Chapter 5
Environmental Collapse and Institutional Restructuring: The Sanitary Crisis in the Chilean Salmon Industry

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1 Introduction

The current export boom in natural resources is considered to be the 'new window of opportunity' for many developing countries endowed with natural resources. Recent studies (Blomström and Meller 1991; de Ferranti et al. 2002; Maloney 2002; Sinnoit et al. 2010; Perez et al. 2009; Iizuka and Soete 2011) indicate that natural resource-based activities can be knowledge intensive, which contrary to earlier understandings, would lead them to productivity-led development pathways.

This positive feature of natural resource-based activities has some serious drawbacks for countries not equipped with the institutions to accurately evaluate the impacts and risks, needed to ensure environmental sustainability. This aspect is of particular importance for activities that are based on interaction with the biosphere such as agriculture, fishery, and forestry. Many case studies show that the regulatory mechanism for controlling ecological sustainability has been rather slow to develop, as emerging countries make economic development their priority (Perfecto et al. 2003; Philpott et al. 2008; Fearnside 2001; Koh and Wilcove 2007; Lenzen et al. 2012). The uneven speed of development—rapid increases in the exploitation of natural resources stimulated by global market demands with slow development of local regulatory institutions—can lead to a 'tragedy of the commons' (Hardin 1968) at the local level, and trigger environmental and economic collapse in the long run.

In an attempt to avoid this future environmental crisis, experts and policy makers are working to identify possible indicators that would help them to evaluate risk. In order to achieve this, knowledge of the local biological environment must be built up and scientific methods for understanding the possibility and probability of

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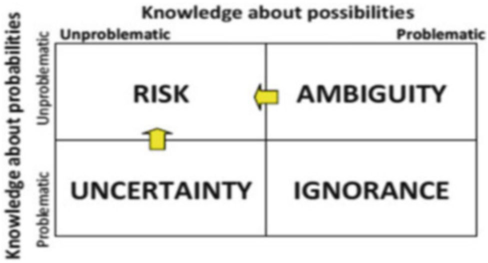
Fig. 5.1 Conceptual map of risk (*Source*: Based on Stirling (2008, 2010))



occurrences of collapse must be followed—that is, identifying the carrying capacity of the local environment. This is a cumulative learning process which converts incalculable 'uncertainty' and 'ambiguity' into a more calculable and predictable 'risk'. This process requires finding the patterns, probable causes (possibilities), and predictors (probabilities) based on information collected in a trial-and-error manner. Such exercises will eventually lead to identifying possible indicators or to a model for regulatory purposes that could prevent the worst-case scenario occurring.[1] Of course, the biological interaction in nature is dynamic and complex, making it impossible to predict all the possibilities. Stirling (2008, 2010) succinctly presents the relationships between risk, uncertainty, and ignorance in his 'Conceptual Map of Risk' (see Fig. 5.1).[2] Stirling admits that ongoing events using scientific understanding, may not fully provide for 'unknown' incidents given our current 'ignorance' (knowledge whose presence is beyond our current comprehension). Hence, there will always be some 'uncertain' elements when dealing with nature.

This chapter, using the case of the 2007 sanitary crisis in the Chilean salmon industry, seeks to explain the following: firstly, how such an environmental collapse occurred in Chile at a time when the industry was expanding so as to integrate itself into the global economy; and secondly, the ways in which the Chilean experts are currently trying to regulate this situation by identifying the indicators that can be used to prevent a crisis from happening. This study will show how natural resource processing activities need to be supported not only by advanced production technology, but also by sound scientific and technological research, which focuses on the way the local environment functions; this emerges as a *sine qua non* to regulate the use of the commons,[3] (Feeney et al. 1990; Ostrom et al. 1999).

[1] An exercise of this sort is currently being applied in an experimental preliminary phase in Chile—see Chap. 7 of this book.

[2] Stirling (2008, 2010) emphasizes the need for democratic and participatory regulatory mechanisms, especially to deal with 'ignorance'—unknown knowledge. Although we fully admit the importance and relevance of his argument, we will use his framework to focus on the areas where experts need to convert 'ambiguity' and 'uncertainty' knowledge into more calculative 'risk'.

[3] Natural resources such as air and water are typical example of commons. Commons has the properties that can 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).

2 The Sanitary Crisis and Its Causes

2.1 Magnitude of the Crisis

The sanitary crisis in the Chilean salmon industry started in 2007 and was due to the spread of infectious salmon anaemia ('ISA') (Sernapesca 2008). Soon after its emergence, the affected cultivation sites suspended their operations (Iizuka and Katz 2011). By 2009, close to 60 % of the cultivation centers had ceased production. In the following year, the production of salmon had fallen to around 200,000 tons from its peak of nearly 700,000 tons in 2006. The collapse of the industry due to sanitary crisis caused serious social, economic, and industrial disruptions (see Chap. 6 for more details on the industrial disruptions). In an attempt to illustrate some of the possible causes for this crisis and illustrate the actions taken to overcome it, this chapter will focus on the sanitary and environmental aspects of this crisis.

2.2 ISA Virus and Sanitary Conditions: An Ecological Triad of Illness

The ISA virus, the cause of sanitary crisis, was first believed to have originated in Norway, arriving in Chile via imported salmon eggs.[4] However, local biologists and veterinarians who have been interviewed (Bustos 2008; Nieto 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 because of the presence of a pathogen but would require systematic collapse over a long period of time to eventually reduce the self-immunological defense capabilities of the fish and create an environment in which pathogens are able to 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 the water quality in the coastal areas of Chile where salmon is cultivated. However, veterinarians have compiled a record of sanitary incidents involving salmon in captivity. This shows that the worsening of the sanitary environment as the production volume of salmon increased started much earlier than the date of the outbreak (Fig. 5.2). The first of the major sanitary incidents—bacterial kidney disease (BKD) and caligidosis—only appeared in 1986 towards the end of the industry inception stage. The rapid growth of the industry in

[4] Many local specialists believe that a variant of the disease had for some time been present in Chile but a combination of environmental conditions triggered its mutation with a rapid spread (Bustos 2008; Nieto 2009).

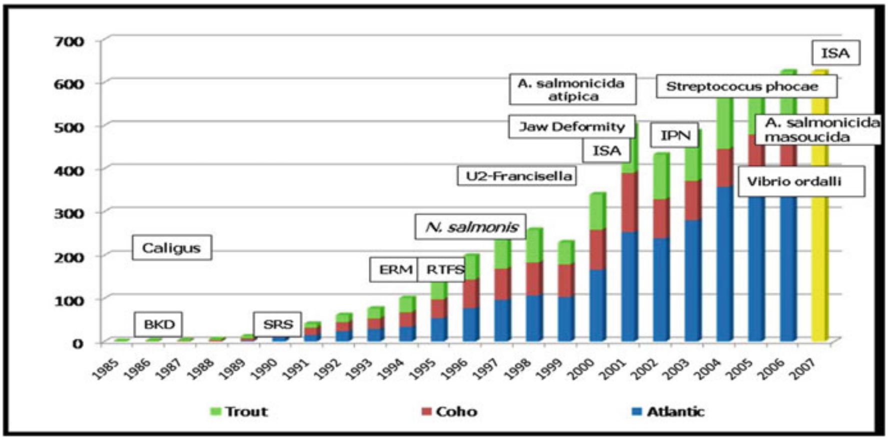


Fig. 5.2 Deterioration of sanitary conditions in salmon farming sites and increase in exports (thousand tons) (*Source*: Based on Sernapesca (2009, 2011) and Nieto (2009))

the 1990s (reaching nearly 300,000 tons by the end of the decade)—and the subsequent period of rapid growth between the 2000 and 2008—(reaching a volume of output of 500,000 tons per annum)—also seem to have coincided with the outbreak of many new diseases affecting the species. It was not only the ISA virus that causes anemia (see Box 6.1 of Chap. 6) but jaw deformation, a typical aeromonas salmonicida, infectious pancreatic necrosis (IPN), streptococcus phocae, vibrio ordalii, and aeromonas salmonicida masoucida also emerged prior to the crisis. For instance, Salmon Rickettsial Syndrome or Piscirickettsiosis (SRS), ISA, and caligidosis are the diseases that have affected the industry most recently (Fig. 5.2). The caligidosis caused by sea lice is suspected to be the vector of the ISA virus. An independent survey of the sanitary situation carried out by veterinarians also confirmed that the sanitary situation had worsened in the mid 1990s compared to the 1980s (Bustos 2008; Johnson 2007; Nieto 2009) (Table 5.1).

