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Mapping Firms' adaptive profiles: The role of experiences and risk perception in the aquaculture industry

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ABSTRACT

The experiences of aquacultural firms regarding past environmental events and their present risk perceptions of environmental and social threats are key factors in understanding their adaptive response. This study aims to understand marine aquaculture firms' adaptive behavior considering firms' heterogeneity and the relationship between past experiences, present perceptions, and willingness to invest in adaptation. We identify different adaptation behavior profiles among the aquacultural firms, showing heterogeneity regarding firms' past responses to perturbations, risk perceptions of social and environmental factors, and their future behavior regarding their willingness to invest in adaptation. We conclude that an adaptive profile, based not only on economic and productive features but also on their social behavior regarding environmental threats, influences future adaptive behavior. Implications for management practice and policy are discussed.

1. Introduction

As the level of CO2 emissions increase, it is likely that the global temperature crosses the 1.5 °C thresholds, triggering unknown changes in precipitation, temperature, and occurrence of extreme events (IPCC, 2018; Pachauri et al., 2014). Those changes could impose high costs on different societal actors, including firms and organizations (Linnenluecke et al., 2012, 2011; Winn et al., 2011). Climate change impacts are a cross-industry phenomenon (Winn et al., 2011). However, some sectors are more vulnerable to changes in climate conditions, such as the food industry -agriculture, aquaculture, and fisheries- (Galbreath, 2011; Soto et al., 2018; Winn et al., 2011).

Global warming and climate variability may impose high economic costs to the food sector, for instance, associated with the loss or decrease of the cultivation area, impact on the tolerance of cultivated species and their biological rates (survival, maturation, fertility, reproduction and mortality), intrusion of natural enemies (predators and infectious agents), environmental pollution, and changes in consumer preference, among other changes (Reid et al., 2019; San Martin et al., 2019). Consequently, there is a growing concern about the food industry's capacity to face the threats and uncertainties that an altered climate system may bring (Smithers and Blay-Palmer, 2001).

Firms can reduce the uncertainty related to climate change impacts by adopting effective adaptation strategies (Busch, 2011; Smit et al., 2000). Although the relevance of implementing adaptation strategies is widely recognized (Eisenhardt and Tabrizi, 1995), the study of firms' adaptation to climate change is still in its infancy (Daddi et al., 2018; Gasbarro and Pinkse, 2016; Halkos et al., 2018; Linnenluecke et al., 2013). Further, most of the current literature addressing firms' adaptation is focused on the corporate dimension (Daddi et al., 2018; Halkos et al., 2018; Linnenluecke et al., 2013), with scarce attention to the heterogeneous responses that could arise when analyzing small and medium-sized enterprises (SMEs) (Halkos et al., 2018; Halkos and Skouloudis, 2019). This is a significant gap in the literature, as characteristics of SMEs such as their size, limited resources, short term thinking, and lack of formal structures (Ates et al., 2013; Hudson Smith and Smith, 2007; Yáñez et al., 2017) make them more vulnerable to climate change than large firms. Moreover, despite the primary sector being one of the most vulnerable sectors to changes in environmental conditions, they have not received the attention they deserve (Gasbarro

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and Pinkse, 2016; Linnenluecke et al., 2013; Ridoutt et al., 2016; Winn et al., 2011).

This study aims to increase the understanding of marine aquaculture firms' adaptive behavior to climate change. Our main goal is to identify different adaptation behavior profiles, addressing the following questions: i) What is the level of heterogeneity across firms' regarding past experiences related to environmental perturbations, present perceptions of social and environmental threats, and their expected behavior regarding willingness to invest in building adaptive capacity?; ii) What is the potential relationship between past experiences, present perceptions, and their willingness to invest in adaptation (WTIad)?; and iii) How does the interpretation of such experiences or perceptions translate into specific types of adaptation behavior?. Based on a single survey instrument, we developed an innovative approach through the integration of graph analysis, which is fed with multiple correspondence analysis (MCA), cluster analysis (CA), and information from a contingent valuation question. This paper uses the Chilean marine-based aquaculture industry, a global player in this market, as a case study.

Clustering has been widely used to group observations (firms) that exhibit similar characteristics or have homogenous behavioral traits or properties (the same "typology" or category). Such characterization using both socioeconomic and productive variables is common in the literature (de Juan et al., 2017; Fernández et al., 2018; Rivera et al., 2017). Regarding aquaculture, there is a large body of literature clustering firms based on socioeconomic and productive variables, including shrimp farming in northeast Brazil (Marques et al., 2016) or in the Mekong Delta in Vietnam (Joffre and Bosma, 2009); brackish-water pond aquaculture systems in the Philippines (Stevenson et al., 2007); the French oyster industry (Le Grel and Le Bihan, 2009); the Asian carp farming systems (Michielsens et al., 2002); the mussel seed production in Chile (Fernández et al., 2018), among others. However, this evidence falls short in building firms' typology in a context of massive climate disruptions, as it neglects the role played by past experiences, present perceptions, and future behavior. This is a serious drawback in the literature, as these variables could determine the engagement on future adaptation strategies, especially for SMEs (Bremer and Linnenluecke, 2016; Gasbarro et al., 2019; Gasbarro and Pinkse, 2016; Kuruppu et al., 2018; Montmasson-Clair et al., 2019).

