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Planning for aquaculture diversification: the importance of climate change and other drivers

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PAPER 3

AQUACULTURE DIVERSIFICATION IN SOUTH AMERICA: GENERAL VIEWS AND FACTS AND CASE STUDIES OF THE REPUBLIC OF CHILE AND THE FEDERATIVE REPUBLIC OF BRAZIL

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1. AQUACULTURE AND AQUACULTURE DIVERSIFICATION IN SOUTH AMERICA

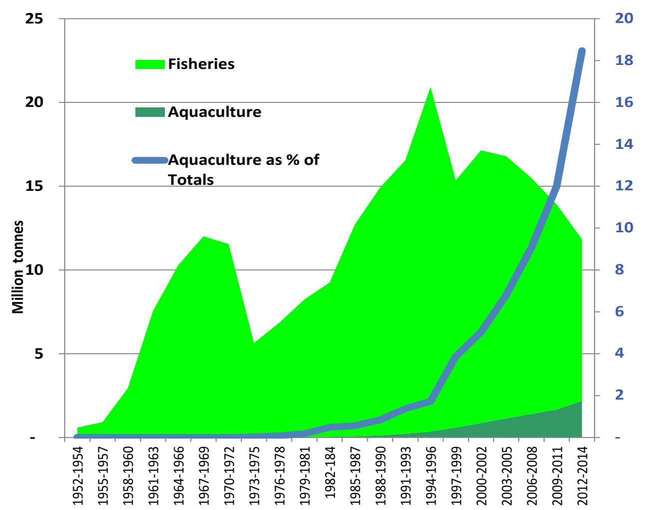
1.1 Facts and figures

South America (SA) is one of the main fishing areas of the world (third economic region, after Eastern and Southeastern Asia, according to the FAO). South America has relatively poor domestic consumption of fish (about 10 kilos per caput in recent years), with wild landings of 9.7 million tonnes per year in 2012–2014, which depend a lot on the pelagic fisheries off the Republic of Chile and the Republic of Peru, whose products are mainly used to produce fishmeal and oil. Wild landings have experienced a serious regression since 1994–1996, when they reached a peak of 20.5 million tonnes.

In contrast, and as a response to fairly open world market opportunities arising from the levelling of marine capture fisheries since the mid-1990s and new technological developments, regional aquaculture has been able to grow, from negligible amounts in the early 1950s, to 2.4 million tonnes in 2014, currently accounting for 18.5 percent of total regional landings and for 3.1 percent of world farmed outputs (average for 2012–2014; Figure 1).

Aquaculture in SA is still a fairly young industry in most countries, and currently (2014) three of them, the Republic of Chile (50.7 percent), the Federative Republic of Brazil (23.4 percent) and the Republic of

FIGURE 1
South America: Wild and aquaculture production, 1952–2014



Source: Basic figures from FAO, FISHSTAT, 2016.

Ecuador (15.4 percent) account for 89.5 percent of production. Of the remaining eleven countries or territories, the Republic of Peru (4.8 percent) and the Republic of Colombia (3.8 percent) also stand out (Table 1).

TABLE 1
South America: Aquaculture production, 1982–2014. Average annual crops, thousand tonnes

Country	1982-1984	1985-1987	1988-1990	1991-1993	1994-1996	1997-1999	2000-2002	2003-2005	2006-2008	2009-2011	2012-2014
Argentine	0.1	0.3	0.3	0.5	1.2	1.2	1.5	1.9	2.7	2.8	3.6
Bolivia		0.0	0.3	0.4	0.5	0.4	0.4	0.4	0.6	0.9	1.2
Brazil	9.2	11.7	18.1	27.9	51.6	110.7	208.6	266.9	297.3	403.7	506.3
Chile	1.6	4.0	19.0	67.5	164.3	279.9	501.1	655.7	805.7	816.3	1 106.4
Colombia	0.6	1.2	6.5	20.1	30.8	47.5	58.9	60.7	68.3	81.6	90.4
Ecuador	30.8	48.4	74.9	103.9	101.4	135.6	65.5	114.2	171.2	267.1	340.9
French Guyana	0.0	0.0	0.1	0.0		0.0	0.0	0.0	0.0	0.0	0.0
Guyana	0.0	0.1	0.0	0.1	0.2	0.4	0.6	0.6	0.5	0.4	0.3
Malvinas/Falkland Is.								0.0	0.0		
Paraguay		0.0	0.1	0.1	0.2	0.2	0.6	1.8	2.4	3.5	6.5
Peru	2.3	4.9	5.0	5.7	6.4	7.9	8.6	20.6	37.0	75.2	104.4
Surinam				0.0	0.0	0.1	0.4	0.3	0.1	0.1	0.1
Uruguay		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
Venezuela	0.5	0.6	0.7	2.0	5.7	9.8	16.0	19.6	20.7	19.0	27.9
Totals	**45.1**	**71.2**	**124.9**	**228.1**	**362.4**	**593.7**	**862.1**	**1 142.7**	**1 406.6**	**1 670.5**	**2 188,0**

Source: Basic figures: FAO FISHSTAT, 2016.

Production is highly concentrated in terms of species farmed. Salmon and trout contribute with 41 percent to SA's crops in 2012–2014, while shrimp, particularly *P. vannamei*, add another 19 percent to totals, tilapias an extra 13 percent and mussels 11 percent of aquaculture production in this subcontinent. It is also interesting to note that the 'production structure' of SA's aquaculture has varied a lot over the years (Table I–2). In the 1950s, this subcontinent produced only molluscs, particularly oysters and mussels. In the early 1960s salmonid production starts, followed by shrimp late in that decade. Only in the 1970s SA does start producing tilapias and other freshwater fishes. Shrimp dominate local aquaculture until the early 1990s, when salmonid production explodes, leading regional crops until now. SA farms 'negligible' amounts of marine fishes, even though several countries have been working for years with introduced species such as turbot, and with native plaices, robalos and the like in warmer waters.

Development and diversification efforts have always been present in SA's aquaculture since its earlier stages of commercial interest. In fact, aquaculture production growth rates in the subcontinent have surpassed world averages for the last six decades, and have reached very high levels, particularly between the 1970s and 1980s (43.2 percent per year, as seen in Table I–3). However since the 1980s, regional growth rates, even if positive and attractive, have started to diminish, to the point that in the last ten years (see Table I–3) these figures tend to approximate world averages.

The situation is much more variable with wild fisheries. Here, growth rates are very dissimilar in different decades, with negative figures for the last 20 years ending in 2014. In the case of world wild fisheries, though, growth rates have been steadily declining since the 1950s, and have been very close to zero during the last two decades ending in 2014. This difference between SA's and world's growth rates have permitted regional aquaculture to increase its global relevance, to a still modest 3.1 percent of totals (2012–2014).

TABLE 2
South America: Species farmed by group of species and environment, 1982–2014 (thousand tonnes)

ISSCAAP Group	1982-1984	1985-1987	1988-1990	1991-1993	1994-1996	1997-1999	2000-2002	2003-2005	2006-2008	2009-2011	2012-2014
Salmons, trouts, smelts	1.7	3.7	18.5	66.2	156.1	257.4	456.2	569.6	642.0	600.7	893.8
Shrimps, prawns	31.5	50.5	81.7	115.6	118.4	159.2	119.5	213.7	266.5	330.7	421.9
Tilapias and other cichlids	0.2	0.5	1.6	9.8	25.4	45.7	77.1	113.3	143.4	248.2	278.4
Mussels	1.1	1.6	2.5	3.4	8.3	20.9	45.1	86.6	169.5	242.5	263.4
Miscellaneous fresh water fishes	8.8	11.1	17.4	27.8	27.2	45.3	75.6	76.9	105.7	161.1	248.0
Scallops, pectens	0.6	2.1	1.1	2.9	10.2	17.9	22.1	28.4	34.4	54.4	54.2
Carps, barbels and other cyprinids	0.0	0.0	0.1	0.2	13.8	40.1	55.8	47.1	39.8	28.4	23.1
Oysters	0.1	0.3	0.4	0.7	1.7	5.0	7.3	5.4	3.6	2.4	3.0
Abalones, winkles, conchs					0.0	0.0	0.1	0.2	0.4	0.8	1.0
Frogs and other amphibians		0.0	0.0	0.1	0.3	0.6	0.7	0.6	0.6	0.6	0.4
Sturgeons, paddle fishes					0.0	0.0	0.0	0.0	0.0	0.1	0.2
Flounders, halibuts, soles				0.0	0.1	0.3	0.3	0.3	0.3	0.3	0.2
Miscellaneous pelagic fishes										0.1	0.1
Freshwater crustaceans	0.9	1.2	1.6	1.3	0.7	0.4	0.5	0.5	0.3	0.2	0.1
Miscellaneous coastal fishes						0.8	1.9	0.0	0.0	0.1	0.0
Cods, hakes, haddocks											0.0
Marine fishes not identified		0.0				0.0	0.0	0.0	0.0	0.0	0.0
Turtles									0.0	0.0	0.0
Miscellaneous marine crustaceans						0.0	0.0				
Miscellaneous marine molluscs	0.1	0.1	0.1	0.2	0.1		0.0	0.0	0.0	0.0	
Total	**45.1**	**71.2**	**124.9**	**228.1**	**362.4**	**593.7**	**862.1**	**1 142.7**	**1 406.6**	**1 670.5**	**2 188.0**
ISSCAAP Divisions											
Aquatic animals,various		0.0	0.0	0.1	0.3	0.6	0.7	0.6	0.6	0.6	0.4
Crustaceans	32.5	51.7	83.3	116.9	119.1	159.6	120.0	214.2	266.8	330.9	422.0
Molluscs	1.9	4.2	4.0	7.2	20.3	43.8	74.5	120.7	207.9	300.1	321.6
Fresh water fish	9.0	11.6	19.1	37.7	66.4	131.2	208.5	237.3	288.9	437.7	549.5
Diadromous fish	1.7	3.7	18.5	66.2	156.1	257.4	456.2	569.6	642.1	600.7	894.0
Marine fish		0.0		0.0	0.1	1.1	2.2	0.3	0.3	0.4	0.4
Totals	**45.1**	**71.2**	**124.9**	**228.1**	**362.4**	**593.7**	**862.1**	**1 142.7**	**1 406.6**	**1 670.5**	**2 188.0**
Environment											
Fresh Water	11.5	15.3	26.2	47.9	78.1	148.6	224.1	256.4	310.1	500.3	646.2
Brackish	30.3	47.7	73.8	101.8	104.2	138.3	64.6	114.7	168.9	235.3	329.4
Marine	3.3	8.2	25.0	78.3	180.1	306.9	573.4	771.7	927.5	935.0	1 212.4
Total	**45.1**	**71.2**	**124.9**	**228.1**	**362.4**	**593.7**	**862.1**	**1 142.7**	**1 406.6**	**1 670.5**	**2 188.0**

Source: Basic figures: FAO FISHSTAT, 2016.

TABLE 3
Growth rates in South American and World aquaculture, 1952–2014 (Mean average cumulative annual rates of variation, percent)

From	To	Aquaculture	Fisheries	Total
		South America		
1952-54	**1962-64**	8.2	31.5	28.3
1962-64	**1972-74**	28.3	-4.2	-3.8
1972-74	**1982-84**	43.2	4.4	4.1
1982-84	**1992-94**	18.8	7.4	6.8
1992-94	**2002-04**	15.3	-2.0	-1.3
2002-04	**2012-14**	7.6	-4.6	-2.9
		World		
1952-54	**1962-64**	6.1	6.1	5.5
1962-64	**1972-74**	6.0	3.3	3.1
1972-74	**1982-84**	7.3	2.0	2.1
1982-84	**1992-94**	11.1	1.9	2.7
1992-94	**2002-04**	8.1	0.3	1.9
2002-04	**2012-14**	6.0	0.2	2.1

Source: Basic figures: FAO FISHSTAT, 2016.

TABLE 4
South America's and World's aquaculture and wild fisheries production, 1952–2014 (thousand tonnes and percentages)

Region	1952-1954	1962-1964	1972-1974	1982-1984	1992-1994	2002-2004	2012-2014
South America							
Aquaculture	0.0	0.1	1.2	45.1	253.5	1 052.5	2 188.0
Fisheries	589.2	9 144.0	5 960.5	9 206.4	18 767.9	15 403.7	9 652.2
Totals	**589.2**	**9 144.1**	**5 961.7**	**9 251.5**	**19 021.3**	**16 456.2**	**11 840.2**
World							
Aquaculture	958.3	1 729.2	3 097.6	6 279.9	18 016.4	39 202.7	70 170.0
Fisheries	23 912.7	43 262.6	60 040.1	72 955.6	87 967.6	90 743.9	92 475.1
Totals	**24 871.0**	**44 991.8**	**63 137.8**	**79 235.5**	**105 983.9**	**129 946.6**	**162 645.1**
South America as % of Totals							
Aquaculture	0.0	0.0	0.0	0.7	1.4	2.7	3.1
Fisheries	2.5	21.1	9.9	12.6	21.3	17.0	10.4
Totals	**2.4**	**20.3**	**9.4**	**11.7**	**17.9**	**12.7**	**7.3**

Source: Basic figures: FAO FISHSTAT, 2016.

1.2 Diversification of aquaculture in South America: a few figures and concepts

A total of 70 different species are currently farmed in SA (2012–2014), down from a maximum of 79 in 2009–2011[37]. Before the 1970s, only between two and six species were farmed in this subcontinent. In 2012–2014, 54 species farmed (77 percent of totals) were produced in quantities of less than 10 000 tonnes per year, thus they represented only 2 percent of the overall production, with an annual average crop per species of just over 1 400 tonnes throughout SA.

Production structures have also changed over the years, with salmonids accounting for nearly 41 percent of SA's farmed production in 2014, the most important aquaculture category in the subcontinent. Only 30 years ago, those species represented only 3.7 percent of farmed production, while farmed production was headed by

[37] As per FAO's FISHSTAT, 2016.

crustaceans (72 percent of aquaculture production). Only the environmental origin of fish farming has remained relatively stable along the years, as in 1982–1984 about 26 percent the crops were associated with fresh water operations, while currently (2012–2014) almost 30 percent is produced in this environment.

Fourteen SA countries and territories currently report their aquaculture statistics to the FAO. By 1952–1954, only one nation, the Republic of Chile, was farming two marine species, i.e., oysters and mussels, totaling 47 tonnes. Twenty years later (1982–1984), there were nine countries farming 34 species totaling 45 116 tonnes, and by 2012–2014, thirteen nations cultivated 139 species[38], totaling 2.188 million tonnes per year.

However impressive this development process might seem, most of it is mainly related to the same small number of species and countries highlighted before. So, even though the number of countries/territories and species farmed in SA have increased along the years, most of them have yet to show their impact in production volumes and values.

Most of SA's aquaculture production until the present is of introduced or non-native species, such as salmon, trout, turbot and abalones in the Republic of Chile; trout in many other countries; tilapia all over the subcontinent; white shrimp in the Federative Republic of Brazil, the Republic of Colombia, the Bolivarian Republic of Venezuela and the Republic of Peru; carps and catfishes in different countries, etc. This has been because, with few exceptions, there were no technologies available to readily farm native species. However, this trend is changing, as most expansion and diversification efforts in current years refer to the development of new technologies to farm native species.

