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Exploring the adaptive capacity of the mussel mariculture industry in Chile

Valeska A. San Martin[a,c,*], Felipe Vasquez Lavín[b,c,d,e], Roberto D. Ponce Oliva[b,c,d], Ximena Paz Lerdón[f], Antonella Rivera[d,g], Leticia Serramalera[c,d], Stefan Gelcich[c,d,e]

[a] Department of Economics, Universidad de Concepcion, Concepcion, Chile
[b] School of Economics and Business, Universidad del Desarrollo, Concepcion, Chile
[c] Center for the Study of Multiple-Drivers on Marine Socio-Ecological Systems (MUSELS), Universidad de Concepción, Concepción, Chile
[d] Center of Applied Ecology and Sustainability (CAPES), Pontificia Universidad Católica de Chile, Santiago, Chile
[e] Millennium Nucleus Center for the Socioeconomic Impact of Environmental Policies (CESIEP), Chile
[f] Department of Economic and Finance, School of Business Sciences, Bío-Bío University, Concepción, Chile
[g] The Coral Reef Alliance, 1330 Broadway, Suite 600, Oakland, California 94612, USA

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ABSTRACT

Societies have adapted to climate and environmental variability throughout history. However, projected climate change poses multiple risks to mariculture because of the increased frequency of environmental threats that lie outside the realm of present day experience. Adaptive capacity evaluated in this study is a characteristic that would reflect mariculture industries ability to anticipate and respond to these changes, and to minimize, cope with, and recover from the consequences and take advantage of new opportunities arising from change. Drawing on a survey to 90 mussel mariculture companies in Chiloe-Chile, we have characterized the way the industry has adapted and recovered from specific stressors in productive capacity, namely; reduced mussel growth rates and reduced larval supply. We additionally assess determinants of the mussel industry's willingness to invest in building capacity to anticipate changes through analysing mussel aquaculture companies' assets to draw upon in times of need (capital; access to credit), the flexibility to change strategies, the companies' perception of the industry's social organization to act collectively (social capital), and their response to hypothetical scenarios regarding shocks in productive capacity. Results show heterogeneity in production decisions when facing environmental stressors. Results also show that the industry adapts in heterogeneous ways and that financial assets and social capital drive willingness to invest in adaptive capacity. Understanding past adaptation strategies and the willingness of the industry to invest in anticipating stressors allows us to begin exploring the consequences of new stressors. Importantly, as Chile and other countries are developing adaptation plans to face the multiple stressors of climate change, information about stakeholders' existing adaptation strategies and their determinants is becoming a critical bottleneck to inform these processes and assure they are in line with stakeholder needs and interest. While we use the Chilean mussel industry as a working example, the approach presented can inform other countries/regions wishing to explore the adaptive capacity of their aquaculture sectors.

1. Introduction

Aquaculture is the fastest growing food production system in the world (Asche et al., 2013; FAO, 2018a). In fact, aquaculture in the ocean's coasts and estuaries has increased its production from 51.7 million tonnes in 2006 (FAO, 2008) to 80.0 million tonnes in 2016, of which 17.1 million tonnes are molluscs (FAO, 2018a). Based on current per capita consumption targets and population growth trends, mariculture has been proposed as the best means of satisfying the world's growing demand for aquatic food products (Duarte et al., 2009). Mariculture could contribute substantially to the income, livelihoods, nutrition and therefore, to the indirect food security of many millions of people (Allison, 2011; Béné et al., 2015). The rapid expansion of mariculture is taking place mostly in developing or underdeveloped countries, areas that are highly exposed to human-induced climate change and depend for a major part of their livelihood on resources whose distribution and productivity are known to be influenced and dependent on local environmental climatic and oceanographic conditions (Handisyde et al., 2017; Allison et al., 2009; Allison et al., 2005).

Mariculture benefits are potentially reduced through the increases in uncertainty that climate change brings (Barange et al., 2014). Vulnerability to climate change is often conceptualized as being made up of

* Corresponding author at: Department of Economics, Universidad de Concepcion, Concepcion, Chile.
E-mail address: valezkasanmartin@gmail.com (V.A. San Martin).