From a policy perspective, there have been calls for more comprehensive clustering approaches considering economic agents' experiences and risk perceptions (Mair et al., 2019). Further, for developing climate change adaptation plans, we need to understand how companies face the past, perceive present risks, and will face the future (Jacob et al., 2021; Schaltenbrand et al., 2018; Zhang et al., 2020). While productive and socioeconomic data provide policymakers with a detailed picture of firms' socioeconomic context, it does not capture their subjective experience, risk perception, and behaviors, even if these may significantly influence their attitudes to future policies (Mudombi, 2018). Further, the literature on the social limits to adaptation has identified risk perception, attitudes, and behaviors to climate change as the foundations of such limits (Adger et al., 2009; Evans et al., 2016; Klein et al., 2015). In this context, recent literature has identified, characterized, and analyzed how social limits or barriers constrain adaptation in primary industries (Abid et al., 2015; Evans et al., 2016; Islam et al., 2014).

1.1. Firms' adaptation behavior

The marine aquaculture sector faces environmental and socioeconomic challenges bringing uncertainties regarding their expected outcomes (Barange et al., 2014). Further, these uncertainties force firms to implement adaptation strategies, whose effectiveness depends on their characteristics and the context in which they develop their business.

In the aquaculture sector, adaptation strategies have been observed aimed at increasing resilience against climate impacts (eg: biosafety measures, water management technologies and introduction of containment infrastructure), changes in cultural practices (eg: crops of species with greater thermal tolerance, changes in the production system, variation in planting and harvest dates), restoration of natural ecosystems (for the conservation of environmental services) and increased investment aimed at improving the availability and accessibility of information regarding the effects of climate change and development of financial tools to reduce risk (Galappaththi et al., 2020).

Several studies have highlighted the relevance of considering firms' characteristics for developing effective adaptation strategies (Allison et al., 2011; Fernández et al., 2018). These characteristics drive not only producers' responses in economic and environmental stress situations (Gelcich and O'keeffe, 2016; Rivera et al., 2017), but also influence their future willingness to invest in specific strategies (Fernández et al., 2018; Horbach, 2008; Li and Tang, 2010).

The literature on firms' adaptation to climate change recognizes the relevance of awareness, vulnerability, perceptions, attitudes, and past experiences on the adaptation process (Arnell and Delaney, 2006; Bremer and Linnenluecke, 2016; Busch, 2011; Gasbarro et al., 2019; Gasbarro and Pinkse, 2016; Hoffmann et al., 2009). In this context, the Theory of Planned Behavior (TPB) could be a useful approach for understanding firms' adaptation behavior. According to the TPB (Ajzen, 1991), any behavior entails (a) an action, (b) performed toward an objective or on an object, (c) in a specific context, (d) at a specific moment (Conner and Sparks, 2005). The TPB claims that beliefs, attitudes, and intentions influence behavior; together, these three factors form an agent's decision-making process (Ajzen, 1991).

Regarding the identification of adaptation behavior, Gasbarro and Pinkse (2016) developed profiles based on the level of both awareness and vulnerability. According to their results, firms exhibit four adaptation profiles: pre-emptive (high level of vulnerability and high level of awareness), reactive (high level of vulnerability and low level of awareness), continuous (low level of vulnerability and high level of awareness) and deferred (low level of vulnerability and low level of awareness). For Bremer and Linnenluecke (2016), firms' attitudes and climate change knowledge influence the perception of adaptation, whereas past experiences help firms to assess extreme events threats (Berkhout et al., 2006), their financial consequences, and ultimately their vulnerability degree (Pinkse and Gasbarro, 2019). Further, Gasbarro et al. (2019) show how past experiences related to a single climate event could produce a strategy to deal with multiple climate events. Here, we extend this evidence by jointly analyzing the influence of past experiences and present perceptions on building adaptive capacity.

This paper makes several contributions to the emerging literature in firms' adaptation to climate change. First, our typology is based on productive and socioeconomic variables, including also the role played by experiences, perceptions, and expected future behavior. Second, we use a quantitative approach to build these typologies, going further than previous literature restricted to qualitative analysis (Gasbarro et al., 2019; Gasbarro and Pinkse, 2016; Pinkse and Gasbarro, 2019). Third, we increase the evidence regarding SMEs adaptation behavior (Halkos et al., 2018; Halkos and Skouloudis, 2019). Finally, by distinguishing the role of past experiences and present perceptions on the willingness to adapt, we present a more nuanced representation of the condition that could foster (or not) the implementation of adaptation strategies. Thus, helping us shed light on the large variation in adopting adaptation strategies at the firm level.

2. Case study

The Chilean aquacultural industry operates within a concession framework (or authorization) granted by the National Fisheries Service (SERNAPESCA). Since 1974, the mussel industry has operated in the context of commercial aquaculture, which continues to the present. This has been driven by a national free-market policy based on the worldwide trade of national natural resources, establishing and growing private aquaculture investments with products exported to international markets (Gonzalez-Poblete et al., 2018).

Currently, Chile is the largest exporter of mussels worldwide, extending its production to >59 countries around the world. The industry is mainly concentrated within the Los Lagos region, where about 99% of the mussels produced are harvested (Carrasco et al., 2014). For 2014, the exports of the Chilean mussel industry generated a total of USD 188.8 million. In 2015, they represented a volume of >59,000 tons (FAO, 2016; Gonzalez-Poblete et al., 2018). At the same time, during the last decade, the mussels' relative participation concerning the total of fish products generated in Chile has been growing progressively, mainly as a consequence of the entry into force of the free trade agreements with the European Union and the USA (the main export destinations) (Fernández and Giráldez, 2013). Fig. 1 shows the share of mussel production on the total volume of fish production, which went from <1% of all fish products produced in 2001 to maintain during 2016 to 2019, participation between 10% and 11%.

