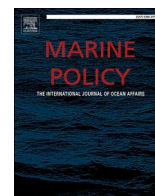Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Chilean salmon farming vulnerability to external stressors: The COVID 19 as a case to test and build resilience

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ABSTRACT

This study addresses the risk and vulnerability of Chilean salmon production to hazards resulting from the COVID-19 pandemic threat, including limited access to farms, limited processing capacity and reduced market demand. The role of different management approaches in reducing risk and vulnerability is also explored. Results suggest that concession areas having the largest accumulated and current biomass have the highest risk, which is also transferred to the municipal level. The scenarios modelled with better management practices that reduce diseases were able to reduce risks by 30–40%. The largest risk reduction is achieved when production biomass is divided in a more equitable manner among concession areas, suggesting the need for strategic improvements in spatial planning of the activity in the marine environment according to ecosystem carrying capacity and better practices. Improving adaptation capacity can reduce vulnerability between 20% and 30% for municipalities; for example, providing local employment can be a win-win management measure under the COVID-19 threat because it reduces movement of people and facilitates handling and responses to emergencies. A larger footprint in local economies and employment can also improve social perception and acceptance of the sector, thus contributing to improve adaptation changes and governance to face the threats. The framework used here to perform a risk and vulnerability assessment of salmon farming to the pandemic-associated threats can also be useful for other aquaculture systems elsewhere, provided that relevant information is available.

1. Introduction

Vulnerability has been defined as the degree to which a system, or part of a system, may react adversely during the occurrence of a hazardous event [1]. The concept implies a measure of risk associated with the physical, social and economic aspects and implications resulting from the system's ability to cope with the resulting event [2]. Understanding vulnerability, risk, and adaptation capacity of human and natural systems may contribute to structure better policies toward resiliency, sustainability, improving management and conservation, with direct effects on income opportunities for local communities that rely on these resources [3]. This becomes very relevant in the planning and management of the food production sector.

The sanitary crisis caused by COVID-19 is the most recent example of

a severe global shock generating hazards beyond those to human health directly, whose environmental social and economic consequences are not yet well understood [4,5]. Thus far the COVID-19 pandemic has caused severe disruption in the production and trade of nature-based goods and services [6,7]. This is the case for the tourism, mining, forestry, fishing and aquaculture industries that participate in international markets. The main effects observed include a reduction in global demand from international markets due to restrictions, closing borders and a general increase in costs of transportation [6]. The impact of the shock is being transmitted through the value chains and also directly affects each stage of the production processes. The fast transmission of the pandemic has opened new concerns and questions regarding risks, vulnerability and adaptation capacity of natural resource-based industries to shocks that are global and affect national and international

chains of production, distribution and consumption.

This paper addresses risk and vulnerability in salmon farming, a natural resource-based industry, associated with hazards resulting from the COVID-19 pandemic threats, using some of the climate change risk-related frameworks as models, increasingly explored in recent years [8, 9].

Aquaculture is a risky endeavour, probably more than agriculture, because often there is less control over farming conditions. This is especially the case when aquaculture is carried on in open floating farm systems such as fish cages. Arthur [10] describes the concept of "risk" in aquaculture as the potential for occurrence of unwanted, adverse consequences to human life, health, property or the environment. Its estimation involves both the likelihood (probability) of a negative event occurring as the result of a proposed action or event and the consequences that will result if it does happen. In biological systems it is very difficult to quantify both the probability of a certain event and its consequences, therefore risk analyses are often conducted using broad qualitative categories, by scoring the probability and consequences from low to high [11]. This is done based on some semi-quantitative assessments using expert opinions as well as quantitative information, an approach widely used including in salmon farming [12].

The analysis was conducted in southern Chile marine ecosystems, where most of the country's salmon farming takes place. We use simple models based on available information and on some semi-quantitative assessments to explore risks of salmon production loss resulting from different hazards related to the COVID-19 pandemic, including: i) limited access to farms; ii) limited processing capacity and iii) limited or reduced market demand. The role of different management approaches by salmon farming concession areas (salmon farming neighbourhoods or ACS)[1] to reduce risk is also explored. Finally, we study the resulting vulnerability and adaptation capacity of the industry and communes (or municipalities, which are the smallest administrative areas in the country) to face the impact of COVID-19 on salmon production in southern Chile. We are using this as an example of an unexpected shock for a fully export-dependent economic sector which could have relevant socioeconomic and environmental consequences; we use these to recommend measures that could build sustainability and resilience in the long term. This approach can be replicated in other aquaculture and fishery systems as well as in other natural resource-based sectors.

The paper is organized as follows: in Section 2 we present a brief description of salmon production in Chile and discuss impacts of the COVID-19 pandemic and related policy responses on the industry. Section 3 presents the methods used for our analysis of vulnerability. Section 4 presents the results and in Section 5 we discuss the main take-home messages from our work.

2. Salmon production in southern Chile and COVID-19

Chile is a country with a diverse geography and a relatively small population of about 17 million people. Most of the income of the country comes from exports of natural resources with reduced or no value added, which make it fully dependent on export markets and the global economy. The country is the second worldwide producer and exporter of farmed salmon, after Norway. Production of salmon increased from one thousand tons in 1985 to more than 800 thousand tons with a value of more than US$ 5 billion in 2018. The development of the farming stage of this industry was initially concentrated in the Los Lagos region, later expanding south to the Aysén region and ultimately to the Magallanes region in the southern tip of the country (Fig. 1). Salmon farming provides about 7% the country's total exports, contributing more than 14% to the "non-mineral" exports; thus the activity is a relevant economic

sector with impacts on social and economic development, especially in remote places and fishery-dependent coastal communities where there are often no other permanent sources of income. Yet this industry does not lack criticism due to environmental impacts to very pristine environments, conflicts about the use of space, vulnerability to shocks and governance and social issues [14,15].

The salmon industry operates through four vertical stages; i) Production of eggs, juveniles and smolt which takes place in freshwater, mostly in land-based facilities in the Regions (the country's administrative units) of Araucanía, Los Rios and the northern part of Los Lagos (approximately from 36°S to 42°S; ii) smolts are then transported to the farming sites in the sea in the Los Lagos, Aysén and Magallanes Regions (41°S to 53°S); iii) when the fish are ready for harvest they have to be transported from the farm sites to the processing plants located in a few communes in the farming regions (Fig. 1); and iv) most salmon from the processing plants is packed and sent to three main airports in the communes of Puerto Montt in Los Lagos, Balmaceda in Aysén and Punta Arenas in Magallanes (Fig. 1).

The distance between land-based hatcheries and farm sites in the sea ranges from hundreds to thousands of kilometres (Fig. 1) and transport of juveniles is normally done by trucks and sea-ferries to reach remote farm sites that often do not have direct land access. In most cases harvested fish have to be transported by specially adapted ships and trucks to processing plants that could also be a hundred kilometres away. Finally, in most cases the processed fish must reach an airport to be exported.

During the first semester of 2020 salmon production and exports in Chile were seriously hampered by the global COVID-19 pandemic [16, 17]. Official data from Chile's National Customs Service (Servicio Nacional de Aduanas) suggest that there was also a negative trend in export prices during that period. Similar trends were also observed in FOB prices for frozen salmon exported to Brazil and China [18]. Threats to human health initially paralyzed and/or blocked some seafood-importing markets such as China, a main destiny for Chilean salmon and also the US and Brazil. Therefore, few thousand tonnes of salmon remained without reaching the markets during the first half of 2020, forcing the industry to slow down production, and where that was not attainable, looking urgently for alternative destinations, sometimes at a large loss. Estimates indicate that fresh exports were initially affected strongly [19]. In late March and April, 2020, the second and very relevant factor started affecting this industry as the COVID-19 virus reached Chilean cities and local communities, government and society pressed for quarantine. This significantly affected processing plants and even more dangerous for the industry, made it difficult for workers and specialized personal to tend the farms, normally located off the coast and often in remote areas. Lack or reduced management of the farms including feed provision, medication, handling etc. can result in lowered growth rates, increased mortality due to diseases and parasites, starvation, escapes, etc. Some of these effects could also generate environmental impacts.

Biosecurity measures for workers and government personnel may also not allow regular controls and monitoring of health and environmental issues around the farms, relying more on self-regulation. This situation can result in biomass loses with relevant economic, environmental and also social consequences; impacts would depend on the length of the "shock" or perturbation of the normal process in the activity. The problem can be exacerbated by the fact that a large proportion of farm workers in the more remote communes, especially in the Aysén and Magallanes Regions, come from communes and larger cities in the Los Lagos Region and are regularly moving to the farm sites for 10–15 day shifts from far away.

