GLOBALISATION, SUSTAINABILITY AND THE ROLE OF INSTITUTIONS: THE CASE OF THE CHILEAN SALMON INDUSTRY

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ABSTRACT
The importance of aquaculture in the fishery sector is increasing. The growth of aquaculture complements the stagnant growth of extractive fisheries. Many countries are now entering this emerging economic activity. This positive feature has some serious drawbacks when the country has no local institutions to ensure the environmental sustainability of aquaculture. The Chilean salmon farming industry has grown dramatically since the mid-1980s to become the leading exporter of farmed salmon after Norway. The sector, however, suffered decline due to the sanitary crisis in 2007. It is said that this crisis was caused by overexploitation and overconcentration of fish farms. This paper tries to explain the mechanisms of the sanitary crisis – a 'tragedy of the commons' – by paying attention to the role of endogenous factors such as local knowledge, capacity building, local ecological conditions and the emergence of local institutions, focusing on the case of salmon farming in Chile.

Key words: Globalisation, environmental sustainability, institution, innovation, Chile

INTRODUCTION

A rapidly expanding global demand for fish and the difficulty of catering for it by extractive fishery (FAO 2012) provide the rationale for the current expansion of aquaculture. Countries where aquaculture is emerging include many developing nations (such as China, Indonesia, Thailand, Vietnam, the Philippines and Bangladesh, to mention just a few). Aquaculture has therefore become a significant new source of income for many developing nations. Despite these positive aspects, expanding aquaculture – like other natural-resource-based activities such as agriculture or forestry – is a major consumer of environmental services and strongly affects long-term environmental sustainability. When production sites are located in developing countries, their environmental regulatory institutions are bound to be either weak or absent because these countries generally prioritise economic growth over environmental sustainability. This means that the industry potentially creates environmental pressure on the local ecology of the producing nations.

Although globalisation seems to offer the same level playing field to all participating countries, some countries forge ahead while others fall behind in their developmental process. This indicates that some endogenous forces may be determining the final outcome.

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This paper, instead of looking at economic performance, seeks to explain how environmental collapse can occur as developing countries struggle to catch up in the global economy without paying due attention to the role of endogenous factors such as local capacity building, knowledge creation and institutions for long-term sustainability. We focus on the case of the salmon industry in Chile, where a highly successful export industry experienced collapse following a major environmental and sanitary crisis in 2007.

This study will show how aquaculture depends not only on advanced production technology (machinery and equipment), but also on institutions that regulate the use of common resources. Successful regulation needs to be supported by scientific knowledge and understanding of how the local ecology operates (social technology). We argue that progress in production capabilities through adapting new technologies – although important to 'catching up' in manufacturing activities – may not be enough to ensure long-term sustainability in aquaculture. Although this paper is written in the context of global market expansion as a determinant of changes in the producing end of the value chain, we focus more on the behaviour of local actors (firms) as they interact with global technology and the local ecology. We argue here that different types of endogenous capabilities and institutions play a crucial role affecting environmental outcomes. This view comes close to, but is slightly different from, the political ecology approach that looks at how the overall socio-institutional interaction and decision-making process affects the behaviour of individual actors and eventually the environmental outcomes (Blaikie 1999; Forsyth 2003; Barton & Floysand 2010).

This paper pays attention to endogenous change within firms (actors) relating to knowledge/technology/knowhow and the co-evolution of the above with local institutions affecting local ecological change. The paper is based on fieldwork and previous research carried out into the Chilean salmon farming sector. Most of the recent data come from interviews conducted after the 2007 sanitary crisis and reflect the opinion of firms, industrial associations, industry experts and Chilean policymakers in the aftermath of the crisis. The first set of interviews took place in July 2009 and the second set in November–December 2011. Magazine articles, newspaper clips, unpublished technical reports and public lectures concerned with the sanitary and environmental conditions surrounding the functioning of aquaculture in Chile are taken into consideration to strengthen the validity of the information collected via interviews with different stakeholders.

THEORETICAL CONSIDERATIONS

Globalisation of economic activities and the impact on sustainability of local natural resources – The importance of aquaculture is growing due to the increasing demand for fish in the global market in the face of the declining capture of extractive fisheries (FAO 2012). A discernible rise in the contribution of aquaculture relative to extractive fishery has been the trend since 1989 (Barton & Staniford 1998). According to recent statistics published by the FAO, fish production through aquaculture expanded 12 times from the 1980s to 2010 at annual rate of 8.8 per cent (FAO 2012). This figure reached all-time high in 2010 with almost 60 million tonnes, which is 60 per cent of total world fish production. Due to increasing demand, numerous countries – most of them developing nations – are now pursuing this activity for export purposes. Despite this positive outlook for aquaculture, blindly responding to increasing global demand can lead to ecological deterioration if the producing country does not have appropriate environmental regulatory mechanisms adequately to protect the use of its natural resources. In fact, FAO recently expressed concern over increasing sanitary incidents of aquaculture at the global level (FAO 2012).