Specifically, Chilean mussel production is characterized by its significant heterogeneity, in which entrepreneurs, small producers, and large firms coexist (Figueroa and Dresdner, 2016; Gonzalez-Poblete et al., 2018). The production chain is divided into four stages (Rivera et al., 2017): i) collection of larvae from the natural environment and fixing and settling larvae in long-line systems ("substrates"); ii) growing individuals in a marine environment until they reach the size necessary for harvesting (fattening stage); iii) industrialization in processing plants; and iv) marketing to national and international markets, in most cases these stages are not fully integrated. Further, within the mussel industry, firms with different degrees of capital and labor intensity use coexist. These are also highly heterogeneous in their socioeconomic and productive characteristics. Moreover, the industry presents a strong concentration, in larger firms, of production and gross income (Gonzalez-Poblete et al., 2018).

Fig. 2 shows that despite the substantial growth of the Chilean mussel industry, it has faced different scenarios with adverse consequences. Fig. 2a shows the evolution of production (tons) between 2007 and 2019 (SERNAPESCA, 2019). Regardless of the production increase of 216% in 10 years (2009–2019), Fig. 2a shows that this increase has not been constant over time, with falls in the general trend between 2008–2009 and 2011–2014. These trends become more conspicuous when looking at Fig. 2b, which shows the dynamics of change in the rate of mussel production (tons), which presents significant decreases between 2008–2009 and 2012–2014 (with a sharp fall in 2011). Between 2008 and 2010, there was a decrease in phytoplankton levels in the environment, affecting the *growth* process, and ultimately the saline level (Carrasco et al., 2014). Further, between 2011 and 2013, there was a substantial decrease in seeds collection from natural banks, which caused a significant reduction in the harvest between 2011 and 2014 (Carrasco et al., 2014; Figueroa and Dresdner, 2016).

Moreover, the industry is also at risk of being affected by multiple climatic stressors. Climatic stressors such as variations in salinity, temperature, ocean acidification, dissolved oxygen, and nutrient (IPCC, 2007; Range et al., 2014), could affect the life cycles of shellfish with an adverse effect on their productivity, viability, nutritional quality, or market value which can have relevant societal implications (Cooley et al., 2012; Ponce et al., 2019; San Martin et al., 2019).

The different firms' characteristics, past experiences, and current perceptions of threats commonly affect their awareness of needs, challenges, and potential solutions to their specific problems. Therefore, by increasing our understanding of the adaptive capacity to climate change and the environmental conditions, firms could effectively evaluate the suitability of policies and programs designed to favor the sector's adaptability to environmental stress conditions (Rivera et al., 2017).

The above goes hand-in-hand with the most recent Adaptation Plan to Climate Change for Fisheries and Aquaculture (SUBPESCA, 2015). This plan develops public policy strategies to establish priorities regarding adaptation to climate change, development of capabilities, research, and coordination among the interest groups at a national level. Considering the general framework of the Adaptation Plan, among the different guidelines that were defined to guide it is to consider adaptation as a progressive process capable of learning from past experiences, considering that fishers have adapted to previous environmental events. Additionally, one of their main objectives is to develop the necessary research to disseminate knowledge and information on the possible threats of climate change to generate greater adaptation capacity for the different sectors.

3. Materials and methods

3.1. Data

The information for our analysis comes from a survey conducted among 87 firm representatives in the Los Lagos Region, Chile (out of 148 nationwide firms). The survey was applied from November 2014 to February 2015 to firms working in the fattening stage. We built the

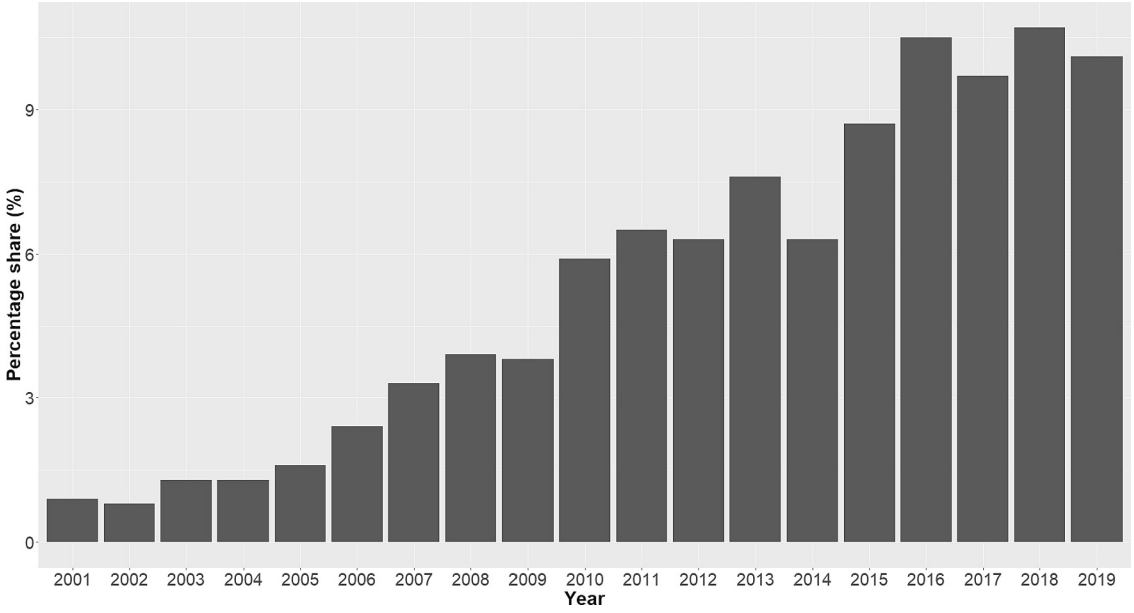

Fig. 1. Percentage share of mussel production about the total volume of fish production in Chile. Data extracted from (SERNAPESCA, 2019).