The Federative Republic of Brazil, with 25 species[39], has the more diversified production in SA during 2012–2014, 18 of which surpass the 1 000 tonnes per year. However, the number of species farmed there has diminished from a maximum of 35 in 2009–2011. Argentina follows, with 19 species farmed, but with fairly insignificant average crop per species (189 tonnes per year) and only 2 of them exceeding 1 000 tonnes per year. Then comes the Republic of Chile, with 18 species, 11 of them exceeding 1 000 tonnes per year, and an average per species of about 61 500 tonnes per year, the highest value for the subcontinent in this last triennium. In all, only 35 percent of the species farmed by each country in SA show mean annual crops of over 1 000 tonnes, with only three countries – the Republic of Chile, the Republic of Ecuador and the Federative Republic of Brazil – surpassing farmed productions of ten thousand tonnes per species and year.

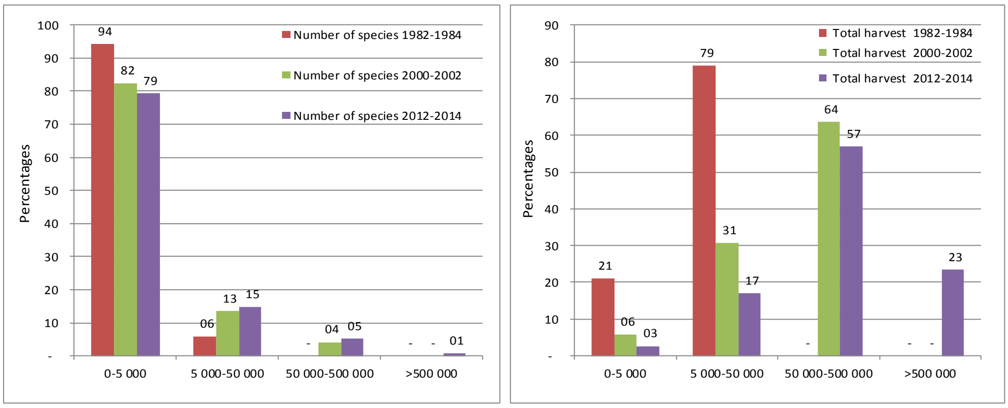
Therefore, it is evident again that, even though aquaculture production is advancing in SA for a limited number of countries and species, this subcontinent is in a very early stage of development of its aquaculture industry. Aquaculture output in SA is highly dependent on a very limited number of species farmed in high volumes. A high number of species is now being considered for aquaculture diversification in SA, but it is clear that a good number of them can hardly be expected to progress significantly in the near future or even in the mid-term.

Present diversification efforts are based on several factors, among which the following are of particular relevance: (1) Governmental desire to create more job

[38] These are mean annual averages calculated over triennial periods. Therefore, decimal values are here acceptable, and are used as such when dealing with other calculations, such as those for the values of mean annual crop per species. Of course, some species farmed in one country are also farmed in another, so that this number does not reflect the actual number of 'different' species farmed in SA. That number is smaller, and equivalent to 70, as stated on previous paragraph.

[39] Here, the number of species is calculated adding species farmed in fresh water to those in marine/brackish environments. As some species are cultivated in both types of environment, the actual number of 'different' species is somewhat smaller than the resulting figure, if one does not take into account this division among environments.

FIGURE 2
Distribution of the number of species farmed (left) and their harvest volumes (right), per harvest interval (expressed in tonnes), 1982–2014 (Percentages of the total number of species farmed and of total volumes harvested, percent)



alternatives and improve food security, replace food-fish imports, etc.; (2) Scientific drive and ingenuity, to move the frontiers of 'what can be learnt and done'; (3) Private sector moves, to explore new business alternatives.

Many species targeted for aquaculture diversification and development in SA will probably not succeed in becoming commercially viable targets in the coming 10–15 years, because the resources needed to complete the R&D efforts and related subjects, the time required, and the need for technical personnel and proper development programs are limiting almost everywhere in this subcontinent. As a consequence, more concentrated efforts, referred to a more limited number of species would be much more convenient for SA, if results of commercial interest are wanted in reasonable periods of time. Practically non-existent country- to- country cooperative efforts and the challenges associated with the marketing of 'new' aquaculture products make the whole diversification process risky, if not unfeasible in many countries and/ or with several species.

Therefore, in the authors' minds, a more creative, realistic and result-oriented SA strategy has to be devised for future action. Here, some basic premises become apparent, such as the need to look at the diversification process from a more holistic perspective. The most significant efforts until now have been devoted to basic biologic and technologic studies, and those studies did not achieve the critical 'mass' necessary to produce results; in parallel, other 'dimensions' of aquaculture development, such as governance, markets and marketing, logistics, social and environmental impacts, human capital, financial backing and the like have been neglected, becoming at some point the weak link that prevented the achievement of results of any significance. If these realities are ignored, aquaculture diversification in SA will consume scarce economic, social and human resources to no avail.

Paiche/pirarucu technology has been developed in the Federative Republic of Brazil, the Republic of Peru and the Plurinational State of Bolivia for well over a decade without producing significant commercial results; cobia has been and is being tried in the Republic of Ecuador, the Republic of Colombia, the Federative Republic of Brazil, the Republic of Panama, the Republic of Chile, the United Mexican States and other places without much commercial success; mussel, salmon, silversides and plaice production have been tried for many years in Argentina, while the Republic of Chile has invested in merluza austral (southern hake), sea urchins, halibut, Atlantic cod, hirame, red abalone, the European scallop and many other species without much achievement, while the Republic of Panama works with yellowfin tuna, the United Mexican States and the Republic of Chile with yellowtail kingfish, etc.

Facts and figures also show that for most part, this subcontinent's production seems to concentrate more on continental (101) than on marine (38) species. Fresh water aquaculture seems to pose relatively fewer demands, and is more readily applicable in small scale, while marine species require more extended R&D, need more financial resources and technical personnel not available in many parts of this subcontinent. Marine aquaculture initiatives could probably be tackled more efficiently by associating local countries, and also including 'foreign' partners to produce results in reasonable periods of time. Whatever the case, efforts should be devoted to deal with issues beyond technology, availability of which is still insufficient to provoke sustainable additional harvest on its own. Countries (and groups of countries as well) need a 'renewed' approach to aquaculture diversification, with fresh, more realistic and cost and socially effective long-term strategies based on well-conceived ideas.

Many SA countries do not have government personnel or scientists/technologists with the abilities and/or knowledge to lead these processes; aquaculture is fairly new to them, and they need support to achieve better results in their farming developments. As well, a more integrated 'subcontinental approach' to diversification, with joint planning and work, can enhance results in the medium term. All these actions require political will, well-conceived ideas and programs, and the concerted efforts of the SA's scientific, governmental and social communities.

TABLE 5
South America: Countries with aquaculture activity, volumes and species farmed, and various coefficients, by type of environment, 1952–2014 (figures are mean annual values for each period)

Country/Territory	1952-1954	1982-1984	1991-1993	1997-1999	2000-2002	2003-2005	2006-2008	2009-2011	2012-2014
Number of species farmed by country									
Argentina	-	1	3	8	9	9	10	18	19
Bolivia	-	-	4	3	5	5	5	5	5
Brazil	-	4	6	26	29	30	30	35	25
Chile	2	7	14	14	15	17	17	17	18
Colombia	-	8	7	14	13	11	8	16	13
Ecuador	-	3	9	7	6	5	8	9	7
Falkland/Malvinas Isl.	-	-	-	-	-	2	2	-	-
French Guiana	-	1	1	2	5	3	3	3	3
Guyana	-	2	2	7	6	6	6	10	9
Paraguay	-	-	3	6	6	5	5	9	5
Peru	-	5	11	11	15	15	17	15	15
Suriname	-	-	1	2	2	1	2	4	3
Uruguay	-	-	3	4	5	7	5	5	9
Venezuela	-	3	6	6	7	5	8	10	8
Total	**2**	**34**	**70**	**110**	**123**	**121**	**126**	**156**	**139**
Number of species farmed									
Fresh water	-	18	45	69	83	82	87	114	101
Marine/brackish waters	2	16	25	41	40	39	39	42	38
Total	**2**	**34**	**70**	**110**	**123**	**121**	**126**	**156**	**139**
Number of species farmed with over 1 000 tonnes per year									
Fresh water	-	1	8	20	23	24	27	30	33
Marine/brackish waters	-	3	11	14	16	16	16	14	15
Total	**-**	**4**	**19**	**34**	**39**	**40**	**43**	**44**	**48**
Percentage of species farmed above 1 000 tonnes per year, %									
Fresh water	-	25	42	59	59	60	63	68	69
Marine/brackish waters	-	75	58	41	41	40	37	32	31
Total	**-**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

TABLE 5 (CONTINUED)

Country/Territory	1952-1954	1982-1984	1991-1993	1997-1999	2000-2002	2003-2005	2006-2008	2009-2011	2012-2014
Number of countries with aquaculture production									
Fresh water	-	8	12	12	12	12	12	13	13
Marine/brackish waters	1	7	8	9	9	10	10	9	9
Total	**1**	**9**	**13**	**13**	**13**	**14**	**14**	**13**	**13**
Aquaculture production, tonnes									
Fresh water	-	11 513	47 924	148 569	224 082	256 367	310 133	500 257	646 151
Marine/brackish waters	47	33 603	180 144	445 175	638 036	886 324	1 096 443	1 170 257	1 541 863
Total	**47**	**45 116**	**228 068**	**593 744**	**862 118**	**1 142 691**	**1 406 576**	**1 670 514**	**2 188 014**
Average annual harvest per species, tonnes									
Fresh water	-	640	1 065	2 153	2 700	3 126	3 565	4 388	6 398
Marine/brackish waters	23	2 100	7 206	10 858	15 951	22 726	28 114	27 863	40 575
Total	**23**	**1 327**	**3 258**	**5 398**	**7 009**	**9 444**	**11 163**	**10 708**	**15 741**
Average annual harvest per country, tonnes									
Fresh water	-	1 439	3 994	12 381	18 673	21 364	25 844	38 481	49 704
Marine/brackish waters	47	4 800	22 518	49 464	70 893	88 632	109 644	130 029	171 318
Total	**47**	**5 013**	**17 544**	**45 673**	**66 317**	**81 621**	**100 470**	**128 501**	**168 309**

Source: Basic figures: FAO FISHSTAT, 2016.

In recent decades much has been gained in scientific/technological knowledge aimed at farming different native species, or in adaptation of foreign technologies to local circumstances. However, more and complementary work is needed to make new production feasible and lasting. Moreover, aquaculture diversification efforts do not necessarily pay sufficient attention to ‘production models’. Here, even if technologies and other aspects can be dealt with reasonably well, ‘new’ species might not be produced competitively enough, because of inadequate production scales, bad selection of sites, excessive restrictions, etc. In these cases, sales prices are higher than desirable, inhibiting domestic consumption and/or favouring imports. These situations mainly occur as a result of pressures exercised by local communities which want to have more access to work, or from poorly evaluated governmental or scientists’ acts, resulting in unsustainable and short-lived activities, and severe social frustration.

Climate change also poses new questions to aquaculture development and diversification. Here, the subcontinent is facing (and has faced) extended periods of drought in some areas; floods in others; desertification of some coastal zones; variable catches in oceanic waters; algae blooms in several countries and regions and other so far unpredictable events that will challenge aquaculture and its future. Even though some efforts have been made within the FAO, other international organizations and in several countries to predict and evaluate the possible outcomes of climate change over this subcontinent, little is known beyond the fact that Governments and producers, together with the scientific communities, have to keep these long term and accentuated effects in mind, paying more attention to R&D in this field, and on their prospective effects in production, employment, community life and environmental change. This variable, scarcely considered until very recently in South American aquaculture, will have to be addressed by planners, governments and other players; more financial resources will be required.

TABLE 6

South America: Distribution of the number of species farmed and of harvest per species, in different harvest intervals, 1952–2014 (intervals are in tonnes. Figures are mean annual values for each period)

Harvest intervals	1952-1954	1982-1984	1991-1993	1997-1999	2000-2002	2003-2005	2006-2008	2009-2011	2012-2014
Number of species in different harvest intervals expressed in tonnes									
<=100 tonnes	2	14	32	50	55	51	54	75	61
100-500	-	12	14	18	20	20	19	21	18
500-1 000	-	4	5	6	6	7	8	15	11
1 000- 5000	-	2	10	13	17	17	18	17	17
5 000-10 000	-	1	3	9	4	7	3	2	7
10 000-50 000	-	1	4	7	12	8	14	14	13
50 000-100 000	-	-	1	2	2	5	2	2	1
100 000-250 000	-	-	-	2	3	1	4	6	5
250 000-500 000	-	-	-	-	-	1	1	-	1
>500 000	-	-	-	-	-	-	-	-	1
Total, species	**2**	**34**	**69**	**107**	**119**	**117**	**123**	**152**	**135**
Percentage of species in each harvest interval, %									
<=100 tonnes	100.0	41.2	46.4	46.7	46.2	43.6	43.9	49.3	45.2
100-500	-	35.3	20.3	16.8	16.8	17.1	15.4	13.8	13.3
500-1 000	-	11.8	7.2	5.6	5.0	6.0	6.5	9.9	8.1
1 000-5000	-	5.9	14.5	12.1	14.3	14.5	14.6	11.2	12.6
5 000-10 000	-	2.9	4.3	8.4	3.4	6.0	2.4	1.3	5.2
10 000-50 000	-	2.9	5.8	6.5	10.1	6.8	11.4	9.2	9.6
50 000-100 000	-	-	1.4	1.9	1.7	4.3	1.6	1.3	0.7
100 000-250 000	-	-	-	1.9	2.5	0.9	3.3	3.9	3.7
250 000-500 000	-	-	-	-	-	0.9	0.8	-	0.7
>500 000	-	-	-	-	-	-	-	-	0.7
Totals	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Volumes harvested per species, in different harvest intervals									
<=100 tonnes	47	375	843	915	892	903	1.079	1.977	1.539
100-500	-	2 405	3 891	5 463	5 720	4 524	4 132	5 385	4 587
500-1 000	-	2 563	3 736	4 254	4 856	5 005	5 759	11 138	8 236
1 000-5000	-	4 177	21 918	27 050	38 497	38 003	38 909	44 185	43 561
5 000-10 000	-	8 500	22 758	60 327	28 056	56 044	23 089	13 453	44 443
10 000-50 000	-	27 096	83 929	131 388	236 305	170 421	243 211	294 828	328 257
50 000-100 000	-	-	90 994	143 106	107 651	408 049	159 247	128 097	68 229
100 000-250 000	-	-	-	221 241	440 142	121 389	565 696	1 171 450	868 640
250 000-500 000	-	-	-	-	-	338 354	365 455	-	308 367
>500 000	-	-	-	-	-	-	-	-	512 155
Totals	**47**	**45 116**	**228 068**	**593 744**	**862 118**	**1 142 691**	**1 406 576**	**1 670 514**	**2 188 014**
Percentages of harvests per species in different harvest intervals, %									
<=100 tonnes	100.0	0.8	0.4	0.2	0.1	0.1	0.1	0.1	0.1
100-500	-	5.3	1.7	0.9	0.7	0.4	0.3	0.3	0.2
500-1 000	-	5.7	1.6	0.7	0.6	0.4	0.4	0.7	0.4
1 000- 5000	-	9.3	9.6	4.6	4.5	3.3	2.8	2.6	2.0
5 000-10 000	-	18.8	10.0	10.2	3.3	4.9	1.6	0.8	2.0
10 000-50 000	-	60.1	36.8	22.1	27.4	14.9	17.3	17.6	15.0
50 000-100 000	-	-	39.9	24.1	12.5	35.7	11.3	7.7	3.1
100 000-250 000	-	-	-	37.3	51.1	10.6	40.2	70.1	39.7
250 000-500 000	-	-	-	-	-	29.6	26.0	-	14.1
>500 000	-	-	-	-	-	-	-	-	23.4
Totals	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: Basic figures: FAO FISHSTAT, 2016.

