# Challenges for developing emerging economies to engage in off-the-coast and offshore aquaculture: the perspective from a case study

**Adolfo Alvial**
*Adolfo Alvial Asesorías*
*Puerto Varas, Chile*
*E-mail: adolfo.alvial@adolfoalvial.cl*

**Alvial, A.** 2013. Challenges for developing emerging economies to engage in off-the-coast and offshore aquaculture: the perspective from a case study. *In* A. Lovatelli, J. Aguilar-Manjarrez & D. Soto, eds. *Expanding mariculture farther offshore: technical, environmental, spatial and governance challenges. FAO Technical Workshop, 22–25 March 2010, Orbetello, Italy*. FAO Fisheries and Aquaculture Proceedings No. 24. Rome, FAO. pp. 297–314.

**ABSTRACT**

The rapid progress of the Chilean salmon farming industry, its state of the art technology and existing off-the-coast autonomous systems, make this a relevant case study for further exploration of the challenges countries face when moving aquaculture offshore. During the second half of 2007, after more than two decades of impressive growth, the Chilean salmon industry has been facing its worst crisis due to the effects of the Infectious Salmon Anemia (ISA) virus on Atlantic salmon (*Salmo salar*). The harvest declined by 50 percent in 2010 in comparison to 2008. The impact of the ISA can only be seen as the final stage of environmental deterioration and fish health decline which has been evident since 2004 due to high farming concentration, very high farming densities, poor management and highly disease susceptible smolt. After three years of ISA impact, thanks to a number of management measures, there are clear indications that the crisis will be controlled. The re-born industry will have new regulations, a new enforcement system and new voluntary measures. A new production model containing very profound changes will allow to become a future leader in this industry not only in quantitative terms but also qualitative. The industry will increase its proportion in offshore operations, principally in the XI and XII regions. The Chilean experience has left in evidence for countries moving aquaculture off-the-coast and offshore that visionary and focused technology transfer processes are essential for high market potential species, as well as, the existence of well qualified workers and professionals. The assignment of aquaculture areas or zones should consider that such adequate areas for aquaculture (AAA) have to be based on the best oceanographic, climatic and environmental scientific information relevant to local conditions. The industry should take into account that at present there are technologies that make technically and economically feasible farming in more exposed

zones, principally finfish, leaving coastal sites for other uses like shellfish and seaweed farming and artisanal fisheries operations. Besides, enclosed, poor water renewal marine areas, estuaries and lakes should be avoided for intensive farming uses or at least used after a previous evaluation of their carrying capacity under the worst scenario. A zone management system should be emphasized in order to produce in accordance with the carrying capacities of the different water bodies in heterogeneous environments, such as the channels and fjord areas in southern Chile. A logistic model should be established to avoid disease dispersion between farms due to navigation routes and cross contamination in ports which should be well supported by a permanent biosecurity system. The success of an off-the-coast and offshore farming system rests on well-qualified personal able to operate sophisticated new generation farming technologies, well engaged workers, with equitable earnings and benefits and appropriate risk assessment of activities and locations. Overall, a participative and ecosystem governance approach should be considered to guarantee stable and sustainable industry development.

## BACKGROUND AND RATIONALE

Due to the rapid expansion of aquaculture worldwide, the demand for more resources such as seeds, feeds, freshwater and inland/coastal space has greatly increased. The search for additional areas to expand and the identification of new farming species to satisfy growing market demand, are forcing entrepreneurs to extend farming activities further off from the coast to offshore where more space is available and competition with other interest groups is currently not as intense.

The development of "off-the-coast" and "offshore" aquaculture" (Table 1) raises a number of biological, spatial, technical, socio-economical, legal and political issues that fall under the consideration of the Food and Agriculture Organization of the United Nations (FAO) and its Member countries. FAO is in the process of collecting global information relating to the potential for off-the-coast and offshore aquaculture which involves the preparation of reviews on specific issues by experts. The current review along with the other technical documents in this proceedings form a global synthesis that culminated in a technical workshop that took place in Orbetello, Italy, in March

TABLE 1
**Coastal, off-the-coast and offshore aquaculture definitions used in this review (working definitions agreed with FAO)**

| | Coastal | Off-the-coast | Offshore |
|---|---|---|---|
| Location/ hydrography | - <500 m from the coast<br>- ≤10 m depth at low tide<br>- within sight<br>- usually sheltered | - 500 m–2 km,<br>- <10 m depth at low tide to ≤50 m<br>- often within sight<br>- somewhat sheltered | - 2+ km, generally within continental shelf zones, possibly open-ocean<br>- >50 m depth |
| Environment | - Hs usually <1 m<br>- short period winds<br>- localized coastal currents, possibly strong tidal streams | - Hs ≤3–4 m<br>- localized coastal currents, some tidal streams | - Hs 5 m or more, regularly 2–3 m, oceanic swells, variable wind periods, possibly less localized current effect |
| Access | - 100% accessible landing possible at all times | - >90% accessible on at least once daily basis,<br>- landing usually possible | - Usually >80% accessible, landing may be possible, periodic, e.g. every 3–10 days |
| Operation | - Regular, manual involvement, feeding, monitoring, etc. | - Some automated operations, e.g. feeding, monitoring<br>- Professional divers needed for moorings and servicing the cages and nets | - Remote operations, automated feeding, distance monitoring, system function<br>- Highly specialized professional divers and technical teams needed for servicing moorings, cages, nets etc. |

2010, that addressed the major components of a global programme for the development of mariculture off-the-coast and offshore.

The present review addresses the economic, technical, legal/political and marketing challenges in the development of existing off-the-coast commercial aquaculture in a developing country. The rapid progress of the Chilean salmon farming industry, its state-of-the-art technology and existing off-the-coast autonomous systems, make Chile a relevant case study for further exploration of the challenges countries face when moving to offshore farming.

## THE EVOLUTION OF THE SALMON INDUSTRY IN CHILE: SOCIAL AND ECONOMIC IMPACTS

### The industry and its social impact

Commercial Chilean aquaculture is characterized by a highly specialized monoculture systems dominated by salmonid species (Table 2), which in 2008, represented more than 529 000 net export tonnes (82,3 percent of contribution) with a value of US$2 474 573 000 (Selling Freight-on-Board or FOB), 82.3 percent and 88.4 percent, respectively (IFOP, 2009). However, by 1980 salmon farming started very small scale, low technology, low investment, moving in few years to a very specialized and high technology industry.