Initially the Los Lagos and Aysén Regions (Fig. 1) avoided lockdown because the number of COVID-19 cases was comparatively low. Yet in April, 2020 local communities, especially in the island of Chiloé demanded to block access to people and transport, claiming that salmon farming activities are a main vector between the continent and the

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[1] ACS ("Áreas de concesiones salmonicolas") are salmon farming areas or neighbourhoods designed as biosecurity management units to address impacts of ISA virus [13].
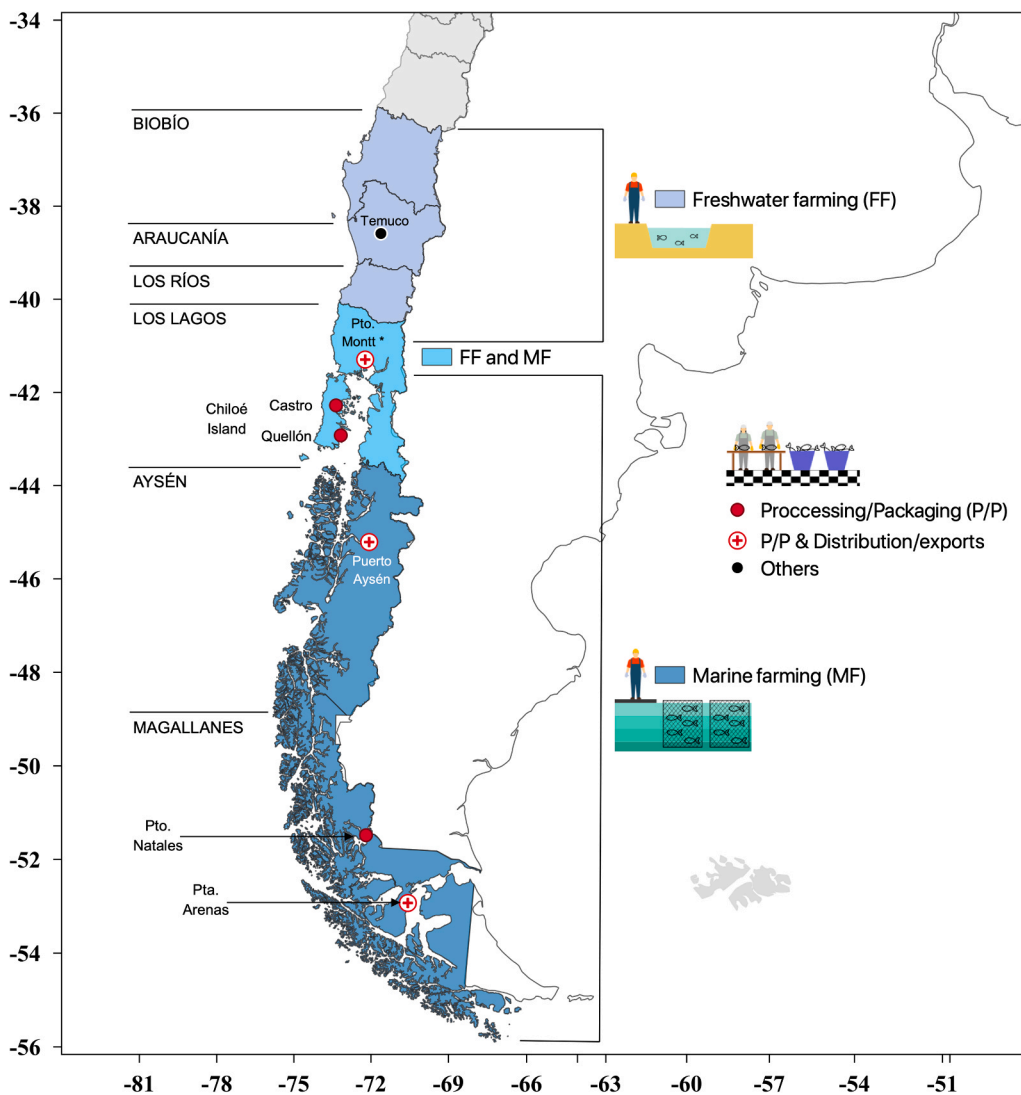
Fig. 1. Geographic distribution of the different stages of salmon farming in the administrative regions in southern Chile. Region names are shown on the left. Freshwater farming to produce eggs and juveniles and marine farming (fattening) areas are shown with different colours. Communes where processing/packaging and distribution for export take place are represented by red symbols. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

island and thus they could spread the virus. People were concerned about lower health care capacity in the island communes than in mainland, and local people tend to have a bad perception of the sector which probably influenced their reaction. Chiloé Island holds a large proportion of the processing capacity for the salmon industry in the country and it was initially blocked from access to mainland. Later on, at the end of July, the city of Puerto Montt, the largest salmon hub in Chile also holding the main airport, entered full quarantine. Some larger salmon farming companies also have processing plants in the Bio Bío region, an area located several hundred kilometres to the north of Aysén and Los Lagos, where most of Chile's farms operate. Considering COVID-19 biosecurity measures, long distance transport is very difficult, increasing the cost of production.

Even if access to farming sites and transport in general may have improved slowly through the second quarter of 2020 due to the rapid adaptation measures and collaboration between the private sector and the government, processing was reduced significantly due to the human health protection measures, especially those related to social distancing which do not allow processing plants to work at full capacity. This situation in many cases forced a slowdown and even stopped harvest from farm facilities, consequently leaving fish in the water beyond normal harvesting time.

3. Methods

Risk assessment is normally performed in aquaculture to address biosecurity and environmental issues [11], and it has been also increasingly used to address climate change threats and the interdependency of different forcing factors in many sectors [20]. A recent evaluation of climate change vulnerability of the salmon farming sector in southern Chile [21] used a model that combines biophysical and socioeconomic elements. The authors modelled the resulting vulnerability using farm concentration, geographical location and management scenarios, providing policy recommendations to increase climate change adaptation and the long-term sustainability of the sector. More recently, climate change risk maps were developed for salmon farming in the country [22]. An adaptation of both approaches is used here to address the COVID-19 pandemic-related threats; we explore potential risks of losing salmon production by salmon farming concession areas and the associated vulnerability of communes where salmon farming takes place.

3.1. Study area

The analysis focuses on the marine farming stage of salmonids, which takes place in floating cages in about 400 fish farming sites (concessions) where they grow until harvest in a 14- to 18-month

production cycle. These sites are distributed in 69 salmon farming concession areas or neighbourhoods (ACS) that were considered as study units and that harvested salmon in the 2017–2018 production cycle, the period for which we had the full information and considered representative of the current situation. The ACS are distributed in 22 communes, the lowest governmental management areas, or municipalities in the three regions, Los Lagos, Aysén and Magallanes (Fig. 2, Table 1).

The risk of losing biomass was estimated by ACSs because this is the current relevant production management scale regarding biosecurity and environmental issues. Then these risks estimate were projected to the commune scale (Fig. 2), since this is the scale where the biophysical risks can be confronted through social and governance elements using the vulnerability assessment.

3.2. Risk assessment

The analysis was done through a semi-quantitative risk assessment using a model developed by the ARCLIM project in Chile [22], modified from the 2014 IPCC-proposed model [9].[2] The model combines the *Exposure of the biological production* (*Eb*), which is the harvested biomass that could be lost due to a hazard, with the *susceptibility or sensitivity (S)* of this production to be affected by that *hazard* (*H*). A risk value was estimated for each of the 69 ACS.

$$Risk(R) = EbxS \; x \; H \tag{1}$$

3.2.1. Exposure

For the present analysis *Exposure* (*Eb*) represents the farmed salmon biomass that could be lost by ACS, using the 2017–2018 cycle as annual average harvested biomass (Fig. 3). The information was provided by the "Servicio Nacional de Pesca y Acuicultura" (SERNAPESCA is its Spanish acronym) through the "transparency information mechanism" (SIAC, [23]). This information could represent well the situation in the current cycle (2019–2020).

In 2018 salmon production was dominated by Atlantic salmon (*Salmo salar*) with 77% of total harvest, followed by Coho salmon (*Onchorhyncus kisutch*) with 14% and rainbow trout (*Onchorhyncus mykiss*) with 9%. We used total biomass for the present analysis, however the species composition by ACS is also considered in the analysis of sensitivity (see Section 3.2.3 below).

3.2.2. Hazard

In this case the hazard is conceived as a COVID-19-related event including the disease prevention or mitigation measures that could indirectly damage or cause the loss of salmon production during the farming and harvest phases, which could be due to the following:

I. Limited access to and from farms due to sanitary barriers and quarantines that would not allow or reduce the transport of feed, the movement of personnel taking care of farms, and also enforcement authorities that conduct monitoring and inspections to control for diseases, parasites, environmental issues, etc. and the transport of harvested biomass. There could be additional environmental risks due to limited or no access and transport of mortality in case of deadly emergencies, e.g. due to escapes, HABs, diseases, hypoxia etc.[24].

II. Limited processing capacity in processing plants due to social distancing to avoid the spread of the COVID-19 virus could hamper normal harvest and fish may need to stay longer in the farms.