This concern is not exclusive to the fishery sector. Lenzen *et al.* (2012) demonstrated that consumption of imported commodities by developed countries can lead to significant losses of biodiversity at the producing end of the global value chain. Several case studies have already linked intensive trade of natural-resource-based commodities – palm oil, coffee and soybean (Fearnside 2001; Perfecto *et al.* 2003; Philpott *et al.* 2008; Koh & Wilcove 2007)

– to the deterioration of biodiversity in the producing countries. More specific reference to salmon farming industry in Chile is made by Barton and Floysand (2010) from a political ecology approach. They described the growth and sanitary crisis of the salmon farming industry in Chile as the outcome of inadequate socio-institutional interaction, such as social relations and alliances, strategies and actions. While the political ecology approach can illuminate important aspects of power relations underlying the functioning of the industry as it became increasingly involved in the global market, it falls short in illustrating interaction at the micro and meso levels of environmental conditions, public policies and firm behaviours. Firm behaviour and regulatory agencies can result in changes in local institutions, so that it is crucial to understand the behaviour of firms.

There is long-standing research on how to managing natural resources or common-pool resources (CPR)[1] at the local level (Hardin 1968; Feeny *et al.* 1990; Ostrom 1990). Management of CPR requires co-ordinating the inner tension between the collective benefit of a group of users and each individual's attempt to maximise his/her return from the 'commons' (Feeny *et al.* 1990; Ostrom *et al.* 1999). If institutions fail to manage CPR, this results in welfare loss for everyone: the 'tragedy of the commons'[2] (Hardin 1968). Hardin, by identifying the difficulties of managing CPR, suggested that environmental resources or CPR should be managed either through strict regulation (role of government) or exclusive private property ownership (role of the market).

Ostrom (1990), however, considered Hardin's suggestions for management of CPR as grossly oversimplified and claimed that, in many cases, local self-governing institutions 'emerge' to deal with the threat of resource degradation. Important to this argument is the fact that stakeholders involved in managing the commons can 'learn' from interactions and thus develop institutions capable of preventing overall environmental degradation. In other words, to support sustainability, stakeholders have to act collectively for common purposes using game-theoretical interaction (Ostrom 1990). CPR management, therefore, highlights the importance of local specific institutions, which can co-evolve with changes in a broader set of global, as well as local, forces, where CPR are located (Dietz *et al.* 2003; Ostrom *et al.* 1999). Here, the institutions are considered to emerge as the result of aligning the interests of stakeholders in a 'location-specific' context. However, it is also true that such institutions may not emerge naturally and may require public sector intervention to induce behavioural changes and collective action among actors.

Institutions, technological progress and environmental sustainability – Institutions are often defined as the 'rules of the game', following the seminal work of Williamson (1975, 1985, 1998) and North (1990, 1991). At the same time, groups of scholars such as Hodgson (1988, 2006), Greif (2006) and Aoki (2007) describe institution as 'how behaviours are formed' or 'the way things are done' rather than rules or governing structures that constrain behaviour. Nelson and Sampat (2001), Eggertsson (2005, 2009) and Nelson (2008) use the concept of 'social technologies' to make a similar distinction as Hodgson and others. Nelson and Sampat (2001) and Nelson (2008), in an attempt to clarify the concept of institution or the mechanisms that determine behaviour, conceptually disaggregated the term 'institution' into three: 'social technologies', 'physical technologies' and supporting institutions. 'Social technologies' are the way work is divided and co-ordinated to facilitate the use of 'physical technologies', a generic knowledge/technology. 'Social' and 'physical' technology co-evolve and are shaped by supportive institutions, such as culture, value systems, existing laws, norms, expectations, governing structures, mechanisms and customary modes of organising and transacting. Together, the three can determine the behaviour of firms/actors.

Nelson (2008) believes technological progress is the driving force behind economic development and considers 'social technology' to play a key role by bridging 'physical technology' and supporting institutions. This model is applicable to cases from the manufacturing sector (Nelson & Sampat 2001; Nelson 2008); however, this cannot be fully applied to the agricultural sector, because the natural/environmental/ecological dimension was not specifically contemplated in Nelson's work. Ruttan (2005), on the other hand, crudely includes this dimension as relative scarcity of resources – in terms of labour and land – accompanied by technological change to explain the driving force for institutional development[3] in the agricultural sector. He presents historical examples as follows: completion of the Suez canal in the nineteenth century increased the demand for rice imports from Thailand, causing land scarcity and leading to the establishment of a property rights system to manage farmland (Feeny 1982, 2002); population growth in Japan during the Tokugawa era (fifteenth century to nineteenth century) also made land a scarce resource, which eventually led to the creation of leasing mechanisms, laying the foundations for the modern private property system (Hayami & Kikuchi 1981); and population growth created land scarcity in the Philippines, while the introduction of new technologies – modern high-yielding rice varieties, double-cropping practices, improved fertilisers and pesticides – improved productivity and hence allowed the creation of an institution called sub-tenancy (Kikuchi & Hayami 1980). Ruttan (2005) considered that relative scarcity of resources (in terms of labour and land) and technological progress co-evolve to 'induce' creation of new institutions that could ensure a new equilibrium in the new context. In such a process, he suggests the presence of 'political entrepreneurs', who would facilitate the building of new institutions through providing resources and consensus among interest groups.