3 Conditions Behind the Worsening Sanitary Environment

The worsening sanitary conditions were caused by several factors. The major factor that contributed to the sanitary conditions was the activities of firms. As will be demonstrated in Chap. 6, it should not be forgotten that two important factors were behind the behavior of firms. Firstly, strong market demand and a harsh competitive global market environment forced firms to behave in a myopic, profit-driven manner (Iizuka and Katz 2011, 2012). Secondly, the regulatory system before the crisis was operated under export-oriented, strong 'pro-growth' sentiments and did not expressly control the use of resources from a sustainability perspective (as explained in Chap. 4). This was partly due to the public sector thinking it

Table 5.1 Appearance of disease: perception of local veterinarians

Disease	1980s	Mid 1990s
Bacterial kidney disease	X	X
Piscinketsiosis		X
Infectiouspancreatic necrosis	X	X
Vibriosis (v.ordeli)		X
Vibriosis (v.angillarium)		X
Ulcerative vibriosis		X
Streptococosis		X
Franciseltosis		X
Atypical furunculosis		X
Kudoa		X
Jandrice syndrome		
Nucleospondiosis	X	X
Flavovacteriosis	X	X
Columnaris	X	X
Yersimiosis	X	X
Saprolegiosis	X	X
Caligus	X	X
ISA (infectious Salmon Anemia)		X
Amoebic gill disease		X

Source: Based on survey taken in the mid-1990s (Bustos 2008)

unnecessary to regulate the salmon farming sector given its small scale during the 1980s and partly because *SalmonChile* (*Salmon Industry Association AG*), was able to exercise its power to ensure less government control over the behavior of firms in the 1990s when the industry grew substantially. As a result there was a vacuum in regulatory power, especially with regard to maintaining sustainability in economic activities involving natural resources, such as the Chilean salmon industry (for details, see Chap. 6).

3.1 Concentration of Cultivation Sites (Cultivation Permits) in Limited Geographical Areas

In Chile, anyone wishing to engage in aquaculture or conduct economic activities in coastal areas, rivers, and lakes needs to obtain permits (concessions) from the public authorities. The concessions are granted only after the applicants have been through several administrative clearances.

Currently, 72 % of the salmon farming concessions in Chile are located in a small territory covering no more than 300 km^2. The concentration of salmon cultivation centers in Chile is striking when compared with Norway, whose total area of cultivation is spread over 1700 km^2 (Pucchi 2009).[5] Despite the high concentration of concessions in a small territory, until 2001 there were no regulations governing the distance between salmon farming centers in Chile (currently 2.27 km).

The granting of concessions for cultivation centers in Chile increased over the period 20 years. In the late 1990s, these concessions were concentrated in the Los Lagos region (10th region). This region was by far the most suitable area for salmon farming, with natural fjords, rivers, and lakes, as well as reasonable access to physical and social infrastructure that ensured access to transportation and a labor force. From the late 1990s, as the industry ran out of space in the Los Lagos region, concessions started to move southwards—firstly to Aysen (11th region) and gradually to Magallanes (12th region) (see Chap. 6 for map and Table 5.5 for the increase in concessions). The granting of concessions also sped up from 2000 to 2005.

3.2 Fish Density Within the Cultivation Center

The production of salmon in Chile increased dramatically from 1999 onward and by 2006 it had reached an all-time historical peak of nearly 700,000 tons. The strong incentive to increase production came from the rapidly increasing global price of salmon (Table 5.3). This increase in demand—without the provision of a regulatory mechanism (for details see Chap. 6) and a collaborative mechanism among firms to control the sustainable use of resources—pushed many firms to increase production by simply adding more fish to the existing tanks and increasing cultivation sites within small geographical areas. In retrospect we now know that this caused something similar to the 'tragedy of the commons' described by Hardin (1968).[6]

The density of the fish population can be increased in various ways: firstly, by increasing the number of fish in each cultivation site and secondly, by increasing the number of cultivation sites in certain geographical areas by way of an increased number of concessions. The former is demonstrated in Table 5.2, which compares the volume of fish per cultivation center in Chile to that in Norway. The table clearly shows a larger volume of fish being cultivated at each cultivation site in Chile. The increase in the number of fish per cultivation was taking place in an already densely populated cultivation site contained within a small geographical area. This fact is confirmed by the data from EWOS—a salmon food company—which shows the increase in average numbers of fish per cultivation center (Table 5.3) from 2003 to 2007. In other words, this confirms the fact that salmon

[5] 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).

[6] Hardin (1968), in explaining 'the tragedy of the commons', used a simple model of 'herder' behaviour. By putting one more cow in a limited space of land (common), the individual benefit maximization attempt—through the eventual overloading of the resource—would cause a reduction in the collective benefits to all users of the common.

Table 5.2 Average salmon weight per cultivation center: Chile and Norway

Chilean cultivation site	Average tons/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 tons/center
Finnmark	255
Troms	499
Nordland	528
Nord-trondelag	518
Sor-trondelag	522
More og fjordane	424
Hordaland	374
Rogaland	506
Ovrige fylker	689
Total	474

Source: Based on EWOS Health (2007)

Table 5.3 Key indicators for productivity in salmon firms

	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 until 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 (000) tonnes	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 (2009, 2011)

farming firms behaved quite similarly to Hardin's 'herder', who added 'one more cow' (fish) to a fixed unit of space in the commons (cultivation site, tank). The individual's maximization of benefit, in this case, is to attain higher profits from an increase in global prices for salmon. Once a given threshold of fish density at the site had been reached, increasing the density further worsened the sanitary condition of the 'common' in which the fish were being raised (Iizuka and Katz 2011).