III. Reduced market demand that could also hamper normal harvest when the expected product is fresh fish, and even frozen fish if storage capacity is limited.

All of the previously described COVID-19-related events could represent a hazard for the biomass in the farms if fish are not fed and tended properly or if they are left in the farm cages beyond harvesting time. Interestingly, while some of these hazards are transmitted backwards through the production chain from international markets (i.e. lower demand first affects processing plants, then farming facilities and then the freshwater stage), others could affect each of the stages of the production chain directly and independently.

We used three hazard scenarios: i) Reduced access for all ACS and all regions, ii) Different access restriction levels for different areas and regions, and iii) General reduced processing. We did not consider a specific time span for this analysis. Obviously the longer the access restriction and/or processing restriction last, the higher the risks of losing biomass due to diseases, mortality due to HABs, weight loss, escapes etc.

3.2.3. Sensitivity

Sensitivity here is described as the group of elements, factors, or conditions that could make the loss due to the hazard more likely. Here we consider several intrinsic and extrinsic farming factors that should be important in almost any fed fish farming system, whether it is intensive industrial farming or when many small scale farms are using a small water body.

I. Accumulated fish biomass produced in each neighbourhood or ACS during the last decade per unit area may represent well the nutrient load to the shared area and is a good indicator of the use intensity of the nearby ecosystem. An ACS that has had a larger biomass has contributed more nutrients that could facilitate or trigger algal blooms and local anoxic conditions than an ACS which has had smaller accumulated biomass [21]. An area with longer and more intense use could also have generated better conditions for parasites to become established and expand [22].

II. Health and sanitary condition of the fish. If fish are already stressed or ill or if diseases are present, they are more likely to die or lose weight in the absence of proper care and handling. In this case we use the amount of antibiotics used during 2017–2018 per ACS as an indicator.

III. Predominance of Atlantic salmon. Since this species is more prone to diseases such as rickettsial syndrome (SRS) and infectious salmon anemia ISA than Coho salmon and trout [13] and is also more prone to be affected by sea lice [25], ACS that produce only Atlantic salmon could be more susceptible to experience mortalities due to these diseases than those that include more of the other species. Atlantic salmon is being harvested all year round and thus farms with this species can also be more affected by processing restrictions than others with Coho salmon that will be ready for harvesting only in late spring.

Some extrinsic factors include:

IV. Unfavourable environmental conditions that could damage the fish such as harmful algal blooms (HABs). In this case the previous presence and impact of HABs at each ACS are used as indicators.

V. Considering that the main hazard is the hampered access and/or harvesting conditions, the study also consider the distance and physical access to the sites as a susceptibility factor. For example, an ACS that is very remote and far from the nearest port and/or processing area is more susceptible to lose fish than an ACS that is closer to ports.

The Sensitivity indicator for each ACS is the mean of the scores (1–5) assigned to the five sensitivity factors previously described and shown in Table 2. Each risk component, namely *Hazard*, *Exposure* and *Sensitivity*,

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[2] The model combines *hazard, exposure* and *vulnerability*. The last is composed of sensitivity and adaptive capacity but in this case only the latter is used.
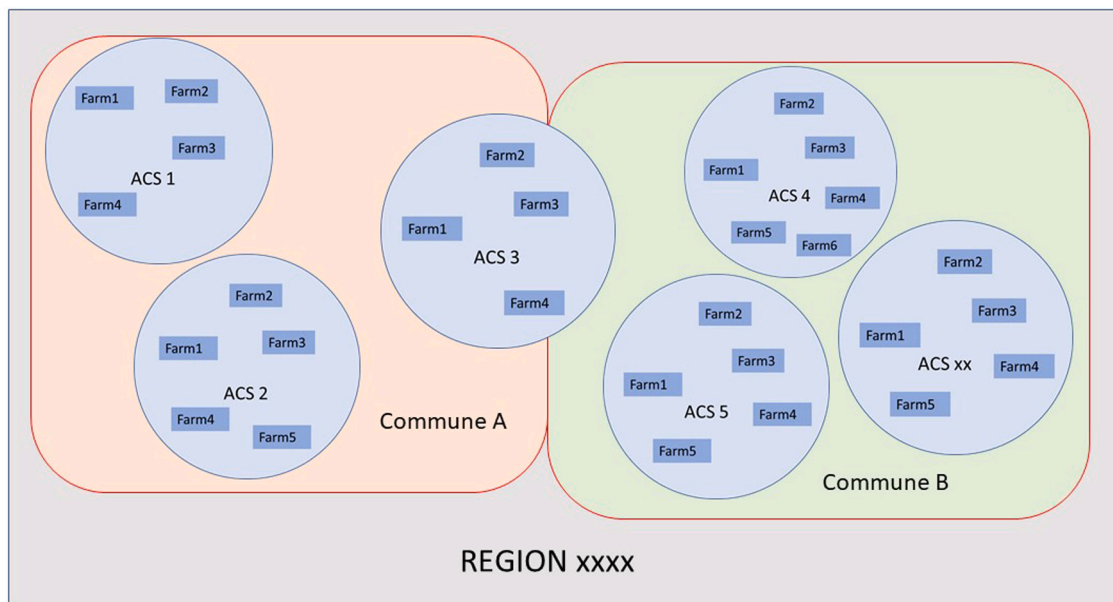
Fig. 2. Schematic representation of farms within neighbourhoods (ACS), distributed within communes in three geopolitical regions; Los Lagos, Aysén and Magallanes (Fig. 1). Some ACS areas cover more than one commune.

Table 1

Salmon farming neighborhoods ("Agrupaciones de concesiones de salmon", ACS) and their code number per commune by region and proportion of ACS per commune. Some communes contain more than one ACS and some ACSs could expand through more than one commune. Chiloé Island Communes and ACSs are indicated (*).

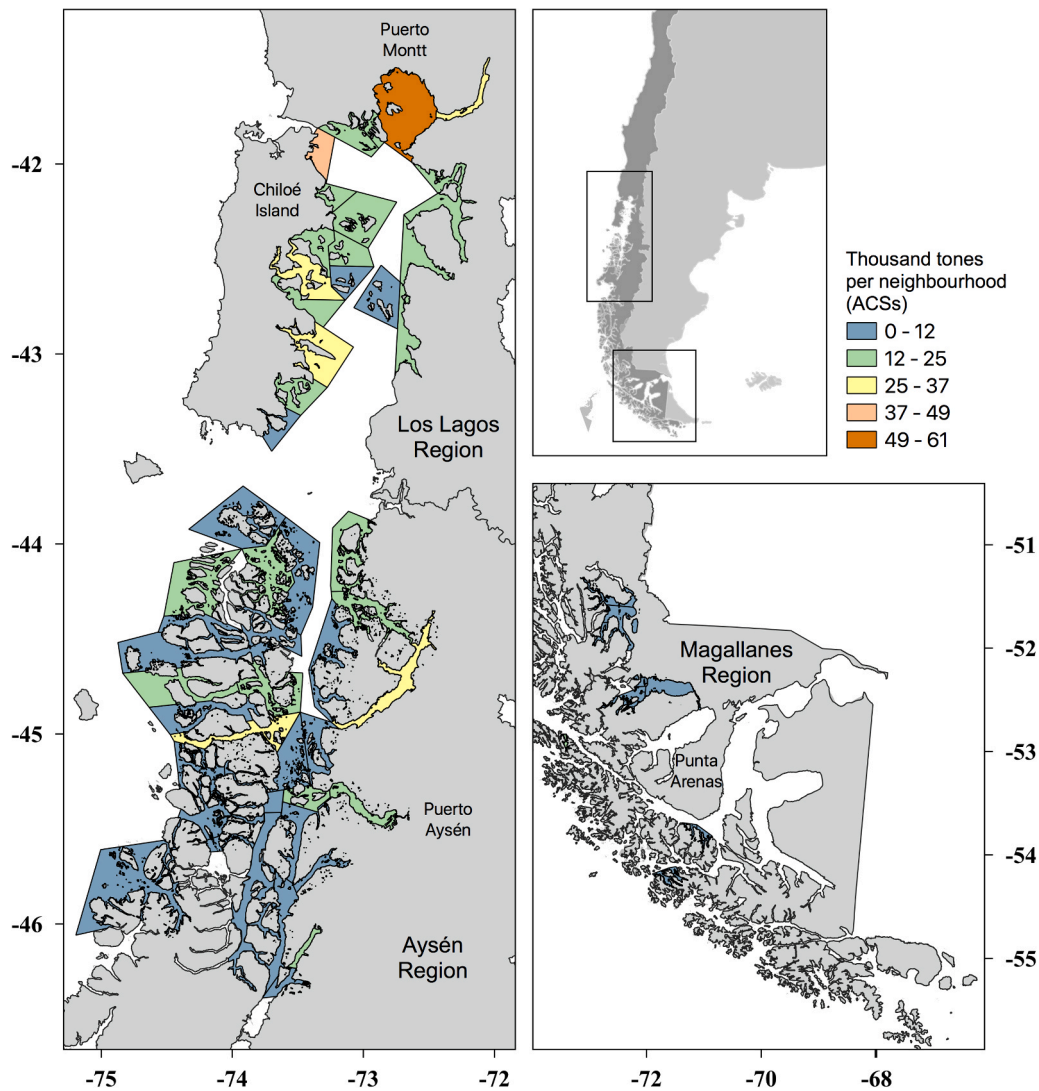| Communes at Los Lagos region	ACS	% production per ACS per commune	Communes at Aysen region	ACS	% production per ACS per commune	Communes at Magallanes region	ACS	% production per ACS per commune
Cochamo	1	100	Guaitecas	18A	46	Natales	44	0
Puerto Montt	2	100		18B	11		45	26
Hualaihué	2	25		18C	43		46	30
	17A	28	Cisnes	18B	2		47A	11
	17B	47		18C	8		47B	0
Calbuco	2	32		18D	4		48	33
	3A	33		19A	12	Rio Verde	49A	35
	3B	35		19B	3		49B	16
Ancud *	6	100		20	6		50A	32
Quemchi*	7	50		21A	7		50B	17
	8	47		21B	9	Punta Arenas	52	51
	9A	3		21C	2		54A	10
Dalcahue*	8	1		21D	6		54B	15
	9A	99		31A	2		55	9
Curaco de Velez*	9A	54		31B	3		56	14
	10A	46		32	15	Cabo de Hornos	57	69
Castro*	10A	100		33	10		58	31
Quinchao*	9A	26		34	12			
	9B	42	Aysén	21C	15			
	9C	15		22A	3			
	10A	16		22B	4			
Puqueldón*	10A	34		22C	2			
	10B	66		22D	6			
Chonchi*	10A	28		23A	4			
	10B	72		23C	5			
Queilen*	11	100		24	6			
Quellon*	11	44		25A	9			
	12A	42		25B	3			
	12B	14		26A	2			
Chaiten	14	31		26B	5			
	15	10		27	4			
	16	36		28A	9			
	17A	23		28B	11			
				28C	1			
				29	2			
				30A	4			
				30B	5			