Ruttan (2005), by bringing in the 'scarcity' concept, partially complements the missing 'natural/environmental/ecological' dimension of Nelson and Sampat (2001) and Nelson (2008). However, Ruttan refers only to scarcity in terms of labour and land. In addition to that, his examples of newly induced institutions are mainly to regulate the use of land, but not the environmental resources, which are more difficult to measure in terms of real economic value. Ostrom (1990), on the other hand, demonstrates how human and ecological interactions enable the creation of institutions via 'collective action'. However, she scarcely looks at technological progress and economic development; her focus is primarily on local institutions, where global interaction is limited.

Each approach mentioned above indicates the different important dimensions that should be considered with regard to creating new institutions – a set of behavioural patterns – for managing sustainable natural resources for economic activities. These dimensions are: technological progress ('physical technology' (Nelson) and 'technological change' (Ruttan)); intermediary institutions that put technology to use ('social technology' (Nelson), 'political entrepreneurs' (Ruttan) and 'collective action' (Ostrom)), supporting institutions that shape the behaviour of stakeholders, ranging from culture, value systems, expected behaviour and rules of the game ('routine' (Nelson), culture (Ostrom and Ruttan)) and ecological environment where natural-resource-based activities take place (Ostrom and Ruttan, partially via labour and land). Each dimension co-evolves with another, while travelling at different speeds and on different trajectories.

In the sections to follow, attempts are made – through the use of the case of salmon farming in Chile – to illuminate how an environmental crisis is caused by individual firms' myopic behaviour induced by global market demand. In the aftermath of the crisis, new forms of interaction among the various stakeholders have gradually emerged and a new set of institutions (regulatory mechanism) is slowly being put in place.

CASE STUDY OF THE CHILEAN SALMON FARMING INDUSTRY

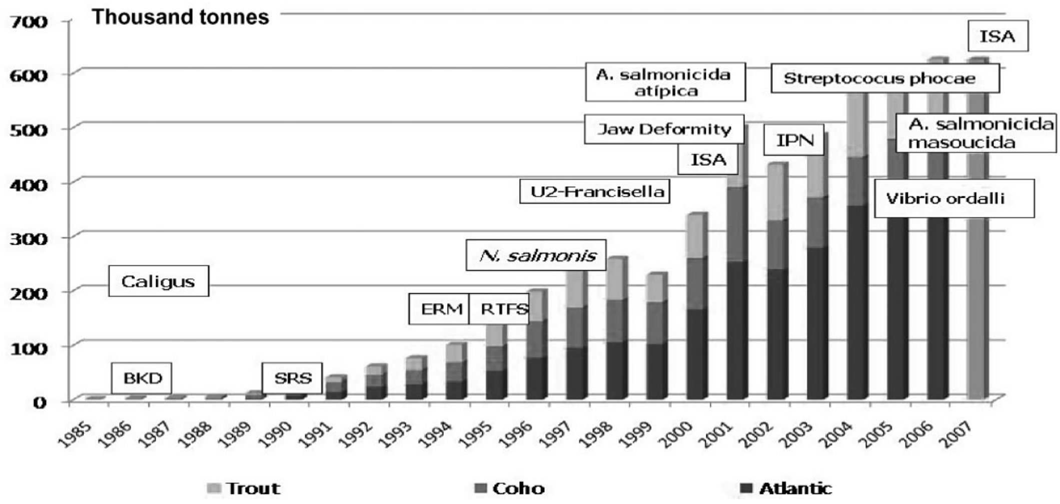
Rapid catching up of the Chilean salmon farming industry – In 1994, Chile became the world's number two exporter of farmed salmon. This achievement was remarkable, given that the knowledge and technology for raising salmon in captivity did not previously exist in the country. The development of the industry dates back to the 1960s, when the Chilean government (SAG) first signed a bilateral co-operation agreement with the JICA (a Japanese agency) for technological transfer regarding salmon farming. Since then the industry has taken off and grown rapidly with the development and diffusion of 'physical technology', that is, introducing imported advanced technology and know-how facilitated by organisations such as FundacionChile, the Association of Producers of Salmon and Trout (later known as SalmonChile) and numerous foreign firms (Nichiro, Union Carbide, etc.) at that time. The iterative process of learning by doing and technological adaptation efforts – 'social technology' – played a major role in the industry's growth during the initial stages of expansion (for more details, see Maggi 2002; Montero 2004; Katz 2006; UNCTAD 2006; Iizuka 2007).

The sanitary crisis and its causes – The growth enjoyed by the industry stopped in 2007 with the environmental and sanitary crisis caused by the spread of infectious salmon anaemia (ISA) (SERNAPESCA 2008). The disease is known to be contagious and to cause high mortality in Atlantic salmon, but does not harm humans, and it quickly spread to the nearby cultivation centres. Soon, the affected cultivation sites suspended their operations (Iizuka & Katz 2011). By 2009, close to 60 per cent of the cultivation centres had ceased production. In the following year, the production of salmon had fallen to around 200,000 tonnes down from its peak of nearly 700,000 tonnes in 2006. The impact of the crisis was not limited to salmon farming firms, but rapidly reached the intermediate input and service suppliers for the industry. Close to 20,000 jobs were lost within just two years. Numerous coastal villages depended entirely on the demand for skilled and unskilled labour by salmon farming companies; the industry's collapse developed into a major economic and social crisis at the local level. The dramatic fall in production resulted in a total estimated bank debt of US$1.6–2.5 billion by the industry at the end of 2009, causing a chain reaction of bankruptcy (Larrain 2011). The sanitary and environmental issue shocked the local economy as well as the whole industry.