Southern Chile, especially the X and XI administrative regions (Figure 1) where salmon farming is currently taking place, displayed the country's poorest social and economic indicators in early 1980. Within two decades, and as a result of the rapidly growing salmon industry, poverty indicators had fallen into the same category as Chile's highest performing regions, especially in terms of employment and

FIGURE 1
**Salmon sea farming zones (X and XI Regions) and sources of feed producing zones (fish meal/oil and grains)**

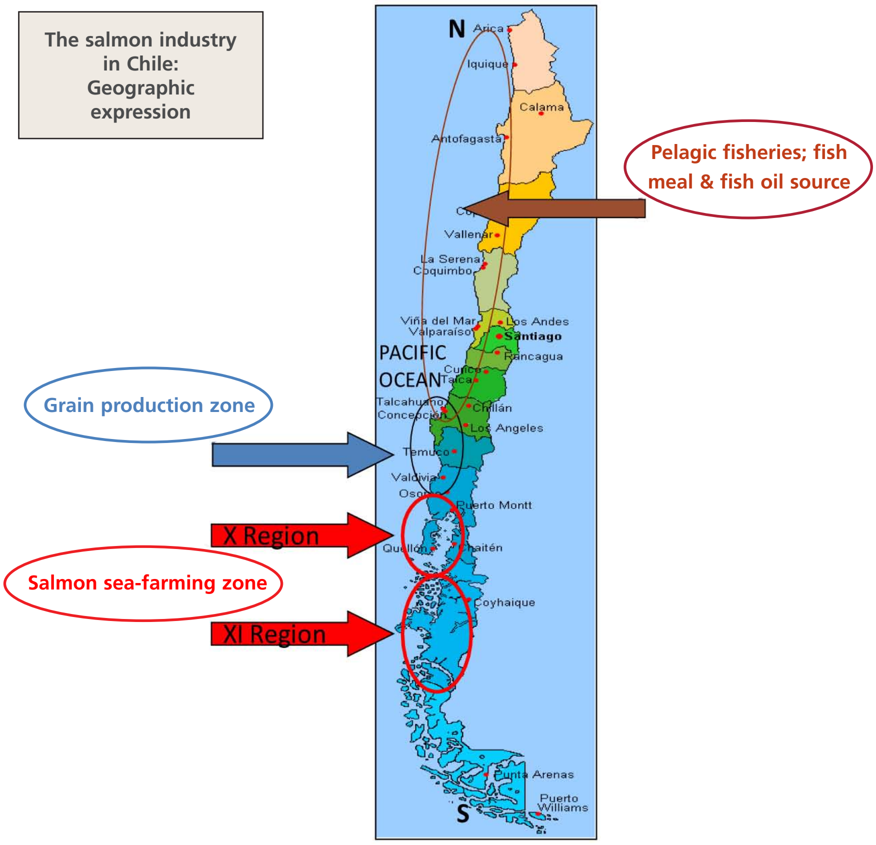


TABLE 2
**Chilean aquaculture production 2010 (tonnes)**

| Species | Total |
|---|---|
| Haematococcus | 12 |
| Huiro (*M. pyrifera*) [Giant kelp] | 12 |
| Pelillo (*Gracilaria* spp.) [Gracilaria] | 12 150 |
| Spirulina | 5 |
| Hirame (*P. olivaceus*) [Olive flounder] | 7 |
| Atlantic salmon (*S. salar*) | 123 233 |
| Coho salmon (*O. kisutch*) [Pacific salmon] | 122 744 |
| Chinook salmon (*O. tshawytscha*) [King salmon] | 636 |
| Rainbow trout (*O. mykiss*) | 220 244 |
| Turbot (*P. maximus*) | 292 |
| Abalon rojo (*H. rufescens*) [Red abalone] | 794 |
| Cholga (*A. ater*) [Cholga mussel] | 1 736 |
| Chorito (*M. chilensis*) [Chilean blue mussel] | 221 522 |
| Choro (*C. chorus*) [Choro mussel] | 757 |
| Ostion del Norte (*A. purpuratus*) [Northern scallop] | 8 840 |
| Ostra Chilena (*O. chilensis*) [Chilean oyster] | 163 |
| Ostra del Pacifico (*C. gigas*) [Pacific oyster] | 94 |
| **Total algae** | **12 179** |
| **Total finfish** | **467 156** |
| **Total mollusc** | **233 906** |
| **TOTAL** | **713 241** |

*Source:* Elaborated based on SERNAPESCA statistics (www.sernapesca.cl).

per capita export. In these same decades, high emigration was replaced by immigration and the poorest segments declined as income per capita increased. The industry was able to offer around 25 000 direct job positions and 20 000 indirect positions up until 2007. Surrounding a nucleus of approximately forty companies, more than 1 200 suppliers, consolidated a natural cluster that has been well documented by different authors (Montero, Maggi and Parra, 2000; Maggi, 2002; Katz, 2004; Agraria Consultores, 2004; Pérez-Aleman, 2005; Torres, 2006; Boston Consulting Group, 2007; Iizuka, 2009).

From 2000 up to 2003 communities with salmon farming industry experienced a larger poverty reduction than the Chilean average, and much more than other communities without salmon farming in the same region (Table 3). The autonomous income of salmon farming within communities has increased by 15 percent, much higher than the country's average of four percent and 10 percent in the whole salmon region (i.e. the X Administrative Region in Chile).

TABLE 3
**Variation of social indicators from 2000 to 2003**

| Variation period 2000–2003 | Not salmon related communes (X Region) (%) | Salmon related communes (X Region + Puerto Aysén) (%) | Total country (%) |
|---|---|---|---|
| Poverty | -17 | -13 | -6 |
| Indigence | -22 | -42 | -10 |
| Autonomous income | 10 | 15 | 4 |
| Monetary subsidies | 27 | 23 | 16 |

*Source:* CASEN, 2003.

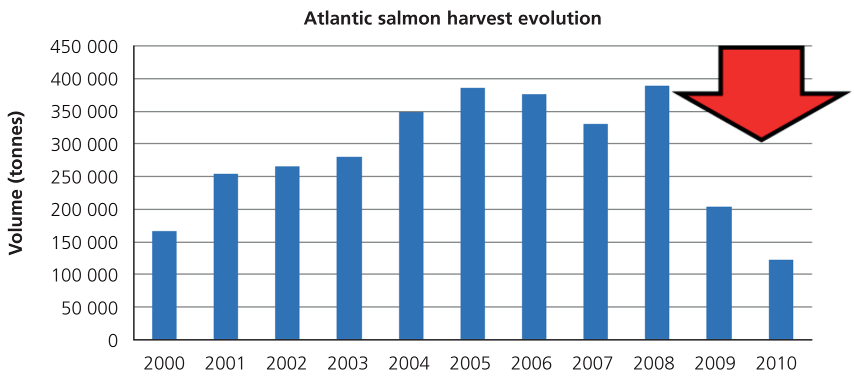
In spite of this accelerated growth, regulations, enforcement systems and research were behind industry development in addition to a low allocation of resources by government. Furthermore the industry did not devote sufficient attention to establishing good links with communities and third parties (such as artisanal fishermen and tourism) sharing common coastal zones and thus in times of difficulty, the sector lacked support from these parties and faced strong criticism.

According to Amtmann and Blanco (2001) there is a strong relationship between agriculture and salmon farming in the southern regions of Chile. It is possible to notice that the depression of one sector is functional to the development of the other and the recent salmon industry crisis illustrates this connection in terms of employment levels. It is also evident that there has been a return to artisanal fishing activities.

## The environmental and the sanitary crisis

Since the second half of 2007, after more than two decades of impressive growth, the Chilean salmon industry has been facing its worst crisis due to the effects of the Infectious Salmon Anemia (ISA) on Atlantic salmon (*Salmo salar*). Consequently, the harvest of this species showed a sharp decline in 2009 and 2010 (Figure 2). However, the impact of the ISA can only be seen as the final stage of environmental deterioration and fish health impoverishment which has been evident since 2004. During that period

FIGURE 2
**Production evolution of Atlantic salmon (tonnes per year)**




*Source:* SERNAPESCA statistics (www.sernapesca.cl).

biomass at any site and density of sites increased particularly in the coastal areas of the X region and most notably in the central and east coasts of Chiloé Island, where approximately 40 percent of the total salmon production was concentrated.