Fig. 3. Spatial distribution of Exposure (average harvested biomass 2017–2018) per salmon farming concession area (ACS) or neighbourhood.

Table 2
Indicator units, interval values and corresponding scores.

Indicator	Description and units	Scores				
		1	2	3	4	5
Exposure	Average harvested biomass (tons, 2017–2018) per ACS representing the potential loss magnitude per ACS	≤5000	5001–10000	10,001–15000	15,001–20,000	>20,000
Sensitivity factors	i Accumulated biomass (2010–2018) per unit area (tons/ha) per ACS, representing accumulated stress to the concession area (potential eutrophication, diseases etc.)	≤300	301–600	601–900	901–1200	>1200
	ii Atlantic salmon dominance (% of total harvest per ACS).	≤20	20.1–40	40.1–60	60,1–80	>80
	iii Health management condition as average (2017–2018) total antibiotic (AB) use (tons) per ACS	≤4	4.1–8	8.1–12	12.1–16	>16
	iv Unfavourable environmental conditions represented by number of algal bloom (HAB) events causing fish mortality within each ACS (2000–2016)	<2	2–5	6–10	11–20	>20
	v-Distance to nearest port (km) and access facility (land and sea)	≤30 Access by land and sea	<30 and ≤50 Access by land and sea	>50 and ≤100 Access by land and sea	>50 and ≤100, Access only by sea	>100, Access only by sea
Hazard	Access reduction due to sanitary barriers and movement of personnel and/or harvesting reduction due to limited capacity in processing plants required to respect social distancing	<20%	20–39%	40–59%	60–80%	>80%

was estimated with a five-point scoring system based on a quintile distribution of values used for this study. Table 2 describes the value intervals and scores to estimate risk based on the baseline information (Annex A). Final risk value was estimated as in Eq. (1) above. Given that each component can have a maximum score of 5, the maximum value of $Eb \, x \, S \, x \, H$ is 125 and therefore we divide by this number to normalize final risk values between 0 and 1, where 1 is the maximum risk.

After evaluating risk level by ACS, the risk level by commune was estimated considering the salmon production contribution of each ACS to each commune, also taking into account that some ACS are within the geographic jurisdiction of more than one commune (Table 1). This generated a weighted risk per commune according to the proportional contribution of each ACS.

3.3. Vulnerability assessment

Vulnerability assessments and indicators have been widely used by the climate change scientific and policy-making communities [26], but not as often in other fields, perhaps because there have been no other popular and pressing global threats until now [27]. This study uses a simple indicator to estimate salmon farm vulnerability to the COVID-19 sanitary emergency-related hazards by linking the *risk* (*R*) of losing aquaculture production per commune to the *adaptation capacity* (*AC*), entailing relevant measures and conditions that allow communes to act as local governance units to prevent and mitigate impacts.

Considering that risk can be modified by the reduction of the hazard (e.g., by a political decision), slightly more weight is given to *AC* than to *R* to calculate vulnerability (*Va*); this also shows better the power of adaptation measures at the commune level.

$$Va = (Rx\alpha) + ((1 - AC) \quad x \quad (1 - \alpha)) \tag{2}$$

With $\alpha \geq 0$. Then we set $\alpha = 0.4$ as a baseline to give slightly more weight to *AC*.

The vulnerability units are the 22 communes where salmon farming takes place. However, the vulnerability of many of these units is linked throughout the supply chain to other communes (where processing plants and owners/providers of labor and other inputs are located), yet adaptive responses need to start at this smallest scale. Each commune may include several ACS and some ACS could also cover two or three communes. Therefore, production adjusted to the areal proportion of each ACS per commune was used to estimate *Va*.

3.3.1. Adaptation capacity

Adaptation capacity indicators describe commune-level properties or conditions that would facilitate addressing and reducing potential loses in salmon farm production due to the COVID-19 pandemic shock or that would mitigate impacts of losses. The indicators used focus on the local conditions following recommendations by Hinkel [26] regarding the need to clearly specify the value and meaning of indicators at a local scale. The indicators described below can also be used and would be relevant in many aquaculture systems, especially in those requiring specialized labour.

3.3.1.1. Local employment and communal belonging.
Salmon farming in Chile has generated a rather poor public perception locally, partly due to negative environmental impacts [14,15,24] but also due to the fact and perception that the industry might not contribute enough to local employment and local economies. The new labour regimes due to regulatory changes, the increase in demand for more qualified labour and the expansion of operations toward the southern regions have weakened the connections between local communities and firms operating in those locations [15]. In fact, salmon farm workers are often moved from larger cities to remote areas where farms are located.

During the early lockdowns in April and May 2020, local people reacted very strongly against the salmon farming industry, especially in Chiloé Island, demanding authorities to reduce or stop their movements completely because the risk of bringing the COVID19 to more remote areas. If most salmon farm workers would belong to localities or communes where farming takes place, there would be more empathy with salmon farming because labor contributes to local economies. Also, considering that transport and movement of people between localities and regions could increase COVID-19 spread, those ACS for which most of the labour needed to tend the farms is local (employees living in the commune where the ACS is located) would be safer, because they could ensure proper fish care without traveling long distances (in some cases up 20 h). This has most likely been an important factor for lockdown pressure to face the pandemic and is one of the main challenges for good governance of the sector to reduce vulnerability to natural or anthropogenic shocks [15]. Therefore, this study used the following indicators:

i. Reliance on local, communal employment. This indicator was calculated as the fraction of the local population that is economically linked to the farming activity with respect to the total population in the commune.

   A difficulty with the information on communal employment and economic dependency is that the information provided by the commune only indicates the geographic location of employment, but does not indicate whether the employee comes from another commune or even another region. Long distance travel is a very common situation for workers of farms who live far from the farm sites. These workers usually work one- to two- (or even more)- week shifts. Therefore, the indicator represents the fraction of employees who are residents in the communes where the production activity takes place.

ii. Local residency of employees. Through authors judge expertise, the study estimated the percentage of local residency of employees. Higher residency percentage was assigned to communes such as Puerto Montt, Castro, Quellón, and Puerto Natales and Puerto Aysén where the processing of salmon takes place because those workers leave nearby, while those working in less populated and more remote communes such as Cisnes and Guaitecas (Fig. 1, Table 1) most likely travel from far away [15].

3.3.1.2. Salmon farming tax revenue contribution.
Considering that half of the taxes for farming concession use are paid to the commune where the farming takes place and that taxes are paid even if there is no production in the specific site, such payment is rather resilient to biomass production fluctuations and could contribute to stabilize the local economy and services. Additionally, considering that most salmon farming is currently owned by 6 or 7 large companies [14,15], tax payment for individual sites do not risk the permanence of the farm or the concession rights in the short term.