Table 5.3 also demonstrates the decreasing trend in the productivity of firms in relation to the cost per volume of fish produced. While the total volume of salmon production increased from 2003 onwards, other indicators showed signs of deterioration. For example, the average weight per fish at the time of harvesting declined from 4.4 to 4.1 kg; the number of days required for harvesting expanded from 487 to 543 days; and the weight of salmon produced (output) per unit of input of smolt and eggs decreased from 3.7 to 3.1 kg for the former and from 1.3 to 1.1 kg for the latter. The economic and biological rate of conversion[7] deteriorated from 1.36 to 1.52 and from 1.24 to 1.34 respectively, i.e. more feed was needed to produce 1 kg of salmon. Table 5.3 also shows that the rate of fish mortality increased from 15 % in 2003 to 25 % in 2007. There must also have been an increase in sunk costs in expenditure on vaccines and antibiotics to prevent the fish from getting ill, and on the additional feed needed as a consequence of the extension of harvesting time for slower growing fish.[8]

No reliable historical data exists to indicate exactly when the deterioration of sanitary and environmental conditions started. However, a Norwegian egg-producing company located in Chile—*AquaGen*—estimated that the sanitary conditions began to worsen at the beginning of the year 2000, around the time when Chilean exports of salmon reached more than 500,000 tons. Corresponding to the growth of exports, there was a rapid increase in demand for eggs from the year 2000 onwards; however, AquaGen claims that the demand for eggs exceeded the increase of actual production of salmon, which indicates an increase in mortality rate. The company came to this conclusion by calculating the total number of eggs needed to produce 500,000 tons of salmon based on the following assumptions: that the mortality ratio of eggs to smolt is 50 %; and, that on average 3 kg of smolt is needed to produce 1 kg of salmon. Using the above assumptions, AquaGen calculated that the required number of eggs would be approximately 330 million (eyed eggs), as shown by the red line in Fig. 5.3. At the assumed level of mortality, egg input beyond that level is considered excessive. The figure demonstrates that the eggs produced grew very rapidly beyond the red line, reaching a peak in 2007—the year of the crisis. It is also noteworthy that most of the growth was accounted for by the domestic production of eggs.

[7] The economic conversion rate is the rate at which kilograms of feed are converted into 1 kg of salmon in economic value terms. The biological conversion rate is only in biological terms.

[8] 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 increased treatment costs, operational costs, and processing costs (Johnson 2007).

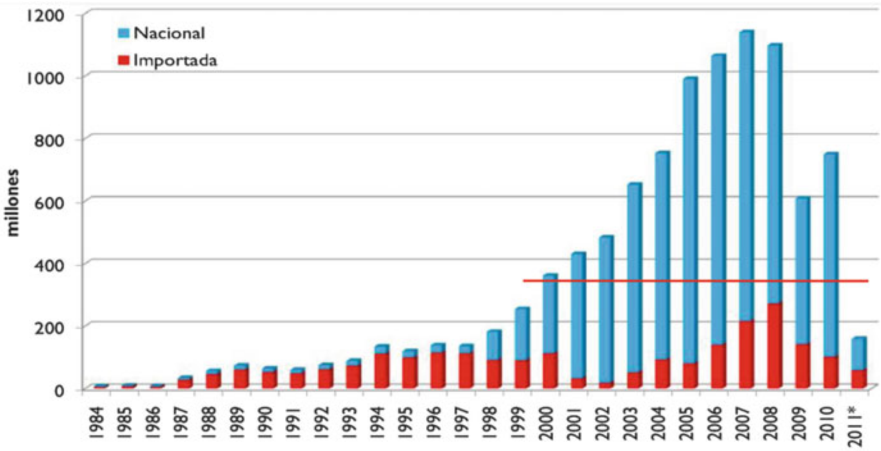


Fig. 5.3 Salmon egg production: 1984–2011 (millions of eyed eggs per year) (*Source*: Based on Dempster (2011))

Despite all the economic and biological indicators pointing to the deterioration in productivity from 2003 to 2007, exports increased substantially aided by the higher price of salmon during the same period (see the lower part of Table 5.3). Based on the above figures, we can say that the growth in profit enjoyed by most Chilean salmon firms was actually created by the rising price per unit of salmon rather than from the increase in unit productivity in biological terms. This is consistent with the claim by Katz et al. (2011a: 21) that:

> productivity gains that are achieved via economies of scale—such as larger crop tanks, various types of technological changes, process-scanning, new feeding technologies and new food formulas etc. incorporated by salmon farming companies during the course of this decade having been totally or partially annihilated by the decline in marginal efficiency of water resources, which ended affecting adversely the aggregated performance of the sector.

The increasing demand for eggs to produce the salmon—as calculated by AquaGen—suggests a high mortality rate at each stage of the rearing process: from egg to smolt and from smolt to salmon. This indirectly indicates that the amount of salmon reared in a given space of water started to exceed the local carrying capacity during the period of increasing export volume from 2000 to 2007 (see Fig. 5.2 for the volume of exports). Despite declining biological productivity, firms continued to employ unsustainable practices due to the increasing profit being generated by the higher global price for salmon (Table 5.3). It is possible to assume that this process was repeated until it reached the threshold level, causing the outbreak of the sanitary crisis in 2007.

3.3 Different Biological Productivity Pattern by Stage of Production and by Species

Experts claim that the survival ratio of eggs to smolt is particularly low in Chile and at 40 % is lower than that of Norway. The cause of such a high mortality is disease, particularly SRS (EWOS Health 2007). The frequent occurrence of disease in the local environment had some impact on the methods of production used by firms. One of the obvious signs was the intensive use of antibiotics to prevent diseases. This became the topic of intensive discussion despite a lack of accessible reliable data.

The survival rate during the freshwater phase (until smoltification) is influenced by locational and seasonal factors, such as the temperature of water. Table 5.4 shows the appearance of diseases by major freshwater sites: Llanquihue, Puyehue, Ranco, and Rupanco areas located in Southern regions of Chile. As can be seen in Table 5.4, despite some similarities, occurrence of diseases is quite different depending on location. This means that there are geographical differences in how nature reacts to the introduction of fish.

Moreover, there are seasonal differences in occurrences of pathogen outbreaks. This also indicates that there are seasonal differences in the pattern of their appearance (Table 5.5).

Table 5.4 Diseases diagnosed in the freshwater phase in different locations, Chile 2008

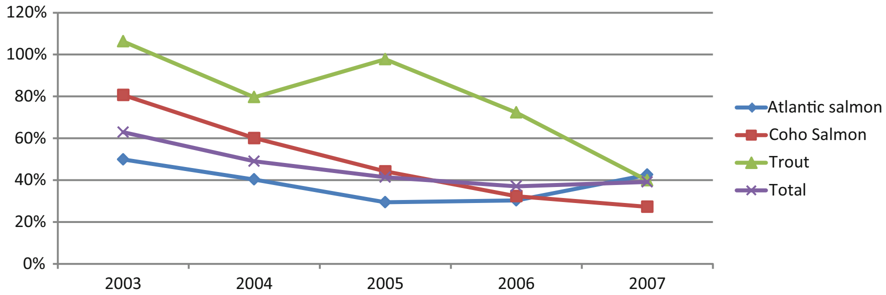
Llanquihue area	Puyehue area	Ranco area	Rupanco area
IPNv	IPNv	IPNv	IPNv
BKD	BKD	BKD	BKD
Francisella	Ichthyophthirius (Ich)	Ichthyophthirius (Ich)	Aeromonas
Fungosis	Fungosis	Flavobacteriosis	Fungosis
Yersimiosis	Yersimiosis		Yersimiosis
Aeromonas			Ichthyophthirius (Ich)

Source: Interview, Dr Nieto (2011)

Table 5.5 Seasonal changes in the spread of diseases

Pathogen	Spring	Summer	Autumn	Winter
F. columnare	x	xxx	–	–
F. psychrophilum	x	–	xxx	xxx
Aeromona	xxx	xxx	xx	xx
IPN virus	xxx	xx	xxx	xx
Fungus	xxx	–	xxx	xxx
R. Salmoninarum (BKD)	x	x	xxx	xx
Ichthyophthirius	–	xxx	–	–
Francisella	xxx	xx	x	x
Y. rucken	xxx	xx	x	–

Source: Interview, Dr. Nieto (2011)
Note: x means less frequent; xxx means more frequent



	2003	2004	2005	2006	2007
Atlantic salmon	50%	40%	29%	30%	43%
Coho Salmon	81%	60%	44%	32%	27%
Trout	106%	80%	98%	72%	40%
Total	63%	49%	41%	37%	39%

Fig. 5.4 Yield of smolt (survival rate of eggs): number of smolt (t)/number of eggs (t–2) (Note: trout in figure indicates trout salmon. *Source*: Authors)

Furthermore, the susceptibility to the disease is also different between type of salmon (Fig. 5.4). For instance, survival rate of egg to smolt is lowest for Atlantic salmon compared to Coho salmon and trout in the period from 2003 to 2007. It is also true that in 2003 Atlantic salmon had the lowest survival rate of the three. This result confirms the earlier claim by AquaGen that the worsening situation for Atlantic salmon had started earlier than 2003.