At the end of 2006 a serious increase in the abundance of sea lice (*Caligus rogercresseyi*) became apparent and was most likely due to a combination of higher water salinity, an increase in the concentration of fish farming, condition of the fish and increased parasite resistance to the only approved drug for years in Chile, i.e. emamectine benzoate. Sea lice spread rapidly through the X and XI regions reaching high levels of infestation, in some cases thirty to fifty parasites per fish. Due to resistance development, the drug used proved to be ineffective. Fish were stressed, immunologically depressed and externally damaged, all of which were key factors contributing to the rapid penetration of opportunistic pathogens.

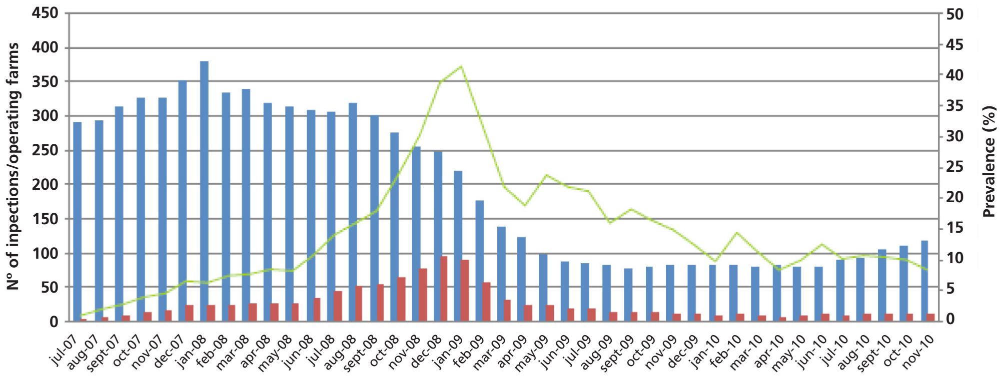
In July 2007, during efforts to control the sea lice epidemic, Marine Harvest Chile (MHC) informed of an ISAv finding in Atlantic salmon pertaining to a site in central Chiloé after first confirming it with local and foreign reference laboratories. Only a few days later other sites were reported to present ISAv outbreaks and from that point on the virus spread rapidly through the X, XI and XII regions despite rapid contingency measures implemented by the government and the voluntary measures agreed to by the salmon companies.

From the first detection of the virus MHC together with Chilean laboratory Biovac and Dr Fred Kibenge's laboratory on Prince Edward Island have been developing an epidemiologic study which has recently shown that the Chilean ISAv is genetically unique, although similar, to an ISAv reported in Norway in 1996. Using the software program, Backtrack, it was estimated that the virus was present in Chile as early as 1996, and suffered a strong diversification around 2005. The virus found in the first reported case by MHC in July 2007 was not the oldest strain of the ISA viruses existing in Chile at that point. This suggests that the virus had been present in the Chilean environment for several years and due to its low prevalence and lack of adequate detection techniques mortality events could not be linked to it.

At present, sea lice is under control due to a successful control plan and damages found on the fish have decreased dramatically. In addition, total biomass and densities have rapidly declined. A number of new regulations and volunteer measures are in place, which support zone management programmes; strict eggs import control and complete biosecurity measures, initiating the process to control ISA (Figure 3). These regulations, together with drastic changes are resulting in a new production model for the industry. Although a biological improvement is becoming apparent, the consolidation of industry change demands law adjustments and company investment, which are presently materializing.

FIGURE 3

**ISA trend in Atlantic salmon. The graph shows the numbers of ISA inspections and prevalence percentage (green line) in operating farms (blue bar), positive farms (red bar), between July 2007 to November 2010**




*Source:* Technical Report of the Specific Health Surveillance and Control Program of ISA virus 2008–2010. www.sernapesca.cl

The crisis will be controlled and the change in production ratios started in the second semester of 2009 while stocking reactivation will start in 2010. Therefore a change in annual production trend can be expected in 2011. The new industry will have new regulations, new enforcement system and new voluntary measures. Finally a new production model containing profound changes will allow Chile to become a future leader in this industry not only in quantitative terms but also qualitative. Knowledge about the environment, its dynamics and carrying capacity will be fundamental to the new industry's success. Without these elements Chile will not be able to manage the sanitary contingencies in the long-term and it will face the risk of new crisis as severe as the present one.

## TECHNOLOGICAL DEVELOPMENT: THE BIRTH AND GROWTH OF AN AQUACULTURE INDUSTRY THAT MUST MOVE OFF-THE-COAST

### Technology and industry evolution

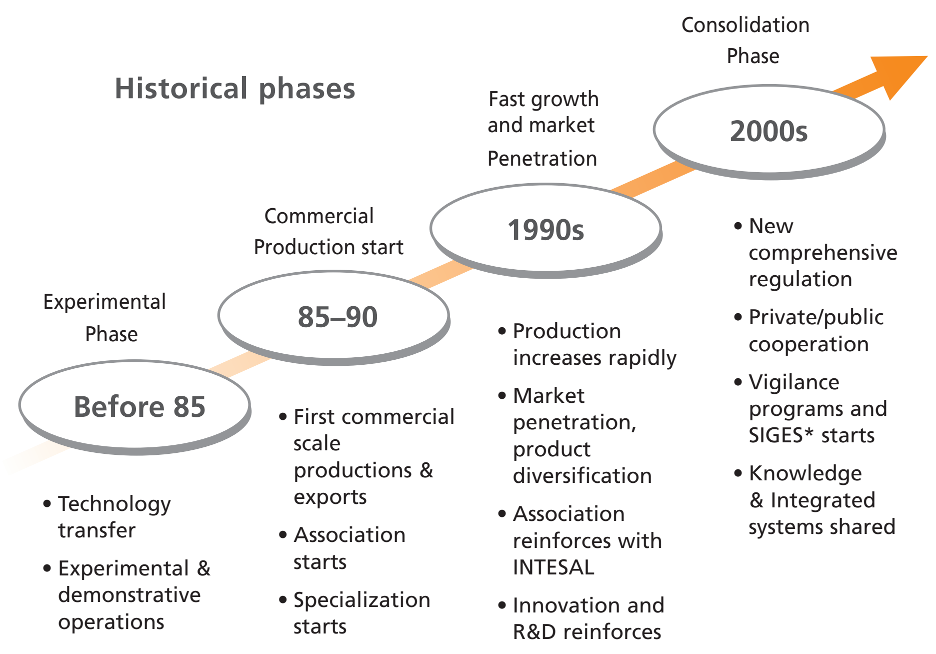
The salmon farming industry in started at the end of the 1970s after some initial management and legal problems. Since then "Fundación Chile" has played a vital role in importing and transferring technology for intensive salmon production in captivity which triggered the new industry based in the X region (Los Lagos).