Tax income to communes, especially in remote areas, could contribute to improve local education and services including human health care and other services that could reduce risks and mitigate impacts of the pandemic. This tax contribution is very relevant, especially considering that other relevant activities in the same salmon farming areas such as tourism are completely stopped.

i. The contribution of salmon farming taxes to the permanent municipal own income is the fraction of salmon farming tax revenues in the commune with respect to the total permanent income (see Annex B for more detail).

3.3.1.3. Education level.
The commune's adaptation capacity will increase with the level of formal schooling of the population, meaning higher education including technical and in some cases university education. The basic idea is that a higher fraction of the population with more years of formal schooling could be better prepared for technical work and service to the industry, including providing better care for the

farmed fish, being able to collect and process information regarding farming conditions, being able to perform biosecurity protocols, early warnings etc.

i. Percentage of inhabitants with at least one year in university or technical education.

3.3.1.4. Health care level of the commune. Given the COVID-19 biosecurity threat, communes that have a higher level of health care systems will be better adapted to face worker illness.

a. Level of complexity and preparedness of the health care system. We gave a 100% score to communes having a high-quality health care system such as a fully prepared hospital, and 25% to those communes with only basic first aid systems.

3.3.1.5. Coordination capacity. Inter-institutional coordination capacity is essential to face emergencies to solve problems and to reduce risks, also the coordination level between public and private sectors and with civil society. We used a similar approach to that described by [21], giving a score to each communal management based on several criteria assessed against past experience and improvements after the last HAB emergency affecting salmon farming during the 2015–2016 El Niño event. Coordination capacity is generally greater in larger cities, regional and provincial capitals.

The inter-institutional coordination capacity was considered to be indicated by:

i. An institution that coordinates the response to catastrophic events regionally in close collaboration with the "national" authority based on the interaction and participatory decision of institutions from aquaculture farmers, other sectors, local communities, authorities,

ii. There is a clear, well-known and transparent mechanism for coordination and communication

iii. Decisions and actions are consensual and transparent, and consider the objectives of social and economic development with equity and environmental sustainability in the long term.

0.33 points are subtracted from the unit for each one of these characteristics that is not found.

All indicators used for the estimation of *Adaptation Capacity* were designed such that they are rescaled to vary between zero and one. A higher value indicates greater adaptation capacity. The final value of *Adaptation Capacity* per commune was obtained as the mean of the different indicator values.

More methodological details can be found in Annex B.

Since some indicators may not be independent, the final Sensitivity value per commune was obtained from the unweighted geometric average of all the indicators.

Table 3
Modelled risk scenarios. Levels (1–5) correspond to the scores described in Table 2.

Threat scenarios	
Scenario A	Partially reduced access (level 3) and/or partially reduced processing (level 3), baseline condition for all ACSs
Scenario B	Access restriction level 5 (maximum) for Chiloé ACSs* and 4 elsewhere
Threat +Adaptation scenarios	
Scenario C	Highest risk level ACSs under scenario B** with improved health management (Antibiotics reduced to level 2)
Scenario D	Highest risk level ACS under scenario B but with Exposure reduced to level 3.
Scenario E	Access restriction level 5 (maximum) in Aysén Region and level 3 elsewhere

* ACS 6–12 (Fig. 4).
** ACSs 9A, 10A, 10B and 11 in Fig. 5 (risk levels ≥0.7).

4. Results and discussion

4.1. Risk level by salmon farming area (ACS)

To explore the role of management of the sector in response to threats, five pandemic-related scenarios (Table 3) were considered to estimate risk levels. Scenario A represents the baseline situation and data (described in Annex A), considering current management and production conditions for all ACS under a medium access restriction (level 3, Table 2). This scenario could also be used for the situation where there is partial limitation of processing everywhere, therefore fish stay longer in the farms. For scenario B we considered maximum lockdown or access restriction to a relevant area for salmon farming, Chiloé Island (Fig. 1). We also considered three scenarios where we mixed **Threat** levels with reduced **Sensitivity**; and **Exposure** we call these "adaptation scenarios" (Table 3).

Fig. 4 below describes the risk level for all the ACS by region for scenarios A and B; risk levels for all ACS under all scenarios can be found in Annex C. Risk values over 0.5 are considered as relevant to be cautious and to take some action while values over 0.7 are considered as requiring immediate action.

ACS that have largest accumulated biomass and current biomass, most of them in the Los Lagos Region, the oldest salmon farming macro area, generally show the highest risks (Figs. 3 and 4 and Annex A) even with the lowest level of threat, and this is relevant for immediate actions.

Scenario A with partially reduced (40%) access to farm sites and/or partial restriction to processing produces the lowest risks, reaching a value over 0.5 only in ACS 10B. Scenario B with more restrictive access measures (Table 3) produces increased risk values in both the Los Lagos and Aysén Regions. The highest risk level ACS are 9A, 10A, 10B, 11 in the Los Lagos Region, and 19A, 21 C and 34 in the Aysén Region (Table 1, Fig. 4). The Magallanes Region, which still has the lowest current and accumulated production, has the lowest risk levels (Fig. 4). This is relevant because salmon farming there is a newer activity and there are efforts to maintain more sustainable conditions such as management options that do not require antibiotic use in most cases.

The analysis continues by choosing the highest risk ACS in scenario B while "improving" pre-existing sanitary conditions by reducing antibiotic use to level 2 (scenario C) and reducing Exposure to level 4 (scenario D), named "adaptation scenarios" (Table 3). Clearly improving management conditions (represented here by a reduction in antibiotic use) produces a reduction in risk up to 20%, but the largest risk reduction takes place by reducing Exposure (Fig. 5); that is, the total biomass that could be lost due to the events resulting from the hazard. Given that the three components in the simple risk model have same weight, changes to either will be more significant than a change in one of the five elements of Sensitivity (in this case the use of antibiotics). Yet the three ACS with highest risk in the Los Lagos Region (Fig. 5) have in common medium to large biomass per ACS (Fig. 3), thus if something goes wrong, for example a very violent harmful algal bloom (HAB in one of these ACS as compared to others with lower biomass, the magnitude of the loss will be much greater. "Splitting (in a more equitable way) eggs in different baskets better" will split the risks. Diseases are not only more likely to outbreak in areas with higher current biomass but also in those that have largest cumulative biomass over time, as is the case in these ACS (Annex A). Thus, more conservative and better split production among neighbourhoods has reduced risk. Reducing average production per ACS is possible without reducing total production, since some ACS would need to increase biomass but ideally production to harvest and cumulative production should not increase beyond exposure level 3 (Table 2, Annex A). Such a management arrangement is not simple and requires analysis and/or consideration of the carrying capacity of each ACS, operating licence ownership, logistics, human resources, avoiding marine protected or conservation areas etc. Clearly these considerations can be relevant for any aquaculture system and are worth exploring with an ecosystem-based management.
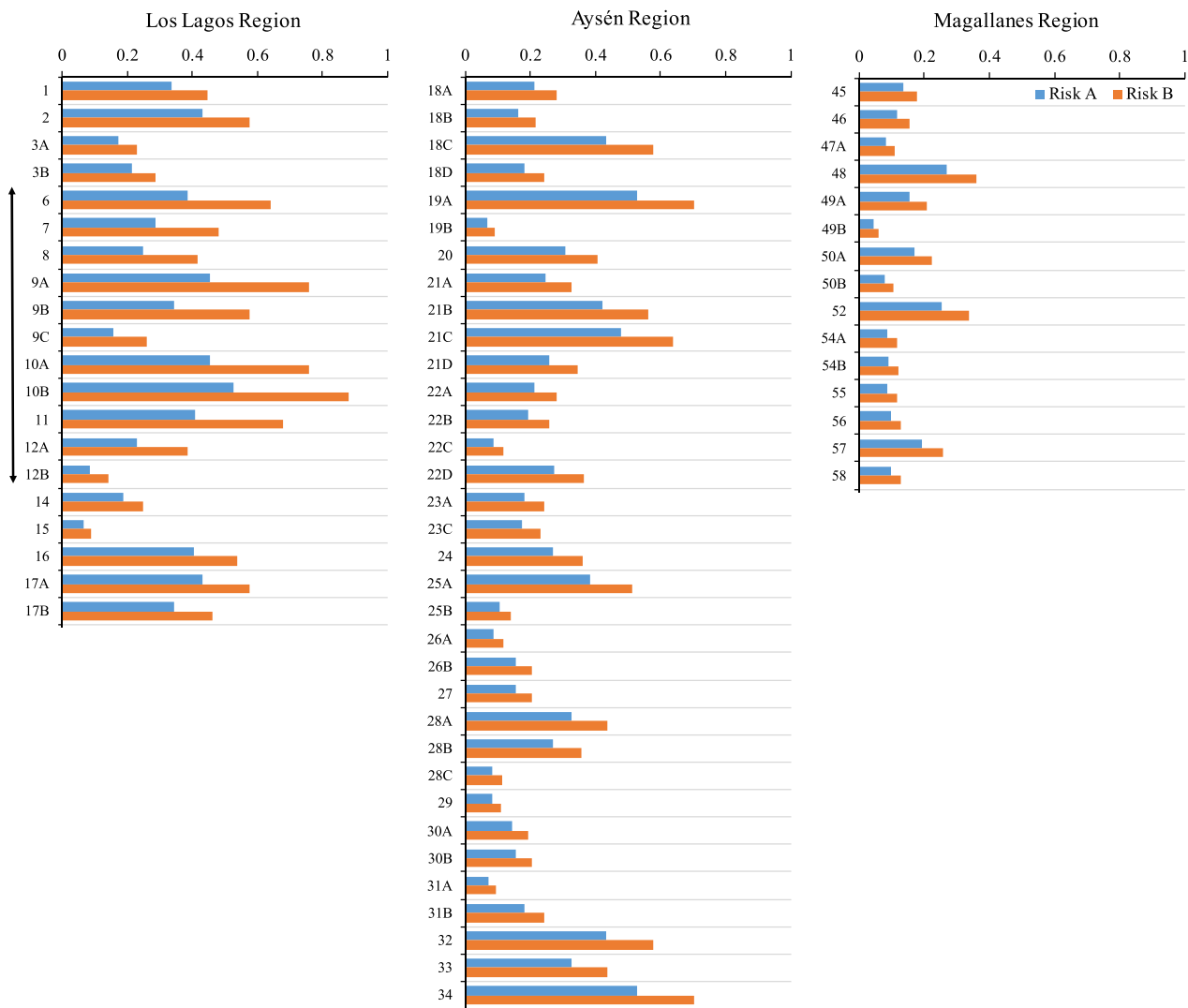
Fig. 4. Estimated risk level for each ACS considering baseline situation (Risk scenario A) and maximum access limitation to Chiloé Island, ACS 6–12B (indicated by the double-pointed arrow in the Los Lagos region, left figure) and level 4 elsewhere (Risk scenario B).
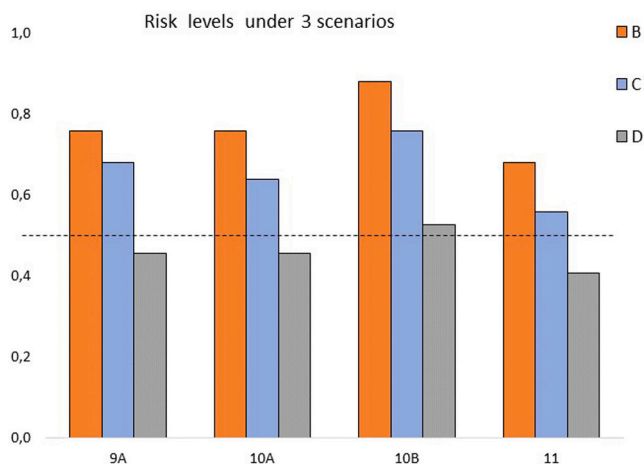