Note: Here the number of species is somewhat smaller than in the former table, as in this case species farmed both in fresh and marine environments are counted only as one and not as two.

2 AQUACULTURE AND AQUACULTURE DIVERSIFICATION IN THE REPUBLIC OF CHILE

2.1 Current situation, production models and strategies

The Republic of Chile is an outstanding world aquaculture producer, currently ranked among the ten most important countries in this field, with the Kingdom of Norway as the only other Western nation in this category. This fact is basically associated with the production of salmon/trout and mussels, which together represented over 98 percent of Chilean aquatic farmed production in 2014. The Republic of Chile ranks second only to the Kingdom of Norway in salmon and trout farming, and is the second largest mussel grower in the world, after the People's Republic of China.

It was not easy to introduce commercial aquaculture in the Republic of Chile, which for decades was mainly concerned with abundant capture fisheries developed since the 1960s with governmental support. Fish farming was not considered to be an important sectoral 'addition' for some time, a view that led to certain degree of complacency both at private and governmental levels. Whatever the reason, the Republic of Chile has evolved to become a leading aquaculture nation whose story is linked to extraordinary natural and environmental conditions, to the opening of the Chilean economy in the late 1970s, and to the drive of many entrepreneurs who, with limited help from government at the outset, led the way in conjunction with institutions such as Foundation Chile and several universities.

FIGURE 3
Chile and Its regions

Table 7 shows aquaculture production evolution since 1990 and the relative importance of the different species being cultivated. Even though growth since 1990 has been substantial (Table 8), the process is slowing down, indicating that the development 'model' used until now[40] has lost dynamism, and suggesting that there is a need for a new strategy in a country which still has ample room for aquaculture progress and diversification. The loss of vitality can be explained by several factors, i.e., lower export growth rates to the main destinations, growing complexities in the assignment of farming permits and other governance issues, disease outbreaks, questionable environmental situations and financial constraints.

Aquaculture development is a highly desirable proposition in many parts of the country not currently involved in this industry, and in others where further diversification is still attractive. The use of diversification, as an alternative for further growth, will be explored in more detail in the following paragraphs.

Up to now, and because of a restricted domestic demand, commercial aquaculture in the Republic of Chile is mostly export oriented, and it was targeted with that intention from its very beginnings. Thus, most farming enterprises related to salmon/trout production, processing and marketing are fairly sophisticated, of a large size and use state of the art technology to compete globally. Following this pattern, the Republic of Chile became the main supplier of imported salmon to the United States of America and Japan, and more recently, in the Federative Republic of Brazil.

[40] Chilean recent growth rates in production are inferior to those observed worldwide as an average.

TABLE 7
Chile: Aquaculture production, 1990–2014 (in thousand tonnes)

Year	1990-1994	1995-1999	2000-2004	2005	2006	2007	2008	2009	2010	2011	2012
Atlantic salmon	22.3	87.7	263.2	385.8	376.5	331.0	388.8	204.0	123.2	264.4	399.7
Coho salmon	22.6	67.5	103.0	102.5	118.2	105.5	92.3	120.0	122.7	159.6	162.8
Rainbow trout	16.9	60.0	108.5	123.0	150.6	162.4	149.4	149.6	220.2	224.5	262.8
Other salmonids	0.7	0.4	2.7	2.9	2.0	1.9	0.1	0.6	0.6	1.1	1.7
Other fish	0.0	0.2	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3
Total fish	**62.6**	**215.8**	**477.6**	**614.4**	**647.6**	**601.2**	**630.9**	**474.5**	**467.2**	**649.7**	**827.2**
Mussels	3.0	9.7	47.0	87.7	127.0	153.4	187.1	175.7	221.5	288.6	257.8
Scallops	4.0	13.3	18.5	17.3	19.4	20.1	21.3	16.5	8.8	11.0	5.8
Abalones	0.0	0.0	0.1	0.3	0.4	0.4	0.5	0.9	0.8	0.8	0.9
Oysters	0.8	3.5	4.7	2.6	1.6	1.0	1.1	0.2	0.3	0.4	0.3
Other mollusks	0.3	0.6	1.3	1.4	1.5	1.7	2.3	2.0	2.5	4.5	2.6
Total mollusks	**8.0**	**27.1**	**71.7**	**109.4**	**149.9**	**176.6**	**212.2**	**195.3**	**233.9**	**305.3**	**267.4**
Gracilaria algae	51.6	71.4	46.2	15.5	33.6	23.7	21.7	88.1	12.2	14.5	10.6
Other algae	0.0	0.0	0.0	0.0	4.6	2.7	6.0	0.0	0.0	0.0	0.0
Total algae	**51.6**	**71.4**	**46.2**	**15.5**	**38.2**	**26.4**	**27.7**	**88.2**	**12.2**	**14.5**	**10.6**
Other species	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**122.2**	**314.3**	**595.5**	**739.4**	**835.7**	**804.2**	**870.8**	**758.0**	**713.2**	**969.6**	**1105.2**
Index, 2005=100	**17**	**43**	**81**	**100**	**113**	**109**	**118**	**103**	**96**	**131**	**149**

Source: SERNAPESCA: National Fisheries Service, the Republic of Chile

TABLE 8
Chile: Average growth rates of commercial aquaculture, 1990–2014 (mean average cumulative rates, calculated between mean average crops of five-year periods)

Species	1990/94	1995/99	2000/04	2005/09
	1995/99	2000/04	2005/09	2010/14
Total fish	28.1	17.2	4.4	4.4
Total mollusks	27.5	21.5	18.7	9.3
Total algae	6.7	-8.3	-3.2	-20.4
Other species	–	14.9	-24.2	–
TOTAL	**20.8**	**13.6**	**6.1**	**4.8**

Source: SERNAPESCA: National Fisheries Service, the Republic of Chile.

Atlantic salmon (*Salmo salar*) is by far the main species produced, followed by Coho salmon (*Oncorhynchus kisutch*) and trout (Oncorhynchus mykiss), with 67 percent, 17 percent and 16 percent of salmonids' crops in 2014, respectively. Salmon farming takes place almost exclusively in Southern Chile, from the Araucanía to the Magellan Regions. In the former area, but also south of it, farming aims at producing smolts in fresh water for later transport to marine sites, to complete the production cycle in cages.

Cage farming at sea takes place in the Los Lagos (Lake), Aysén and Magellan Regions, where temperatures and other environmental conditions – such as sheltered sites on a very indented coastline – are optimal for these purposes. Lately, Aysén has surpassed the Lake Region as the main source of production. In Magellan, commercial farming started more recently, and so far accounts for about 5–6 percent of total crops. However, production there is advancing rapidly.

Mussel production was initiated as a low-scale family oriented undertaking in the 1960s and 1970s, and changed significantly when Spanish entrepreneurs started operations in the Lake Region late in the 1990s, bringing in new technologies and developing unexplored market opportunities abroad. There currently are many medium size mussel farmers, a few large scale ones, and just a handful of huge processing plants dominating the export trade, producing their own crops and/or buying from third parties. They have enormous capacities and use state of the art technology. This trade, again, is export oriented, highly technical and large scale in processing, and increasingly mechanized in primary production.

Mussel farming takes place almost exclusively in the Lake Region; production reached 290 000 tonnes in 2011(240 000 tonnes in 2014) and employment in this trade is estimated at 17 000 direct and indirect posts.

For both salmon and mussels, the main production drivers have been the excellent local environmental conditions plus technology brought from abroad. In the case of salmon/trout, production models were adapted mainly from the Kingdom of Norway, Japan and the United States of America, while farming technology from the Kingdom of Spain and New Zealand have shaped local methods to produce mussels. Producers, universities, and technologic institutes have successfully adapted and improved foreign systems. However, the Republic of Chile still lacks the scientific/technological capacities to produce world class equipment and to fully develop local solutions in several matters that need further attention. Even though efforts are being made, in several subjects the country will still have to rely on foreign technology and equipment for farming and processing in the years to come.

In sum, most Chilean aquaculture is highly sophisticated, increasingly technical, able to compete globally, but still highly dependent on two products only: salmon/trout and mussels. Large scale production dominates the domestic scene. Local producers of salmon currently number less than 25, but, there are about 1 200 enterprises that provide them with all sorts of services, being a part of a big ‘cluster’ in the Lake Region, around Puerto Montt and Castro (Chiloé Island)[41].

Most other farming enterprises are small or medium-size in terms of production, and are not always organized so as to be able to compete globally or with eventual imports.

Because salmon and mussel farming are well established and have their own dynamics, when talking about aquaculture diversification in the Republic of Chile, reference will be made mainly to other species farmed, mostly in southern Chile, and to other promising possibilities that might have the ability to ‘open’ new fish farming activities in other parts of the country where environmental conditions are different (for example, there are fewer sheltered marine sites, and less fresh water available).

Whatever the story of aquaculture development and diversification, it has to be said that sectoral governance in the Republic of Chile is the cause of many problems and limitations. For instance, small producers have not yet received sufficient attention; they face difficulties with farming authorizations and many other bureaucratic procedures; they badly need technical assistance and a proper statute to facilitate their incorporation in this industry, etc. Poor regulations about the carrying capacity of the different water bodies are behind disease outbreaks in salmon production; farms have been authorized and sited based on insufficient scientific knowledge; there is overcrowding in some areas; R&D activities are insufficient and poorly focused; suppliers of goods and services are not treated fairly by primary producers; there are short and mid-term financial shortages and difficulties, etc. Production cycles in mussel farming are longer than they used to be, demonstrating the existence of overcrowding and poor management in many areas. On a social level, aquaculture has not shown the capacity to properly interact with local people or to integrate in their communities, facts that also deserve further consideration.

[41] Prospectus Consulting, 2016, Consultoría para Construir Hoja de Ruta de Programa Estratégico – Salmón Sustentable, Unpublished study carried out for the Salmon Strategic Program, CORFO, Santiago.

There are growing concerns that the Chilean industry might not be sustainable in the long term without corrective actions and the enhancement of the whole 'production model'. It is also true that the Republic of Chile has excellent and ample space for further aquaculture development, not only from a spatial standpoint but also in terms of market prospects, process sophistication, R&D or in many other aspects connected to 'diversification' and governance.

2.2 The aquaculture diversification process in the Republic of Chile: recent history and current status

2.2.1 More on salmon and mussels

Since the early years of the twentieth century, aquaculture activities changed dramatically in orientation, size, economic and environmental importance in the Republic of Chile.

Late in the nineteenth century, salmon and trout eggs were brought from the United States of America and Europe, aimed at producing juveniles to seed southern rivers and lakes and enhance sports fisheries. Governmental facilities were built to handle ova and produce juveniles that were released in lakes and rivers, and sometimes in the sea. This work was complemented in the 1960s by trials led by the Servicio Agrícola Ganadero (SAG) with assistance from JICA (Japanese International Cooperation Agency), to generate 'salmon runs' in the Aysén Region by producing and releasing pink and chum salmon[42]. This program was not at all successful despite a decade of costly efforts. Those exploratory moves were widened with activities led by American and Canadian experts during the 1970s and early 1980s, showing that cohos and chinooks were the species with higher probabilities to return to their sites of release. Juvenile releases were carried out in Chiloé (Curaco de Vélez, Lake Region), and were very successful. However, local fishermen started to catch those juveniles and the whole process was discontinued. These last trials were conducted by Foundation Chile, a remarkable technology transfer institution (50 percent ownership by the Chilean Government) that bought Curaco's farm and later started with intensive farming in that same area, while continuing with 'ranching' trials, this time in the more isolated but equally promising Magellan Region.

During the 1960s, as well, IFOP (Fisheries Development Institute), an institution created by the Chilean Government with technical support from FAO, started experimenting with Spanish and French technologies to produce mussels, other molluscs and Chilean oysters, to help providing local populations in the Lake Region with new work opportunities to improve their livelihoods. These activities were partially successful, but took 25 years to positively affect local communities, when Spanish mussel entrepreneurs started large-scale activities in Chiloé Island.

Commercial aquaculture in the Republic of Chile only 'took off' with trout and salmon intensive production late in the 1970s and the early 1980s in the Lake Region, after promising results from experimental work with cohos in Aysén. At this point, a few private entrepreneurs and Foundation Chile started farming operations in cages at sea[43]. Environmental conditions were considered optimal for these purposes, there were plenty of sites available, temperatures were ideal and an indented coastline permitted farmers to work with fairly cheap components (cages) in well-sheltered areas.

From the outset, salmon farming was seen as a large-scale and export oriented activity. It incorporated the best technology available and adopted very high production and sanitary standards to be able to access the most demanding world markets. Interestingly, the first local salmon farmers did not have a fisheries background. They came instead from agriculture, construction, trade, etc., bringing fresh energy and

[42] Introduction into Aysén, Chile of Pacific salmon Program

[43] Several unpublished reports by Foundation Chile, where the author directed the Marine Resources Division for many years

drive, at a time when the Chilean economy was opening to the world, exports became attractive and foreign trade firms were looking for diversification options. In parallel, foreign capital brought technology and good management, and institutions such as Foundation Chile and some universities started to provide technical assistance and prepare staff to back these new salmon farming enterprises.

Crucial to these developments were showcase enterprises put in place by Foundation Chile, (Salmones Antártica, Salmones Huillinco and others), which demonstrated that salmon farming was feasible and attractive; that technology was locally available; that trained personnel could be found or formed, and that world markets were anxious to buy locally farmed salmonids. Foundation Chile also provided technical assistance, evaluated investment proposals, looked for sites and was able to supply smolts and feed. It also created a highly reputed fish health service, developed quality standards for this new industry, and encouraged the formation of the Association of Salmon Producers, an institution instrumental in the promotion of Chilean salmon in different markets and in discussions about governance issues. In parallel, it also approached insurance companies, shipping agencies, airlines and governmental institutions to inform them about salmon developments in the Republic of Chile, helping to avoid bottle-necks, and facilitating the inception and growth of many salmon farms owned by foreign investors.

As noted, at the beginnings of intensive salmon farming there already existed trained technicians to handle the fresh water stage of production. Cage farming technologies were brought from abroad; they have been well adapted locally, and have evolved substantially through the years. However, the country still relies mainly on foreign developments for these purposes, as local R&D efforts are still limited and/or financially frail.

2.2.2 Farming of other species

Work of some relevance with other species dates back to the 1960s, when IFOP experimented with the farming of mussels (*Mytilus chilensis*) and the native oyster (*Ostrea chilensis*). Results were was not very appealing in commercial terms, but helped training personnel and facilitated the starting of several small scale farms until the 1980s, when the Pacific oyster was introduced first in central Chile and later in the Lake Region. Native oyster and mussel production were mainly based on the collection of seeds from the wild[44]. Only Pacific oyster seeds were produced in hatcheries. That process continues, and supplies both Chilean and foreign farmers located in the United Mexican States, the Republic of South Africa, Canada and other countries.