Basic technology was imported principally from Canada, United States of America, United Kingdom and Norway. Hatchery equipment and cage designs were based on models being applied in those countries with minor adaptations in some cases to Chilean necessities. Eggs were also imported from those countries. It was clear that Chile had the natural conditions to develop a very competitive industry together with professionals and technicians well prepared to take position in the emerging industry.

The evolution of the industry can be seen in Figure 4 which shows the different stages of development up until now. It is important to mention that at the beginning of the experimental phase sea cages were manufactured *in situ* and gradually some imported cages were introduced from the northern hemisphere.

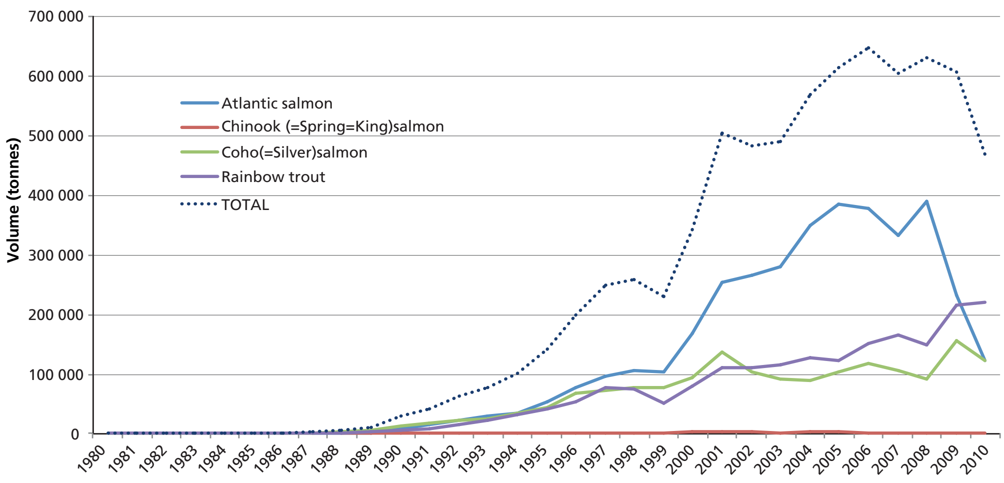
It is also important to mention that in the beginning of the industry and up to 1995, three species; rainbow trout (*Oncorhynchus mykiss*) coho salmon (*Oncorhynchus kisutch*) and Atlantic salmon (*Salmo salar*) shared the production volume. After 2000 Atlantic salmon became the dominant species (Figure 5) due to its highest market demand. The salmon disease crisis since 2008 did not cause a sharp decrease in total salmonid production in Chile until 2010 also due to the increase in trout and coho salmon production.

FIGURE 4
**Salmon industry evolution phases in Chile**




*SIGES: Sistema integrado de gestión.

FIGURE 5
**Evolution of production of the farmed species of salmon and trout in Chile**

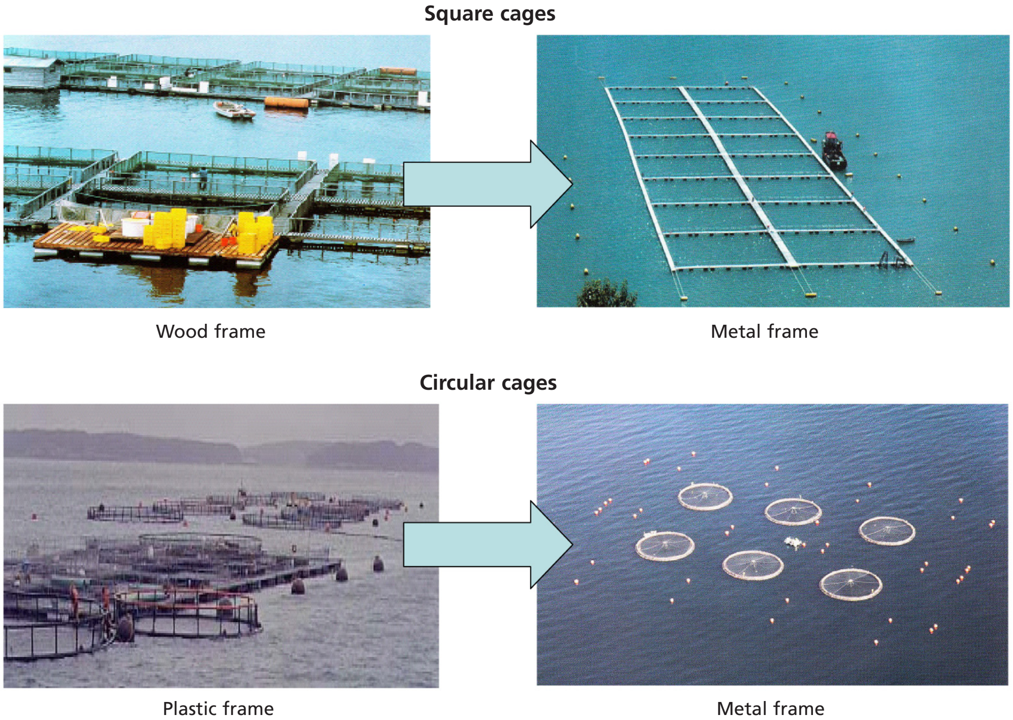



*Source:* Global dataset of aquaculture production (quantity and value) 1950–2010. Released in March 2012, by Fisheries and Aquaculture Statistics and Information Service, FAO.

## Farming environment and equipment

Enclosed coastal waters were preferred for the initial operations of sea cages settlement, all of them within the adequate areas for aquaculture (AAA) range or areas where aquaculture was authorized in the sea. Protected bays and fjords were utilized to mitigate impact by strong, predominantly north western winds, as well as, short but intense periods of southern winds during the spring and summer months. Usually these sites did not exceed 20–30 m in depth and had low water renewal. At that stage, all salmon cage frames and farm set up in the emerging Chilean industry were made of wood and their fragility emphasized the need to protect them from severe weather

FIGURE 6
**Different types of cages used in seawater conditions in the Chilean salmon industry representing technology evolution. Top left: early 1980s; top right: represents late 1980s; bottom left: mid-1990s; and bottom right: mid-2000s**




conditions. Sites normally had one or two modules of 10 square cages, 10 × 10 × 10 m or 15 × 15 × 15 m in dimension. With the exception of some "coastal" experimental units most of the cages installed in the sea for salmon growout were, according to the definition used in the present document (Table 1) "off-the-coast" as it was not viable to settle these cages in locations less than 10 m in depth ("coastal" farming) due to sediment re-suspension and wave effects.

By the end of the 1980s, square metal-framed cages were introduced allowing farms to be settled in more exposed areas which could be classified as further off the coast centers. Favoring the colonization of more exposed areas, the circular polyethylene and metal-framed cages were also introduced in the 1990s (Figure 6).

At present all types of cage models are produced by national and foreign companies in Chile. Only a small fraction is still imported, especially the circular models highly suitable for exposed zones. Table 4 summarizes cages characteristics and evolution.

Most recent sea cage structure innovation includes polyethylene nets followed by copper based nets, a recent innovation in Chile. Polyethylene nets are being used in commercial operations in the XI region with satisfactory results while copper nets are still in the experimental and validation phase. Other innovations in the making include developing submerged feeders and innovating present pen systems to improve vertical cage movement. New submerged cages, developed by a company in Israel, are also being offered to Chile.