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three dimensions: exposure to change (e.g. increases in ocean acidification); sensitivity to change (e.g. how much mariculture would be affected by ocean acidification); and the capacity to anticipate, respond to, and recover from change (referred to as adaptive capacity) (Adger, 2006; Allison et al., 2009; Ekstrom et al., 2015). Studies indicate that dimensions of exposure and sensitivity determine the potential impact generated by a change, while the capacity for adaptation influences the final impact on mariculture and society (Cinner et al., 2015). In addition, adaptive capacity relates to the capacity to recover from the losses derived from climate impacts and exploits the new opportunities that arise in the adaptation process (Allison et al., 2007).

Societies have adapted to climate and environmental variability throughout history (Adger and Vincent, 2005). However, future climate change projections for mariculture pose multiple risks due to environmental threats presented with increasing frequency (Adger et al., 2003). Adaptive capacity reflects the capacity of the mariculture industries to anticipate, modify and/or respond to the risks associated with climate change and to minimize, confront, and recover from the consequences, exploiting new opportunities arising from the adaptation process (Adger and Vincent, 2005; Grothmann and Patt, 2005). In this way, high levels of adaptive capacity would be associated to greater chances to deal with the changes (Handisyde et al., 2017). After the Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (AR4 IPCC), scientific literature has established a series of conceptual frameworks to deal with adaptive capacity (Hughes et al., 2012; Cinner et al., 2015; Cinner et al., 2018). Many of these frameworks consider breaking the concept down into dimensions, such as assets, the role of flexibility, learning, and social organization (Cinner et al., 2018; Hughes et al., 2012; McClanahan and Cinner, 2012). Establishing key dimensions has been helpful to assess potential strengths and weaknesses in adaptive capacity (Hughes et al., 2012; Cinner et al., 2018).

Mussel mariculture provides a unique setting for studying adaptive capacity, it is a growing industry which is composed of small rural producers and large-scale farms, in which production depends on natural supply of larvae and natural food availability (Kroeker et al., 2016; Menge et al., 2009). Mussel mariculture is at risk of being affected by multiple climatic stressors, such as variations in salinity, temperature, reduced pH (Ocean Acidification), and dissolved oxygen and nutrient (Range et al., 2014; IPCC, 2007). These environmental threats could affect the life cycle of shellfish with adverse effects on their productivity, viability, nutritional quality, or market value, which may have relevant societal implications (Ponce Oliva et al., 2019; San Martin et al., 2019; Cooley et al., 2011). Despite the growing body of knowledge, considerable gaps still remain on the adaptive capacity of mariculture, mainly: 1) our basic understanding of how mariculture has devised local-scale adaptive strategies and how they can vary according to different scales of operation (large mariculture enterprises, small enterprises) and 2) understanding the determinants of the industry's willingness to invest in building capacity (i.e., knowledge) to anticipate for change.

Drawing on the previous adaptation experiences of the mussel industry in Chile, we characterized the way in which the industry has responded and recovered from the stressors in productive capacity due to reduced growth rates and reduced larval settlement. We additionally determine industry drivers for investing in building capacity to anticipate change. We assess willingness to invest in building capacity to anticipate changes through analysing mussel aquaculture company assets to draw upon in times of need (capital, access to credit), the flexibility to change strategies, the companies' perception of the industry's social organization to act collectively (social capital) and their trust in science. While we use the Chilean mussel mariculture sector as a working example, the analysis can inform other countries/regions wishing to explore the adaptive capacity of their mariculture sectors.

2. Material and methods

2.1. Case study

Chile is currently the country with the highest growth rate in mussel mariculture (FAO, 2016). From the early 1990s to 2012 production has increased from 3000 to 257,800 tons, with a record year in 2017 exceeding 300,000 tons (FAO, 2017; FAO, 2018b). In addition, at the time of this study, the mussel mariculture industry had suffered two important crises, one in 2009–2010, which related to the lack of microalgal food (Lara et al., 2016; FAO, 2017) and another between 2011 and 2013, a larval supply crisis, which caused a reduction in mussel harvest of 18% between 2011 and 2014 (SSPA, 2014; Figueroa and Dresdner, 2016). Studies have also shown the potential detrimental impacts of multiple stressors over mussel aquaculture under different acidification scenarios (Gazeau et al., 2010; Bibby et al., 2008; Parker et al., 2013).