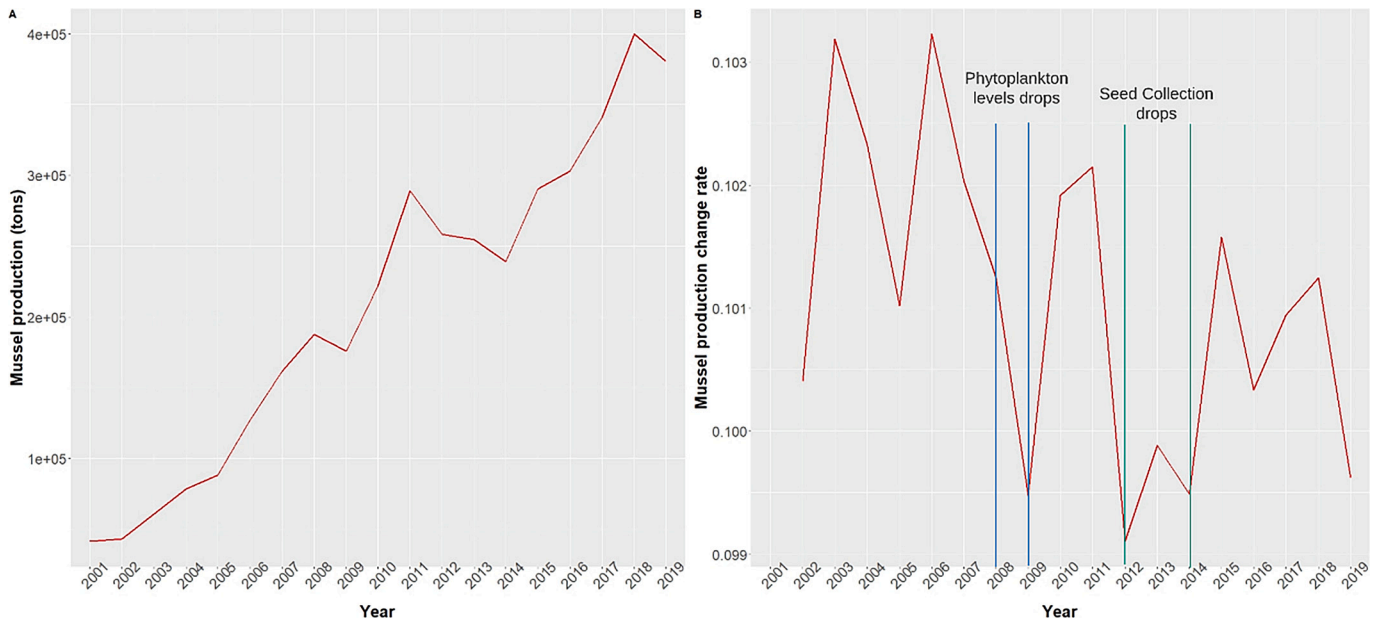

Fig. 2. Dynamics of mussel production in Chile: A) Evolution of production in tons 2007–2019 B) Production change rate [log X (t) / log X (t-1)]. Data source: SERNAPESCA (2019).

survey using information from 20 semi-structured interviews with key stakeholders from the industry. We also test the survey instrument using one pilot study (10 observations). We work closely with the Chinquihue Foundation (a private non-profit organization that promotes artisanal fisheries and small-scale aquaculture sectors) and the Chilean mussel industry association (AmiChile) in designing and applying the final version of the survey. After data cleaning, our sample was constrained to 75 firms.

The first section aimed to gather information regarding past experiences related to environmental perturbations. Two specific disturbances were considered: i) the food crisis (under-nutritional supplement by phytoplankton) that affected the growth process in 2009/2010 and ii) the reduction of seeds presented in 2012. Both were closed questions with two options: yes or no, indicating if they were affected or not by these disturbances. The second section asked if producers consider a threat (yes or no) any of the social or environmental factors presented in a list, including unawareness of environmental quality, global warming, and labor shortages, among others. The third section addressed firms' contingent behavior in the face of hypothetical scenarios of changes in the marine environment. The contingent valuation question aimed to assess the willingness to invest a positive amount of money for a hypothetical program that could provide an early warning signal to the industry, anticipating changes in the marine environment. Other survey sections asked about socioeconomic and productive variables (total production per season, extension, number of people working) and their participation in any link of the industry's whole productive chain. Table 1 shows the variables used in our analysis.