### Farming sites and equipment trends: what to expect in the future

Further development of salmon farming in Chile will have to continue the trend of moving off-the-coast and offshore, both due to the current diseases crisis, but also to allow expansion and to avoid environmental impacts and conflicts with other users of channels and fjords.

TABLE 4
**Square and circular cages – characteristics and evolution**

| Square cages | 1993 | 1995 | 1998 | 2002 | 2006 | 2010 |
|---|---|---|---|---|---|---|
| Side (m) | 12 | 15 | 20 | 30 | 30 | 30 |
| Depth (m) | 9 | 12 | 15 | 15 | 15 | 15 |
| Volume ($m^3$) | 1 296 | 2 700 | 6 000 | 13 500 | 13 500 | 13 500 |
| N° Fish (avg)/site | 300 000 | 500 000 | 700 000 | 900 000 | 1 000 000 | 1 200 000 |
| N° Fish/cage | 7 500 | 13 889 | 25 000 | 45 000 | 50 000 | 85 714 |
| N° Cage/site | 40 | 36 | 28 | 20 | 20 | 14 |
| N° Fish/$m^3$ | 231 | 185 | 117 | 67 | 74 | 89 |
| N° modules | 2 | 2 | 2 | 2 | 2 | 1 |
| Depth of sites trend | 15–30 | – | – | 30–50 | – | 40–80 |
| Estimated production/site (mt) | 1 200 | – | – | 3 500 | – | 4 500 |
| **Circular cages** | **1993** | **1995** | **1998** | **2002** | **2006** | **2010** |
| Diameter (m) | – | 24,5 | 30 | 31,6 | 35,8 | 34,1 |
| Depth (m) | – | 15,9 | 18 | 18 | 16,5 | 16,8 |
| Volume ($m^3$) | – | 7 496 | 12 723 | 14 099 | 16 562 | 15 334 |
| N° Fish (avg)/site | – | 200 000 | 700 000 | 1 000 000 | 1 200 000 | 1 800 000 |
| N° Fish/cage | – | 20 000 | 35 000 | 35 714 | 30 000 | 45 000 |
| N° Cage/site | – | 10 | 20 | 28 | 40 | 40 |
| N° Fish/ $m^3$ | – | 27 | 55 | 71 | 72 | 117 |
| N° modules | – | 1 | 1 | 2 | 2 | 2 |
| Depth of sites (m) | – | 20–40 | – | 30–50 | – | 50–100 |
| Estimated production/site (mt) | 0 | – | – | 3 500 | – | 6 700 |

Note: The circular cage diameter and depth is representative of weighted average values of specified years.

- No further salmon sites will be licensed in the X region (already under enforcement) and stricter control and requirements will be established in the XI and XII regions.
- A review of existing authorized aquaculture areas will take place with the view of expanding them and allowing the relocation of some "coastal" salmon farming sites. This is currently under discussion based on new law adjustments and will involve abandoning shallow and enclosed bays where water dynamic is poor for more exposed sites, in other words a movement further off-the-coast and possibly towards offshore can be expected in Chilean salmon farming. Offshore aquaculture areas are not expected in the next ten years, given the rough conditions of the Pacific coast, but certainly more exposed zones in the canals and interior waters will be colonized.
- A review of established salmon neighborhoods will take into consideration environmental zones or waterbodies. There is a wide consensus that the "aquaculture neighborhoods" currently in place do not reflect homogeneous zones in environmental terms, but it is accepted that this is a good beginning and that a review based on the best scientific information including elements of carrying capacity is going to be necessary. Future assignment of salmon environmental zones should consider specific management plans for each in order to effectively protect biodiversity and ecosystem services.
- Different companies will try to concentrate their farms in discrete zones by exchanging licenses, and also companies will be able to merge some of their own licenses in order to create more distance between their site clusters and others. This option has been considered in the discussion of the new law.
- New ports will be established to serve specific aquaculture zones avoiding complex navigation tracks that increase the risk of disease dispersion. In addition, area segregation in ports will be established and ports for specific and compatible uses are expected.

FIGURE 7
**Examples of submersible pens designs used for offshore mariculture. Left image: Cates International Inc. system; right image: AquaPod Cage**

COURTESY OF DANIEL BENETTI

COURTESY OF DANIEL BENETTI

- Navigation control of aquaculture supplier boats will be established making it possible to detect deviations or use of unauthorized routes.
- Mortality will be stored in hermetic containers and immediately neutralized out of the sites, to avoid the risk of disease dispersion and contamination.
- Harvesting with biosecure well-boats will be increased to avoid sanitary risks and improve final product quality. Several systems are being evaluated based on this approach.
- As a result, logistic as well as investment costs will increase, but it is expected that they will be compensated with higher productivity and less risk of collapse due to environmental or sanitary disruptions.

In short, the industry will increase its proportion of operations further off-the-coast and offshore, mainly in the XI and XII regions and initially, it is likely to depend on foreign supplies such as Subflex-Navtec (Israel), Open Ocean System Inc. (Canada), Ocean Farm Technologies Inc. (USA) and Aqualine (Norway), including submersible sea cages type (Figure 7). At the same time, adjustments to present off-the-coast sea cages will be made to move them within the water column itself in conjunction with the development of feeders and extractors for deceased fish. In parallel, new copper and plastic based net materials will diminish the biofouling impact and sanitary risks on sites. In general, Chilean companies are not considered innovative and tend to import technologies from overseas (Aqua, 2007) but this is changing out of necessity to the present environmental/sanitary crisis.

## VALUE CHAIN COSTS, STRUCTURE AND SOURCES OF FINANCING

### Value chain and cost structure

Table 5 puts into perspective the contributions of the different cluster components of the salmon value chain in Chile over time, illustrating the three farmed species: Atlantic salmon, rainbow trout and Coho salmon for 2002, 2004 and 2008.

It is interesting to note the following trends in the cost structure over time:

- Sanitary and environmental pressures have increased production costs for fish farming. Therefore farming conditions and biosecurity measures have increased. In addition, feeding costs and higher mortality rates increased from 2004 to 2008.
- Higher fuel costs have in turn increased internal transport costs.
- Consolidation of the industry within its target markets has decreased administration and sales costs.
- Processing costs have also diminished due to higher plant efficiency.