The ISA virus was believed to have originated in Norway, arriving in Chile via imported salmon eggs.[4] However, local biologists and veterinarians who have been interviewed (interview with Mr. Adolfo Alvial in 2008, interview with Dr. Patricio Bustos in 2009; interview with Dr. Daniel Nieto in 2009) seem to agree that the cause of this sanitary crisis was more systemic than just the single introduction of a pathogen. According to them, 'illness' does not occur simply by the presence of a pathogen, but would require systematic collapse for a long period of time to eventually reduce the self-immunological defence capabilities of the fish, and create an environment in which pathogens can spread quickly. In other words, the crisis should not be seen as a consequence of ISA but as the long-term, cumulative outcome of sanitary and environmental mismanagement dating back years before the outbreak.

There is no historical record of water quality in the coastal areas where salmon is cultivated in Chile; however, a record of sanitary incidents of salmon in captivity by veterinarians shows the increase in disease as the production volume of salmon increase, demonstrating that the worsening sanitary environment for the fish started much earlier than the outbreak. An independent survey of the sanitary situation carried out in the mid-1990s by local veterinarians also confirmed that the sanitary situation was already worsening in the mid-1990s, almost 10 years before the epidemic actually started (Johnson 2007; interview with Dr. Patricio Bustos in June 2009; interview with Dr. Daniel Nieto in 2009). Experts indicate that eight sanitary diseases were observed in the early 1980s; in the mid-1990s, this increased to 18 (Figure 1).

The sanitary and environmental 'rules of the game' for the industry were, for a long time, absent or weak. Until the 2000s, regulation for Chilean aquaculture was not effectively organised to prevent environmental degradation. This does not mean that regulatory bodies were absent; however, the national fishery administrations – the Undersecretary of Fisheries (Subsecretaria de Pesca) and National Fishery Service (Servicio Nacional de Pesca: SERNAPESCA) – did not pay much attention to regulating the emerging economic activity, aquaculture. This is partly due to path dependence, because regulating extractive fisheries has historically been their mainstay of business and partly due to the small scale of activity at that time, which was described as 'very small to regulate . . . [and] was not significant' interview with Mr Felipe Sandoval, former secretary of fisheries, November 2011 and interview with Ms Edith Saa, an official of SERNAPESCA, December 2011). Even though some regulatory mea-



Source: Based on SERNAPESCA, various years and Nieto (2009).

Figure 1. *Deterioration of sanitary conditions in salmon farming sites and increase of exports.*

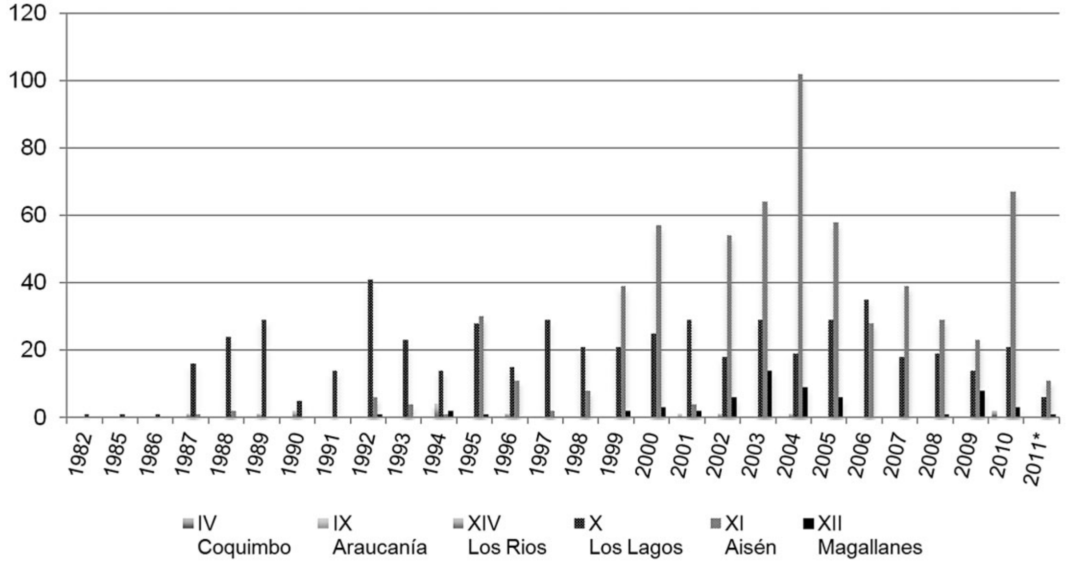
sures specific to aquaculture were put in place during the 1990s,[5] these regulations were aimed mainly at facilitating the expansion of the industry rather than monitoring its environmental impact.