Fig. 5. Estimated risk level for ACS with the highest-level risk under scenarios B (maximum access limitation to Chiloé, Fig. 3), C (health management threat reduced to level 2) and D (reduced Exposure to level 3).

The ecosystem approach to aquaculture (EAA) is a strategy that could be useful to develop management plans for aquaculture areas and larger aquaculture zones [28] using risk assessment as normal tool for decision-making even on short notice. The way aquaculture is distributed in the marine ecosystem and considerations to the capacity of the environment to contain aquaculture become essential elements to manage risks and this is valid for any aquaculture or farming system.

In any case, the higher risk spatial units (e.g. Fig. 5) would require a higher level and quality of monitoring to ensure early warning and rapid management responses, also considering risks for the environment [21]. This is indeed a very relevant conclusion of almost any aquaculture risk assessment, ensuring appropriate monitoring, communication and early warning [10].

Scenario E with access restriction to maximum level only in Aysén shows increased risk level but in a smaller proportion of ACS (Fig. 6, Annex C) because even though total production in the Aysén region is slightly larger than in Los Lagos, it is more evenly distributed in a larger area in smaller-production ACSs (Figs. 1 and 3, Annex A).

It is important to consider that the risk of losing biomass often does not only imply the cost of lower production, investment loss etc. but also environmental risks such as those associated with disease outbreaks, large mortalities, escaped fish [24], absence of enough care, reduced feeding etc., or if fish remain in the farm beyond planned time.
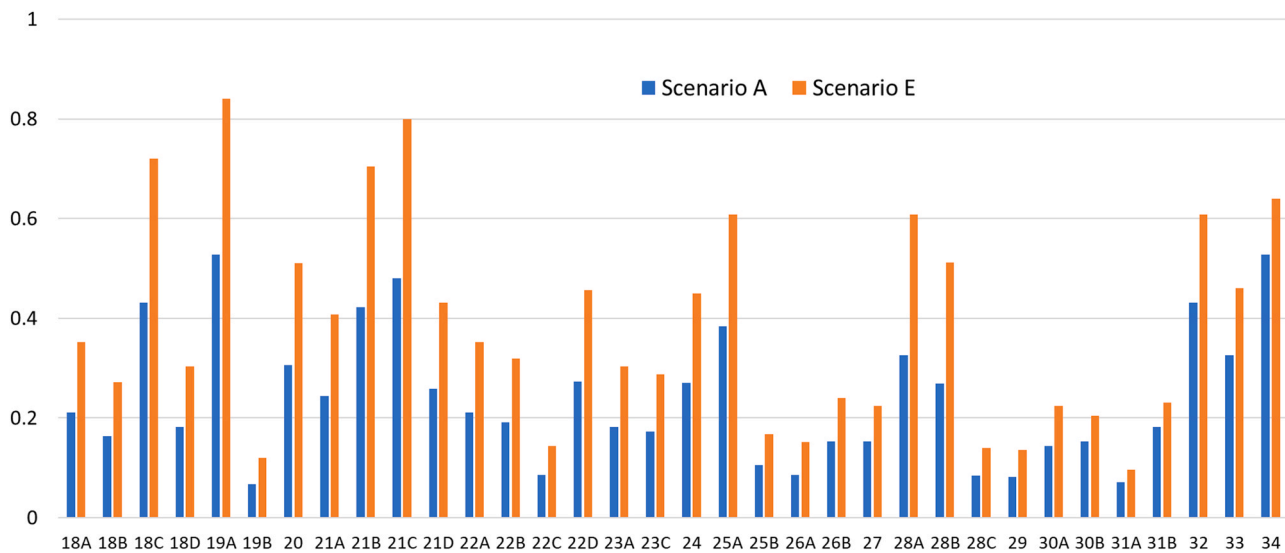
Fig. 6. Estimated risk level for ACS in the Aysén Region under scenarios A (equal restriction level 3 for all ACS) and E (maximum access limitation to the Aysén Region).

Lockdown conditions may ease or farm owners may find a way to maintain minimal access, but the limitation may be access to processing, in which case the fish may be kept in the farms for much longer than expected. This is considered as a level 3 threat.

We did not explore the impacts on *Risk* of modifying species composition by ACS, that is, the effects of reducing the dominance of Atlantic salmon and increasing proportionally the representation of Coho salmon and trout. However, a more diverse production of the three species by ACS should contribute significantly to reduce disease risks because both Coho and trout are more resistant to *Caligus* (sea lice) and are not so affected by SRS due to shorter and different life cycles. Thus these species could possibly resist longer without optimal care and assistance and help to reduce the spread of fish diseases. Why is there a dominance of Atlantic salmon? Probably mainly because of market demand and better prices. Yet a more diverse salmon farming would be more resilient and could probably have lower environmental impacts. This appears to be another example of a market failure in which prices do not include the social and ecological cost of less diversified production due to potential increase in risk and vulnerability. Interventions toward correction of this failure have a role in improving resilience and sustainability of salmon farming beyond individual farm certification, which is the most common way at the moment.

4.2. Risk level by commune, results and implications of different scenarios

Some of the Chiloé communes have larger area shares of the highest risk ACS and therefore their risk level is higher, namely; Curaco de Velez, Castro, Puqueldón and Chonchi (Table 4). Risk levels per commune are diluted in Aysén because there are many ACS with lower risk (Fig. 6), mostly due to the fact that their biomass is not very high (Annex A) and they are spread over three communes covering larger geographic areas (Figs. 1 and 3). Even when there is maximum restriction access to Aysén, which shows some ACS with high risk, this is much lower in the communes (Table 4).

A drawback of the modelling approach used is that it gives equal weights to all the different sensitivity factors (Table 2), including the distance between the ACS and nearest port and/or processing point, and it is possible that this is a more relevant factor when facing an emergency. This could be relevant for communes such as Cisnes and Guaitecas that are very remote (Fig. 1), therefore risks could be underestimated with the current approach. This can easily be revised and changed in future analysis.