TABLE 5
**Specific weight of value chain components over time. This analysis does not include export costs, distribution costs and margin in the target markets**

| | 2002 [1] | | 2004 [2] | | 2008 [3] | |
|---|---|---|---|---|---|---|
| **Phases, subsectors and components** | **US$ (millions)** | **Value (%)** | **US$ (millions)** | **Value (%)** | **US$ (millions)** | **Value (%)** |
| **Hatchery and smolt production** | **49** | **5.0** | **50** | **3.3** | **156** | **6.30** |
| **Growout/seawater production** | **535** | **55.0** | **830** | **55.30** | **1 508** | **61.00** |
| Fish Feed | 341 | 35.0 | 500 | 33.3 | 965 | 39.0 |
| Labour | 117 | 12.0 | 120 | 8.0 | 135 | 5.5 |
| Feed additives (pigments, vitamins, minerals) | 29 | 3.0 | 120 | 8.0 | 198 | 8.0 |
| Health | 10 | 1.0 | 40 | 7.0 | 109 | 4.4 |
| Cage structure and nets | 29 | 3.0 | 20 | 1.3 | 30 | 1.2 |
| Diving services | 5 | 0.5 | 15 | 1.0 | 12 | 0.5 |
| Other inputs and services | 5 | 0.5 | 15 | 1.0 | 59 | 2.4 |
| **Processing plant** | **146** | **15.0** | **290** | **19.3** | **327** | **13.20** |
| Labour | 107 | 11.0 | 180 | 12.0 | 223 | 9.0 |
| Packaging | 19 | 2.0 | 60 | 4.0 | 74 | 3.0 |
| Other expenditures | 19 | 2.0 | 50 | 3.3 | 30 | 1.2 |
| **Domestic transport** | **39** | **4.0** | **80** | **5.3** | **143** | **5.8** |
| Maritime freight | 19 | 2.0 | 40 | 2.7 | 72 | 2.9 |
| Inland freight | 19 | 2.0 | 40 | 2.7 | 72 | 2.9 |
| **Selling and administrative expenses** | **68** | **7.0** | **80** | **4.7** | **92** | **3.7** |
| **Financial cost and profit** | **136** | **14.0** | **40** | **12.0** | **247** | **10.0** |
| **TOTAL** | **973** | **100.0** | **1 500** | **100** | **2 474** | **100** |

[1] *Source:* Maggi, 2002.
[2] *Source:* CORFO, Región de Los Lagos, 2004.
[3] Estimates based on information collected and/or provided by the Instituto de Fomento Pesquero (2009) and INTESAL.

Projections for the next five years:

- Relative weight of freshwater production will have a tendency to increase by approximately 10 percent due to more frequent use of recirculation systems to produce smolt on land and the need for larger fish to be stocked in the sea.
- The relative cost of production in the sea should drop back to 55 percent due to the higher smolt quality and size and also due to the effects of biosanitary measures and implemented logistics which will reduce mortality and increase efficiency.
- Processing should stabilize at about 13 percent and internal transport at about 6 percent.
- The need to re-conquer Altantic salmon markets after the crisis will raise the cost of administration and sales to around 5 percent and both the financial cost and profit margin by 11–12 percent.

## Financing sources

Investment in cages, logistics, landing sites, boats, etc., is strictly financed by producers. They are able to obtain bank credits but like any other private agent in the country they need to comply with contractual obligations.

After evaluating the viability of the industry and companies, banks have renegotiated the debt for most of them. In parallel, banks have pushed for tighter regulations and practices that provide better management of sanitary/environmental risk. Despite debt renegotiation, credits were almost suspended motivating some companies to try to get financing from the stock market after environmental/sanitary industry improvement.

Due to these circumstances the Chilean Government has instigated co-financing and endorsement for company projects directed at developing improvements in sanitary/environmental management. Although these aids are being used to a certain extent, it is crucial that the new law meets with approval and fulfills many obligations that will restore confidence within financial systems and potential new investors.

Additionally, some Norwegian companies, using co-financing, are offering sea cages to Chilean investors. These co-financial instruments are based on Norwegian funds promoting technology exports to other countries.

Nowadays, most sea cage components are produced in Chile. However, it is still optional to import some special parts and supplies from different countries such as ropes from Greece or marine lights from Australia. Nevertheless, over time, local suppliers have been able to incorporate the latest technology to their local offer and have developed a variety of elements and parts including automatic feeders, electronic control equipment and related software.

The design of the above elements is specific to the requirements of individual Chilean companies and takes into consideration environmental control needs. It is currently possible to find a wide variety of high quality services and products in Chile that are also actively exported with the exception of large circular cages, 100 m in diameter, for offshore conditions such as it was planned by Aqualine for the Tripanko project, south of Chiloé Island.

Local suppliers are able to supply amongst other, environmental site evaluation and characterization, site design and mooring, feeding systems and automatic control installation, all to an exceptionally high standard. Such supply services, highly specialized are also very sensitive to fluctuations of the salmon production and markets and therefore suffered from the Atlantic salmon crisis. However, the more recent development of finfish cage culture in other countries in the region, e.g. Brazil, Ecuador and Peru has created a market for such products and services.

## SITE SELECTION AND ZONING

### Zoning and scientific knowledge

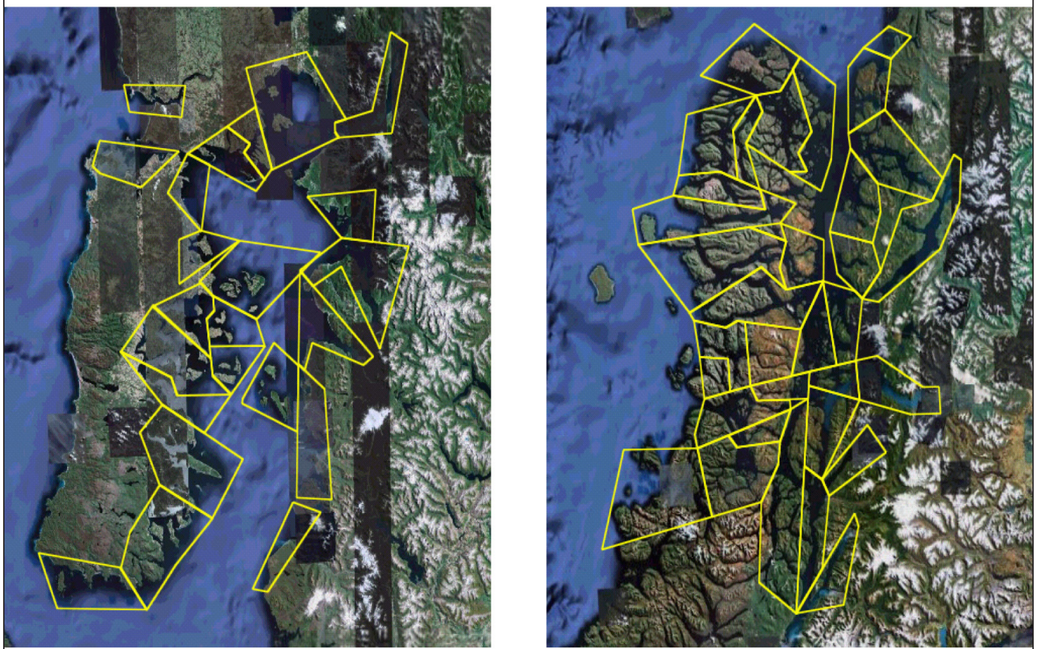
Since 1980, salmon Farming has been forced to comply with regulations regarding aquaculture siting only in allowed areas (or adequate areas for aquaculture – AAA). This measure, as well as the initial search for protected areas, proximity to basic services such as ports, lodging, etc., has produced a high level of farms concentration in some areas such as central Chiloé Island. Out of necessity, salmon farms had also occupied areas that are not naturally suitable for farming, but more favorable for mussels, abalone and algae farming. As a result of such siting, conflict with artisanal fisheries has often arisen, given the proximity to natural banks, ports of operation and navigation routes.