By the 2000s, the industry reached a substantial size and started to put pressure on the local environment. As a result, several regulations specific to aquaculture were introduced.[6] These regulations demanded that firms comply with international environmental and sanitary standards; nevertheless, this was not effectively enforced and monitored due to lack of resources in the public sector (interview with Mr. Ricardo Norambuena, former director of aquaculture, Undersecretary of Fisheries in December 2011). In addition, there were strong pro-growth sentiments for exporting sectors, such as salmon. The above conditions made the enforcement of environmental regulations quite difficult to pursue. In fact, during this period the government relied upon so called private–public partnership initiatives to control and monitor firms' environment and sanitary behaviour. The clean production agreement (Acuerdos de Produccion Limpia: APL), an agreement for firms to voluntarily 'self-regulate' their environmental impact, was implemented for the salmon industry.

In Chile, any person wishing to start aquaculture needs to obtain a concession from the public authorities. The concessions are granted after the applying party has gone through several administrative clearances.

Figure 2 shows the number of concessions for aquaculture granted from the early 1980s to 2011. A gradual increase in concessions is observed in the 1980s; the number then increases at a faster rate in the 1990s and rapidly in the 2000s. Until the late 1990s, most of the concessions concentrated in the Los Lagos region (X region), as it was by far the most suitable area for salmon farming, with reasonable access to physical and social infrastructure that ensured transportation and a labour force. From the late 1990s, concessions started to move southwards, first to Aysen and gradually to Magallanes, as the industry ran out of space in the Los Lagos region.

In the early 2000s, the government actively promoted the growth of this industry with a clear target: to double the value of export of salmon in 10 years from US$1.2 billion in 2004 to US$2.4 billion by 2014 (interview with Mr. Ricardo Norambuena, former director of aquaculture in Undersecretary of Fisheries 2011 and interview with Mr. Felipe Sandoval, former head of Undersecretary of Fisheries, November 2011). To facilitate the above, the granting of



Note: *2011 is preliminary figure.
Source: Subsecretaria de Pesca (2011b).

Figure 2. *Transition to the concession right given by the Undersecretary of Fisheries (1982–2011).*

concession rights – which used to take 7–8 years from application to actual granting – was speeded up. As a result, many concessions were given out in the 2003–2005 period (Iizuka & Katz 2011) (see Figure 2).

Currently, 72 per cent of salmon farming concessions in Chile are located in a small territory covering no more than 300 square kilometres. The concentration of salmon cultivation centres in Chile is striking if compared, for example, with Norway, whose total area of cultivation is spread over 1,700 sq km (Infante 2008).[7] Despite the limited areas of the territories used for farming in Chile, there were no regulations monitoring distance between salmon farming centres until 2001.

The production of salmon in Chile increased dramatically from 1999 onwards, and by 2006 it had reached an all-time historical peak. The strong incentive to increase production came from the rapid increase in global prices. This external increase in demand – without an accompanying regulatory mechanism – pushed many firms to increase production simply by adding more fish to the existing tanks, thereby increasing fish density beyond biologically sustainable levels.

Table 1 compares the volume of fish per cultivation centre in Chile with that of Norway. The table clearly shows the larger volume of fish being cultivated at each cultivation site. Furthermore, to consolidate the high density within the cultivation site, data from EWOS – a salmon food company – effectively shows the increase in the average number of fish per cultivation centre (see upper part of Table 2) since 2003.

Table 2 demonstrates the decreasing trend in physical productivity as fish production increased. While the total volume of salmon production increased from 2003 onwards, other indicators showed signs of deterioration. The average weight per fish at the time of harvesting declined from 4.4 kg to 4.1 kg, the number of days required for harvesting expanded from 487 days to 543 days, and the weight of salmon produced (output) per unit of input of smolt and egg decreased from 3.7 kg to 3.1 kg for the former and 1.3 kg to 1.1 kg for the latter. The economic and biological rate of conversion[8] deteriorated from 1.36 to 1.52 and from 1.24 to 1.34 respectively, namely, more feed was needed to produce 1 kg of salmon. Table 2 also shows that the rate of fish mortality increased from 15 per cent in 2003 to 25 per cent in 2007. The cost of vaccines and antibiotics to prevent fish from getting ill also increased, as did the cost of feeding the fish as a consequence of the extension of harvesting time.[9]

Table 1. *Average salmon weight per cultivation centre: Chile and Norway.*

Chilean cultivation site	Average tonnes/center
Chiloe centro	1,136
Melinka	1,106
Chiloe sur	859
Estuario reloncavi	1,142
Aysen	757
Hornopiren	1,079
Cisnes	892
Seno reloncavi	1,076
Total	1,021
Norwegian cultivation site	**Average tonnes/centre**
Finnmark	255
Troms	499
Nordland	528
Nord-trondelag	518
Sor-trondelag	522
More& fjordane	424
Hordaland	374
Rogaland	506
Ovrige fylker	689
Total	474

Source: EWOS Health (2007).

Despite all the economic and biological indicators pointing to a deteriorating trend in productivity from 2003 to 2007, we can observe that exports by volume and value increased substantially, due to the higher price of salmon during the same period (see the lower part of Table 2). The growth of profit enjoyed by most Chilean salmon firms actually came from the rising unit price of salmon and not from higher productivity; meanwhile the pressure on the local environment increased dramatically during those years.

UNBALANCED DEVELOPMENT OF 'PHYSICAL' AND 'SOCIAL TECHNOLOGY' AND SUPPORTING INSTITUTIONS LEADING TO THE SANITARY CRISIS

Central to our argument is that supporting institutions and 'physical' and 'social technologies' proceeded at quite different paces, opening up a wide space in which the sanitary and environmental crisis could emerge. We shall now examine both these aspects at the level of the firms and then at the level of the industry.