2.2. Research setting: mussel mariculture in Chile

In Chile, mussel mariculture began in 1943 in Quellón, Chiloé (Navarro and Gutierrez, 1990). In 1967, semi-intensive suspension systems began to be used (López et al., 2008). At the beginning of the 1980s, due to the growing demand, the private sector developed the commercial cultivation of mussels (Díaz, 2010). Although the extraction of *Mytilus chilensis* dates from 1930–1940s, the development of commercial scale cultivation began in the 1990s (Plaza et al., 2005), with the arrival of Spanish capital that invested in processing plants and the opening of international markets. These factors led the industry to an exponential growth phase. Chilean mussel production is mainly exported to Spain, the United States of America, Russian Federation, France, and Italy (FAO, 2017).

Mussel production is divided into four stages: seed collection, grow-out, processing and marketing or export (Gonzalez-Poblete et al., 2018; Rivera et al., 2017). The mussel production cycle lasts between 14 and 20 months, beginning in the spring with the natural collection of larvae in the estuaries of the Los Lagos Region. One hundred percent of the *seed uptake* process is obtained from the natural environment by artisanal fishers, who act as aquaculture entrepreneurs (Fernández et al., 2018; Saavedra Gallo and Macías Vázquez, 2016). Competent planktonic larvae are collected with suspended artificial substrates through ropes that hang from buoys at different depths in the water column and deployed in areas of high larval availability (Lara et al., 2016; Avendaño et al., 2011). Then, these ropes are transferred to different areas to the culturing systems for *fattening* and growing around 12–18 months in relation to environmental conditions and food availability. The *processing stage* corresponds to the cleaning and packaging of the raw material received from the growing sites, to be sent to the final markets (Díaz, 2010). The final product can be marketed in several ways, including fresh, frozen, ice-packed, vacuum-packed or cooked and processed. Exported products come in a frozen form, either shell-on, in half a shell, or as individually quick frozen (IQF) meat (Monfort, 2014).

Most of the mussel mariculture in Chile is developed on the inner sea of Chiloé (Gonzalez-Poblete et al., 2018; Figueroa and Dresdner, 2016; Fernández et al., 2018). This activity is subject to multiple sources of variability, including environmental and anthropogenic disturbances (Barria et al., 2012; Goldburg et al., 2001). In addition, previous studies have indicated that phytoplankton biomass and sea surface temperature can alter larval supply and growth rate (Lara et al., 2016; Figueroa and Dresdner, 2016). Although hatchery technology is available, it is seldom used due to the high cost/benefit ratio.

Each stage of production is carried out by specialized actors, in this research, we focused exclusively on actors involved in the growth production phase. These actors depend both on the supply of larvae, as they have to buy it from suppliers, and on the environmental conditions, which determine growth rates. This activity is also most likely

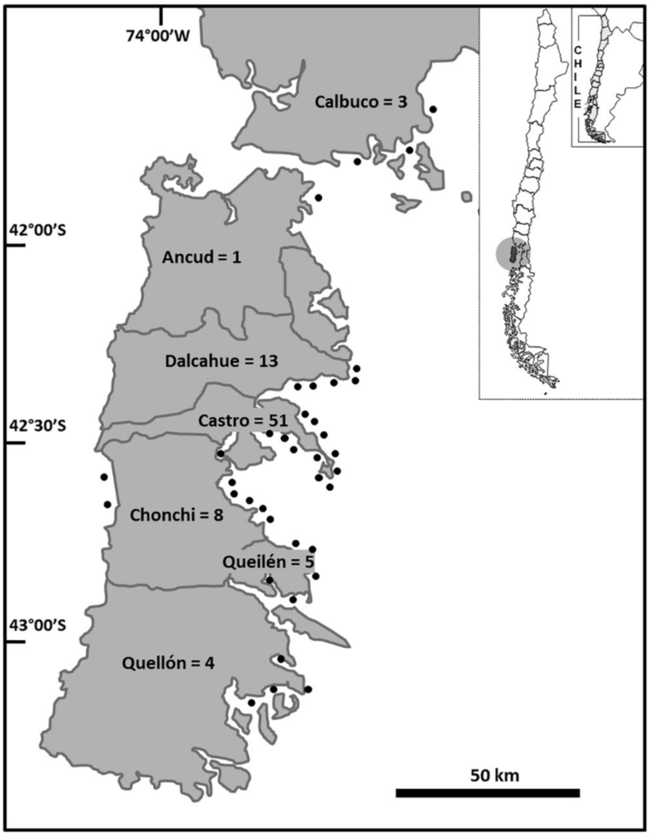

Fig. 1. Map of the Region of Los Lagos study area. Different areas ($n = 7$) where surveyed and questionnaires were distributed among producers: small $n = 25$, medium $n = 43$ and large $n = 17$. Two interviewees did not give information about the total production per season and were not considered in the data set (final sample size: $n = 85$).

subject to market fluctuations (demand and prices). In addition, actors involved in the growth production phase are the most heterogeneous in the production chain and can range from small producers to large ones (Fernández et al., 2018).