At that time, the lack of knowledge about these zones enhanced the problems described above. However, current scientific and technical information has altered the perception and demands for such zones. The situation became remarkably difficult in the X region where it was necessary to close the authorization of new licenses. Concessions in the XI and XII regions will also be frozen for the next few years until a review of all the zones can be completed (Figure 8).

### Farm settlement regulations

In spite of the above difficulties, site selection is based on environmental, sanitary and logistic criteria. Salmon farming companies use external professionals and experts to make a site evaluation and then develop a type of environmental impact assessment known as "environmental declaration" (ED) as current environmental regulations, do not require a full environmental impact assessment (EIA). The ED is presented when applying for a farming area license. A complete breakdown needs to be presented specifying projected production, species and technology to be utilized. This documentation requires approval by all organizations and institutions involved, amongst others: fisheries and aquaculture authorities, regional and local governments, environmental authorities, maritime authority, sanitary authorities, artisan fishery unions, research institutes, tourism authorities, First Nation organizations, and

FIGURE 8
**Salmon industry neighborhoods located in the X and XI regions, Chile**



X Region XI Region

*Source:* Sernapesca (2001).

others, all of which are consulted through a unique window process. The regional environmental authority makes the final decision to approve or deny authorization or suggest adjustments. The project is then required to demonstrate that it is operating in compliance with the requirements established in terms of impact on sediments and benthos (Environmental Regulation for Aquaculture [RAMA]).

Current regulations, request all projects to participate in the zone management programme respecting fallow periods established for the area, smolt entrance period and sea lice treatment coordination, among some of the principal measures.

## Zoning and logistics

The main challenges in the future will be to review salmon and aquaculture zones and initiate a long-term integrated management plan of coastal zones considering that most southern Chile fjords and channels are very deep and exposed waterbodies. Focused research will need to be conducted thus providing essential support for each zone. This needs to be a public-private effort of maximum urgency. At the same time, the government should develop a strong and efficient legal system that will support the management and sustainable development of the salmon industry. Collaboration from the private sector via voluntary agreements and special measures is also considered essential.

The XI and XII regions of Chile have enormous potential for aquaculture, but to realize this potential in a harmonious and sustainable way, it is essential that this be done in coordination with a logistic plan containing the elements indicated above. There is wide consensus on this.

Currently there are not enough airports to transport workers to pickup points where they can be taken by boats to farms. Furthermore, existing air transportation is unsafe and inadequate, made worse by the region's stormy conditions. There is a demand for increased and higher quality housing plans for workers and transportation services to move products and storage materials within remote areas.

All the conditions above are essential for any off-the-coast and offshore aquaculture to develop in more remote areas.

## CHANGES ASSOCIATED TO THE NEW PRODUCTION MODEL

### Smolt production

The emerging production model requires the industry to concentrate the freshwater phase entirely on land-based facilities. At the moment this is a voluntary measure agreed to by the salmon farmers association, SalmonChile, and it is likely that over the next two years salmon broodstock will be maintained only in tanks or in special areas in the sea. In addition, the smoltification process will be completed in on-land tank facilities and the smolt will more than likely be sent to the sea when they reach approximately 300 g.

There are at least three large projects close to completion developing land-based smolt production facilities starting with broodstock. This trend is congruent with the intensive control of imported eggs. Audits of suppliers' facilities are already being applied. In addition, there are three smoltification units on land will avoid this intermediate phase in lakes and/or estuaries.

Investment in facilities of this kind ranges from US$6 million (smoltification units) to US$15 million in the case of freshwater production based entirely on land facilities. In summary, it is expected that smoltification units in lakes and estuaries will decrease and there will be more land based operations with the tendency to produce the entire freshwater cycle on land. Although this will represent higher investment costs it is expected to lead to higher quality smolt showing improved performance and ability to resist the challenges in the sea.

### Seawater phase

Under the newly established zoning model with neighborhoods, companies and private owners will have to coordinate and manage production within the criteria of the zone management programme. Each zone will demand, in a coordinated manner, services such as ports, navigation routes and mortality transport and management (in some cases under joint contracts), as well as, harvesting.

It is expected that each zone will have its own administration and information sources, such as an environmental and sanitary observatory, and there should be indicators in place to evaluate the efficacy of the measures for each zone.

The quality of the smolt should be checked before sending them to seawater and in addition they should be vaccinated against diseases likely to be present in the next phase.

### Processing plants

Along with improved harvesting methods and fish harvesting transport, it is expected that coastal "waiting cages" to receive the harvested fish will be eliminated and replaced by tanks on land. From these tanks fish will be transported to processing plants.

Waste treatment, including disinfection, is already mandatory in processing plants as well as hatcheries.

### Transport

Improvements in the transport of live fish from one phase to the other are expected and will diminish fish stress levels and create better transition conditions thus reducing the shock caused by movement between containers.

### Other products and services

A number of new products and services that illustrate the tendencies of the industry are being developed. Amongst these: oceanographic and epidemiological services, bioassay units, innovation in farming units (sea cages), a diversity of biosecurity (disinfection) services, ports with segregation of areas, closed well-boats, live harvest well-boats, silage mortality containers; mortality extractors, submerged feeders, new net materials, net cleaners *in situ*.

In general, all the measures described above should be considered when moving aquaculture further off-the-coast in order to make the production systems more efficient, less energy demanding, more biosecure (e.g. by coordinated transport) and more environmental friendly.

## CONCLUSIONS

- Salmon farming technology was transferred and adapted to Chile through a fast and effective process initially lead by public-private institution promoting production technology and development, i.e. Fundación Chile, at the end of the 1970s.
- Some operations were initially "coastal" although most of them corresponded with off-the-coast type (Table 1) or quickly moved off the coast due to the requirements for salmon farming and to increase operation size.
- In spite of the range of area available for salmon farming, there was nevertheless a high concentration of fish farms in areas where companies were able to find ports and on-land services more easily available, such as in central Chiloé Island.
- Salmon farming operations in the sea were forced to be spatially concentrated due to the regulations of the AAA and proximity of services.
- Most of the equipment, products and services originally imported from abroad began to be produced in Chile which avoided high import costs. A "true cluster" was then developed in the south of the country with around forty producers and 1 200 suppliers from which around 500 depend fundamentally on the salmon industry. Several universities and research and development centers were established in the X and XI region. As a result, the salmon farming produced an important spillover benefit with relevant social and economic consequences.
- Both X and XI regions were positively impacted by the industry in social terms and they moved from being areas with the highest rates of unemployment in the country to areas having the lowest unemployment rates in twenty years. In fact, these regions presented the highest rates of improvement in terms of poverty and extreme poverty reduction. Emigration changed to migration in less than two decades as a large number of people and businesses moved to these regions in search of employment within the industry and related servicing.
- The economy of both regions relied heavily on the industry which resulted in more than 80 percent of exportation. It sustained job positions and thus replaced agriculture industry in this regard. More than 25 000 direct employment positions and more than 20 000 indirect positions were produced by the salmon industry in the X and XI regions.
- When the sanitary/environmental crisis emerged in the second semester of 2007, a decline of social indicators became rapidly evident as more than 15 000 job positions were lost in less than two years and salmon production reduced by 30 percent during 2009.
- The rapid reaction of the government as well as the industry has allowed for the first signs of recovery during the second semester of 2009 and, as a result, a change in the production tendency can be expected from 2011 onwards.
- The crisis has lead to heavy modifications in regulations, enforcement systems, production model, Research and Development (R&D) and innovation. As a consequence new licenses within the X region have been suspended, and in the XI and XII regions delayed. Changes in regulation will push for reduction of biomass load per area, and increased distance between farms, establishing a zone management programme and a set of biosecurity measures.