Progress of 'physical technology' and deterioration of 'social technology' – During the mid-1990s, salmon firms became more capital and technologically intensive with use of imported capital equipment such as computers, automatic processing technologies, scientific food formulas, to name a few. The technological

Table 2. *Key indicators of productivity in salmon firms and some export statistics.*

	2003	2004	2005	2006	2007
Kg/smolt	3.71	3.66	3.57	3.34	3.14
Kg/egg	1.3	1.28	1.25	1.17	1.1
Average weight at the harvest time	4,444	4,555	4,342	4,219	4,130
Economic factor conversion rate	1.36	1.4	1.38	1.42	1.52
Biological factor conversion rate	1.24	1.27	1.28	1.3	1.34
Days required unitl harvesting	487	497	484	488	543
Number of fish per cultivation center	650,000	700,000	670,000	825,000	945,000
Mortality rate (%)	16	18	17.5	20	24
Volume of production net tonnes (000)	286	355	384	387	397
Export US$(million) FOB	1,146	1,439	1,721	2,207	2,245
Price US$ per kg	4.0	3.6	4.5	5.9	6.0

Source: Based on EWOS Health (2007) and SalmonChile, various years.

gaps *vis-à-vis* the international 'state of the art' were gradually reduced, particularly so for the larger Chilean firms as well as for foreign-owned companies. As the 'physical technology' got closer to the frontier, the internal organisation of firms became more hierarchical, that is, a larger 'distanc' appeared between company managers and cultivation tanks (based on interviews with Dr. Daniel Nieto and Dr. Patricia Bustos 2010). In the early days of the industry, most of the pioneer managers started by interacting with the fish rearing process in the cultivation sites. As firms increased in size, their tasks became more routinised and managers became more detached from the fish rearing process. It is quite likely that 'non-routine' activities of professional veterinarians diminished in importance as 'foreign' production organisation routines acquired more prominence and local incremental knowledge generation became less significant. Hence Chilean salmon firms may have acquired 'competence' in the production of salmon ('physical technology'); but they did not simultaneously acquire knowledge and understanding ('social technology') regarding how to deal with local environmental sustainability as their size expanded rapidly. The ecological dimension of their daily operation was somehow missed out *pari pasu* with their expansion.

Underdevelopment of local ecological 'social technology' – Despite the fact the public sector funds for R&D (research and development) activities became available from the end of the 1980s, a great deal of knowledge obtained was 'incremental', resulting from learning by doing and from in-house efforts to 'adapt' technology, coming mostly from FundacionChile, a public–private sector organisation, and from some early incumbents such as Nichiro and Union Carbide. During the mid-1990s, salmon firms became technologically more sophisticated but very few efforts were made to address more complex R&D topics and environmental protection issues, particularly when compared to Norway and Scotland.

The above does not mean that Chile completely lacked R&D efforts. Two public organisations, the National Commission for Scientific and Technological Research (CONICYT) and the Chilean Economic Development Agency (CORFO), made efforts to promote innovation and research via financing R&D in the 1990s (Bravo *et al.* 2007; Iizuka & Katz 2011). Table 3 shows that R&D in salmon farming was conducted by universities, technological centres, suppliers and producers between 1987 and 2005. Despite efforts made to promote innovation and research in this sector, innovation projects supported by CORFO were focused on short-term problem

Table 3. *Salmon farming research projects by thematic areas in the period 1987–2008.*

Thematic Areas	No. of projects	%	Chilean pesos M$	%
Pathology and sanitary management	77	26.8	12,140,701	28.9
Genetics and reproduction	38	13.2	7,752,516	18.4
Nutrition and food	29	10.1	6,327,948	15.1
Environment and clean production	33	11.5	3,842,839	9.1
Technology centres	5	1.7	3,736,752	8.9
Engineering and technology	44	15.3	3,489,769	8.3
Cultivation and production	14	4.9	1,573,375	3.7
Training and transfer of technology	18	6.3	1,026,484	2.4
Processing and quality control	13	4.5	877,022	2.1
Recreational fishery	10	3.5	829,549	2.0
Administration and regulations	4	1.4	346,458	0.8
Small scale aquaculture	1	0.3	46,874	0.1
Biology and ecology	1	0.3	43,043	0.1
Total	287		42,033,331	

Source: Bravo (2009).

aspects of production technology, while those financed by the CONICYT were not fully utilised by the industry due to lack of adequate university–industry linkages (OECD 2007). Bravo *et al.* (2007) and Bravo (2009) showed[10] that much of the research was conducted to enhance productive technology, but did not address more fundamental issues specific to the Chilean context. Very little was actually one to understand the local carrying capacity of different salmon farming areas in Southern Chile (see Table 3). The knowledge needed during the period of rapid expansion was not that required to adapt imported know-how into the local settings; also, scientific knowledge and understanding about local ecological conditions was needed in order to develop appropriate regulations on production volumes in order to secure long-term resource sustainability. In other words, 'social technology' did not evolve at the same speed as 'physical technology'.