The yield of smolt compared to harvested salmon (in tons) shows different patterns by species (see Fig. 5.5). Clearly the largest decline from 2002 to 2008 was observed in Atlantic salmon due to the ISA crisis, while coho salmon and trout suffered a smaller decline. The difference in the size of the salmon species at maturation affects the pattern of growth (one grows heavier than the other as measurement is taken by the weight); hence the figures are not comparable across species in a simple manner. However, we can compare the trends from 2002 to 2008. Although coho salmon and trout were not affected by ISA, the survival rate also demonstrates a general decline. Of course, during this period, the largest decline is observed in Atlantic salmon, which started with a yield higher than the other species in 2002 and ended up with a significantly lower yield in 2008.

The above differences in yield by species are reflected by the amount of smolt sown during a similar period, as shown in Fig. 5.6. The number of Atlantic salmon smolts sown increased rapidly from 2003 to 2006, while coho stayed stable. A minor increase is also observed for trout. The circumstantial evidence above demonstrates the degrading biological productivity in the salmon industry but the impacts were felt differently by species and in localities of production.

	2001	2002	2003	2004	2005	2006	2007	2008
Atlantic salmon		0.40%	0.33%	0.25%	0.29%	0.32%	0.25%	0.03%
Coho Salmon	0.34%	0.34%	0.20%	0.21%	0.20%	0.30%	0.28%	0.25%
Trout	0.32%	0.35%	0.18%	0.24%	0.16%	0.20%	0.23%	0.17%
Total	0.35%	0.32%	0.20%	0.25%	0.25%	0.26%	0.19%	0.20%

Fig. 5.5 Yield of harvested salmon (survival rate of smolt): harvested salmon (tons)/number of smolt (Note: trout in figure indicates trout salmon. *Source*: Authors)

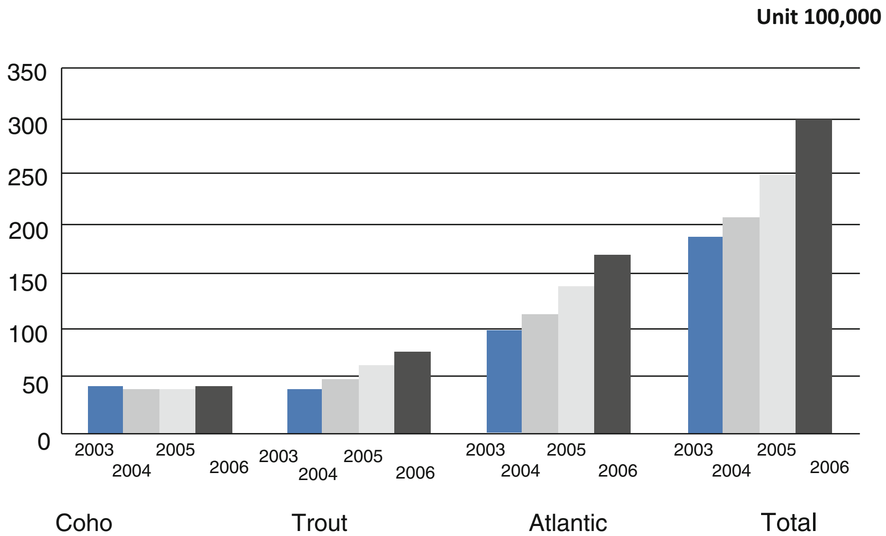


Fig. 5.6 Increasing sowing density by species: 2003–2006 (*Source*: EWOS Health (2007))

The above sanitary evidence suggests that the following factors influence the mortality rate of fish: the amount of fish introduced into the limited geographical space—the density of fish; the species of salmon; the location of cultivation sites; and the season. Accordingly, efforts to come up with effective preventive measures must include the above variables.

Thus far we have ‘visited the past’, looking for a better explanation of what triggered the ISA crisis. We now move to the present to examine the process involved in attempting to convert ‘ambiguity’ and ‘uncertainty’ into calculable ‘risk’ in a way that supports regulatory institutions and is suitable for the Chilean salmon industry. So far, several factors that may cause the difference in sanitary and environmental outcomes have been identified as: fish density; geographical locations; and the type of salmon produced. To effectively prevent the further occurrence of diseases of this nature, information from different settings must be considered.

As will be discussed in Chap. 6, since the establishment of Mesa de Salmon in 2008 attempts to recover from the ISA crisis have been well under way. The experts, public officers, and industries are trying to identify how to manage and control the situation. One of the prominent endeavors is the establishment of *barrios* and macrozones, and regulatory institutions to monitor the behavior of firms with regard to sanitary conditions. The measures that have been implemented correspond to the above findings on the salmon industry.

4 The Restructuring of the Industry into *Barrios* (‘Neighbourhoods’) and Macrozones

4.1 Creation of Barrios *and Macrozones*

In order to reduce the systemic risk of new diseases in the future, the National Fisheries Service (Sernapesca) required salmon farming firms to group their cultivation centers according to geographical location into *barrios* or ‘neighbourhoods’. The National Fisheries Service also obliged firms operating in cultivation centers within the same *barrio* to synchronize their sowing and harvesting calendars, and provide for a 3-month resting period to allow the *barrio* to recover its biological properties after use. The coordination of the production calendar was thought to facilitate sanitary controls aimed at minimizing the transit of navigation, often instrumental in transmitting pathogens.

Figure 5.7 presents a ‘stylized’ description of the idea, and Fig. 5.8 shows how the idea has been implemented in southern Chile, which is highly populated with salmon farming centers.

Each macrozone houses different *barrios*, each of which is home to various cultivation centers. These cultivation centers belong to different firms. Each firm

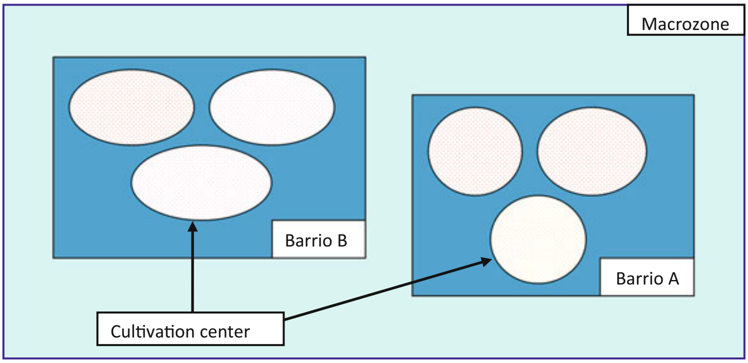


Fig. 5.7 Macrozones, neighbourhoods (*barrios*) and cultivation centers (*Source*: Authors)

has its own production strategy, organization, and 'core capabilities'. Some of them produce only Atlantic salmon (salar). Others produce coho and trout in various proportions. Coho and trout do not suffer from the ISA virus, so we have a priori expectations that large differences would prevail among firms as a result of the differences in output mix, the total amount of salmon being cultivated in the neighborhood, and the distance between cultivation centers.