The survey results show a high degree of heterogeneity across firms (Table 2), consistent with previous studies (Gonzalez-Poblete et al., 2018; Rivera et al., 2017). Firms' size is within 1.67–300 ha, with 50% of firms smaller than 7 ha, while the average size is 32 ha. A similar pattern can be seen regarding annual production, observing that about 50% of firms produce <700 kg, with an average production of 1809 kg; permanent and temporal workers, where the average is 26 and 35 respectively, with a median around 3 and 8. These substantial differences between firms seem to align with the large concentration reported by Gonzalez-Poblete et al. (2018). Few firms concentrate the largest area to exploit the resource, have a significant labor concentration, and show higher production levels.

Nearly 52% of the firms are non-vertically integrated, meaning they are entirely focused on the fattening process. The remaining 48% presents different levels of vertical integration (integrate different stages of the production process) with backward and forward linkages of the productive chain. Among this latter category, most represent a low degree of backward vertical integration between seed collectors and fattening process (37.3% of the total firms). Fully integrated firms, those including from seed collection to the marketing and export process, account for 6.7% of the sample, whereas 4% are forward vertically integrated, meaning that include from the fattening process to the marketing and export process.

Regarding past experiences, most of the firms declare that the 2009 and 2012 crises caused damage to their business. Approximately 87% of the companies claim that the food crisis that affected the mussels' growth in 2009 harmed them. This appreciation drops to 65% when asked about the decline in the seed collection during 2012. On the other hand, when evaluating the perception of different environmental factors as potential threats, the main threats are pollution generated by the salmon industry (94.7%), decrease in phytoplankton (92%), global warming (89.3%), contamination with heavy metals (88%) and pollution in general (81.3%). In contrast, environmental factors that are less recognized as threats are anoxia (29.3%), ocean acidification (34.7%), and eutrophication (44%). Regarding WTIad, considerable variability is found among the different firms, with a mean value of CLP$ 835,000 and a median of CLP$ 200,000.

3.2. Methods

We followed a three-stage approach (Fig. 3). First, we cluster firms in three time periods: past, considering its experiences related to environmental perturbations; present, considering its perceptions of social and environmental threats; and future, considering the expected behavior regarding willingness to invest in building adaptive capacity. Second, we rely on graph analysis to show the different firms' trajectories across these periods. Third, we identify emerging firms' adaptation behavior profiles by contrasting the willingness to invest with past experiences and present perceptions.

The method is based on MCA, CA, and information from a contingent valuation (CV) question. MCA applies a factor analysis technique for categorical data (Greenacre and Blasius, 2006). CA looks for the aggregation of different observations space into disjoints groups (Alvarez

Table 1
Variables analyzed to characterize *grow out farming* mussel firms.

Past experiences to perturbations	
Variables	Categories
1. Did affect you the 2009/2010 crisis?	1. Yes; 2. No
2. Did affect you the 2012 crisis?	1. Yes; 2. No
Present risk perceptions of social and environmental factors	
Variables	Categories
Environmental factors	
1. Unawareness of the environment	1. Yes; 2. No
2. Salmon Farms Contamination	1. Yes; 2. No
3. Heavy metals Contamination	1. Yes; 2. No
4. Environmental Pollution	1. Yes; 2. No
5. Acidification	1. Yes; 2. No
6. Global warming	1. Yes; 2. No
7. Water anoxia	1. Yes; 2. No
8. Decrease of phytoplankton	1. Yes; 2. No
9. Eutrophication	1. Yes; 2. No
Social factors	
10. Too many certificates	1. Yes; 2. No
11. Labor shortages	1. Yes; 2. No
12. Environmental requirements	1. Yes; 2. No
13. The growth of large companies	1. Yes; 2. No
Future Behavior: Willingness to invest in building capacity to anticipate changes	
From a contingent valuation question, we gathered information about whether or not the firms are willing to invest a positive amount of money for a hypothetical program that could provide an early warning signal to the industry aid in anticipating changes in the marine environment.	
Firm characteristics	
Variables	Categories
1. Area (ha)	1. Small and medium producer farmed area ≤ 30 ha 2. Large producer farmed area > 30 ha
2. Production (kg)	1. Production less than or equal to 700 kg 2. Production above 700 kg
3. Level of vertical integration	1. None or backward integrated 2. forward or complete integrated
5. Permanent workers per year	1. Less than or equal to 20 permanent workers 2. >20 permanent workers
6. Casual workers per year	1. Less than or equal to 30 causal workers 2. >30 causal workers
7. Number of centers	1. Between 1 and 5 centers 2. >5 centers

et al., 2018; Hennig et al., 2015), whereas CV gathered relevant information to elicit economic agents' willingness to pay for a good or service (Bateman et al., 2001; Carson et al., 2003). A description of each stage is presented below.

3.2.1. Stage 1: Multiple correspondence analysis (MCA) and cluster analysis (CA)

The statistical analysis is conducted exclusively on those firms that participate in the *fattening stage*. The statistical analysis was conducted through a two-step treatment where the first one was used to analyze the relationship between dependent categorical variables through a Multiple Correspondence Analysis (MCA). MCA is the equivalent for qualitative data of Principal Component Analysis (PCA) when it predominates qualitative variables (variables related to past experiences, present perceptions, and expected future behavior) over quantitative ones (economic and productive variables). The Multiple Correspondence Analysis (MCA) functions used in the analysis were implemented in the R software through the FactoMineR package (Husson et al., 2020). As a second step, individual firms are then grouped into firm types using Agglomerative hierarchical clustering (HC), in which the components of the MCA are used as input variables. HC was performed through the HCPC function (Hierarchical clustering on Principal Components) on the MCA outputs. The HCPC function uses Euclidean distances to define the distance between individuals and Ward's agglomeration method to construct the hierarchical tree. A hierarchical tree is a sequence of nested partitions, from the individual as a class to a more general partition that includes all individuals. Each branch groups individuals with a shared set of properties. Apart from the similarity among them, firms in a group differ from other grouped firms. Ward's agglomeration method consists of regrouping firms by maximizing the quality of the partitioning. To find the "optimal" number of clusters, we used the Duda-Hart test (Duda and Hart, 1973) through the R package NbClust (Charrad et al., 2014).

