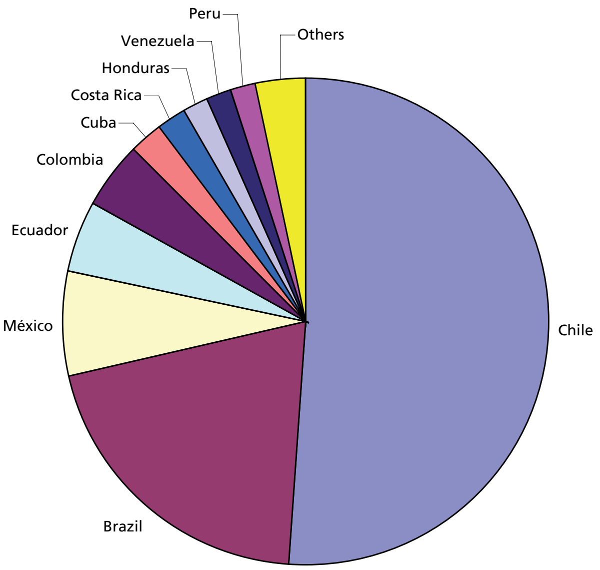
From the 1970s to the 1990s, the focus was on production, but now other areas such as genetics, health and pathology, environmental improvements, harvest processes and the market have become very important in the development of aquaculture. Training programmes in planning, regulations, financing and 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

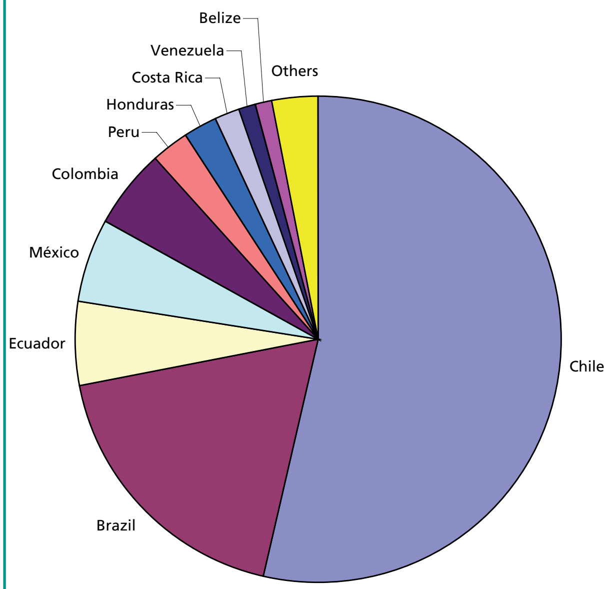
Rainbow trout and coho salmon were first introduced into Chile in the nineteenth century for sport fishing. Farming commenced in 1978 and by

FIGURE 2
Aquaculture production in Latin America and the Caribbean in the year 2004, by volume



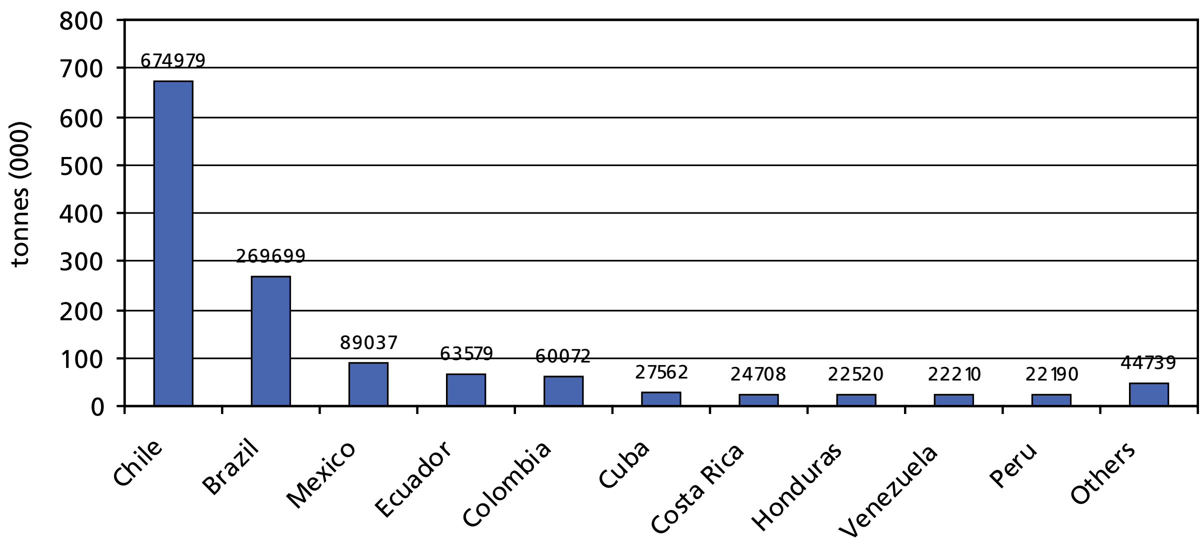
Source: FAO, 2005

FIGURE 3
Aquaculture production in Latin America and the Caribbean in the year 2004, by value