2.3. Field methods

Data collection was conducted on the island of Chiloé (42° 40′ 36″ S; 73° 59′ 36″ W) (Fig. 1) over the period from November 2014 to February 2015 through face-to-face interviews with mussel farmers, with a total of 87 questionnaires answered.

Interviewees informed about their total production per season and self-classified into groupings according to production. Interviewees were classified into 3 groups as: small, with a total production of < 400 t / season, medium, with a total production between 400 t/season and 1350 t / season, and large, with a total production of > 1350 t / season.

2.4. Survey

Through information obtained from semi-structured interviews with key representatives of the mussel industry, we designed and administered 87 surveys (out of 148 nationwide firms), between November 2014 and February 2015, to firm representatives. The survey was tested through one pilot study (10 observations). The final version of the survey included four sections.

I. *Perception*: This section provides information on the main impact of different environmental and social factors. For this evaluation, a list of potential threats was used, asking the producer: How important are these threats to your business? A scale of 1 to 10 score was used, where 1 is not important and 10 is very important.
II. *Past responses to perturbations*: Here, we asked about the past responses to two specific disturbances in the following way: (1) Do you consider that the food crisis (under nutritional supplement by phytoplankton) that affected fattening in 2009/2010 harmed your business? and (2) Did the crisis of reduction of seeds presented in the year 2012, damage your business? Both were closed questions with two options: yes or no. Furthermore, we also asked: (3) What were the main effects on your business? and (4) What were the measures taken after these crises? Both corresponded to open-ended questions.
III. *Contingent behaviour*: Here, we asked what would their reactions be in the presence of two different hypothetical scenarios. The scenarios are used for several reasons, including helping us explore the ability of people to anticipate change and to develop strategies to respond (Cinner et al., 2011). The mussel producers were asked what they would do in response to (1) 50% declines in their normal production and (2) 50% decrease in the international market price. For the answers, there was a list of possible options to choose from, among them the option of "other" was considered (if your answer did not match the mentioned options). In addition, the interviewee was consulted about the time the centre was willing to remain in production during the chosen situation.
IV. *Relations between different adaptive capacity dimensions and Willingness to pay for early warning program*: This section defines adaptive capacity through five dimensions related to: **Assets** = financial, technological, and service resources that people have access to (Cinner et al., 2018); **Social Capital** = reflects the organization to allow (or inhibit) cooperation and the exchange of knowledge for the collective good (Moser and Stein, 2011); **Agency** = capacity that peoples have to freely choose how to respond to events that affect their lives (Bandura, 2000); and **Flexibility** = this dimension reflects opportunities for switching between adaptation strategies and captures the diversity of potential adaptation options available as well as the capacity to shift into different occupational sectors. These dimensions determined the willingness to invest in the anticipating of change (**Learning**), essential capacity of knowledge construction, and learning to generate and process disturbance information, evaluating possible answers (Badjeck et al., 2010). Finally, through contingent valuation (CV), we evaluated the industries willing to pay (WTP), a positive amount of money, for a hypothetical program that could provide an early warning signal to the industry, which would aid in anticipating changes in the marine environment.

CV uses questionnaires to elicit economic agents' WTP for a good or service, creating a hypothetical market in which people can declare their preferences for the good. There have been thousands of CV applications in diverse areas of economics; the main results have been summarized in numerous publications on theoretical and empirical issues (Bateman et al., 2001; Carson et al., 2003; Hoyos and Mariel, 2010).