In other words, differences among *barrios* and macrozones are expected to reflect not just differences in 'state conditions' (such as water quality, oceanographic conditions, ocean currents and more) but also differences in 'control variables' (such as biosecurity and environmental routines) strategically chosen by different firms. In another words, a firm's strategy for implementing preventive measures will influence greatly the degree of likelihood that they will cause a crisis—this is termed the 'risk score'.

Figure 5.8 shows the reorganization of salmon farming into *barrios* that has taken place in the regions of Los Lagos (macrozones 1, 2, 3 and 4) and Aysen (macrozones 5, 6 and 7).

4.2 Incidence of ISA Virus in Barrios[9] *from 2007 to 2011*

In the initial years of the epidemic, cultivation centers affected by the ISA virus (ISA) rose to 134 (from July 2007 to October 2008). Most of them were initially only suspected of having the virus and later developed into serious stage outbreaks. As can be seen from Fig. 5.9, the first positive cases of ISA virus were in Los Lagos

[9] There are some changes in the division of *barrios*; for details, see Chap. 6.

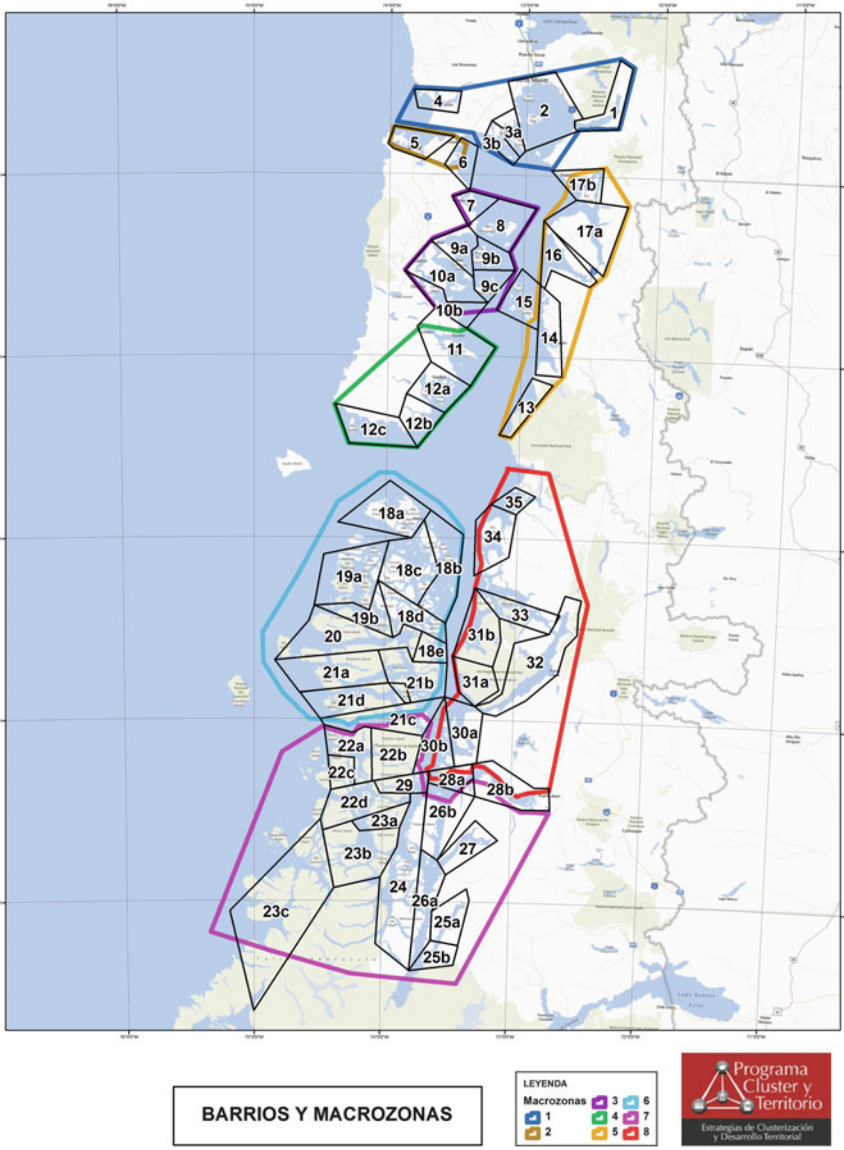


Fig. 5.8 Neighbourhoods, barrios, and macrozones in 10th and 11th regions (*Source*: Sernapesca (2010; see also Chap. 6, Fig. 6.1))

(tenth Region). The virus later spread to the Southern regions of Aysen and Magallanes. It can also be seen from Fig. 5.9 that the peak of disease detection was in 2008 and decreased significantly from 2009 to 2010, with some increase in 2011.

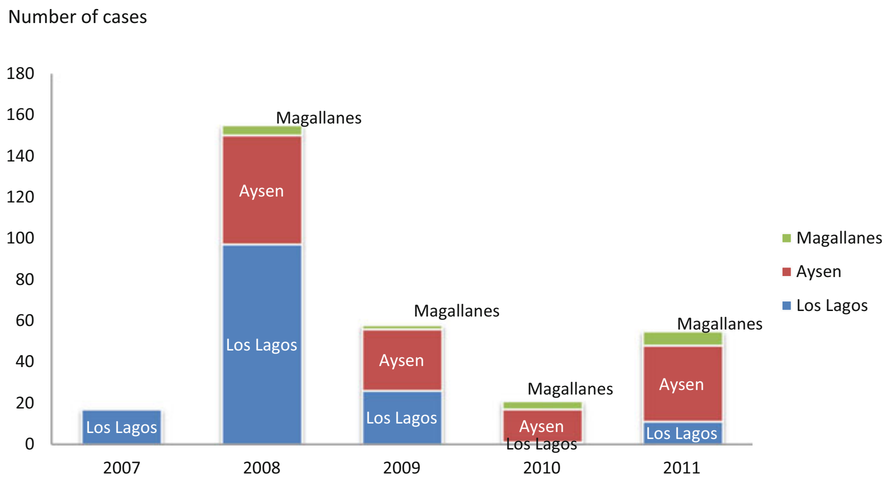


Fig. 5.9 Positive incidents of ISA virus in the *barrios* by regions: 2007–2011 (*Source*: Based on Sernapesca (2012))

4.3 Categorizing Barrios *into Clusters, 2007–2011*

Based on the available information regarding ISA, virus occurrence levels (high, medium, and low), the concentration of biomass (tons of fish per square km), and the percentage of types of salmon (Atlantic, coho, trout), cluster analysis was conducted within the *barrio*.

The results of cluster analysis separated the distinctive characteristics of *barrios* into five clusters, as can be seen in Fig. 5.10.