The information about the expected future behavior used on the MCA analysis was gathered by asking each firm's representative about the maximum amount of money they would be willing to pay for an early warning system, which we consider here as the willingness to invest in adaptation (WTIad).

3.2.2. Stage 2: Graph analysis (adaptive behavior mapping)

We used graph analysis to represent each of the firms' adaptive trajectories over time (past, present, and future). For each of the three periods, the clusters obtained through the MCA and HC analyses were represented as nodes. Each cluster categorizes a set of firms that share similar characteristics for each of the three periods. The links between the nodes, which are binary and unidirectional, represent the firms' flows between the clusters at different times. In this way, the analysis allows graphically representing the trajectory of firms over time, contextualizing the potential relationships between past experiences, present perceptions, and future behavior. This type of data processing allows identifying possible trends that help recognize the main factors that could guide firms' decision-making concerning future investments and participation in different management programs (Borgatti et al., 2009; Greve, 1995; Hoang and Yi, 2015; Scott, 1988).

3.2.3. Stage 3: Firms behavior profiles

After identifying the firms' trajectories between clusters at different times, we used a similar approach as Gasbarro and Pinkse (2016) and Gasbarro et al. (2019). They also assess the adaptive capacity over time to identify different adaptation profiles. However, we extend those approaches by describing: i) how clusters were affected by past environmental crises (non-affected or highly affected); ii) their risk perception of environmental factors (low-medium or high); and iii) their willingness to invest in adaptation capacity (yes or no).

4. Results and discussion

4.1. Firms' clustering

Following, we present the results from the clustering performed on the MCA outputs and the number of clusters suggested by the Duda–Hart criterion for each stage.

4.1.1. Cluster description: Past experiences

The Duda–Hart criterion suggests extracting four clusters (ps_1, ps_2, ps_3, ps_4). The main characteristics are shown in Table 3. To easily differentiate between the different clusters, we categorized the variables in four groups: *All* means that 100% of firms within the cluster have the corresponding attribute, *Great Majority*, between 80 and 99% of firms within the cluster have the attribute, *Majority* (between 60 and 79% of firms within the cluster), and *Nearly Half* (between 40 and 59% of firms within the cluster).

The first cluster (ps1) is characterized by small and medium-sized firms. The size of the *Great Majority* of firms is smaller than 30 ha

Table 2
General Statistics of the total sample.

Firm Characteristics						
	Mean	Deviation	Min	Max	Frequency	Percentage
Area (ha)	32.95	60.58	1.67	300.0		
Production (Kg)	1809.34	4086.55	12.00	20.000		
Permanent workers	26.56	88.41	0.00	570.0		
Casual workers	35.45	98.03	0.00	620.0		
Vertical integration level						
Not integrated					39.00	52.0%
Backward					28.00	37.3%
Forward					3.00	4.0%
Complete					5.00	6.7%
Past experiences to perturbations						
Did affect you the 2009 crisis?						
Yes					65.00	86.7%
No					10.00	13.3%
Did affect you the 2012 crisis?						
Yes					49.00	65.3%
No					26.00	34.6%
Present risk perceptions on social and environmental factors						
			Frequency		Percentage	
			Yes	No	Yes	No
Unawareness of the environment			52.00	23.00	69.3%	30.4%
Environmental Pollution			61.00	14.00	81.3%	18.7%
Too many certificates			0.00	75.00	0.0%	100%
Labor shortages			57.00	18.00	76.0%	24.0%
Environmental Requirements			42.00	33.00	56.0%	44.0%
The growth of large companies			49.00	26.00	65.3%	34.7%
Acidification			26.00	49.00	34.7%	65.3%
Global warming			67.00	8.00	89.3%	10.7%
Water Anoxia			22.00	53.00	29.3%	70.7%
Decrease of phytoplankton			69.00	6.00	92.0%	8.0%
Eutrophication			33.00	42.00	44.0%	56.0%
Salmon Farms Contamination			71.00	4.00	94.7%	5.3%
Heavy metals Contamination			66.00	9.00	88.0%	12.0%
Future Behavior: Willingness to invest in building capacity to anticipate changes (CLP$)						
	Mean	Median	Min	Max		
WTP	$8.35*10^5$	$0.2*10^5$	0	$10*10^5$		

(14.1 ha average), whereas 55% of firms produce equal or <700 kg/season (712.22 kg/season average). This cluster includes 24% of the firms, with *All* of the firms belonging to the group of "none or back integrated," among which 55.6% are non-integrated while the other 44.4% are "backward integrated." Regarding past experiences, *All* firms claim that they were affected by the phytoplankton crisis during 2009/2010, while none claim they were affected by the reducing seeds in 2012.