Econometric specification: Each industry representative was asked about the maximum amount of money that she/he would be willing to pay (WTP). A regression between WTP and the set of explanatory variables described above was performed. As the dependent variable is truncated at zero (we cannot observe values lower than zero) the maximum likelihood estimator was used. Using the traditional ordinary least square regression would bias the estimates. This model is known as the TOBIT model in econometrics, (Amemiya, 1984). The equation estimated is:

$$y_i = \beta' x_i + u_i \quad (1)$$

where y_i is the individual's WTP, $i = 1,2\ldots,N$ denotes individuals; x_i is a

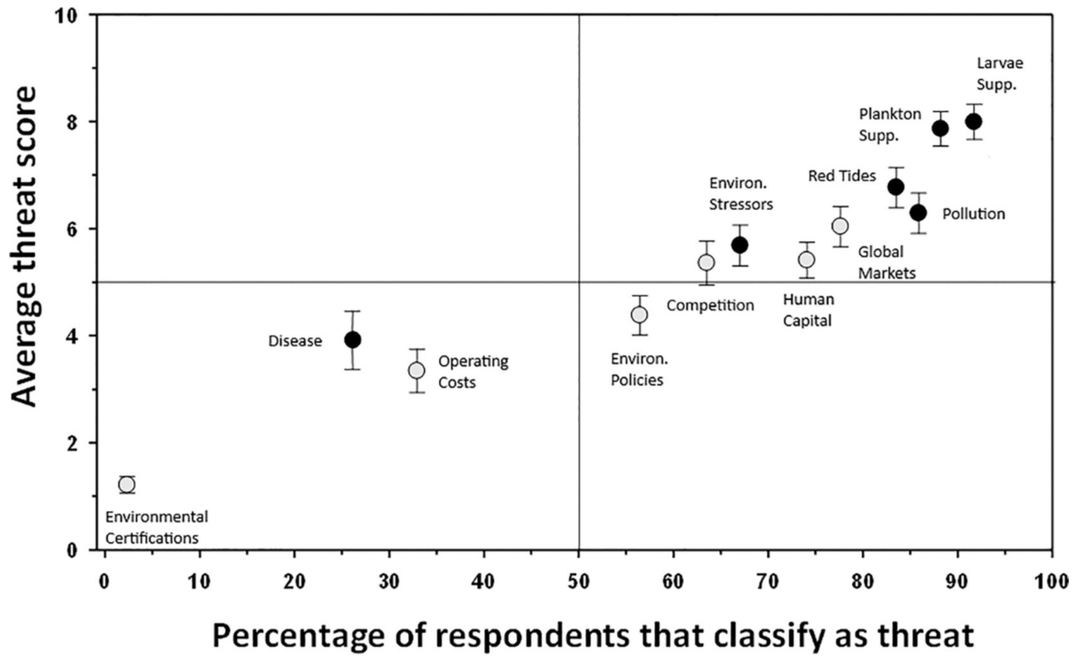

Fig. 2. Mussel producers' perceived level of importance on different threats. Dark circles show environmental threats and grey circles social threats. Bars represent the mean ± SE.

vector of explanatory variables, and u_i is an error term with mean zero and variance σ^2. Eq. (1) is identical to the multivariate regression equation, but we need to consider that the dependent variable can only take nonnegative values and that we will have two types of respondents, those that have a positive WTP ($y_i > 0$) and those whose WTP = 0 ($y_i = 0$).

Therefore the maximum likelihood function is given by:

$$l(\beta,\sigma) = \prod_{j=1}^{N}\left(\frac{1}{\sigma}\varnothing\left(\frac{y_i-\beta' x_i}{\sigma}\right)\right)^{d_i}\left(1-\Phi\left(-\frac{\beta' x_i}{\sigma}\right)\right)^{1-d_i}$$

Where d_i takes the value 1 if $y_i > 0$ and 0 if $y_i = 0$. Moreover, $\varnothing(\cdot)$ is the standard normal density function and $\Phi(\cdot)$ is the corresponding cumulative distribution function. By maximizing the likelihood function it is possible to estimate both parameters of interest (β and σ).

3. Results

3.1. Perception

The threats with the highest level of importance for producers are associated with environmental stressors (Fig. 2) related to the main crises experienced in aquaculture: plankton supply and larvae supply (over 85%), followed by red tides and pollution (80–85%). On the other hand, the social threats are viewed as secondary nuisance, with only 5–80% of the respondents classifying them as a threat.

3.2. Past responses to perturbations

When consulting the different groups of producers on the phytoplankton crisis of the year 2009 (decrease in food by phytoplankton), most of them suffered effects (Fig. 3a). Small producers were the most affected (91,67%) (Fig. 3a). Considering only the producers that were affected, 65% delayed the harvesting and 35% decreased their production (Fig. 3b). On the contrary, for the medium and large groups of producers, the main response to the crisis was decreasing their production followed by delaying the harvesting date.