Until the late 1990s, when ‘industrial-size’ mussel production started, native oysters and mussels were almost exclusively destined for local consumption, a fact that limited production and incentives to introduce more competitive technologies. On the contrary, the growing availability of Pacific oyster seed encouraged the formation of several on-growing farms, which introduced more modern production methods motivated by export prospects, which after several years of trials did not produce consistent results. Here, diseases and poor market performance have resulted in an almost complete stoppage of these export-oriented farming activities in more recent years.

In parallel, scallop farming (*Argopecten purpuratus*) aimed at exporting to the French Republic and other destinations started in Central Chile, following Japanese methods, and established an industry in Tongoy and Caldera. This new crop exceeded 20 000 tonnes in 2007 but has diminished considerably since then, as a result of competition with Peruvian farmers and wild scallops from that origin, proving that the Republic of Chile’s production structure was neither competitive enough nor sustainable. Most local producers have very small farming capacities, and rely almost

[44] Even today, when Chile ranks among the most important mussel farmers of the world, local production is almost 100 percent based on wild seed, collected by many farmers, and thereafter sold to growers.

completely on wild seed, factors responsible for disruptions which prevented achieving a sustainable and competitive production pattern. Restructuring of production models, better technology and the opening of new markets could again attract the attention of investors. Local conditions to farm scallops in northern waters are excellent, and those improvements can help compete with the Republic of Peru.

Other local molluscs such as cholga (*Aulacomya ater*), choro zapato (*Choromytilus chorus*) and some clams are also farmed, mainly in small quantities, to satisfy local demand, supplement declining wild stocks and/or create future exports. Cholga are similar to New Zealand's green mussels, a species which can be used as an example on what 'creative marketing' can do to promote consumption in different markets. Local seed is again mainly collected from the wild[45], and at least with cholga, better technology and the opening of new foreign markets can dramatically enhance future farming prospects.

Farming technologies developed in the United States of America and Japan for red abalone from California (*Haliotis rufescens*) and green abalone (*Haliotis discus hannai*) were also fairly successful when those species started to be farmed during the 1980s. The former showed good success, while the latter yielded limited results only. Today, Chilean abalone farmers produce close to 1 200 tonnes per year (2014), almost all of them 'reds' exported to Asian markets. [46]

Accessing foreign technology also permitted farming turbot (*Scopthalmus maximus*) in the country in the early 1990s. This first effort to farm marine fish in the Republic of Chile with European technology was a 'technologic success', but it was almost completely discontinued in 2014 because of difficulties related to marketing that species abroad. Production never surpassed 400 tonnes per year, a level that scarcely justified sufficient marketing efforts and was not attractive to foreign buyers. Even if turbot farming did not succeed in establishing a new work alternative in sustainable commercial terms, it permitted training a number of technicians in marine fish farming, opening the gates to further developments with other introduced marine species like hirame (*Paralichthys olivaceus*), and several native ones such as the local plaice (lenguado, *Paralichtys adspersus*), merluza austral (*Merluccius australis*), bacalao de profundidad (the well known Chilean seabass, *Dissostichus eleginoides*) and more recently, palometa or dorado (yellowtail kingfish, *Seriola lalandi*), corvina (*Cilus gilberti*) and conger eels such as congrio dorado (golden kinkclip, *Genypterus blacodes*) and congrio colorado (red kingclip, *Genypterus chilensis*) among other species.

Currently, development work is evolving favorably with yellowtail kingfish, conger eels and corvina, leading many to believe that in the next 5–10 years these species will be farmed at commercial levels of some importance, again aiming at foreign destinations. In the case of the Chilean seabass expectations are also high, but practical results will not become available before 10 to 15 years. In other cases, such as that of hirame, prospects are also fair. Farming technology brought in from Hawaii and Asia in the early 1990s is well mastered, but there are no juveniles or brood stock locally available, as all remaining fish used to do experimental and pre-commercial work were unexplainably sacrificed. Local plaice, a species which does not grow very well after reaching one kilo, along with turbot, well mastered technically and a faster grower, need to be completely reevaluated in economic and market terms, if a second chance is ever going to be offered to these species by local entrepreneurs.

Yellowtail kingfish, available in the wild in very small quantities in Chilean waters, has been targeted for farming because of its market prospects in several countries and the evolution of recirculation farming technology. Most development work

[45] Reference should be made to the fact that even though seeds come from the wild, there is human intervention that facilitates seed fixation in artificial devises, which are thereafter cropped, to proceed with further on-growing on other locations and with different methods.

[46] All these references are based on the author's recollection of events.

undertaken in the Republic of Chile refers to this last technology, while experiments to on-grow *Seriola* in cages are also under way. Work is carried out in northern Chile, because higher temperatures are required. Here, cage farming takes place in more exposed sites, requiring more demanding offshore technologies. R&D activities with this species have created high expectations regarding the opening of new fish farming opportunities in the north of the country, to the point that some have branded it as 'the salmon of northern Chile'. In any case, the R&D work with *Seriola*, which already stretches for almost a decade and is carried out at pre-commercial scale, is undertaken by four different groups, at least two of which have governmental support. The most advanced R&D efforts in the coming 4–5 years will be concentrated on recirculation, but grow-out trials in cages will also take place, to gain a good understanding on which system works better. In parallel, the production capacity of juveniles will be enhanced, to be able to offer them in due course to prospective producers of this excellent fish.

Three additional introduced marine fish species are also farmed experimentally. Cobia (*Rachycentron canadum)* is produced in very limited quantities under recirculation, with eggs/juveniles originally brought from the Federative Republic of Brazil. This fish requires a much higher temperature than that naturally available in Northern Chile, and therefore production takes place using cooling waters from a huge thermoelectric power plant in Mejillones, close to Antofagasta. Halibut (*Hippoglossus hippoglossus*), originally brought from Europe, has been the subject of trials and technical assistance schemes since 1997, without scaling up to commercial production. The third species is the Atlantic Cod (*Gadus morhua)*. There are no indications, though, that cod or halibut will ever be permitted to be grown in open ocean conditions, and if at all successful, those species might have to be farmed exclusively inland, most probably under recirculation.

Sturgeon farming in fresh water has also been tried for over 20 years, without practical results, because of a poor handling of this idea. Trials are being undertaken simultaneously with white sturgeon (*Acipencer transmontanus*) and Siberians (*Acipencer baerii*). Curiously enough, there are still interested parties willing to insist in these endeavors, with still unforeseeable prospects.

Other farming trials involve freshwater fish and aquaponics. In this case reference is made to tilapia (*Oreochromis spp)* and pirarucú/paiche (*Arapaima gigas*), species being tried in Arica, in Northern Chile, with imported juveniles. Both species are intended for human consumption. Other small-scale undertakings are also under way in that same region, with fresh water ornamental fish, whose juveniles are mostly brought in from the Republic of Peru or other origins, when brood stock are not available in the Republic of Chile. These fish are thereafter grown to commercial size, and sent to southern Chile to be marketed with other imported ornamentals, to be sold in the domestic market.

In the case of macro algae, where farmed volumes surpassed 105 000 tonnes in 1996, most local efforts have been devoted to produce pelillo (*Gracilaria spp*), a species with high but fluctuating demand and prices. Its farming has been adopted by hundreds (if not thousands) of small scale producers, mainly in the Lake Region but also north of Santiago in more limited quantities. The Republic of Chile is one of the world's most important producers of wild algae, so farmed production tends to fluctuate a lot with respect to market conditions. There also exist several commercially oriented operations to farm huiro (*Macrocystis spp*) and chascón o huiro negro (*Lessonia nigrescens*), either to be used as feed in abalone farming or to be sold as raw material, but local statistics are not accurate enough to capture these activities in adequate detail.

Other macro algae are also targeted for farming, as yet without results of commercial importance. Chances are, however, that this situation might change in the coming decade, if enough resources are allocated to these aims. For now, it is evident that the Republic of Chile will widen its supply of most of these species in the future. It is still uncertain if local capacities will lead to further processing of these species in this country (to prepare fillets, smoked products, and the like), or whether the Republic of Chile's role will be that of a supplier of raw materials, with limited value added.

The Republic of Chile has also produced micro algae for several years, but rather inconsistently. Today's farming efforts mainly refer to Spirulina (*Spirulina spp*.) and Haematocuccus (*Haematococcus pluvialis*). The former is used as a food supplement of commercial interest, and the second is aimed at producing the antioxidant astaxanthin, important in aquaculture feeds, human health and cosmetics. In both cases, but mostly with *H. Pluvialis*, production is still fluctuating, and takes place north of Santiago, in continental areas exposed to high radiation and with good temperature patterns. Again, the Republic of Chile has the potential to becoming an important producer and exporter of these species and several others. In any case, it is still unknown if the country ends up producing raw materials only or will further process these crops. The Chilean market for salmon feed can probably absorb most foreseeable supplies of locally produced astaxanthin, but producers will also target international destinations.

Over the years, farming experiments in the Republic of Chile have referred to well over 50 species, including Australian lobster, *P. vannamei*, puye (*Galaxias maculatus),* carps, octopus, razor clam (macha, *Mesodesma donacium*), loco (Chilean abalone, *Concholepas concholepas*), several clams, sea snails, sea urchin, sea cucumbers, the very valuable centolla (king crab, *Lithodes antarctica*), the locally demanded camarón de río del Norte (*Cryphiops caementarius*),several crabs, frogs, and many others, native or exotic, none of which have reached commercial production levels as yet. Almost always, trials with these species have been aimed at developing intensive production methods. Alternatively, in the case of sea urchins, loco, and even the local plaice (lenguado) the idea has been to produce seed or juveniles, to be released in the wild to enhance small scale fisheries.

2.2.3 Drivers

Different drivers are responsible for these diversification efforts, the majority of which have not led to results of commercial significance. However, they have certainly enhanced domestic research capabilities of several groups, which currently run laboratories, hatcheries and consolidated teams that can readily continue the work on diversification if required. Hopefully, future efforts will concentrate mainly on a reduced number of species, so that whatever resources are used have a better chance of succeeding and producing practical results.

Among these drivers, the most relevant ones are (1) Market opportunities, (2) The availability of farming techniques abroad, (3) Scientific curiosity and drive, (4) Governmental programs that back R&D in this field, (5) The drive of different institutions (such as Foundation Chile, etc.), (6) The lower availability of wild species, and the wish to replenish coastal areas, (7) Ample space available, (8) Trained personnel at all levels, (9) The idea of creating job opportunities in different parts of the country, of enhancing exports, etc.

In sum and this far, successful commercial aquaculture in the Republic of Chile has been based on introduced species, adapted foreign technologies and ample world market opportunities. As well, the country has tried to develop more commercial farming opportunities with native and exotic species. The ample availability of natural conditions and space, and a limited domestic market, have also helped direct this industry towards exports. For this reason salmon, trout and mussel farming enterprises are large scale, use state of the art technology, and are competitive worldwide. With the exception of abalones and perhaps gracilaria algae, no other species have reached this development stage, and many struggle to survive, with doubtful prospects.

By now, the state has also learnt that it makes poor sense to continue backing too many development projects at any one time. It has become evident that whatever money is available has to be concentrated on a limited number of programs (composed of many projects), confined to a small number of species, and conducted continuously for as many years as necessary. It is known that to develop commercially viable aquaculture production methods with 'new' marine species can take as long as 10–20 years, while 5–10 years might be necessary with fresh-water species.

2.3 Diversification and the role of government and private industry

2.3.1 The scope of diversification

Aquaculture diversification does not only refer to increasing the number of species farmed. In the Republic of Chile, this process is understood to encompass new production technologies and work in non-traditional geographic areas, and the opening of further opportunities to small-scale farmers, long forgotten in the current development process. The concept can also include the widening of commercial opportunities with new products, new destinations and/or different consumers abroad and/or domestically.

As noted before, up to now, Chilean commercial aquaculture has been mostly linked to the southernmost part of the Republic of Chile and to salmon and mussels. The remaining part of the country, with a more exposed coastline and other challenging geographic and environmental conditions, remains nearly untouched or under-developed, as do several other species. The center-north and northern parts of the Republic of Chile (north of Santiago) do not offer a wide range of work opportunities to local populations, so aquaculture would be most welcome there. The same applies to southern Chile, where additional aquaculture production, under sustainable patterns, would again be much appreciated.

It was shown (Table II–2) that during the last 25 years or so aquaculture growth rates in the Republic of Chile are continuously diminishing. Here, diversification is certainly an option, and a desirable one for the ample space available. Clearly, though, irrespective of whatever might be done regarding aquaculture diversification, and perhaps for several decades, Chilean aquaculture will remain highly dependent on salmon and mussel production, even if the first grow at diminishing rates in the future and mussel production stabilizes at current levels or grows only slowly. Past growth rates are unlikely to be repeated. With oyster and scallop crops in sharp declinev variable and cyclical algae yields and limited progress signs with other molluscs and fish species, it has become evident that the Republic of Chile has to change its strategy if further success and sustainable aquaculture development are desired.

2.3.2 Trends in species selection

So far, commercial aquaculture in the Republic of Chile has been focused on exotic[47] species, such as salmon and trout, turbot, abalone, Pacific oyster, sturgeon, hirame, halibut, etc. In several cases, complete environmental impact reports were prepared before introduction trials were permitted. The main motivations to work with these exotic species were the availability of farming technology and equipment from abroad, as well as market opportunities.

More recently, though, all over Latin America (LA) there is a clear trend to devote most R&D efforts to native species, because environmental concerns have made it difficult to introduce exotic species, even if they have proven farming technologies elsewhere.[48] This move towards native species will be far more challenging and farming them at commercial levels will certainly face inconveniences. For instance, R&D work to develop husbandry techniques and equipment to farm native marine species might be

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[47] Salmon and trout cannot be fairly categorized as exotic species any longer, as their introduction efforts started in the second part of the XIXth century.

[48] Atlantic Cod is the only exotic, not yet commercially farmed in Chile, for which R&D efforts have been devoted in recent years. In previous ones, work to introduce the Atlantic scallop was also undertaken, but it was discontinued at some stage.

more costly and time consuming compared to salmon and mussels, where technology 'packages' were easily bought in different places. And while salmon and other species such as shrimp, tilapia, oysters etc. are generally well known in many countries, and production can target several markets, most native species will have to rely more on domestic demand before pursuing exports. These species are not normally known abroad, and their market introduction elsewhere requires financial resources and consistent work for several years. However, whatever has been learnt in the Republic of Chile in the past 30–40 years facilitates future R&D efforts, thus shortening the path to achieving commercially applicable results.

Other desired aspects of diversification include stretching production to the central and northern parts of the Republic of Chile, opening new production systems such as offshore farming, reseeding of coastal areas, additional production under recirculation, further use of aquaponics, a better use of desert areas (microalgae and the like), etc. Of course, widening market options and products are also wanted, as most Chilean aquaculture exports are highly concentrated on a limited number of destinations, and there are many unexplored commercial opportunities.

2.3.3 Diversification and its main actors

But for few notable examples, private firms do not normally invest in production diversification, nor it is expected that they change their attitude. Diversification is fairly expensive and risky, and technologic developments for little known native species might take a long time.