The clustering was identified by the geographical area of the *barrio*, the concentration of fish, and the species of salmon (Fig. 5.11). The above figure demonstrates that cluster 1 consisted of just one *barrio*, *barrio* 1 that had a medium occurrence of ISA with a high concentration of trout-coho with 94 %. The cluster 2 consists of barrios 2,3,6,7, 8 and 17 (see Fig. 5.11 for location), and had a high occurrence of ISA and a lower concentration of coho-tout of 56 % compared to Barrio 1. Cluster 3 consists of barrios 18, 19, 20, 21, 31, 33, 34, and 35, which had a medium concentration, high occurrence of ISA with a higher proportion of Atlantic salmon, 58 %. Cluster 4 consists of barrios 9, 10, 11, 12, 13, 14, 15 and 16. These barrios had a high concentration, a very high occurrence of ISA, and the proportion of trout and coho was 64 %. The last cluster 5 consists of barrios 22, 23, 24, 25, 26, 27 28, 29 and 30. The density of fish was medium, the occurrence of ISA was medium, and the trout and coho consisted of 64 %. Interestingly, the barrios clustered together were geographically located close to each other (see Fig. 5.11 for location). This suggests that the concentration of fish, the geographical location of the *barrio*, and the type of salmon (coho-trout vs atlantic) significantly influence the occurrence of ISA.

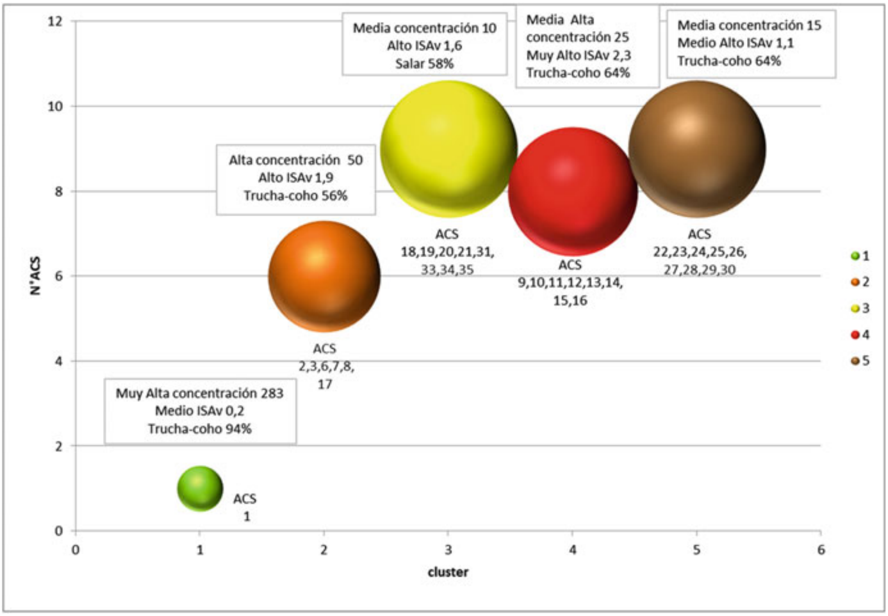


Fig. 5.10 Results of cluster analysis for grouping *barrios* in Los Lagos and Aysen by characteristics (Note: ISAv denotes ISA virus. *Source*: Authors)

Separate from the above, Vera and Zanlungo (2011) conducted correlation analysis between concentrations of fish in the area and positive cases of ISA by *barrio*. The results suggested a positive correlation between the two variables except for some anomalies found in the centers with a higher concentration of Atlantic salmon. Despite the anomalies, both analyses seem to suggest the general relationship between the concentration of fish and the occurrence of sanitary incidents, ISA.

4.4 Complex Reality Within Barrios *and Macrozones*

In order to understand the complex nature of the reality in the *barrios* and macrozones, Zanlungo and Vera (2010) took the case of macrozone 6 as an example and studied the details of how it functioned with regard to sanitary conditions. Understanding the current complexity is necessary for establishing a model for calculating risks and indicators for regulatory purposes.

Macrozone 6 has eight different *barrios*: 18A, B, C, D, 19A, B and C, and 20 (see Fig. 5.8 and Table 5.6). These *barrios* are home to 173 cultivation centers, of which only 32 are currently in operation. About half the cultivation centers produce Atlantic salmon, the species affected by ISAv. The other half of the centers

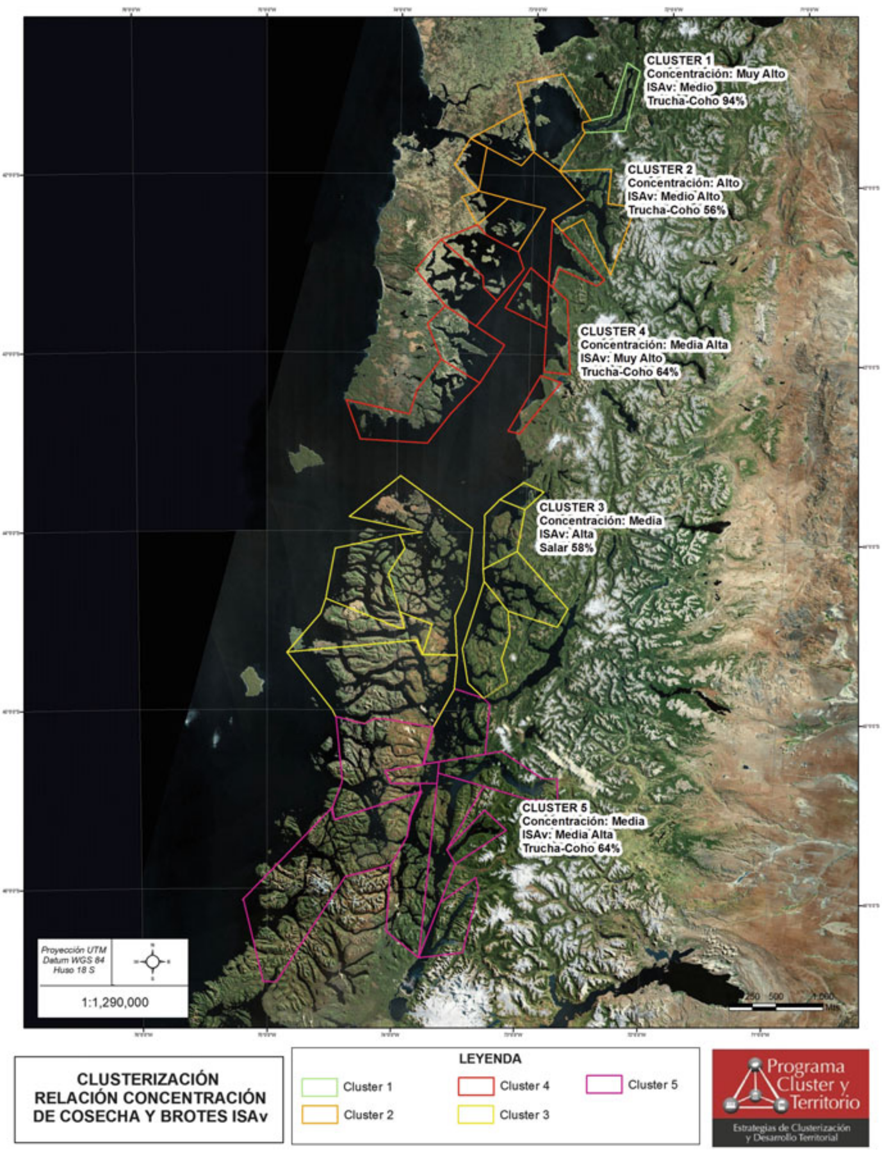


Fig. 5.11 Clusters in geographical locations (*Source*: Zanlungo (2011))

active in this macrozone produce trout and coho salmon, which do not suffer from ISA.