Pro-growth trajectory of institutional development – In the early days of the industry, the government played a developmental role. The industry was rather small and did not need public sector regulation, so government was much more concerned with extractive fishery. The regulatory development, therefore, was insufficient to ensure environmental sustainability. After the 2000s, with mounting pressure on the environment, regulatory mechanisms emerged. However, these regulations were not properly enforced due to the pro-growth sentiments of public officials. The speeding up of granting concessions provides clear evidence to that effect.

In sum, as far as salmon farming in Chile is concerned, the relationship between 'social', 'physical technologies' and institution deepening became highly unbalanced as the industry grew and production increased. Balance could be maintained when the industry was small and negative externalities were almost unnoticed. Government strategy prioritised rapid growth and exports. However, as production increased and negative externalities became more evident, affecting ecological equilibrium, the balance between production and social technologies became more difficult to maintain and institutions took much too long to develop in order to secure environmental sustainability. In other words, 'physical technology', 'social technology' and institution building travelled at different speeds, failing to incorporate the ecological dimension. Chile, unlike Norway and Scotland, failed to create institutions to ensure long-term environmental sustainability in aquaculture.

INDUCING NEW INSTITUTIONS FOR SANITARY AND ENVIRONMENTAL SUSTAINABILITY

Shortly after the ISA incident, the government established an institution called Mesa De Salmon (Roundtable for Salmon – hereafter referred to as the Roundtable) among members of the public sector to resolve the 'crisis' as swiftly as possible. The Roundtable had the following tasks: modifying the existing sanitary norms and the rules for environmental protection; and creating new 'routines' namely, operational protocols capable of ensuring the sustainable future growth of this sector. The Roundtable played a crucial role in co-ordinating the interests of different stakeholders, enabling them to modify the General Law of Fishery and Aquaculture (LGPA), a formal legal structure to regulate aquaculture.

The new legal framework (law no. 18.892) put in place the following measures: (i) changing the concession granting system; (ii) strengthening sanitary and environmental regulations; (ii) creating collective management mechanisms of the 'commons'; and (iv) strengthening the authority of the National Fishery Service to enforce environmental and sanitary regulations. All these changes concern creating new institutions, both in terms of 'rules of the game' and 'social technology'. Below we highlight some of the most relevant efforts made by public sector.

Strengthening sanitary and environmental regulations – Under the new law, existing sanitary regulations (Appropriate Areas for Aquaculture – AAA; Regulation on Sanitation for Aquaculture – RESA; and Regulation on Environment for Aquaculture – RAMA) were strengthened. The new reporting system for environmental information (Informacion Ambiental – INFA) was established to make necessary environmental information available to the government. The important new developments in regulation for aquaculture are its integration into a comprehensive zoning plan for coastal areas and the establishment of specific regulations and norms for the use of chemicals and antibiotics. Most importantly, for the first time, measures/methods and standards for implementing sanctions and punishment were clearly stipulated.

Creation of mechanisms for collective action: 'barrios' (neighbourhoods) – Concessions located in areas of similar geographical characteristics have been grouped together in 'barrios' (neighbourhoods)[11] or 'groups of concessions'. The 'barrio' is a new institution that encourages collective management of environmental and sanitary conditions with stakeholders within the 'barrio'. The firms within the same 'barrio' must synchronise the production calendar. This means that different owners need to agree on same dates for implementing each step of the production process, including sowing, harvesting and fallowing, a resting period. Co-ordination of production allows better control of the transmission of pathogens. High contamination risk activities such as transportation for feed and other inputs and slaughtering are better controlled. Other necessary measures, such as fish escapes and creating appropriate distances between the cultivation centres, are also to be jointly implemented among the firms within a 'barrio'.

The 'barrio' encourages the owners of different concessions to collaborate. The decision-making process within the 'barrio' must follow the democratic rule of one concession, one vote. According to the zoning established by the RS. No. 450 in 2011, there are currently seven macrozones and 61 barrios, 24 in the 10th region and 37 in the 11th region (Subsecretaria de Pesca 2011a res, extebti 18.96). The 'barrio' system is currently being implemented on a trial-and-error basis.

Strengthening the authority of the public sector, National Fishery Service and Undersecretary of Fisheries – The modification of the law has included strengthening government authority on aquaculture matters by the Undersecretary of Fisheries (SUBPESCA) and the National Fishery Service (SERNAPESCA).[12] For instance, before the modification, the National Fishery Service had limited authorisation for inspection; however, after the modification it is entitled to inspect all registered property related to aquaculture.[13] In addition, it now has authority to stop any transit of vessels between macrozones as well as between 'barrios' during sanitary emergencies. For the first time in history, companies have been fined for not complying with the law.

CONCLUSION

By examining the case of Chilean salmon farming, this paper aimed to demonstrate how a crisis – 'a tragedy of the commons' – occurred as a result of social and physical technologies proceeding at different tempos without appropriate supporting institutions to orient and pace the overall progress of aquaculture under long-term sustainable conditions. The case study also aimed to capture the ongoing efforts made by the Chilean government to create new institutions by enhancing 'social technology'. Following a political ecology approach, Barton and Floysand (2010) described the mechanism by which the Chilean salmon industry collapsed, illustrating the power relationships between the global and local levels. Our analysis, on the other hand, has tried to illustrate the more micro level, individual firms' behaviour as they interact with local conditions including environmental quality, globalisation integration process and changing regulatory me chanisms.