Therefore, to diversify aquaculture production with 'new' native species, governmental resources and leadership are required, at least in the early stages, where stakes are higher and costs can hardly be recovered through future income flows. However, to ascertain the desirability of the diversification process, private partners should be identified and their monetary contribution – however small – secured. Additionally, R&D institutions should also work in these endeavors. The difficult part is to secure a long-term financial commitment, eventually stretching for 8–10 years or more, particularly by governments that last for only four years. Additionally, experience has shown that the dynamics of R&D institutions can also be challenging, as scientists and technologists tend to give priority to publication rather than to obtaining results of practical interest. Therefore, governance for these programs should balance the interest of all participating partners, and ensure cost-effectiveness and speed.

International technical assistance through institutions such as the FAO will always be important, but increasingly, local scientists and technicians have gained confidence and expertise. In other Latin American countries, where aquaculture is less developed, institutional help on wider terms can still be highly appreciated. Horizontal cooperation among LA countries can also be envisaged, particularly with the Republic of Chile, the Federative Republic of Brazil, the Republic of Ecuador and the United Mexican States having good possibilities of offering technical assistance to sister nations.

2.4 Technology and expertise, markets, institutional facilities and governance as drivers and/or constraints to aquaculture diversification in the Republic of Chile

Market opportunities worldwide have shaped much of Chilean commercial aquaculture until now, and prospects are equally attractive for the future, both domestic and international. 'Static factors' such as environmental conditions are excellent and promising. The learning of farming techniques from elsewhere and work with exotic species have also been instrumental to achieving current standings and are an asset to be highly regarded.

Additional 'dynamic conditions' are now at the center of the decision making process leading to expand the frontiers of Chilean aquaculture. They include governance, legislation, fitness of governmental action, capacities to exercise adequate controls, conditions to give fair access to small scale producers, more economic resources and long term commitment to financing R&D, the formation of human capital, the abilities of the scientific/technical community and the capacity to appraise the cost-effectiveness of development strategies.

Many other factors influence diversification and development possibilities beyond salmon and mussels. They include infrastructure needs, conflicts with artisanal fishermen and various other users of the coastline, marine and fresh water environments, working conditions offered to employees, as well as a poor appreciation of aquaculture by local communities and public opinion in general. In all, there are a good number of drivers and constraints that will make aquaculture development and diversification more complex than in previous years. However, opportunities are so wide that they should be able to adequately offset challenges and invite private and state actors to become involved in widening current farming options through the introduction of 'new' species; the 'conquest' of new and untouched areas north and south of Santiago, in the Lake Region and further south; the development/adoption and/or streamlining of new technologies, etc.

Lessons learned to date suggest some basic criteria for producing results in reasonable periods of time:

a. To concentrate financial and other resources on a limited number of species, to be chosen very carefully; to develop all necessary knowledge in parallel, so as to avoid the situation where a neglected link might inhibit achieving practical results;
b. To make sure that whatever is done will guarantee sustainability from environmental, social, market and economic perspectives;
c. To work in a more holistic manner, considering that even if technical developments are crucial, other factors such as governance, market knowledge, production models and the like are also important to achieve meaningful results;
d. To promote cooperation and interaction between state and private actors, and between them and technical/university institutions;
e. To first validate objectives with local communities and with national public opinion; and
f. To make sure that plans and financial resources are subject to continuous evaluation of their economic, environmental and social cost-benefit; to ascertain that all other resources are wisely used and intermediate results are promising enough to continue working on any particular field.

2.5 The future of aquaculture diversification in the Republic of Chile

The Republic of Chile should benefit from aquaculture diversification because current growth rates in this field are poor. Future prospects are good; there is plenty of space available throughout the country; there are excellent environmental conditions and wide open market opportunities worldwide.

Future aquaculture development in the Republic of Chile will have to follow two basic principles: (1) Salmon and mussel production should continue to grow, ensuring sustainable development with these species, and (2) There is a need to incorporate 'new' native species in the production matrix.

In the first case, short term efforts will have to be devoted to reshaping current production structures and to regaining a lost and badly needed sustainability. After completing this process, there are good prospects for further growth in the foreseeable future, the Republic of Chile should remain second only to the Kingdom of Norway with world salmon production. Less conflictingly, mussel crops can also expand, and will certainly find market opportunities in different countries. Therefore, sustainable growth can also be expected in this field.

For native species, as there are no readily available technologies to farm most of them commercially in the short run, diversification with these species will take a long time, and will require financing, ingenuity and determination.

In addition to technical matters, the Republic of Chile will also have to face the need for renewed, modern and simpler governance, with better and firmer leadership from both government and private industry, as well as new models for coordination, arbitration and agreements among all stakeholders. A lot will have to be done to incorporate (and support) small scale farmers into the development and diversification processes, and to work with and integrate local communities where production will take place. All these changes are required so that aquaculture can gain wider social acceptance in the Republic of Chile and abroad.

The Republic of Chile has come a long way in the handling of technologies during the last 40 or so years. Universities have organized programs to prepare aquaculture scientists and technicians (and lately, for postgraduate studies); sophisticated laboratories and pilot plants have been built; private entrepreneurs and R&D institutions have bought technology and trained personnel abroad. Thus there is a lot of accumulated experience related to the development of salmon, trout and mussel farming to world class levels and with R&D with other species; whatever needs to be done in terms of further diversification can take advantage of all these gained abilities.

The next section will focus in more detail in opportunities and restraints faced by the aquaculture development and diversification processes in the Republic of Chile, specifically for species other than salmon/trout and mussels.

2.5.1 Opportunities

Basic opportunities for further diversification and aquaculture development in the Republic of Chile are based on the following aspects:

a. Open market opportunities worldwide and in local markets, for the decades to come. No restrictions are envisaged in this field, except for those that may arise from lack of competitiveness or in relation to product characteristics and/or quality;
b. Ample space and excellent environmental conditions to sustainably increase production levels with currently exploited species, and in the near future, with the introduction of native species to the farming matrix;
c. Good and experienced scientific and technological communities, with well-established labs and pilot facilities in most parts of the country (however, the Republic of Chile still needs to prepare human capital, to achieve the standards observed in more developed and competing nations);
d. A work force skilled in fresh-water and marine farming techniques, together with manufacturing and logistic processes at all stages of production and the value chain;
e. A large number of enterprises rendering specialized services to current aquaculture production, that could widen their activities to serve new farming initiatives; and
f. Governance experience that has already shown what should best be done to facilitate and consolidate future diversification and development actions.

2.5.2 Challenges

Several problems have to be addressed and solved, to foster sustainable and more diversified aquaculture development processes in the Republic of Chile. Here, the following aspects should be considered.

2.5.3 Planning needs an overall vision of the future

To progress and diversify, it is desirable to have a clear ‘vision’. Objectives and measurable goals have to be defined, and a good strategy (roadmap) is needed to guide the development process. This basic planning approach has not existed in the past. Consequently, efforts, financial, human resources and equity have probably been lost or mismanaged during an interesting but bumpy development process. Currently (2015–2016), new efforts are being made to devise roadmaps and direct future aquaculture activities along well established paths. Even if a 'fully integrated planning exercise' is not being carried out, proposals for further development regarding salmon and trout, mussels and aquaculture in general are being elaborated separately by different 'programs'. Each of these programs will have its own vision, objectives, goals and roadmap. Given their synthesis, Chilean aquaculture will shortly have access to a good proxy for a concerted vision of where to go, where to concentrate scarce financial and human resources, and above all where to focus governmental and private actions according to long term views and requirements.

Considering only the day to day needs of industry, as has normally been the case, results in erratic moves that confuse sectoral actors and even stop a healthy evolutionary process. Such consequences are well reflected in recent production statistics, in overcrowding of several water bodies, and in severe losses of competitiveness in salmon farming because of disease outbreaks, excess costs related to the use of vaccines and other therapeutics, more production controls, and the like.

2.5.4 R&D

Government should support R&D through different organizations, taking good care to coordinate their actions. It should also concentrate funds on a limited number of promising species, and finance whole 'programs' rather than 'isolated projects', as this last approach has shown poor results in the past. R&D programs should be financed for as long as required, without interruptions, and if so needed, for six, eight or even more years. Joint ventures by government, several private enterprises and R&D institutions should be favored. All R&D initiatives financed with government funds should be evaluated on their achievements on intermediate dates, with the option of cancelling those exhibiting poor results or mishandling. They should also be evaluated at the end, making as much information available to the community as practically possible[49]. Participating enterprises and/or R&D institutions that perform improperly should have to comply with much more stringent requirements in their next eventual bid for funds, or should be banned at all from bidding for public resources. Evaluation of project proposals should be as stringent and dedicated as possible, to ascertain that scarce public and private funds are duly used. Government should only call for project proposals on subjects that are relevant to the global development/diversification strategy[50]. There is a need for consistency on what should and should not be done, following the above-mentioned criteria.

2.5.5 Governance

Governance has been the most fragile of drivers in recent years and the cause of much frustration to industry, communities, workers, etc. Governance has to improve in many areas to address severe problems that jeopardize diversification and development efforts, some of which are outlined here:

- Effort should be made to devise regulations that guarantee aquaculture sustainability, from environmental, economic, financial, social and market perspectives;

[49] Measure should be taken to safeguard proprietary information, resulting from these projects, particularly when private enterprises and/or R&D institutions co-finance these initiatives.

[50] There is no such thing as a detailed aquaculture development plan for the coming decades, but several studies with official funding are proposing strategies to further promote this trade sustainably, in what refers to salmonids, mussels, aquaculture diversification and others topics. These studies provide a good background on what is most desirable. However, they do not show priorities 'among' different options, a fact which should therefore receive detailed attention.

- Aquaculture authorizations should only be granted after assessing the carrying capacities of the different water bodies, whether in fresh water or marine environments. If studies take more time than is available, a precautionary approach should be used at the beginning. A trial-and-error approach can also be used, with certain limits;
- Appropriate 'sanitary corridors' should be devised to avoid as far as possible the dissemination of diseases. In parallel, rules to identify and control other disease vectors should be devised and put in place;
- Further attention has to be given to small scale production, incorporating a special statute applicable to small-scale farmers, to 'level the ground' with large scale aquaculture, and make small scale activities feasible and sustainable;
- Ensure that technical assistance is given to initiatives addressed to support small scale farming activities. The same should be applicable to small scale providers of services along the production chain;
- Evaluate on a regular basis the performance of this industry, addressing its impacts on all perspectives, and proposing corrective measures, when applicable, and development strategies, where needed;
- Support the collection and timely analysis of good quality environmental, production, economic, market and social data, and get it published as soon as practicable;
- To devise control procedures that work and that can be properly applied, establishing strong penalties to offenders
- Revise all current measures applicable to aquaculture production and control, suppressing or modifying all restrictions and procedures that are not essential to safeguard the long term sustainability of this industry;
- Devise measures to further facilitate and promote investment in aquaculture development; and
- Safeguard animal welfare.

2.5.6 Communities, coordination, workforce

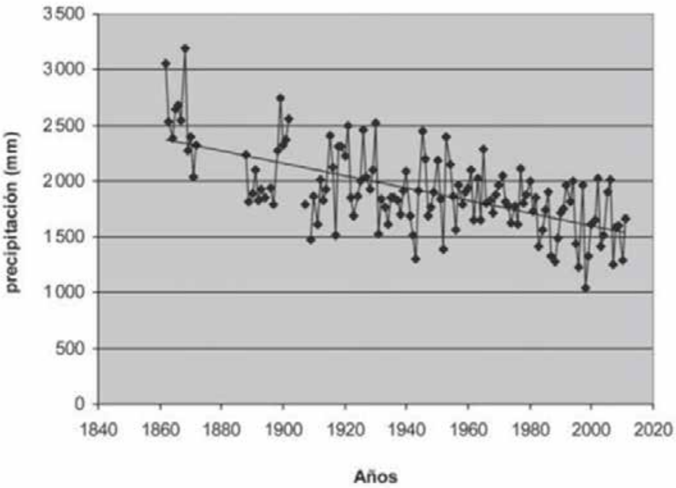
The aquaculture industry in the Republic of Chile has not been successful in relating properly to local communities. As well, labor relations in this industry should be improved. Moreover, the public image of aquaculture within the domestic population is also poor, and relations between primary producers and the enormous amount of firms that service them need to be upgraded. Efforts should be devoted to solve all of these problems, to gain social acceptance of aquaculture and the full development/ diversification processes.

2.5.7 Climate change

The Republic of Chile is already affected by climate change. One of its results is the desertification of several coastal areas; others include changes in fish availability in coastal and oceanic waters and a marked change in rainfall levels in many parts of the country. In the first case, sand dunes are advancing in many areas, while in the case of fish availability, patterns are changing. Artisanal as well as industrial fishermen are feeling these effects, which in several cases mean diminishing fish landings and very fluctuating availability of pelagic species, some of which provide the raw material for fishmeal and oil that Chilean and world aquaculture require.

Declines in rainfall levels in many parts of the country is also accompanied by erratic behavior of rivers, and several flooding episodes have affected thousands of people in several occasions in recent years. Algae blooms, which recurrently but 'unexpectedly' hit some parts of the country, have also been present with noticeable strength, particularly during the early months of 2016 in southern Chile. They have distressed salmon production and prevented the extraction of wild bivalves affected by poisonous 'red

FIGURE 4
Rainfall levels in Puerto Montt, Lake Region, the Republic of Chile, 1860–2010



Source: J.J. Sanz Donaire, 2012. Estudios Geográficos Vol. LXXIII, 273, 'Las series anuales de precipitación anual más largas de Chile: estudios y enseñanzas'. Extracted from a power point presentation by Rodrigo Torrijos, April 2016, 'Nuevas Tendencias en la Producción de Agua Dulce y sus desafíos para el sector en la Araucanía'.

tides' in locations where these events were not ordinarily present. Clearly some of these events should happen more or less periodically, linked to 'El Niño' events, but others are bound to become established in the long run as a net effect of climate change.

As an example of diminishing rainfall levels, the city of Puerto Montt, at the heart of the Lake Region, and Valdivia, the capital city for the River Region north of it, have seen diminished precipitations for a very long time (see Figure 3 for P.Montt figures). The availability of fresh water has affected animal and agriculture production at large, and could also have effects on the long term availability of fresh water resources for the production of salmon smolts, trout, etc., and in oceanic conditions in neighboring areas.

Other effects, such as higher temperatures between one and three (moderate scenario) or two and four degrees Celsius (severe scenario) by the end of the century could also be expected[51], with further changes in rainfall patterns, glaciers and snow storage capacity in mountain areas. These changes can result in still unpredictable but meaningful effects on the regional capacities to continue farming hydro biologic species, as used now.

However important these events might be, the truth is that little can still be predicted on the precise effects of climate change on the future of aquaculture in the Republic of Chile. In any case, though, as these changes take some time to occur and to get established, there might be chances for adequate responses, or in the worst scenarios, to apply whatever mitigation measures are possible. The warming of the oceans can certainly affect fish aquaculture production in many different manners, for instance, limiting salmon production and/or production densities in some southern areas, but encouraging the farming of species such as yellowtail kingfish in the northern seas, as a result of higher and 'more favorable' temperatures.

In all, because of the many worries and uncertainties attached to climate change, there is no doubt that the Republic of Chile will have to invest much more on R&D dealing with this subject, as the only means to learn on how to predict, solve and/or mitigate the several unwanted effects that could be forthcoming. As well, aquaculture stakeholders will also have to learn on how to make the best of any positive effect related to climate change.