Table 4

Estimated risk values for each Commune for the different scenarios.

Los Lagos Region	A: baseline	B:max restriction access Chiloe	C: as B but with reduced AB	D:as B with reduced E	E: max restriction access to Aysén
Cochamó	0.3	0.4	0.4	0.4	0.3
Puerto Montt	0.4	0.6	0.6	0.6	0.4
Hualaihué	0.4	0.5	0.5	0.5	0.4
Calbuco	0.3	0.4	0.4	0.4	0.3
Ancud	0.4	0.6	0.6	0.6	0.4
Quemchi	0.3	0.6	0.5	0.5	0.3
Dalcahue	0.3	0.6	0.4	0.4	0.3
Curaco de Vélez	0.5	0.8	0.7	0.5	0.5
Castro	0.5	0.8	0.6	0.5	0.5
Quinchao	0.4	0.6	0.5	0.4	0.4
Puqueldón	0.5	0.8	0.7	0.5	0.5
Chonchi	0.5	0.8	0.7	0.5	0.5
Queilen	0.4	0.7	0.6	0.4	0.4
Quellón	0.2	0.4	0.4	0.3	0.2
Chaitén	0.3	0.4	0.4	0.4	0.3
Aysén Region					
Guaitecas	0.3	0.4	0.4	0.4	0.4
Cisnes	0.3	0.4	0.4	0.4	0.5
Aysén	0.2	0.3	0.3	0.3	0.3
Magallanes Region					
Natales	0.2	0.2	0.2	0.2	0.2
Rio Verde	0.1	0.1	0.1	0.1	0.2
Punta Arenas	0.1	0.2	0.2	0.2	0.2
Cabo de Hornos	0.1	0.2	0.2	0.2	0.2

4.3. Vulnerability per commune and the role of adaptation capacity

Vulnerability and adaptation capacity indicators have been widely used within the climate change community and are slowly being used to evaluate the COVID-19 pandemic [7]. Yet it may be relevant to consider the vulnerability to shocks and adaptation capacity of the food production and natural resources sectors such as fisheries and aquaculture on a permanent basis. Such information and understanding can help to improve and strengthen resiliency mechanisms to face new shocks or even longer lasting ones such as those related to climate change. To analyse the resiliency of a sector such as salmon farming it is necessary

to consider not only the farming and management aspects but also the governance aspects and local public administrative conditions where farming and processing takes place, since the sector cannot adapt in isolation of government institutions, policies and even civil society [29]. Therefore, analysing vulnerability of the sector in communes, the smallest scale political level where decisions and actions take place in current study, is relevant.

Adaptation capacity (AC) indicators and the overall AC index per commune are shown in Table 5, while Fig. 7 shows both components of vulnerability, R and AC. Adaptation capacity based on the selected indicators shows larger values in larger cities or regional capitals and cities where the processing plants are located, such as Puerto Montt, Castro, Quellón, Puerto Aysén, Puerto Natales and Punta Arenas (Table 5). These communes generally have lower vulnerability. The most vulnerable communes, Curaco de Velez, Puqueldon and Chonchi, are those that showed highest risks because most of them have comparatively lower AC (Fig. 7). Yet these communes are not very far from a larger city such as Castro, therefore it is also possible to consider AC based on collaboration or networks of communes, which is not explored here.

Since some of the shocks described here are related to hampered access to the farm sites or to the processing plants due to COVID-19 threats (to people), an alternative vulnerability situation for risk scenario B (Table 3) including improved adaptation capacity indicators was modelled. The purpose of this analysis is to explore the potential of local adaptation capacity to compensate for risks and thus reduce vulnerability to shocks. The analysis increased the quality of local higher education (reaching 50%), increased local employment (to reach 80%), improve health care facilities (to reach 75% of the optimal situation such as in the largest city, Puerto Montt) and local coordination capacity of institutions (to reach 60% of the optimal condition). As a result, the overall AC index increased and vulnerability declined by 20–30% in most communes (Fig. 8).

Table 5

Adaptation capacity indicators and Index per commune. PD = Proportion of population dependent on salmon farming activity; SC = Salmon farming contribution (taxes) to the Commune Municipal local income (proportion); EC = Proportion of farm and processing plant employees that reside in the commune; SE = Proportion of the population with secondary education; CCI = Coordination capacity index; HH = Access to high quality human health care systems index.

Communes	P.D	S.C	E.C	S.E	C.C. I*	H.H	Adaptation Capacity Index
Cochamó	0.04	0.28	0.30	0.13	0.30	0.25	0.22
Puerto Montt	0.07	0.01	0.90	0.29	0.60	1.00	0.48
Hualaihué	0.02	0.48	0.30	0.13	0.30	0.25	0.25
Calbuco	0.14	0.26	0.50	0.13	0.30	0.50	0.30
Ancud	0.17	0.03	0.50	0.18	0.30	0.75	0.32
Quemchi	0.02	0.64	0.50	0.08	0.30	0.25	0.30
Dalcahue	0.09	0.10	0.50	0.12	0.30	0.25	0.23
Curaco de Vélez	0.04	0.47	0.50	0.14	0.30	0.25	0.28
Castro	0.34	0.03	0.80	0.23	0.60	1.00	0.50
Quinchao	0.02	0.62	0.50	0.15	0.30	0.50	0.35
Puqueldón	0.04	0.63	0.50	0.08	0.30	0.25	0.30
Chonchi	0.01	0.15	0.50	0.14	0.30	0.25	0.23
Queilén	0.03	0.54	0.50	0.11	0.30	0.50	0.33
Quellón	0.28	0.17	0.80	0.13	0.50	0.50	0.40
Chaitén	0.04	0.50	0.30	0.20	0.20	0.50	0.29
Guaitecas	0.11	0.35	0.10	0.16	0.20	0.25	0.19
Cisnes	0.12	0.78	0.30	0.20	0.20	0.50	0.35
Aysén	0.24	0.35	0.30	0.21	0.20	0.75	0.34
Natales	0.07	0.16	0.50	0.23	0.50	0.75	0.37
Río verde	0.09	0.52	0.10	0.32	0.20	0.25	0.25
Punta Arenas	0.01	0.00	0.30	0.34	0.60	1.00	0.37
Cabo de Hornos	0.04	0.08	0.10	0.37	0.20	0.75	0.26

* (0 = null, 1 = optimal coordination capacity between relevant institutions).

Interestingly, the effect of local capacity on vulnerability is a long-run, permanent effect, as it involves increasing human and social capital, strengthening institutions and changing perceptions of the local coastal communities about the industry. Thus reducing vulnerability by increasing local adaptation capacity may also contribute to improve governance, and there is increasing literature support for this [29].

Clearly the increase in local employment not only will reduce COVID-19-related biosecurity issues but will also increase local dependency, local ownership and a stronger community acceptance of salmon farming activity, which could aid industry functioning during the pandemic. This requires greater efforts toward mutual trust between the activity and the local civil society, and will also require greater effort to develop local technical capacities, especially in more remote villages and communes in Aysén and Magallanes. Greater ownership of the sector would undoubtedly also reduce the risk itself because it can reduce hazards such as societal pressure to lock down localities. Improved integration of social aspects in the planning and management of aquaculture locally seems to be essential and goes beyond tax contributions and/or farming companies' social contributions to local communities but rather involving long term local labour and a sense of belonging to the sector or ownership [also see 29].

Having local well-trained trusted technical people to care for the farms can also improve fish welfare, health and environmental conditions around the farms, also reducing risk. Therefore, improving the level and quality of education locally essential to reduce vulnerability to the analysed threats.

The vulnerability assessed per commune has mainly comparative value, allowing analysis of its two components to increase overall resilience of the commune where the activity takes place and of the sector as a whole. Clearly the salmon industry functions at a much broader geographic scale. Often main offices of the different companies are in the main cities/communes[3] near processing plants and airports.[4] These cities also have better higher education options, so most likely a larger proportion of the direct employment of sector concentrates in these cities.

5. Conclusions and main take-home messages

The COVID-19 pandemic has caused more than 2 million deaths by early 2021 and has caused global disruption of food production systems, trade, transport, etc. Such disruptions generate different types of threats for natural resource production systems whose consequences are still uncertain, therefore it seems reasonable to borrow risk and vulnerability assessment frameworks from climate change science and policy to study vulnerability of natural resource-based industries.

A relevant difference with climate change science may be that we are dealing with a threat that is happening while this manuscript is being prepared but whose temporal extension and consequences are not known. Of course, compared to climate change the current situation can be considered as a short-term pressure on human systems. Short-term pressures (i.e. a couple of years) of this kind provide a unique opportunity to test the resilience of natural resource-based sectors such as fisheries and aquaculture that depend strongly on foreign market demand.

The modified climate change framework used here to perform a risk and vulnerability assessment of salmon farming to the COVID-19 pandemic-associated threats can be useful also for the analysis of other aquaculture systems and even fisheries systems elsewhere, provided that relevant information is available.