The firms in cluster 2 (ps2) represent the most numerous ($n = 40$) group of the past stage. It is characterized by being the only cluster where *All* firms indicate that they were affected by both crises. Within this group, the *Great Majority* of firms' size is smaller than 30 ha (with an average of 15.16 ha), while the *Majority* of them produce equal or <700 kg/season (687.5 kg/season average). *All* the firms are non or backward integrated, among of which 60% are non-vertically integrated, and 40% are "backward integrated."

The third cluster (ps3) represents 13.3% of the sample. This cluster is characterized by heterogeneous firms' features within the group and mixed experiences regarding past perturbations. The *Majority* of firms' sizes is smaller than 30 ha (with an average of 22.75 ha), producing equal to or <700 kg/season. The *Great Majority* of firms are non or backward integrated, among of which 50% are non-vertically integrated, 40% are "backward integrated," and 10% are "complete integrated." *All* firms indicate that they were not affected by the food crisis that affected growth in 2009/2010, and *Nearly Half* (40%) indicate that they were affected by the crisis of reducing seeds presented in the year 2012.

Cluster 4 (ps4) is entirely different from those mentioned above and it is the most homogenous cluster. *All* the firms are larger than 30 ha, produce >700 kg/season, and are entirely- or forward-integrated. This cluster represents 9.3% of the sample, where *All* firms were affected by the 2009/2010 crisis (100%) while the *Majority* were affected by the 2012 crisis (71.4%).

4.1.2. Cluster description: Present risk perceptions

We identified 4 clusters (pr1 to pr4) regarding present risk perceptions about environmental and social factors that can potentially threaten the sector (Table 4). We use the average frequency (in percentage) of affirmative responses about both environmental and social threats to analyze the social and environmental risk perceptions. Then to facilitate the differentiation of these clusters based on their risk perceptions, we categorized this variable as i) low-risk perception (below 40% of the average frequency of affirmative responses); ii) moderate-risk perception (between 40% and 50%), and high-risk perception (>50%).

Cluster 1 (pr1) is characterized by a *high-risk perception* of environmental and social factors as a threat, being the only cluster showing *high-risk perception* on both factors (environmental and social). The firms grouped in cluster 2 (pr2) have a *moderate perception* of environmental and social factors. On the other hand, clusters 3 and 4 (pr3 and pr4) are characterized by a *high perception* of environmental threats and a *low-risk perception* of social factors — the cluster with the lowest risk perception of social factors (26%). The main difference between pr3 and pr4 is related to the firm size. Cluster 4 is represented by large companies

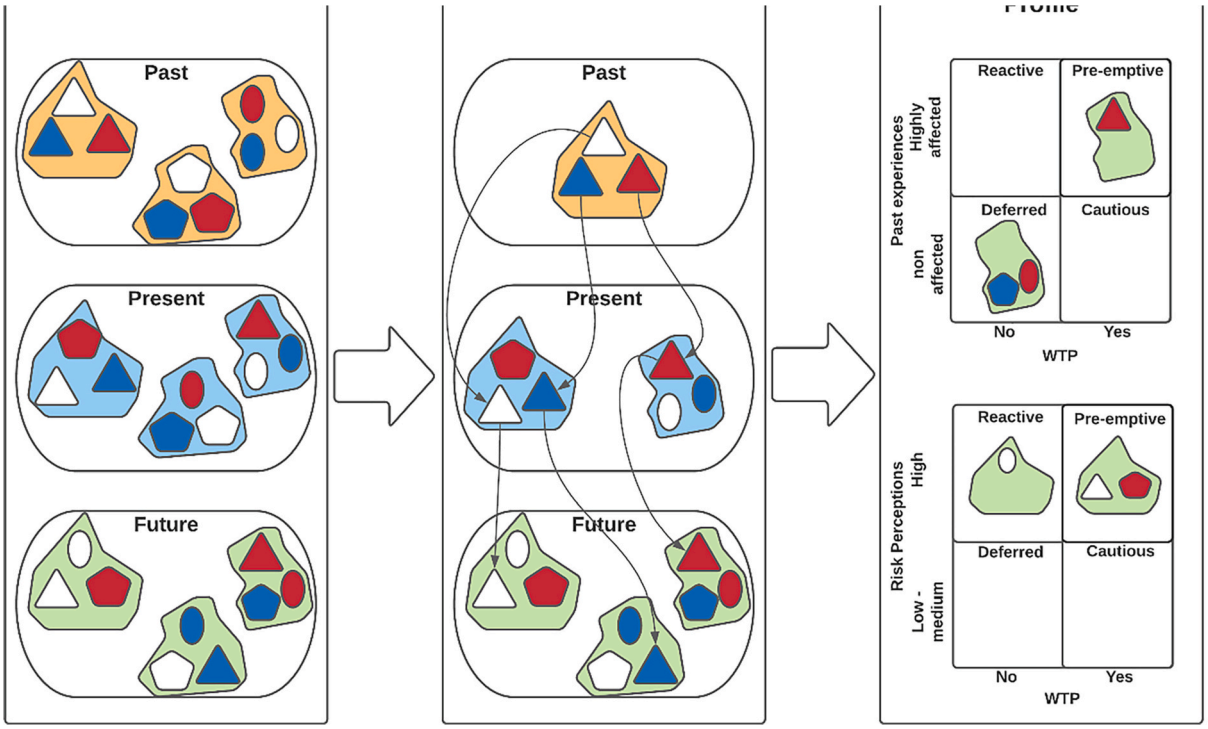

Fig. 3. Three-stage approach scheme. Shapes (triangles, circles, and pentagons) represent firms' diversity, whereas colors represent the different clusters: past experiences (orange clusters), present perceptions (light blue clusters), and willingness to invest in adaptation (green cluster). Arrows in the second stage represent the firms' trajectories across the clusters previously identified, while, within the 3rd stage, clusters identified from the future and their firms are categorized on particular adaptation profiles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Clusters: past experiences to perturbations.