2.5.8 New species and other options for diversification

Concerning species, the diversification process should start by considering which species currently farmed commercially with poor technology and/or in reduced volumes and/or facing other difficulties should receive further help. Among these, the following should be assessed:

[51] Peter Muck, 2012 Chile: National Adaptation Plans to Climate Change, Climate Change Office at the Ministry of Environment, Chile. P.point presentation available at: www.oecd.org/env/cc/50426634.pdf

1. Red and green abalone: Further R&D efforts should mainly come from private actors, and could be supported by eventual R&D funds from different governmental sources.
2. Native and Pacific oysters: Subject to market considerations, could receive eventual support from Government and private firms.
3. Cholga and Choro zapato: With eventual support from Government.
4. Spirulina algae: To be supported mainly with private sector efforts.
5. *H. Pluvialis:* Still requiring governmental and private-sector support to scale up and stabilize farming and processing technologies.

Here, efforts should concentrate in the coming years only, and if any or all of them do not show adequate results, support should be discontinued.

With reference to species whose technologies are still fragile and/or under development, a recent study of 2015[52], financed by CORFO, suggests the following for diversification, implying that this selection will be heavily backed with long-term financing from governmental sources. Marine fish targeted for intensive farming are:

1. Bacalao de profundidad or Chilean seabass	*Dissostichus eleginoides*
2. Congrio dorado or golden kingclip	*Genypterus blacodes*
3. Congrio Colorado or red kingclip	*Genypterus chilensis*

Chilean seabass aquaculture is just starting in the Republic of Chile and in a few other locations, but it certainly is the most promising venture in projected commercial terms. If practical aquaculture solutions are devised after a prudent period of time – say 10–15 years – this industry will have 'found a 'new salmon', with wide market possibilities for high end customers.

Congrio dorado is also an excellent species with promising market prospects abroad, although at a smaller scale, while congrio colorado could be directed mainly to a domestic market which has been facing decreasing supplies of wild species for several decades. Two more species are to be added to the former three:

4. Palometa o dorado or yellowtail kingfish	*Seriola lalandi*
5. Corvina or croaker	*Cilus gilberti*

Work with these species is already under way, but will be reinforced in the coming years with further financing, to finalize their development processe with adequate and highly efficient farming techniques.

This same study selects as well the following species for diversification purposes, but this time in the production of juveniles/seeds, to be further released and grown in the wild:

1. Erizo rojo or red sea urchin	*Loxechinus albus*
2. Loco or Chilean abalone	*Concholepas concholepas*
3. Almeja venus (clam)	*Venus antiqua*
4. Almeja taquilla (clam)	*Mulinia edulis*
5. Almeja culengue' (clam)	*Gari solida*
6. Macha or razor clam	*Mesodesma donacium*

This novel line of action for the Republic of Chile will not have much future unless formulas to permanently finance these efforts are devised and applied. Otherwise, whatever investments are made to improve seed/juvenile production techniques and/or further farming facilities will be completely lost. Here, government should probably subsidize seed/juvenile production for a number of years. Thereafter, fishermen that

[52] Cooperación y Desarrollo Limitada. May 2015, Informe Final Consultoría de actualización de ranking de especies prioritarias para la diversificación acuícola, CORFO, Gerencia de Capacidades Tecnológicas, Santiago.

take advantage of these seeding efforts should pay an agreedupon fee, so as to finance the costs involved in producing and seeding these juveniles.

Additionally, it is this author's opinion that further attention should be given to the full development of intensive farming techniques for king crab (centolla) and red sea urchin. The latter is a valuable species that could enhance aquaculture prospects in the Magellan Region and further north, and for which seed production is fairly well handled by now, while intensive growing methods are being developed in the Kingdom of Norway, Australia and in other countries. Those advances can very well be applicable in the Republic of Chile. In the case of king crab, local scientists have already closed the production cycle in captivity, but there still remain a good number of aspects to be researched until commercially viable methods are devised, most likely during the coming 10–15 years.

New farming technologies should be incorporated in future years, or some currently at use should be improved to open new avenues to innovations and to working not only in southern Chile, but as well in central and northern continental or marine areas. Here, there is a need to further develop 'open ocean' aquaculture techniques and equipment, as the Republic of Chile will need to compete with foreign countries that will certainly move towards high-energy areas in the near future, with projects that will challenge local salmon/trout exports[53]. These techniques and equipment are also required to incorporate new areas for salmon and new species production in the Republic of Chile. In the case of salmon, this is particularly promising as it might help redeploying some heavily seeded production sites, diminishing biomass there and lessening prospects of disease outbreaks and dissemination, and of environmental damage. The same applies to recirculation, a technology that, if improved and made more accessible, will help eliminate smolt production in southern lakes, and will contribute substantially to enhancing small and medium-scale marine aquaculture production along the country's coastline, and in fresh water projects as well.

Finally, diversification of markets is also a must, to diminish dependency on just a few major destinations for Chilean exports. It is also needed to respond to a change in commercial paradigms, as a good part of future demand will be associated with developing countries, a fact that needs further preparation of local market and marketing people, new products, new commercial practices and the like. All these factors will also challenge customary practices with new requirements that will have to be met by the aquaculture industry.

In sum, the Republic of Chile has enormous growth and diversification possibilities for aquaculture in the coming decades, including the introduction of 'new' species (mostly native ones), technologies, markets and/or new production areas. The basis for diversification is strong, and even if there are problems to be addressed, chances are that if adequate resources are devoted to these aims, aquaculture diversification efforts could evolve reasonably well in coming years. However, even if a selection process has been undertaken by official sources as recently as in 2014–2015, their results plus other priorities will most probably require financial and human resources that are not readily available in the Republic of Chile or, alternatively, cannot be sustained for the required number of years to produce meaningful results. Therefore it is evident that ***a new prioritization effort will be needed to narrow the diversification focus****, as otherwise, the handling of this ample set of options will not produce the required outcomes and will again frustrate the wishes and expectations of many.*

In the foreseeable future, local aquaculture production will still be concentrated on very sophisticated and massive production units, supplemented by a number of small

[53] Reference is made to probable salmon production in oceanic waters in front of the US coastline; in Europe; in Australia, New Zealand, China, etc., which at some future date will challenge Chilean salmon exports to the US, Europe, Asia, etc.

and medium size enterprises that until now were mostly nonexistent in the country. However important diversification efforts might be, it will still be true that local productions and exports for at least the coming 15 years or more will still be highly reliant on salmon, trout and mussel farming.

A final point on the much-wanted incorporation of the small-scale farmer to Chilean aquaculture. Here, as in several other countries, it should be understood that, particularly in the case of many marine species, neither the production techniques nor the capital required to produce seed or juveniles or handle brood stock are easily accessible to small-scale farmers. If the Republic of Chile wants to incorporate them to aquaculture production, chances are that juvenile/seed production and/or availability might become critical or limiting, and a formal solution to this restriction has to be devised. On top of this, a proper statute to govern small-scale production will also be required, as will adequate financial schemes and technical assistance.

3. AQUACULTURE AND AQUACULTURE DIVERSIFICATION IN THE FEDERATIVE REPUBLIC OF BRAZIL

3.1 Current situation and main species farmed

3.1.1 Current situation

Brazilian aquaculture offers many opportunities for future diversification. There are options in freshwater and marine ecosystems with different production systems, from small to large scale. A continuous improvement of technology and the domestication of a few native species, focusing on market demands, can have lasting benefits for the development of Brazilian aquaculture.

Considering FAO data, Brazilian aquaculture grew 58.9 percent in terms of volume from 2008 to 2014, reaching over 561 803 tonnes (FAO, 2016). Aquaculture in the Federative Republic of Brazil is mostly inland, despite the enormous potential for marine production using the long coast (more than 7 000 km) and estuarine areas (2.5 million ha) (Table 9). Introduced species such as tilapia (*Oreochromis niloticus*) and the white legged shrimp (*Litopenaeus vannamei*) are the most important species produced inland and in mariculture, respectively.

TABLE 9
Brazilian aquaculture production 2008 till 2014 (metric tonnes)

Aquaculture production	2008	2010	2012	2014
Inland	247 876	325 989	381 648	474 693
Marine	83 357	85 058	98 502	87 110
Total	331 233	411 047	480 150	561 803

Source: FAO, 2016 (excluding aquatic plants and miscellaneous aquatic animals products).

Beyond growth in recent years and government actions for the development of this activity in the Federative Republic of Brazil, there is considerable potential to increase aquaculture production and diversification, due to the large quantity of water resources and the huge biodiversity in the country. This diversity is illustrated by the Brazilian Institute for Geography and Statistics (IBGE, 2015), which listed 28 different species and five different hybrids farmed in 2014 in the official national production statistics. Possibilities for increasing farmed production are diverse, and recently much attention was given to hydroelectric reservoirs and estuarine areas, where aquaculture parks regulated by the Brazilian government are used by local producers. As an example, there are 219 hydroelectric reservoirs distributed in 22 states throughout the country, comprising a total area of 3.14 million hectares of surface waters. Moreover, and according to estimates of the Brazilian Agricultural Research Corporation (EMBRAPA), the 37 largest reservoirs have an annual aquaculture production potential of approximately five million tonnes of fish (Table 10), a figure representing over ten times the production levels reached in 2010.

TABLE 10
Annual freshwater fish production potential in the 37 largest Brazilian reservoirs, 2015

Region	Production (tonnes)
Northeast	1 934 100
Southeast	1 569 660
North	872 025
Midwest	429 435
South	173 750
Total	4 978 970

Source: Pedroza, M., personal communication. 2015.

However, even considering recent growth in production and its potential, the Brazilian aquaculture industry still has many structural problems. For instance, this country has many different ecosystems and its size makes it difficult to provide the needed infrastructure and logistics, a special challenge for product distribution.

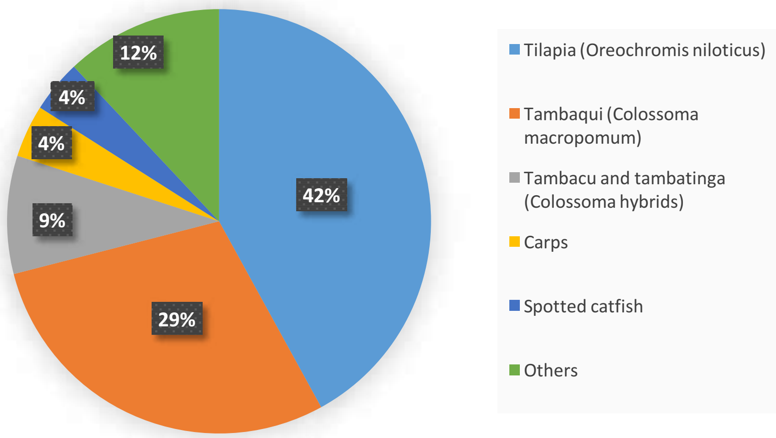
Rabobank (2013) identified this situation as being of importance for Brazilian aquaculture development, as many farms are located in isolated areas and do not necessarily have access to proper roads, nearby ports, feed producers and/or big consumption markets; challenging logistics affect the economic feasibility of those enterprises. The Federative Republic of Brazil is also affected by climate change, experiencing extreme conditions and generating unforeseen impacts in all sectors, including aquaculture. Longer dry seasons with irregular rainfall are causing negative impacts on the water levels of reservoirs and on grain production for aquaculture feeds. Climate changes may force changes in production profile and business strategies in the near future. Fortunately, native species, naturally adapted to different climate conditions, could make diversification a key strategy for sustainable aquaculture in a time of climate change.

3.1.2 Main species

According to the IBGE, freshwater fish account for about 82 percent of Brazilian aquaculture production volumes in 2014. Shrimp is the second most important category, representing nearly 14 percent of total production (IBGE, 2015). Shrimp farming began in the Federative Republic of Brazil during the 1970s; after 1995, the reintroduction of *Litopenaeus vannamei* accompanied by more advanced technology made industry experience a period of continuous development.

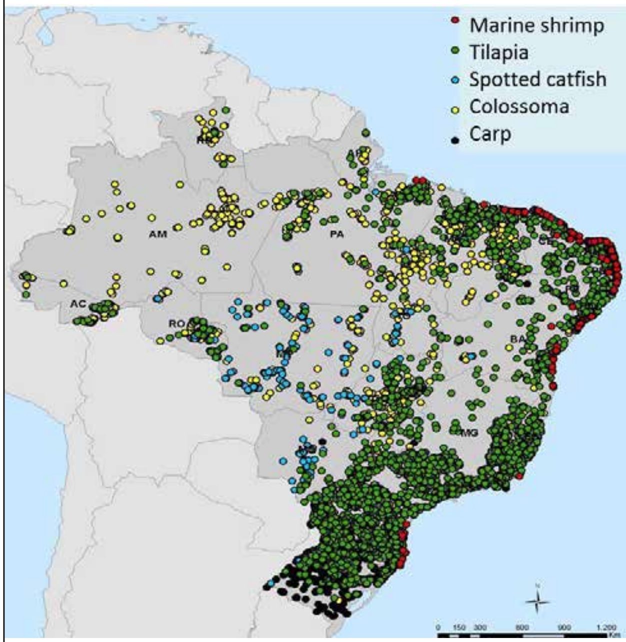
About 28 different species of freshwater fish have been farmed in the Federative Republic of Brazil in recent years, with the Nile tilapia (*Oreochromis niloticus*) and tambaqui (*Colossoma macropomum*) being the most important so far. These two species combined accounted for nearly 71 percent of fish farming production in 2014. Tilapia farming has had one of the fastest growth rates in Brazilian aquaculture at a compounded rate of eight percent per year from 2008 to 2014.

FIGURE 5
Fish farming production in the Federative Republic of Brazil by species in 2012



Source: IBGE (2014).

FIGURE 6
Geographical distribution of Brazilian aquaculture by main species in 2008



Source: Data adapted from MPA (2013).

The expansion of tambaqui farming (*Colossoma macropomum*) has also caught the Federative Republic of Brazil's attention in recent years. This omnivorous Amazonian fish has become increasingly popular among local consumers, given its low fat content and characteristic flavor. Here, besides being largely available in most Brazilian supermarkets, a small amount was exported in recent years.

In terms of geographical distribution, Brazilian aquaculture is spread throughout the country (Figure 6). Nile tilapia is produced almost everywhere, but it is more important in the northeast, southeast and south regions, where production is carried out in net cages in large reservoirs and on earthen ponds. The great adaptability of this species to different climate conditions, low-cost feed and intensive culture systems allows for this wide distribution.

Production of tambaqui (*Colossoma macropomum*), pirapitinga (*Piaractus brachypomus*), pacu (*Piaractus mesopotamicus*) and its hybrids is mostly located in the northern and midwestern regions, because of this species' preference for warmer waters. Local market demand also justifies the interest in tambaqui farming in these regions. The production of tambaqui is mostly carried out in earthen pond system, but in recent years farming in cages has also started, with limited success.

Due to environmental restrictions on tilapia production in northern Brazil, tambaqui and other species of *Colossoma* spp. and, *Piaractus* spp. and their hybrids are increasingly becoming an alternative to explore the great potential of the large reservoirs, and also an option to recover degraded forest areas of that region.