According to Table 5.6, the *barrio* with the most number of active cultivation centers in macrozone 6 is 18D, with 10 out of 26 centers currently in operation.

Macrozone 6's 173 cultivation centers belong to 23 different salmon farming companies (Table 5.7). Among other firms, Marine Harvest owns 35 of them and

Table 5.6 *Barrios*, cultivation centers and species cultivated by firms in macrozone 6

					Active centers producing		
Barrios	N° of firms	N° of active firms	N° of centers	N° of active centers	Coho	Trout	Atlantic
18A	4	1	15	5		5	
18B	7	2	19	2		1	1
18C	11	0	55	0			
18D	6	2	26	10	3	1	6
19A	5	2	13	3			3
19B	5	3	17	5		1	4
19C	No data						
20	6	2	28	7		2	5
Total	44	12	173	32	3	10	19

Source: Katz et al. (2011b)

Table 5.7 Firms and number of cultivation centers they own in macrozone 6

Firm	N° of centers
Marine Harvest	35
Camanchaca	29
Los Fiordos	26
Multiexport	22
Pesquera Eicosal	13
Aquachile	12
Aguas Claras	8
El Golfo	7
Chace Kehler Thomas	3
P. FishFarm	2
PacificStar	2
Ventisqueros	2
Yadrán	2
Avalos Escuderos Alfredo Julio	1
Barra Rebecco Cecilia Ximena	1
Barria Montiel, Jaime Felipe	1
Chileseafoods	1
Inversiones Chipana Limitada	1
Invertec	1
Pacheco Alvarado Luis Jorge	1
Productos del Mar Ventisqueros S.A.	1
Prov.FishFarm	1
Tornagaleones	1
Total	173

Source: Katz et al. (2011b)

Table 5.8 Firms[a] owning active centers in macrozone 6

Firms	N° of centers
Los Fiordos	12
S.Multiexport	8
Aquachile	5
Australis mar	3
El Golfo	2
Camanchaca	1
Pesquera Landes	1
Total	32

Source: Katz et al. (2011b)
[a]Ownership of cultivation centers and names of the firms are often different due to the M&A and takeovers that took place at various times in the past. The registered name is not easy to change; therefore many firms keep using the same name. Also, the registered name of the company and the name used in public can vary in some cases. Here, it was not possible to match up all the names listed in Table 5.8 with those listed in Table 5.7

therefore controls around 20 % of total installed production capacity of this macrozone. The ownership concentration of cultivation centers however, is not synonymous with having it in operation. In the particular case of Marine Harvest, in 2010 there was no active cultivation center in this macrozone. This means they have a 20 % share of the cultivation centers but 0 % are used for production.

Only seven firms have active cultivation centers in macrozone 6. Of those 7 firms, Los Fiordos is the company with the largest number—12 active centers accounting for 40 % of the total active centers (see Table 5.8).

By regulation (see Chap. 6), the rule 'one cultivation center one vote' applies when making decisions within the *barrio*. As this is not specified by the active/non active status of the cultivation center, this may not ensure the fair representation of the production structure.

5 Towards a Model for Risk Calculation[10]

Negotiations were expected to take place among actors within *barrios* and macrozones as the regulation pushed firms to come up with an agreed production calendar. The difficulties in creating a uniformed production calendar would encourage M&A (large firms acquiring smaller firms) or the relocation of cultivation sites by swapping the cultivation sites between firms in future.

[10] This section is based on Katz et al. (2011b).

Table 5.9 Risk of sanitary events in macrozones 1, 2, 3 and 4 (Los Lagos)

Macrozone	N° of risk events	N° of critical risk events	N° of high risk events
1	31	0	11
2	39	8	21
3	19	0	6
4	17	1	10

Source: Vera and Zanlungo (2011)

Katz et al. (2011b) consider that one can calculate the risk of each firm based on a mix of 'state' and 'control' variables. The state variable is the environmental/ecological factors that are essentially present with geographical location. The control variable is the firm's strategy. For instance, all the firms within a *barrio* have a similar 'state' variable because they are situated in a similar geographical location and operate under one production calendar enforced by the National Fisheries Service. Nevertheless, firms can have different 'control' variables due to different strategies chosen by the firms. If a firm follows more meticulous biosecurity and environmental practices than other firms, this firm will lower the risk. Of course, there is a collective aspect to difficulties due to the fact that firms in the same geographical area share the same bodies of water. This means if other firms in the same *barrio* 'free-ride' excessively—i.e. they do not follow regulations—on the environmental regulation, even with the strict regulatory strategy the firm can face the high risk of having environmental and sanitary crises due to lack of collective action. This feature of collective action was portrayed by Ostrom (1990).[11]

5.1 Calculating the State Variable: Locally Specific Risk Factor

Leaving consideration of the collective aspect of actions within the *barrio* aside, Vera and Zanlungo (2011) carried out an estimation of the imminent risk of ISA based on the four following factors that affect the state variable: (1) the type of salmon under cultivation (Atlantic salmon being more vulnerable to the risk than the other species); (2) the distance between cultivation centers (greater proximity between centers means higher risks); (3) the number of active centers in the given *barrio* (larger number of active centers means higher risk); and (4) the volume of

[11] The authors are aware that the dynamic game-theoretical notion needs to be incorporated into the model to be more realistic. However, the following section will deal only with the static model to calculate the risk. The calculation of game-theoretical interactions would require data that are not available.

production (a greater total weight of fish in the given area contributes to a higher risk). On the basis of expert opinion the risk model was specified as follows[12]:

$$Risk = 0.4^{*}Specie + 0.3^{*}Distance + 0.15^{*}N^{\circ}Centers + 0.15^{*}Production$$

Notice that the model deals only with 'state' variables, i.e. environmental/ecological variables that are supposed to be common within the same *barrio*. Here, the 'control' variable, the strategy of the firm, is not yet incorporated. Using the above equation with available data from *barrios* in the Los Lagos region (10th region), Vera and Zanlungo (2011) calculated the risk of sanitary events occurring in macrozones 1, 2, 3 and 4 (which are in the 10th region) (Table 5.9).

This simple exercise tells us that the likelihood of new critical sanitary episodes in the near future is by no means small. Differences in geographical locations—macrozones—are significant, and this should be taken into consideration by the National Fisheries Service when regulations are planned and enforced. However, given the fact that the above model estimated risk only by the differences in 'state' variables—i.e. an estimation of environmental and sanitary conditions in a certain location—it does not give a complete picture.

5.2 Calculating the Control Variable: Firm-Specific Risk Factor

We now know that different risk factors are specific to each geographical location. It is difficult, at the moment, to know a firm's strategy for implementing biosecurity. However, we can obtain evidence of the distribution of cultivation centers by the firms across *barrios* and macrozones. The available evidence shows that each firm's cultivation centers are unevenly distributed between *barrios* and macrozones. Considering Los Lagos (10th region)[13] for example, Table 5.10 shows significant inter-firm differences in the percentage of cultivation centers owned in macrozones 1 through 4.

By way of example, a firm called Caleta Bay has five cultivation centers located in macrozone 1, while Salmones Humboldt has its three cultivation centers in two different macrozones. On the other hand, Mainstream—the largest firm in the group in terms of active cultivation centers—has its production capacity distributed in all macrozones, but is strongly concentrated in macrozones 2 and 3. Marine Harvest—the third largest in the group—has 15 active cultivation centers mostly concentrated in macrozone 2.