In the face of the 2009 crisis, producers responded and managed the uncertainty of stress differently. Forty seven percent of total respondents indicated that the main action was to sell the available products and save money and assets to invest the following year (Table 1). However, 34.67% simply extended the growth phase, while a smaller percentage (15%) decided to abandon the activity until next season.

3.3. Contingent behaviour

The contingent behaviour of producers against hypothetical scenarios of possible decrease in the international market price (50% decrease) showed that the main response is to intensify production (over 40%), then continue with the activity for a certain number of seasons (mainly 2–3 season) and to a lesser extent (close to 20%) to retire or change activity (Fig. 4a). While, for the scenario of a 50% decrease in production, the producers clearly responded to continue with the activity (over 60% of the answers, mainly in the second season), close to 30% retired or performed another activity, and a small percentage (< 10%) intensified its activity (Fig. 4b).

3.4. Relations between different dimensions and willingness to invest in adaptive capacity

We examined a total of five indicators representing adaptive capacity that were derived largely from the broader economic and policy landscape (Table 2). Our results show that producers (regardless of their size) adapt in a heterogeneous way, where financial assets stimulate the willingness to invest in the capacity of adaptation. As Table 2 shows, the variables with statistical significance, explaining the WTP are related to assets and agency.

The size of the producer is one of the relevant characteristics that make a significant difference when choosing to invest in adaptation measures, the larger the producer, larger the probability of paying for the early warning program. Regarding agency, responses to a price decrease are statistically significant, meaning that those producers that decided to stay in business after a price shock have larger WTP for the early warning program. This suggests that producers are willing to invest more in measures instead of waiting for the harvest till the market price recovers. Historical response to crises also explains the WTP.

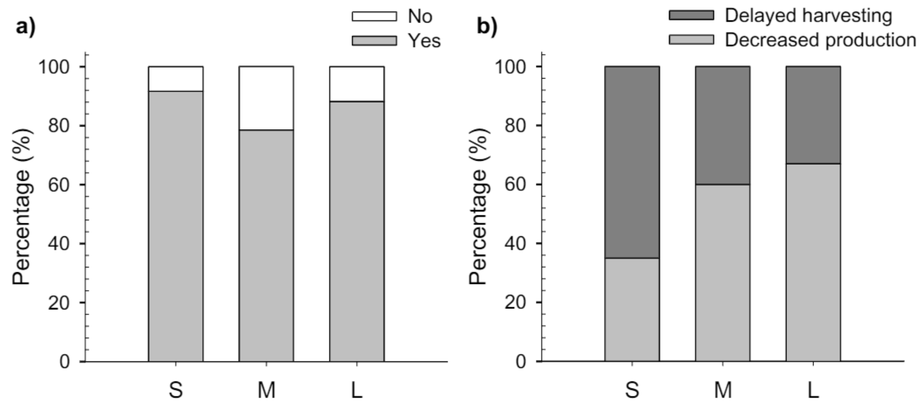

Fig. 3. a) Percentage of respondents that were affected by the phytoplankton crisis in 2009. (b) Effects of the crisis of 2009 in different groups of producers: S = small, M = medium, and L = large.

Producers that delay their production in 2009 display a higher WTP, indicating that those who have already faced the cost of a crisis are WTP more to avoid it. Finally, the mean WTP for a research program is around USD $1000 (CLP $674,000), while the median is slightly smaller (USD $920).

4. Discussion

Adaptations have stimulated and favoured innovation, allowing societies to overcome challenges (Cinner et al., 2018). This ability to adapt reflects the ability of a society to anticipate and face change (Adger and Vincent, 2005). Previous research emphasizes that the capacity of adaptation is determined by the availability of financial capital (Hinkel, 2011). However, it is necessary to have both the willingness and the ability to transform resources into an effective adaptation strategy (Coulthard, 2012). Here, we build on the adaptive capacity literature linking 1) future hypothetical scenarios of climate change with 2) past experiences in the mussel culture industry, allowing creating a base of reference on the current capacity of the industry to anticipate and develop response strategies.