The Chilean salmon farming sector was able, in a very short period of time, to expand production, gaining large economies of scale while undergoing a sustained process of 'technological deepening' and growth. From this point of view, the industry managed to attain sound production capabilities. However, 'social capabilities', those related to the understanding of the carrying capacity of the resource and regulatory institutions, did not develop *pari passu* with production capabilities to ensure the long-term sustainability of the industry. As a result, the country ran into a conventional tragedy of the commons episode as far as aquaculture is concerned.

Following the crisis, Chilean public agencies, firms and university laboratories are trying to develop the required institutions by strengthening the 'rules of the game' as well as 'social technologies' that integrate local ecological factors into production 'routines'. The attempt to create a new institution that takes into account ecological factors is a step in the right direction; nevertheless, whether the current pace of institutional change will be able to catch up with the biological and ecological deterioration remains an open question.[14]

Notes

1. Common-pool resources (CPR) include those properties that have excludability – it is costly to exclude others from using the resources – and subtractability – each user is capable of subtracting from the welfare of other users (Feeny *et al.*, 1990, Ostrom *et al.*, 1999). Examples include use of resources such as fisheries, wildlife, surface and groundwater, grazing land and forests.
2. Hardin (1968) addressed 'the tragedy of the commons' with a simple example of 'herd' behaviour. Putting one more cow in a limited space of land (common), the individual's maximization attempt – through the eventual overloading of the resource – causes a reduction of the collective benefits of all users of the common.
3. Ruttan (2005, p. 2) defines institution as follows: 'Institutions are the rules of a society or of organizations that facilitate coordination among people by helping them form expectations, which each person can reasonably hold in dealing with others. They reflect the conventions and ideologies that have evolved in different societies regarding the behavior of individuals and groups relative to their own behavior and the behavior of others'. Ruttan (2005) differentiates institutions into: (i) organisations; (ii) rules and structure of governance; (iii) relationship between firm and regulatory agency (such as innovation system); (iv) culture, and value systems. Having distinguished them, he states that he uses the term 'institution' in an inclusive sense. From this perspective, it is possible to interpret that his 'institution' is closer to the 'social technology' of Nelson (2008) and Eggertsson (2005, 2009), rather than narrowly defined 'rules of the game'.
4. Many local specialists believe that a variant of the disease had been present in Chile for some time, until the combination of environmental conditions triggered its mutation into a rapidly spreading outbreak (Inverviews with Mr. Adolfo Alvial in 2008; Dr. Patricio Bustos in 2009 and Dr. Daniel Nieto in 2009).
5. Such as the General Law of Fishery and Aquaculture (Ley General de Pesca y Aquicultura: LGPA) of 1991, the Supreme Decree no. 475 (1994), DS. no. 499 (1994) and the DS. no. 464 (1995) and Ley de Bases del Medio Ambiente (Law no. 19.300).
6. These are DS no. 320 on environmental regulations for aquaculture (RAMA) and DS no. 626 on measures for protection, control and eradication of diseases of high risk for hydrobiological species (RESA) in 2001.
7. This was confirmed in the recent public lecture by Mr. Mario Pucchi, of AquaChile SA – the largest Chilean salmon farming firm. He said: 'production is 50% larger per concession in Chile while total cultivation area is 70% smaller' (Pucchi, 2009).
8. The economic conversion rate is the rate in which kg of feed are converted into 1 kg of salmon in economic value terms. The biological conversion rate is only in biological terms.
9. One of the former directors of a salmon firm estimated the industry's total loss as a result of the ISA crisis at US$550–600 million. This included overall loss of biomass, loss of growth, loss of added treatment costs, operational costs and processing costs (Johnson, 2007).
10. The analysis showed that there was emphasis on egg production, disease control etc.; however, none was dedicated to basic research to find out the local carrying capacity, for instance. For more details about R&D expenditure, see the document by Bravo *et al.* (2007). Note that the figures given below do not distinguish between knowledge of an adaptive nature and 'major innovations'. Adaptive knowledge creation refers to when an entity – whether business, university or other organization – adapts existing knowledge to its particular reality; this means it is not at the level of the 'science frontier', unlike major innovations.
11. The original proposal for dividing fish farming areas into barrios in the 10th and 11th regions was made by SalmonChile.
12. On 3 August 2012, a law (Law No. 20597) was passed by Congress to further strengthen the

authority of the above two institutions with regard to aquaculture. The law officially changed the name of the Undersecretary of Fisheries to that of Undersecretary of Fishery and Aquaculture and upgraded the Department of Aquaculture to Division, giving it the same legal status as the National Commission. In a similar manner, the National Fishery Service was changed to National Fishery and Aquaculture Service (Aqua, Crean Nueva Subsecretaria de Pesca y Acuicultura, 6 August 2012).

13. Farms, stores, warehouses, slaughter facilities (processing plants), fish nurseries, ships, aircraft, trains, vehicles, boxes, packages and packaging materials.
14. We are aware that there are some recurrent incidents of sanitary crisis as well as problems in implementing regulations (i.e. assigning the correct indicators, identifying maximum levels etc.). These can be considered as a process of institution building to prevent a 'tragedy of the commons' (see Ostrom, 1990), but through policy intervention.

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