- Fish farms will be encouraged to move to more exposed waters increasing the number of offshore sites which will rely on foreign cage technology in the beginning particularly large 100 m in diameter cages that will increase distances between neighborhoods. Most coastal licenses will probably be changed for others in more exposed waters releasing the coastal licences for third party coastal users such as small aquaculture producers (mussels, abalone, seaweed, etc.) and artisanal fisheries sites and logistics.
- This situation has revealed the need to develop comprehensive, integrated coastal and "off-the-coast" management zone plans taking into consideration all parties that use the zone from the very onset. At the same time it is evident that any zone management plan of aquaculture activities has to bear in mind the carrying capacity or indirect indicators reported by independent third party entities. This is needed even if the industry moves further offshore. Also, in the case of sanitary/ environmental zoning, the government has to play a leading role, inviting all parties to express their opinions and views but taking the final decision with regards to course of action. The worse scenario in the middle of a crisis is inaction.
- The Chilean salmon farming model will change dramatically and this process is already underway. As a result, freshwater production will be developed entirely in fully controlled mostly recirculation on-land facilities and seawater production in environmental zones with enough separation between farms and between zones to minimizing sanitary and environmental risks. A clear increase in the proportion of offshore sites will be evident, particularly far off-the-coast in the highly dynamic channels and fjords of the XI and XII regions.
- It is clear that this production activity should developed in off-the-coast and offshore sites and supported by a logistic master plan that will allow the sustainable colonization of remote areas, taking care not only of business efficiency and fish welfare, but also of the quality of life of workers who have to move to remote areas for considerable periods of time.

## LESSONS AND EXPERIENCES FOR COUNTRIES MOVING TOWARDS OFF-THE-COAST/OFFSHORE AQUACULTURE

Based on the Chilean salmon farming experience described above, it is possible to summarize the following lessons and experiences for countries moving towards off-the-coast and offshore:

- **Authorized areas for aquaculture settlement**
  Adequate areas for aquaculture (AAA) should be established (or updated) based in the best scientific information with regards to oceanographic, climatic and local environmental conditions, integrating data and knowledge and presenting it for open discussion that will enable an informed decision process. The AAA plan initially developed in Chile did not favour off-the-coast and offshore expansion and, on the contrary, it caused the initial high concentration of farms especially in the X region.

- **Flexibility of the adequate areas for aquaculture**
  AAA regulations have to be somewhat flexible in order to recommend adjustments in the system based on new scientific evidence technologies while establishing an eventual compensation system for those licenses that may become affected by the new measures adopted.

  In a higher flexibility of the license system is currently being considered. This would allow relocating coastal salmon licenses to more exposed zones, to merge licenses and also to exchange them. These measures will benefit a general movement of salmon farming to more exposed areas and reduce geographical concentration of farms.

- **Exclusion of sensitive zones (or precautionary use)**
  Enclosed, low water renewal marine areas, estuaries and lakes should be avoided for intensive fish farming or at least used with a previous evaluation of their carrying capacity under the worst case scenario.
  More exposed sites (off-the-coast and offshore) demonstrated in the recent ISA virus crisis in Chile to be more resistant to disease outbreaks.

- **Qualified human resources and basic equipment access**
  The success of an off-the-coast and offshore aquaculture systems rest on qualified personal able to operate sophisticated systems, like automatic feeding systems, monitoring and interpretation of environmental variables, submerged camera control, programme and monitor complex logistic operations like feed supply and harvest operations. At the same time these more exposed systems require high quality and resistant cages and access to supporting floating units (floating pontoons) to store feed, other raw materials and equipment as well as to accommodate the site team (Chile has reached an important development in this field and presently it is exporting these units to other salmon producer countries).
  Proper investments are needed in technical training both at management and production levels. Adequately addressing capacity building can be a key element in increasing the direct and indirect impacts of off-the-coast and offshore aquaculture through the provision of jobs and associative services.
  Countries should always ensure that aquaculture is not only environmentally safe, but that it also benefits society by addressing the needs and expectations of the broader society and stakeholders. This is particularly relevant when cage culture is using aquatic environments, normally considered under most regulations as a "common resource".

## REFERENCES

**Amtmann, C. & Blanco, G.** 2001. Efectos de la salmonicultura en las economías campesinas de la Región de Los Lagos, Chile. *Revista Austral de Ciencias Sociales*, 5: 93–106.

**Aqua.** 2007. *La reinvención de la industria del salmón en la XI Región*. (available at www.aqua.cl/noticias/index.php?doc=17470).

**Boston Consulting Group.** 2007. Estudios de competitividad en clusters de la economía chilena- acuicultura. Documento de referencia acuicultura. Boston Consultancy Group. CORFO. Chile.

**CASEN.** 2003. Informe Regional – Región de Los Lagos. Encuesta de caracterización socioeconómica nacional (CASEN). Gobierno de Chile. Ministerio de Planificación. (available at www.ministeriodesarrollosocial.gob.cl/casen/publicaciones/regiones/2003/Region_de_Los_Lagos.pdf).

**Agraria Consultores.** 2004. Fortalecimiento del cluster del salmón en la zona sur austral de Chile. Informe Final. CORFO Region de los Lagos. Agraria Consultores. Chile.

**Iizuka, M.** 2009. Standards as a platform for innovation and learning in the global economy: a case study of the Chilean salmon farming industry. *International Journal of Technological Learning, Innovation and Development*, 2(4): 274–293.

**Instituto de Fomento Pesquero (IFOP).** 2009. Sección de Economía, Instituto de Fomento Pesquero (available at www.directorioaqua.com/contenido/otras_exportaciones.php).

**Katz, J.** 2004. Economic, institutional and technological forces inducing the successful inception of salmon farming in Chile. University of Chile and CONICET. DfID/World Bank. WB0133 Project.

**Maggi, C.** 2002. Cadenas Productivas: Lecciones de la experiencia internacional y regional- El cluster dcl cultivo y procesamiento del salmon en la region sur austral de Chile. Documento basado en el proyecto de cooperacion tecnica: BID-FOMIN. 36 pp.

**Montero, C., Maggi, C. & Parra, C.** 2000. La *industria de salmon en la X region: un cluster globalizado*. Working Paper, Comisión Económica para América Latina y el Caribe (CEPAL). Santiago, Chile.

**Pérez-Aleman, P.** 2005. Cluster formation, institutions and learning: the emergence of clusters and development in Chile. *Industrial and Corporate Change*, 14(4): 651–677.

**Torres, C.** 2006. Development of technology- intensive suppliers in natural resource-based economies: The case of aquaculture in Chile. Von der Fakultät für Geschichte, Kunst und Orientwissenschaften, Universität Leipzig. (Ph.D. dissertation).

**SERNAPESCA.** 2011. *Technical report of the specific health surveillance and control program of ISA virus 2008–2010*. (available at www.sernapesca.cl).