[12] Notice that the elasticity involved in the model reflects a certain amount of discretion. It was chosen with the advice of industry experts.

[13] The exercise is carried out only for the Los Lagos region due to data availability.

Table 5.10 Number and percentages of active cultivation centers in the Los Lagos region by firm and macrozones, July 2011

Firms	MAC1	MAC2	MAC3	MAC4	Total no. of active centers by firm
Aquachile	54.5 %	18.2 %	27.3 %	0.0 %	11
Caleta Bay	100.0 %	0.0 %	0.0 %	0.0 %	5
Camanchaca	57.1 %	14.3 %	0.0 %	28.6 %	7
CM Chiloé	40.0 %	60.0 %	0.0 %	0.0 %	5
GMT	25.0 %	0.0 %	75.0 %	0.0 %	8
Holding – Trading	0.0 %	50.0 %	50.0 %	0.0 %	8
Invertec	0.0 %	75.0 %	25.0 %	0.0 %	8
Mainstream	10.0 %	40.0 %	45.0 %	5.0 %	20
Marine Harvest	13.3 %	73.3 %	0.0 %	13.3 %	15
Mirasol	0.0 %	0.0 %	0.0 %	100.0 %	3
Multiexport	0.0 %	0.0 %	0.0 %	100.0 %	2
Pacific Star	0.0 %	0.0 %	100.0 %	0.0 %	5
Salmones Antártica	12.5 %	37.5 %	0.0 %	50.0 %	8
Salmones Humboldt	33.3 %	0.0 %	0.0 %	66.7 %	3
Trusal	64.7 %	11.8 %	0.0 %	23.5 %	17
Ventisqueros	16.7 %	0.0 %	0.0 %	83.3 %	12
Average part.	26.7 %	23.8 %	20.1 %	29.4 %	8.5
Macrozone total active cultivation centers	40	40	29	30	139

Source: Katz et al. (2011b)
Note: The results reflect cultivation centers active during July 2011
MAC macrozone

Remembering that different macrozones have different risk rates (see Table 5.9), we can now combine geographical location and differences in risk across macrozones in order to calculate a static firm-specific indicator of risk which considers the relative participation of each company in each macrozone. We present this estimate in Table 5.11 to explain the sanitary conditions upon which salmon is being cultivated.

The individual firm coefficients reported in Table 5.11 should be considered 'static' indicators of the risk each company faces as a result of its geographical location and its programmed sowing and harvesting calendar for the period 2011–2014. The parameter does not capture the differences in individual-firm risk resulting from differences in 'control' variables, i.e. those reflecting its sanitary and environmental protection efforts, and the dynamic aspects of collective action.

We notice a certain degree of variance in individual company risk levels. Eleven out of 16 companies in Table 5.11 show a risk coefficient between 19 and 31 i.e. they are relatively close to each other in the level of risk. There are two outliers—Mirasol and Multiexport—which have a low risk indicator of 17, while three firms—Invertec, Marine Harvest and CM Chiloe—exhibit a high-risk parameter above 34.

Table 5.11 Firm-specific risk in the Los Lagos region

Firms	Risk 2011
Aquachile	29.2
Caleta Bay	31.0
Camanchaca	28.1
CM Chiloé	35.8
GMT	22.0
Holding – Trading	29.0
Invertec	34.0
Mainstream	28.1
Marine Harvest	35.0
Mirasol	17.0
Multiexport	17.0
Pacific Star	19.0
Salmones Antártica	27.0
Salmones Humboldt	21.7
Trusal	28.6
Ventisqueros	19.3
Average	26.4
Est. Desv.	6.3

Source: Katz et al. (2011b)

Note: Our estimate of company risk rates was obtained using the risk coefficients of Table 5.9 for each macrozone and the percentage participation of each company in each macrozone, as in Table 5.10. For example: the risk rate for Marine Harvest for 2011 results from: 31*0.45 + 39*55 + 19*0 + 17*0 = 35.4

Individual firm risk can also be seen as a reflection of company-specific control variables—i.e. its sanitary and environmental control routines—and involving dynamic considerations not yet explicitly incorporated in the coefficients of Table 5.11. Although the estimated risk parameters reported in Table 5.11 reflect a certain dynamic—insofar as they include the incidence of company production plans for the period 2011–2014—they do not incorporate dynamic changes in company strategy in a more fundamental sense. This will influence a firm's risk rating in the future. It is also possible for the firm gradually to change their risk factor by changing their geographical location and moving its production activities to less risky environments—even though the firm must realize that this change will probably reduce risk levels in the macrozone the firm leaves but might increase risk levels in the macrozone it moves into. Additionally, the firm could introduce changes in production organization routines leading to more meticulous sanitary and environmental protection practices. More collective action to jointly improve the sanitary and environmental conditions in the *barrios* may also influence the outcome. An increase in a firm's size through M&A may also allow it to exert more control over sanitation measures. By changing its 'control' variables and moving from quantity to quality in its production organization, a firm will reduce company-specific risk and also positively affect its state risk in the *barrio*. These decisions are not taken merely for sanitation purposes, but involve other decisions of a collective nature, such as logistics for transport, infrastructure, and available human resources, making it even more firm-specific and rendering it more difficult to predict the risk.

6 Conclusion

Any country will exploit natural resources for development purposes. As identified in the earlier chapters, the globalization of production and consumption has created an opportunity to exploit the comparative advantages of resources through export so that economic activities can be transformed for greater productivity. However, once the industry is being shaped and has started to increase its production scale, unexpected negative externalities may emerge to threaten the very existence of activity. Environmental/ecological problems are typical of such cases especially because these resources are accessible to all users free of charge, creating the problem of 'free riding'. This is a clear case of market failure in which the policy intervention is justified—in the form of creating rule of law and enforcement mechanisms—to regulate the use of resources and distribution among involved stakeholders. Yet, this is still a difficult task in many countries, particularly developing ones.

This chapter illustrated the process of making 'evidence-based' regulations using the case of the salmon farming industry's challenge to create effective institutions for monitoring sanitary conditions. It did so in two steps: firstly, by understanding the mechanisms behind the sanitary crisis of the Chilean salmon industry in 2007; and secondly, by understanding the process of converting (sanitary) knowledge into indicators to be used in the monitoring process.

The first part identified that various factors such as geographical location, fish density, and the type of fish reared contributed to the worsening sanitary and environmental conditions. The latter part illustrated the attempts made to create a model by simplifying the complex mechanism of risk with 'state' and 'control' variables. The 'state' variable represents the geography/location-specific risks, while the 'control' variable represents firm-specific risk. Despite the lack of data on 'control' variables, this chapter was able to calculate the risk factor of firms based on the locations of their production sites. The development of these measures is still in its incipient stages and requires further fine-tuning with the inclusion of additional data such as information on firm-level biosecurity measures implemented, dynamics of M&A, and density of fish by firm cultivation site, so as to create more detailed 'control' variables. The same is true for the 'state' variable which would need to include geographical, oceanographic, and ecological data (such as depth of water, direction of current, temperature of water, locational ecological conditions, and luminosity) specific for each *barrio*.

As this case shows, creating new institutions to regulate the sustainable use of natural resources requires translating the scientific evidence into implementable institutional mechanisms. As activities based on interaction with the biosphere follow a dynamic evolutionary path, the process of fine-tuning the regulatory indicators for monitoring is expected to continue in a trial-and -error manner.

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