Chilean mussel producers are exposed to climatic threats, which can affect their profitability directly by reducing larvae and phytoplankton or indirectly by altering operating costs related to the inputs used in mariculture. Importantly, our study shows that producers are developing a suite of adaptive responses to these stressors. Our results indicate that the producers perceive environmental stress as the main threat to the industry, possibly due to events that occurred in the past, such as the decrease of food (phytoplankton) and mussel seeds. A similar effect was reported by Adams et al. (2011), evidencing that producers feel more vulnerable to possible environmental stress events if they have been previously affected. The negative experiences that have impacted the industry have forced producers to take measures, which respond a priori to a negative event (Barton et al., 2012), in order to achieve a sustainable activity over time. In addition, when we evaluate the contingent behaviour of producers against hypothetical scenarios, they demonstrate to be optimistic from the environmental point of view, continuing in the industry (~ 70%), behaviour of a society that reflects an initiative to learn and develop knowledge when confronted to change and uncertainty (Carpenter and Gunderson, 2001). However, from an economic point of view, they turn out to be pessimistic to the point where they stop participating (~ 20%) and sell their production when they feel the crisis.

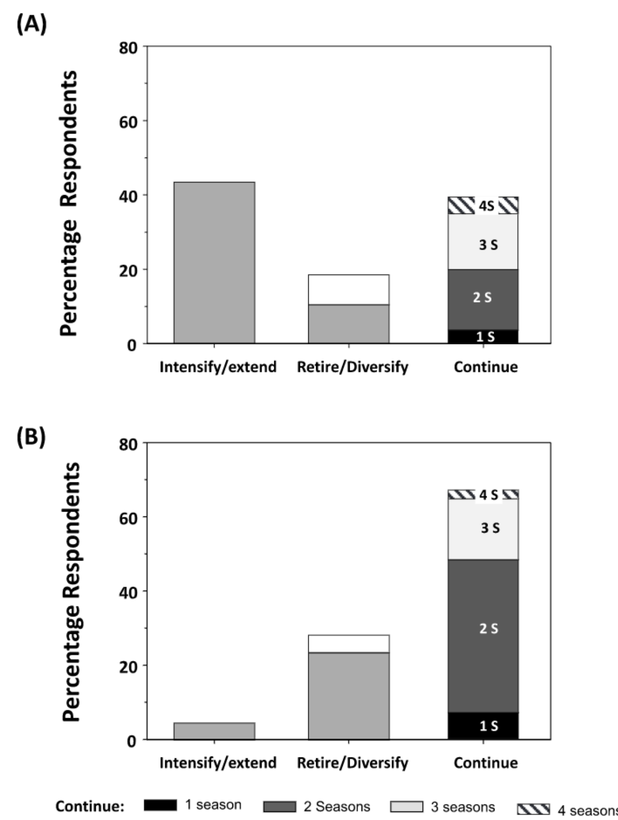

Fig. 4. Mussel producer's response to contingent behaviour exercise for (a) 50% decreases in price and (b) 50% drop in yield.

The analysis of the different domains of adaptive capacity as determinants of WTP to anticipate change, showed that the key domains are: learning, assets and agency. We can consider that the **learning**

Table 1
Main responses of mussel producers when confronted with the lack of plankton and consequent mussel growth crisis in 2009 (past responses to perturbation).

Response	% Respondents
Stopped participating: Sold as soon as crises was felt and retired for 1 season	15.29
Decreased harvest: Continue in the industry by selling what was available. Save money to re-invest following year (Risk Adverse).	47.05
Delay harvest: Continue in the industry by waiting until mussels grow, in order to sell at larger sizes, assuming costs associated with delay (Risk-acceptant).	37.64

Table 2
Regression on factors, which determine willingness to invest in anticipating change (capacity to learn).

Variable	Description	Coefficient	Std. error	T	P
Assets: Small Producer	Binomial: 1 = small size producer (< 400 t/season) and 0 = other sizes	−50.87397	12.53741	−4.06	0.000
Assets: Medium size Producer	Binomial: 1 = medium size producer 400-1350 t/season) and 0 = other sizes	−27.3549	11.0499	−2.48	0.016
Social Capital: Invest in collective action for standardization in industry	Binomial: agreeing to act collectively to standardize quality protocols: 1 = grade > 5 and 0 = grade < 5	−1.286959	1.372837	−0.94	0.352
Agency: Contingent response to production decrease	Binomial: Staying in the business after a production decrease (1).	−14.71723	10.58502	−1.39	0.169
Agency: Contingent response to price decrease	Binomial: Staying in the business after a price decrease (1)	19.40761	10.01869	1.94	0.057
Flexibility: Invest in quality standards as market diversification	Binomial: Agreeing that investing in quality standards is positive (1).	−9.570078	9.322577	−1.03	0.308
Flexibility: current off-sector diversification opportunities	Binomial: Having an alternative occupation (1).	11.41318	9.06827	1.26	0.212
Agency: Historical Response to crises	Binomial: response to phytoplankton crisis in 2009, 1 = decreased production and 0 = delayed harvesting	−23.90706	8.923296	−2.68	0.009
Constant		58.03282	15.54569	3.73	0.000