Hopefully when the current global pandemic is over there will be an

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[3] The information was provided by the "Servicio de Impuestos Internos" (SII) through the "Estadísticas de empresa"[30]

[4] Puerto Montt, Castro and Quellón in the Los Lagos Region, Puerto Aysén-Balmaceda in Aysén, Puerto Natales and Punta Arenas in Magallanes (Fig. 1).
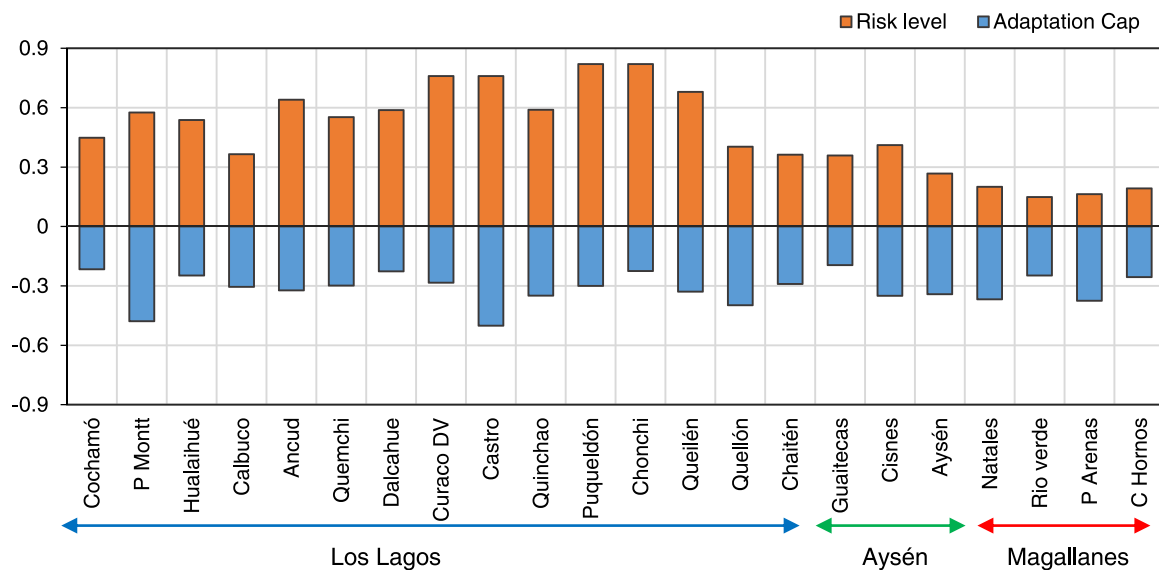
Fig. 7. Vulnerability components with Risk (scenario B) as the positive orange bars and Adaptation Capacity the blue negative bars, thus vulnerability increases with risk and decreases with Adaptive Capacity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
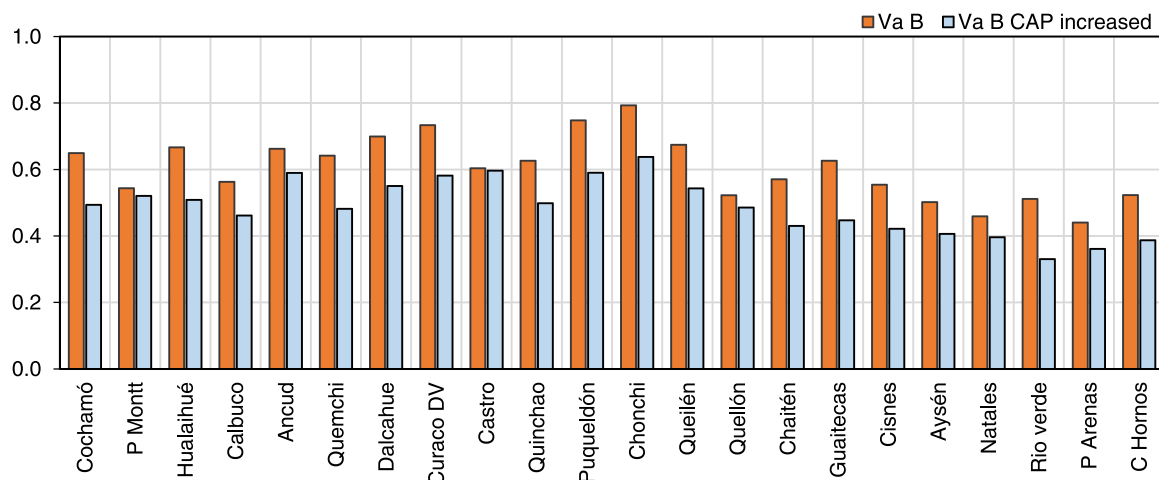

Fig. 8. Vulnerability for every commune under scenario B (Va B) and under the same conditions but with significant improvement in capacity of adaptation (Va B CAP increased). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

opportunity to test some of the present assessment predictions. Lessons from such analysis could be useful to improve resilience to different kind of threats to the sector and could also be useful to other aquaculture systems and even to other farming systems.

Farming concentration, density and management conditions of any aquaculture system will generally affect its resiliency in the face of shocks. Better management practices are known as win-win approaches or non-regret approaches [21,31] in climate change adaptation; many practices could help under the hampered market system which is forcing aquaculture production to stay in the water beyond the planned time, as it has been worldwide under the COVID-19 pandemic.

Although in our analysis there are no specific ecological and productive carrying capacity indicators [see 32] for the salmon farming neighbourhoods (ACS), the current production and especially the cumulative production per area provide comparative proxies of the use intensity of each neighbourhood, which correlate with risks to both the production and the environment [21,24]. Thus, consideration of ecosystem carrying capacity is essential to limit maximum production per water body to reduce aquaculture risks under almost any kind of external stressor and greater efforts are needed to effectively introduce

the concept into policies [33].

The analysis of this study underscores the need for a more strategic and risk-based approach to the marine spatial distribution of aquaculture production, considering not only fish biosecurity but also heterogeneous environmental and social risks. Clearly, the design, distribution, and management of salmon farming areas in southern Chile can be improved with such considerations. Reducing the average production per ACS to reduce fish health risks, harmful algal bloom risks, hypoxia conditions, etc. [21,22] is possible without reducing total salmon production. However, this is not simple and requires, among others, the analysis and consideration of each ACS carrying capacity, operating licence ownership, logistics, human resources, respecting conservation areas, interinstitutional and public-private cooperation.

Our study suggests that better management practices, less stressed fish with no diseases and parasites can resist much better periods of fasting and/or with lower care. This is one of the best adaptation approaches to face other external stressors such as climate variability and climate change.

Improving local employment can be a win-win management measure to improve adaptation capacity under the COVID threat but also under

almost any threat. Local specialized personal can handle issues and deal with changing management faster. A larger footprint in local economies and employment can improve significantly and permanently social perception and acceptance of the sector, consequently contributing to improve governance. Improving coordination capacity even in the more remote communes including both inter-institutional and public-private coordination is essential to address disasters and emergencies. During the present study there has been increasing evidence of coordination and collaboration efforts within the salmon industry, with government and with other sectors to face the difficulties of the quarantine and other pandemic-related measures. Actions tend to be more successful around larger communes and cities and less effective in remote areas [also see 21]; additional efforts are needed to design innovative emergency protocols.

Tax revenue contributions to the farming communes can be a good resilience mechanism but we must ensure that such income is spent on increasing communal resiliency. This contribution can be very relevant, especially given current conditions where other relevant sectors such as tourism are also shut off and are likely to be for much longer after the pandemic is over. Supporting and even increasing such taxes provides resilience to the commune during the shock, for example increasing emergency assistance, and could contribute to rebuild social and economic conditions after it.

Salmon farming is likely to be one sector that will recover faster from the pandemic effects than others such as tourism and even fisheries, as international salmon demand starts to recover (rebound effect) in countries that are already overcoming the crisis. Therefore, the sector could become more important than ever for local employment, livelihoods and development, including tax contributions to communal income, and all efforts must be made to ensure sustainable management of the production.

Finally, spatial distribution of marine fish farming according to carrying capacity, better management, better local governance and other strategic considerations will be essential if mariculture is going to contribute to food security in the future, considering ocean sustainability and uncertainty including climate change [34], and unexpected global events such as that produced by the COVID-19 pandemic.

CRediT authorship contribution statement

Doris Soto: Conceptualization, Methodology, Investigation, Data curation, Writing - review & editing, **Carlos Chavez**: Investigation, Writing - review & editing, **Jorge León-Muñoz:** Methodology, Data curation, Writing - review & editing, **Carol Luengo:** Methodology, Investigation, Data curation- review & editing, **Yuri Soria-Galvarro**: Investigation, Data curation.

Declaration of Competing Interest

The authors declare no conflict of interest with local authorities or data providers.

Appendix. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104486.

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