3.2 Recent history and current status of aquaculture diversification: Main drivers, constraints and species

3.2.1 Tilapia

Tilapia was introduced in the Federative Republic of Brazil in the 1950s, *Tilapia rendalli* being the species chosen by São Paulo state agencies for fisheries restocking. In the 1970s, the National Department of Works against Droughts (DNOCS) introduced Nile tilapia, *Oreochomis niloticus* and Zanzibar tilapia, *Oreochromis urolepis hornorum* in Ceará State reservoirs, located in the northeast region, to increase local fisheries output. In the 1980s, fee-fishing private farms made tilapia more popular near potential big markets such as those in São Paulo State and also helped raising other native species known by the local market. However, and due to lack of adequate technical knowledge, tilapia off-flavor became a strong deterrent that affected consumption in Brazilian main cities in those years.

Kubitza (2011) summarized the main drivers for tilapia development in the Federative Republic of Brazil as:

- Improvement in seed quality through the adoption of sex reversal technology in the early 1990s and the Genetically Improved Farmed Tilapia (GIFT strain), introduced by World Fish Center in 2005. These genetic advances shortened the grow-out phase, increased productivity and allowed for the production of large

size tilapia, adding value to the cultured products as compared to reservoir wild-caught tilapia;
- Intensive culture using small volume/high density cage technology, which allowed production to expand rapidly in the southeast (São Paulo and Minas Gerais States) and northeast (notably in Ceará, Bahia and Pernambuco States);
- Brazilian animal feed industry enabling the production of feeds for tilapia and other fish species; and
- A large domestic market, which so far has absorbed most part of production.

Tilapia products became more widely available in the domestic market around 2005 as the United States of America dollar devaluation against the Brazilian real made exports of tilapia fillets less competitive in the United States market. This industry's productive chain is professionally run and can be considered as being the basis for further diversification of freshwater fish aquaculture. In fact, Brazilian tilapia culture became a basic "platform" for diversification of aquaculture in the Federative Republic of Brazil, as most technological advancements obtained by the tilapia industry are helping to establish protocols to further develop technology for other species, and also by providing well trained personnel that can be employed in new and more professionally run developments.

3.2.2 Tambaqui and other native fishes and hybrids

In the 1980s, Governmental agencies including DNOCS, the Irrigation Development Agency for the São Francisco River (CODEVASF), the State University of São Paulo (UNESP) in Jaboticabal and the Aquaculture Research and Training Center in Pirassununga in São Paulo State (currently called CEPTA), were the key players responsible for most fish farming developments in the Federative Republic of Brazil. These government institutions played an important role in understanding the biology and reproduction of different fish indigenous to the Federative Republic of Brazil. Here, development of techniques for fingerling mass production of different fish species was the first big step towards Brazilian aquaculture diversification (Kubitza, Ono and Campos, 2007).

For the Brazilian Fish Farming Association (PEIXEBR), the private sector played an important role at the beginning of commercial production of native fish species in the 1980s, mainly in Mato Grosso and Mato Grosso do Sul States. At that time, the main fish farmed was pacu (*Piaractus mesopotamicus*) based on a strong regional demand and the ease of producing fingerlings. However, the non-availability of adequate feed was a main constraint that limited production. There was no information regarding the digestibility of different ingredients used in feeds, such as corn, cassava and fruits. Moreover, consortia that dealt with other animals, such as swine, devised and offered unbalanced feeds for farmed fish. Most of the time, cultured fish presented off-flavor, and compared poorly with the taste of fish coming from natural stocks. Initially, growth rates observed with farmed pacu were low. To solve these limitations, farmers started to bring in tambaqui (*Colossoma macropomum*) fingerlings from northern states and different basins. However, tambaqui has low resistance to low temperature, and high mortality peaks were experienced in winter (Ferrari, Lucas and Gaspar, 1991).

CEPTA started to diversity scientific experiments, testing crosses of different fish species, and creating the 'tambacu' hybrid, resulting from the crossbreeding of ♀ *Colossoma macropomum* (tambaqui) and ♂ *Piaractus mesopotamicus* (pacu) (Bernardino *et al.*, 1986). This hybrid became a great success among farmers in the midwest region and also in São Paulo State, due to the combination of tambaqui's fast growth performance and pacu's resistance to lower temperatures.

During the 1990s, the private sector introduced commercial production of tambaqui in Rondonia State, taking advantage of suitable temperatures that favored growth, survival and yields in earthen ponds. Improvements in the grow-out technologies and best management practices (BMPs) also helped to increase productivity. Some years later, the state government started to provide technical assistance and helped with simple procedures to get environmental licenses for those who wanted to start businesses by diversifying animal production, going from cattle to fish. Good quality ingredients locally available also contributed to produce better feeds. The main market was – and still is – Manaus, where tambaqui from wild stocks have been declining since then. Today, a 2kg fish is also sold in the domestic market in other Brazilian states.

Also in the 1990s, the fish farm "Projeto Pacu" started the production of another hybrid in Mato Grosso do Sul State. The new hybrid was a cross of two native catfishes, 'pintado' (*Pseudoplatystoma corruscans*) and 'cachara' (*Pseudoplatystoma reticulatum).* The hybrid advantage was based mainly on the availability of mature females of 'cachara' for longer periods throughout the year and the fact that 'pintado' was already well known by local consumers (Campos, 2013). Some public funding helped to build more modern hatcheries and proper ponds. However, commercial production faced problems, including the lack of fingerlings all year round and their high cost, the need to lower feed costs for carnivorous fish, and competition in the market with wild fish. Today, it is possible to find this catfish hybrid in a few farms of Mato Grosso do Sul State only. Frozen fillets are exported to Europe, but most production is targeted for the domestic market.

Another important hybrid introduction took place at the beginning of the year 2000, in Mato Grosso state, with 'tambatinga', a cross of 'tambaqui' ♂ (*Colossoma macropomum*) with 'pirapitinga' ♀ (*Piaractus brachypomus*). This hybrid became very popular for its faster growth and better carcass yield and started to replace 'tambacu' in farms. Today, even Rondonia farmers are raising this hybrid. Recently, the hybrid 'pintado-da-amazônia' or 'jundiara', a crossbreed of two different catfishes (*Pseudoplatystoma punctifer*) and 'jundia-da-amazônia' (*Leiarius marmoratus*) showed a performance similar to that of 'tambatinga'.

Today, most Brazilian fish farmers prefer to grow hybrids because they generally result in higher productivity, accelerated growth, disease resistance and better meat quality (Porto-Foresti *et al.*, 2013). In spite of higher performance and profitability, there are many concerns about fish hybridization and its production. Hybrid sterility is an important characteristic that can reduce the possible impacts of aquaculture escapes, but released in nature, hybrids can compete for habitat and feed with wild stocks. There are few studies regarding possible risks of hybridization of Brazilian fishes. Almeida-Toledo *et al.* (1996) found that a production. Hybrid sterility is an important characteristic that can reduce the possible impacts of aquaculture escapes, but released in nature, hybrids can compete for habitat and feed with wild stocks. There are few studies regardin stage, when they are usually sold to farmers. This can be seen as a market issue, because consumers do not know which fish species they are buying and, from an environmental standpoint, fish farms represent the main source of hybrid escapes (Porto-Foresti *et al.*, 2013).

3.2.3 Carps

Carp culture became popular in the 1980s with its introduction into different regions of the Federative Republic of Brazil. However, after the reproduction success of other fish species, carp farming is now mainly restricted to southern Brazil, where polyculture and extensive farming methods still prevail. Lately, this small scale system was improved and farmers adopted aeration along with commercial feed in the last three months of the grow-out period, reducing the farming cycle to ten months, with a higher productivity of up to 1.4 tonne/ha/year. Carp markets are concentrated in small cities in western Santa Catarina and Rio Grande do Sul states, where there is a strong tradition of buying live fish and eating carps (Casaca, Tomazelli and Warken, 2005; Borghetti and Silva, 2008).

3.2.4 Shrimp

This sector started with its first operations during the 1970s with a government – run Project "Projeto Camarão" in Rio Grande do Norte in northeastern Brazil. Several different species were tested, including the Kuruma shrimp *Marsupenaeus japonicus,* the native southern brown shrimp *Farfantepenaeus subtilis* and the white legged shrimp *Litopenaeus vannamei*. Production systems were extensive, with very low stocking densities and little technology applied. Much government funding flowed into the activity, but productivity was not good. It was only around 1995 that commercial culture really took off, when industrially formulated aqua-feeds and hatchery-produced postlarvae of *Litopenaeus vannamei* became available (Nunes and Rocha, 2015). Brazilians brought in expertise from the Republic of Ecuador and other countries, where shrimp farming was based on *Litopenaeus vannamei*.

From 1989 to the 1990s, public universities started several developments in southern Brazil. There were a few experimental grow-out trials with native species, such as pink shrimp (*Farfantepenaeus paulensis*) and white shrimp (*Litopenaeus schmitti*), but survival and productivity were not attractive. Commercial farms started to run, but by the end of the 1990s they had all adopted the exotic *Litopenaeus vannamei*. Most production from small and large farms was exported to Europe and the the United States of America. Around 2004, the white spot virus hit almost all commercial farms, closing down the activity in southern Brazil. In the same period, an endemic virus, the Infectious Myonecrosis Virus – IMNV appeared in the State of Piauí in the Federative Republic of Brazil's northeast. Before that event, industry was obtaining high productivities, reaching 6 000 kg/ha/yr seeding up to 100 shrimp/m^2. Today shrimp stocking densities can range from 30 to as many as 70 post-larvae (PLs)/m^2 but can be 15 PLs/m^2 or less in ponds without artificial aeration (Nunes and Rocha, 2015). The United Stated dollar devaluation against the Brazilian real changed dramatically production destination from exports to the domestic market, helping local industry to keep going. In 2011, the Brazilian Association of Shrimp Farmers (ABCC) carried out a survey and estimated there were 1 222 farms in operation. The study found out that on 89 percent of the farms, stocking densities during grow-out were below 30 shrimp/m^2 (ABCC, 2013).

3.2.5 Bivalve molluscs

The first farm trials with the native brown mussel (*Perna perna*) and the Japanese oyster (*Crassostrea gigas*) in Rio de Janeiro were recorded in the 1970s by the Marine Research Institute – IPqM, managed by the Brazilian Navy, under the project "Cabo Frio". It was only in the early 1990s that commercial culture started to develop in the southern State of Santa Catarina. Production systems were low-cost and enabled fishermen to get an extra income in sheltered and very shallow bays. After 20 years, Santa Catarina is the leading state in brown mussel production, with around 20 000 tonnes per year. Here, there are several constraints for further development, such as the lack of enough wild mussel seed and that almost all the oyster industry relies on a single public hatchery for its seed. Additionally, complex legislation for becoming legally established as a farmer in federal waters and scarce public funds for water quality monitoring also increase challenges faced by farmers.

3.3 The role of government, private industry and international organizations in aquaculture diversification

Government and the private sector have shared the responsibility for developing Brazilian aquaculture since the beginning of the process. Most introductions of exotic species were promoted and funded by governmental institutions. In the 1970s and 1980s, there were not many concerns regarding the risks of importing diseases or negative environmental impacts, related to the introduction of exotic species.

Most actions undertaken in those days were aimed at recovering fish stocks in water reservoirs, to facilitate wild fisheries.

Nowadays, government policies still prioritize production growth, whether the process refers to established exotic species, such as tilapia or white-legged shrimp, or to new ones (MPA, 2015). The Federative Republic of Brazil presents high aquatic biodiversity whose aquaculture potential still has to be investigated. However, federal and state government elections every 4 years combined with the lack of long-term policies have inhibited long term investments, necessary to develop complete technology packages required to introduce and/or improve new farming alternatives. This fact is more evident in the case of native species such as tambaqui and the mangrove oyster. Additionally, legislation is complex and can change from time to time; and environmental agencies exercise pressures that inhibit/restrict production. Thus the lack of a continuous sustainable aquaculture policy in recent decades has meant that aquaculture diversification of any significance has been driven mainly by the private sector.

This legal and political scenario makes the Federative Republic of Brazil a country that should look into better governance and institutional stability to offer solid investment conditions to develop any further its aquaculture industry. A good example of the frailty of governmental support to aquaculture is the absence of a good breeding program for target species, where good results demand a long-term approach. Without a program like this, the private sector is always forced to look for alternative methods and technology to reduce production costs and gain productivity.

When it comes to international players, some interest is starting to be shown by foreign investors, and the experience with tilapia and shrimp in the Federative Republic of Brazil is enabling aquaculture diversification and attraction of new investors; farmed production of those species has led to specialized production of aqua-feeds, the availability of imported vaccines, and more and better hatcheries and trained technicians and personnel. Furthermore, the Federative Republic of Brazil is a huge market for aquatic food, and domestic demand surpasses by far local capabilities to produce the necessary supplies, a fact that has meant that recently the Federative Republic of Brazil has been importing seafood products for values in excess of US$1.4 billion per year, a record figure for a Latin American country, where consumption per caput is fairly low.

Several international organizations have had a long experience in aquaculture cooperation and diversification efforts in the Federative Republic of Brazil. The FAO has worked for the past 40 years at federal level, regarding aquaculture development and diversification. The Project (FAO/UNDP/RLA/76/010) established the Latin American Regional Aquaculture Centre (CERLA) aiming at: (a) undertaking applied research, (b) providing training in aquaculture for high-level staff and (c) establishing an aquaculture information system. The project's most significant achievements in the field of applied research include the development of commercial modules for the production of pacu and tambaqui (Commission for Inland Fisheries of Latin America, FAO, 1987). In 2001, the Brazilian Government started an FAO Technical Cooperation Project (TCP/BRA/0065) for the development of seaweed farming for coastal communities of the northeast region (Ceará, Rio Grande do Norte and Paraíba). As a follow-up, the project entitled "Coastal Communities Development (UTF/BRA/066/BRA)" started in 2006 with the following objectives: a) consolidation of the *Gracilaria sp.* seaweed culture; b) diversification of mariculture; c) development of pilot projects on co-management of marine resource and d) establishment and organization of inter-institutional committees. This project opened new options for aquaculture diversification with a clam, *Anomalocardia brasiliana* and the mangrove oyster, *Crassostrea gasar,* however, with limited success, so much so that it was discontinued in 2012. In its turn, the Canadian International Development Agency

(CIDA) funded the project Brazilian Mariculture Linkages (Project BMLP) from 1993 to 2002. Its activities involved cooperation between Canadians and Brazilian universities for capacity-building, technology transfer, and community economic development aimed at promoting sustainable mariculture in the impoverished coastal regions of north and eastern Brazil.

These last two projects helped the Federative Republic of Brazil to develop technologies for oysters, mussels, clams and seaweed culture. Small scale farms are still working on these subjects in northeast states, but community organization, cost of production and restricted local demand still constrain production development. In Santa Catarina, bivalve mollusc culture became an organized production chain, well recognized by society, but local government did not succeed in establishing a national reference mariculture center, through which it was expected to replicate and disseminate technology to other regions.

3.4 Technology and expertise, markets and institutional facilities as drivers and constraints

The Brazilian aquaculture diversification process has been influenced by government, private sector and international organizations. Government hatcheries built through international cooperation projects made knowledge available for fingerling production of several species. Capacity building and training also drove diversification. As aquaculture became important, the number of higher education courses increased. Thus, and according to data from the Coordination for the Improvement of Higher Level Personnel (CAPES) of the Ministry of Education, the Federative Republic of Brazil has 18 graduate courses specifically related to aquaculture. Most of those courses are concentrated at public universities in southern and northeast states with a few institutions in northern and midwestern regions, exactly where outstanding aquaculture growth has taken place in recent years (Figure 7). Moreover, the majority of the students are mainly trained to become scientists, in some cases without enough hands-on experience or not well prepared to face and solve real industry problems.