incorporated by the producers after living a crisis shows that large producers are more willing to invest in anticipating change. This would probably be related to larger producers being expected to have more resources to invest, since having more **assets** could be used to help them to anticipate an event with negative effects on their production. This has been mentioned previously in the literature by Cinner et al., 2018 and Fenichel et al., 2016, where assets can be chosen to help in times of need. Additionally, having more assets also implies greater risk, as they have more to lose during an external shock (crisis), thus the potential cost of not investing is also high. Moreover, the **agency** indicators presented under the price decrease scenario and historical response to crises proved to be statistically significant. The first one indicates that the producers who stayed in the business after a price decrease have a higher WTP for the research program, whereas the second one indicates that those producers that delay their production in 2009 display a higher WTP. For both cases, this may indicates that those producers that already faced the cost of a previous crisis have increased awareness and are willing to invest to anticipate change.

Learning to adapt to the events generated by climate change requires an investment in research that will help evaluate potential risks and patterns of climate change and reduce losses in aquaculture. Research has shown that access and availability to science has helped shellfish farmers identify and avoid some of the consequences of ocean acidification, in the Pacific Northwest (Ekstrom et al., 2015; Brooks et al., 2005). Considering the analysis of adaptive capacity through the different domains, Cinner et al., 2018 mentions that learning can only allow adaptation when other domains of adaptive capacity, such as agency, flexibility, and social organization are sufficiently developed. Our results show that those who invest in domains of assets and agency are the same ones who are willing to invest in the early learning program.

Our results suggest the need to design some type of innovative financial scheme to pay for the science, which can provide early warning signals to the industry. The program could take many forms and the determinants for the WTP could provide a starting point to design a scheme that will probably need government and private investments, but could also benefit from a kind of derivatives market (Caballero et al., 2002; Little et al., 2014) or insurance mechanisms (Sainsbury et al., 2019). Such markets would allow parties with different tolerances and expectations about risks to transact for their mutual benefit and, in so doing, finance early warning adaptation programs (Little et al., 2015). Future research is necessary to scope the ways in which these systems could operate for the Chilean mariculture sector, ensuring equity and justice.

Climate stressors will continue to affect the mussel industry, as evidenced by a critical event of red tide in 2016 (Mascareño et al., 2018; Fernández et al., 2018). The intensity presented in the 2016 red tide was unprecedented (Cabello and Godfrey, 2016). The mussel industry suffered great economic losses (Clement et al., 2016), associated to extraction prohibitions (Bustos and Román, 2019) and the implementation of adaptation plans became evident. Opportunities that could be embraced to develop these adaptation plans are the National Adaptation Programs of Action (NAPAs) which are being funded by the World Bank/ United Nations Environment Program Global Environment Facility. These plans will need to include further knowledge of the industries heterogeneous responses, determinants of the industries engagement in adaptation strategies and possible new financial mechanisms to finance mariculture adaptation science.

5. Conclusion

Here we have shown that the historical response of mussel producers who were affected by past crisis (i.e. 2009) and responded by decreasing their production, have high WTP to anticipate further crisis through the development of scientific knowledge. The need to develop adaptive capacity to environmental changes will continue to grow and depend on multiple domains. Approaches such as the one presented here can provide a better understanding of the role of these domains and therefore aid in the design of adaptive capacity programs.

Compliance with ethical standards

Through the consent of the Ethics, Bioethics and Biosafety Committee of the Vice-Rector for Research and Development of the University of Conception, President: Dr. Andrea Rodríguez Tastets. Checked compliance with the ethical, bioethical and biosecurity norms and procedures established nationally and internationally for research in the field of environmental sciences, Written informed consent was obtained from the respective institution in Concepcion, Chile, previously approved the ethic protocol from all subjects for this study. In addition, the choice experiment survey, which complied with ethical approval of both, Project Musels and Universidad del Desarrollo.

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Data availability

Any data used in this paper can be obtained by contacting the corresponding author.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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