Source: FAO, 2005

FIGURE 4
Aquaculture production in Latin America and Caribbean countries in the year 2004



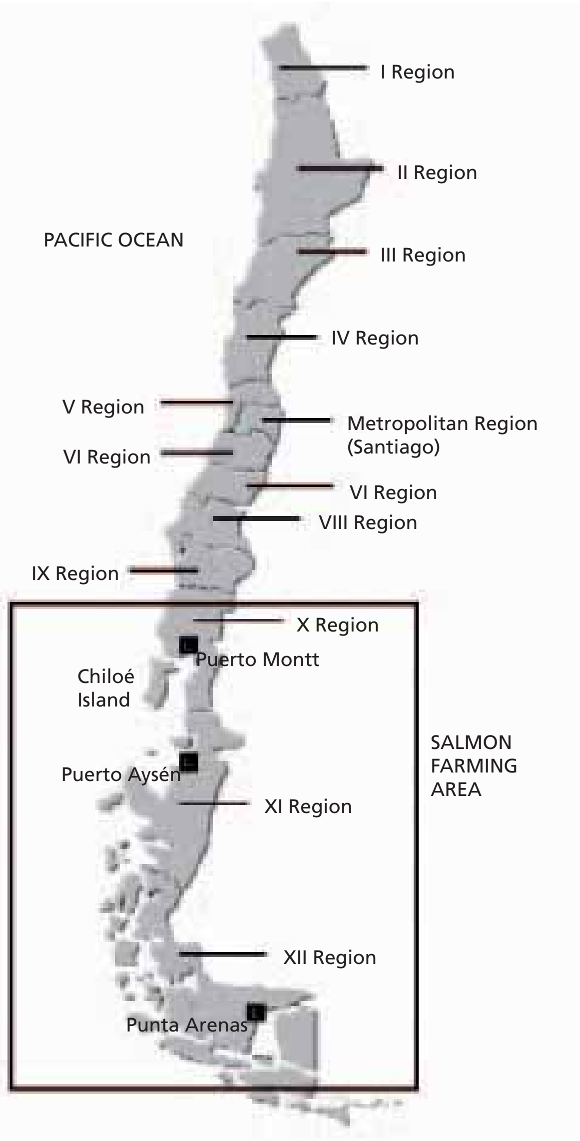
Source: FAO 2005a

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).

FIGURE 2
Salmonid farming areas in Chile



Source: Bjørndal, 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 m^2 (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 6
Plastic circular cages in Chile

COURTESY OF MAINSTREAM SA

FIGURE 7
Feeding process in a plastic cage using an adapted water pump

COURTESY OF MAINSTREAM SA

FIGURE 8
Metal cages in Chile

COURTESY OF MAINSTREAM SA

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

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 10
Typical marine site in Chile

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

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

FIGURE 13
Automatic feeding silo with feed collecting system (Chile)

FIGURE 14
Use of an underwater camera to control feed supply (Chile)

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 theses systems are complementary to field surveys and risk assesment.

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

FIGURE 15
Anti-predator nets deployed around a metal cage in Chile. An additional net has been added to the surface of the pen to prevent bird predation.

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.

FIGURE 16
Anti-predator nets deployed above sea level to prevent sea lions jumping into the pens

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 ("*Polítca 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 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

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

FAO/A. Odoul

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 faming 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/m³)	Productivity (kg/m³)
Small (< 5 m³)	100 – 600	150
Large (> 5 – 100 m³)	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

FAO/A. 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 *Steptoccocus iniae*, to parasites like *Ichthyophthirus 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, underlinings 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 m^3 (Figures 24, 25 and 26). Fish densities can range from 2–5 kg/m^3, 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 MARÍA TERESA VIANA

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

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

COURTESY OF NOAA

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 m^3) (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.

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

COURTESY OF NOAA

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

COURTESY OF NOAA

THE WAY FORWARD

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