One of the main challenges of R&D in Brazilian aquaculture relates to establishing priorities, considering the large number of potential native species for aquaculture diversification and development purposes, and their corresponding high demand for technology improvements and developments, together with very scarce human, private and governmental resources split among too many objectives.

FIGURE 7
Geographical distribution of Brazilian graduate courses in aquaculture

Source: Data adapted from CAPES (2016).

To partly address these problems, and in order to raise more funds and respond to scientific and industry demands for more and better aquaculture technology, the Ministry of Fisheries and Aquaculture (MPA) jointly with the Ministry of Science and Technology has called nine times for project proposals between 2003 and 2010. These calls always considered potential native species for diversification and have enabled funding for around 210 projects, focusing on different species, through grants, scholarships and research facilities worth around BRL[54]60 million (Routledge *et al*., 2012). Around 74 potential species were considered in those projects, with the top seven species studied representing 46 percent of the projects (Table 11). In more recent calls, government stressed the need to work on applied research through professional networks, and thus, interesting advances have been possible with a few species.

TABLE 11
Aquaculture R&D projects funded by Brazilian agencies, by species studied, 2003 to 2010

Species	Common name	Projects
Oreochromis niloticus	Tilapia	31
Litopenaeus vannamei	White legged shrimp	14
Rhamdia quelen	Jundia – Southern native catfish	14
Arapaima gigas	Pirarucu	12
Colossoma macropomum	Tambaqui	11
Piaractus mesopotamicus	Pacu	8
Centropomus paralellus	Robalo – Brazilian snook	7

Source: Routledge, personal communication (2016).

It is generally believed that these funds helped the Brazilian institutions to upgrade equipment and redesign experimental hatcheries and pilot farms, to be better prepared to develop applied technology and reduce aquaculture costs within industry.

The situation described by Ostrensky, Borguetti, and Soto (2008) regarding the Brazilian aquaculture industry still applies. There are many well-established providers of services, equipment and supplies, and an increasing number of hatcheries for the most commonly cultivated species. These hatcheries are being modernized with water treatment and biosecurity systems. There is still plenty of space for improvements and automation, as qualified workforce is becoming more expensive in rural areas. Processing facilities and other links within the aquaculture industry also need to move fast to apply more and modern technology in order to back whatever is being done with diversification of aquaculture products.

Feed availability and production systems are improving, but feed conversion rates for tambaqui and hybrids cannot still compare to those observed with tilapia farmed in earthen ponds and cages. Good genetic material and specific feed makes tilapia production systems more efficient. There are also several groups of people that want to intensify further work with native species. Amazonian small farmers are culturing tambaqui with aerators up to 10 Hp/ha in earthen ponds and medium-scale farmers in Mato Grosso have started testing hybrids of tambaqui, pacu and pirapitinga at commercial scales in large volume cages, with promising results.

On the market side, the appreciation of the Brazilian Real against the United States of America dollar and the global economic crisis in 2008 reduced the competitiveness of Brazilian seafood exports and consequently the domestic market became more attractive. Indeed, in that period, and after the implementation of social policies aimed at improving living standards of poor populations, average per capita income grew significantly. As a result, Brazilian consumers have increased their demand for fish products. That demand has been satisfied by a growing domestic production, but also through increasing imports, mainly from the Republic of Chile, the People's Republic of China and the Kingdom of Norway. Farmed salmon from the Republic of Chile is one of the main aquaculture imports. This fact is reflected in Brazil's international trade accounts, which show increasing levels of fish imports. Here and in 2014, a negative trade balance of more than US$1.3 billion dollars was mainly due to the increase in

[54] 1 USD = 3.123 Brazilian Real (BRL).

imports (Kubtiza, 2015). Despite the appreciation of dollar and the internal economic crisis since 2015, imports of seafood remain very high in the Federative Republic of Brazil.

In 2016, the domestic political and economic crisis may affect shrimp and tilapia exports. Production of freshwater native species is still not large enough to support exports and compete with other producing countries like the People's Republic of China. However, in the domestic market, several native fish species are increasing their share, not only at traditional markets in northern and midwestern regions, but also in big cities such as those in São Paulo and Rio de Janeiro States, where consumers are becoming freshwater fish eaters.

3.5 The future of aquaculture diversification: Main concerns, opportunities, restrictions, main species to consider

There is no doubt that the Federative Republic of Brazil is a strong player when it comes to aquaculture diversification. Native freshwater species production has been rising based on government investments, international institutional projects and private sector initiatives over the last 40 years. However, the Federative Republic of Brazil presents options for diversification based on both native and exotic species.

The main constraints faced by aquaculture diversification are: (1) the legal framework concerning the use of water for aquaculture, (2) the long process needed to get an environmental license, and, (3) insufficient fish processing plants constraining value-adding and market access. There are considerable bureaucratic procedures needed to obtain all of the permits/licenses required to start an aquaculture operation. The pioneering work with the Santa Catarina mollusc industry is an example of the benefits of working together with all stakeholders, and considering an 'ecosystem approach' for aquaculture planning and legislation. Aspects of coastal zone characterization were considered in the elaboration of Local Plans for Mariculture Development (PLDM), including environmental, legal, socio-economic and possible impacts of mariculture. This experience has high potential to be adaptable to other Brazilian states wanting to develop mollusc farming (Suplicy *et al*., 2015).

Bivalve mollusc farming offers a wide range of opportunities for aquaculture in the Federative Republic of Brazil. Because molluscs are filter feeders, the cost to raise and run a small farm is usually small compared to other species (based on lower feed costs). Normally, production systems are simple and family based. The native lion´s paw scallop (*Nodipecten nodosus*) and the mangrove oyster (*Crassostrea gasar*) are considered the best options for further diversification in southern and northern regions, respectively. However, there are still constraints regarding the availability of seed. Scallop seed is only produced through hatchery work, and mangrove oyster seed source is based on natural spat collection on artificial collectors. This system can also result in a mix with another mangrove oyster (*Crassostrea rhizophorae*), which does not reach commercial standards. However, both mangrove oyster species are salinity tolerant and offer opportunities for social development at traditional communities based on simple production systems for grow-out.

Plenty of suitable areas for marine fish farming can be found along the Brazilian coast. Brazilian universities already have considerable experience with experimental production of potential species. The main ones are the common and fat snook (*Centropomus sp.*), flounder (*Paralichthys orbignyanus*), snappers (*Lutjanus sp*.) and cobia (*Rachycentron canadum*). The first commercial farm experience in the Federative Republic of Brazil focused on cobia off the coast of Pernambuco State. Growth rates observed (up to 5 kg in 15 months) were very attractive. However, after only a few years in operation, this offshore cage farm closed down for several reasons, among which lack of a specific feed for this carnivorous species was particularly relevant. Today small private hatcheries and farms are raising cobia in relatively large cages, but in small quantities, in the north of São Paulo State and south of Rio de Janeiro State. A partnership with a local feed company that produced a specific feed is still not showing good results, with survival and growth rates up to 3kg in 12 months (Kubitza, 2014). Current limited production is sold to restaurants specializing in oriental cuisine, mainly in São Paulo. As production scales up, cobia could become an option for local fishermen to become fish farmers, if they obtain environmental licenses. Shrimp farmers could also drive further marine fish farming developments, focused on estuarine species in deactivated earthen ponds. The accumulated knowledge concerning fingerling production and grow-out could also open opportunities for diversification with other native species.

Concerning freshwater native species, pirarucu, also known as paiche (*Arapaima gigas*) is always going to be a potential fish for aquaculture in the Amazon and other countries outside its natural distribution (Hill and Lawson, 2015). This carnivorous fish, which can reach 10 kg in a year, is attractive to any fish farmer. The main challenge here is the limited availability and high prices of fingerlings, which represents around 25 percent of production costs, with fingerling price around US$3.00 (Pedroza Filho *et al.*, 2016). To date, fingerling production relies on natural spawning, as artificial reproduction is not controlled yet. This fact also puts pressure on the natural stocks, as the use of fingerlings from the wild for farming purposes is difficult to control, and for several reasons, this species is already considered as 'threatened' by CITES.

Problems with the reproduction of *Arapaima gigas* in captivity start with the lack of reliable techniques for sex identification. Recent technologic advances for sex identification have yielded a portable kit for this purpose (Chu-Koo *et al.*, 2009). Today, this technology is helping farmers to increase the quantity of fingerling produced as establishing fish couples into earthen ponds seems to enable reproduction in the rainy season (Núñez *et al.*, 2011). A current project in the Federative Republic of Brazil leaded by Embrapa is dealing with a range of problems related to the reproduction of *Arapaima gigas*, such as tools for assessment of maturation, protocols for hormonal treatment and also the genetic variability of captive broodstock in the Federative Republic of Brazil. Despite the many technological unsolved issues, pirarucu production is growing from year to year and official data indicate that over 11 000 tonnes were produced in 2014, mainly in the northern state of Rondonia.

Nowadays, the introduction of a new exotic species for aquaculture must follow different procedures. First, a potential farmer or institution must apply for a specific environment license that involves a lengthy risk-assessment study. Normally, Brazilian environmental institutions are precautionaryprecautionary on aquaculture licensing. Even species introduced decades ago and established as an important industry in the Federative Republic of Brazil (tilapia, white legged shrimp and Japanese oyster) are subject to environment license revisions which can restrict their development. Furthermore, in Brazilian scientific circles, the subject is controversial and the argument that the Federative Republic of Brazil has many potential native species for aquaculture usually prevails. Industry, however, cannot wait for a fully developed technologic package produced locally, and from time to time, considers new introductions. Recently, the exotic catfish (*Pangasius sp.*) and barramundi (*Lates calcarifer*) were considered for feasibility studies, but the idea did not prevail due to license constraints.

Hybrids in Brazilian aquaculture are a reality. It is difficult to imagine today's industry without hybrids. Concerns about hybrid escapes and possible interaction with wild populations could affect the future of Brazilian aquaculture. Assessment studies, hatchery monitoring procedures and breeding programs for species such as tambaqui and pirarucu should be considered as strategic governmental actions to secure sustainable aquaculture.

Currently, domestication efforts with target native fish for cage production are taking place, with interesting results, and could finally help diversifying production while relieving pressures on the farming of tilapia in northern Amazonian states, where legislation constraints regarding exotic species are higher. Good examples of cage fish farming are under evaluation in Mato Grosso state, considering tambaqui and pacu hybrids in big cages from 100 m^3 to 1 400 m^3 (F. Medeiros, personal communication, 2016).

3.5.1 Climate change

The effects of climate change on Brazilian aquaculture is becoming a general concern in different regions. The industry started to worry about its effects on farming systems due to the economic impacts caused by production losses. It is difficult to find official data regarding these impacts. However, more frequently, extreme weather events (such as flooding, water scarcity and storms) probably increased the frequency of diseases, fish and shrimp escapes and toxic algal blooms events on different production systems around the country.

The shellfish industry in Santa Catarina has faced climate change events recently. Algae blooms are becoming more frequent, preventing commercialization and pushing local government to establish an insurance policy to cover periods without sales. Future studies regarding the impact of sea acidification on the main mollusc species should also be encouraged. Brazilians are not avid consumers of bivalves, and to further promote consumption, specific campaigns need to be considered to open new market opportunities.

For the last five years, several reservoirs used for tilapia farming are facing lower mean annual rainfall levels. As the main purpose of the majority of these reservoirs is to generate electricity, fish farming is considered a secondary activity only and reservoir levels tend to be adjusted, affecting fish farming, and thus increasing the negative effects of lower reservoir volumes. In Ceará State, long dry periods affected several reservoirs. This scenario has been changing the geography of both production and trade, once farmers move from one reservoir to another searching for better environmental conditions and industries from southern states take advantage of the market gaps in the affected regions. To avoid losses, farms reduce stocking densities and feeding rates and move cages to deeper waters or other reservoirs in other states, whenever possible. All these procedures can maintain water quality and control mortality, but fish production has fallen in the main reservoirs used for fish farming in Ceará.

The Brazilian government is establishing measures that will help to deal with climate change effects on aquaculture following De Silva and Soto's (2009) overview on climate change impacts on aquaculture. Thus, during this last decade, the former Ministry of Fisheries and Aquaculture (MPA) funded several carrying capacity studies to support aquaculture planning, which in turn are seen by the same authors as insurance to improve resilience against climate change, as environmental limits should be respected as the main criterion to define space to be leased for aquaculture use.

An Aquaculture National Monitoring Program is also being planned by government. The plan is to provide real time data on physical and chemical conditions for aquatic environments, in order to manage inland cage culture farming. The program is waiting for funds in order to be implemented.

De Silva and Soto (2009) considered that the spread of pests and diseases is a major threat under climate change scenarios, and that this issue must become a priority for aquaculture, considering relevant biosecurity measures. A few years ago, the National Network of Laboratories of the Ministry of Fisheries and Aquaculture (Renaqua) was created, and became responsible for monitoring, analysis and the provision of official data regarding fish health. These laboratories also provide training and define strategies to prevent disease outbreaks in this industry.

3.5.2 Conclusions

The Federative Republic of Brazil is well known for its aquatic biodiversity and favorable climate for aquaculture development. These characteristics could convert the country into a strategic player among world aquaculture producers. Moreover, different authors already consider that there is a clear tendency to diversify farmed species, technologies and production systems. In evolutionary terms, it is commonly understood that diversity provides the ground for natural selection and for adaptation, and therefore, it can also be proposed that culturing more species provides a form of insurance and offers better adaptation possibilities under different climate change scenarios, especially when unexpected events such as diseases occur (De Silva and Soto, 2009).

Brazilian aquaculture presents a production model based mainly on small farmers with poor technology. This scenario is changing and today it is possible to find a few vertically integrated farms. However, most farmers are still small scale and family based. Under these conditions, production growth becomes more challenging and products show low diversification and high prices, factors that affect competitiveness of Brazilian farmed products with imports, challenging the sustainability of Brazilian aquaculture.

Imports can also be seen as an opportunity for the Brazilian industry to become more competitive, as local farmers, needing to sell their products try to improve their management practices and biosafety procedures, and there are more and growing initiatives for new equipment developments such as for automatic feeders and graders, to promote productivity and further aquaculture development.

Sidonio *et al.* (2012) from the Brazilian National Development and Social Bank (BNDES) pointed out several options to modernize this industry. Among governmental measures, they suggest stimulating the installation of more structured industries (leading companies), which could accelerate the introduction of technologies adapted to Brazilian conditions and species. Additionally, they state that technology transfer and partnerships could make small and medium farms more competitive and would foster production growth and develop products for export, which would help in replacing part of current imports. The Brazilian government could encourage a research and technology network program (research institutions and industry) focusing on applied research to face challenges and bottlenecks. Credit lines could encourage international investment and technology transfer for aquaculture diversification (species, production systems and products).

The Brazilian government should also consider the effects of climate change on aquaculture and translate these concerns into formal policies. As well, further actions to implement a more competitive framework to enable private sector investments are also needed to better explore the Federative Republic of Brazil's aquaculture potential and biodiversity.

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