Cluster	Area (ha)	Production (kg)	Vertical Integration	Number of workers (perm/temporal)	Frequency (%)	2009 Crisis. Did affect your business? (% of affirmative responses)	2012 Crisis. Did affect your business? (% of affirmative responses)
ps1	*GM* ≤ 30	NH ≤700	All-NB	(All ≤20/ All≤30)	24	*All*	0
ps2	*GM* ≤ 30	*M* ≤ 700	All-NB	(GM <20/ GM < 30)	53.3	*All*	*All*
ps3	*M* ≤ 30	*M* ≤ 700	GM-NB	(All ≤20 All≤30)	13.3	*0*	*NH*
ps4	All >30	All >700	All-FC	(All >20 All>30)	9.3	*All*	*M*

All (100% of firms)/Great Majority (GM; 99–80% of firms)/Majority (M; 79–60% of firms)/Nearly Half (NH;59–40% of firms)/NB (non or backward integrated)/FC (forward or complete integrated).

Table 4
Cluster: present perceptions of threats.

Cluster	Area (ha)	Production (kg)	Vertical Integration	Number of workers (permanent/casual)	Frequency (%)	Environmental factors*	Social factors**
pr1	GM ≤ 30	M ≤ 700	All-NB	GM <20/ GM < 30	53.3	.2%	66.8%
pr2	M ≤ 30	GM ≤ 700	All-NB	All <20/ All<30	5.3	44.4%	50%
pr3	GM ≤ 30	M ≤ 700	GM-NB	All <20/ All<30	32	67.6%	26%
pr4	All >30	All>700	All-FC	All >20/ All>30	9.3	88.8%	28.6%

All (100% of firms)/Great Majority (GM; 99–80% of firms)/Majority (M; 79–60% of firms)/Nearly Half (NH;59–40% of firms)/NB (non or backward integrated)/FC (forward or complete integrated). *Percentage of the average frequency of affirmative responses about environmental factors; **Percentage of the average frequency of affirmative responses about social factors.

exploiting over 30 ha, producing levels above 700 kg, and having the larger number of workers.

4.1.3. Cluster description: Future behavior

We identified 4 clusters (ft1 to ft4) regarding firms' WTIad in an early warning system (Table 5). To facilitate the differentiation of these clusters based on their WTIad, we categorized this variable as: i) willingness to invest above the average (AB), ii) willingness to invest below the average (BA), and iii) unwilling to pay (UN). The first cluster (ft1) shows a future willingness to invest below the sample's average, and it also represents the most numerous ($n = 30$) group. On the contrary, *All* the firms from the second cluster (ft2) show a willingness to invest for the early warning system above the sample's average, also characterizing its significant heterogeneity in production, presenting an average production of 925.3 kg/season with a minimum of 290 kg/season and a maximum of 2000 kg/season.

Table 5
Future Behavior. Willingness to invest in building adaptation capacity.

Cluster	Area (ha)	Production (kg)	Vertical Integration	Number of workers (permanent/casual)	Frequency (%)	Willingness to invest*
ft1	GM ≤ 30	M ≤ 700	All-NB	(GM <20/All<30)	40	All-BL
ft2	GM ≤ 30	M > 700	All-NB	(All <20/All<30)	22.7	All-AB
ft3	M ≤ 30	M ≤ 700	GM-NB	(All <20/GM < 30)	28	All-UN
ft4	All >30	All>700	All-FC	(All >20/All>30)	9.3	NH-UN

All (100% of firms)/Great Majority (GM; 99–80% of firms)/Majority (M; 79–60% of firms)/Nearly Half (NH;59–40% of firms)/NB (non or backward integrated)/FC (forward or complete integrated). *Unwilling to pay (UN)/ Willing to pay values below the average (BL)/ Willing to pay values above the average (AB).

The third cluster (ft3) is characterized because none of these firms are willing to invest in the early warning system. In contrast, firms in the fourth cluster (ft4) present an uneven willingness to invest, with 42.8% unwilling to pay while 57.2% willing to invest above or below the sample's average. Similar to the above typologies, an important difference observed is between large firms (ft4) and SMEs (ft1, ft2, and ft3). *All* firms categorized in cluster ft4 are large producers regarding the area, production, permanent and casual workers.

4.2. *Firms' trajectories*

Fig. 4 presents the different pathways taken by firms grouped in past (ps1 – ps4), present (pr1 – pr4), and future (ft1 – ft4) clusters. Although clusters were built based on the same firm characteristics, they differ by i) past experiences, ii) present perceptions, and iii) their future behavior.

From Fig. 4 (starting from past clusters) is possible to differentiate between two distinctive firm types: 1) SMEs: represented by ps1, ps2, and ps3, and 2) large firms: represented by ps4. These differences remain when considering the present clusters (large firms grouped in pr4) and future clusters (large firms grouped in ft4). Thus, a common pathway is observed for large firms, while SMEs do not show a homogeneous one, where, for instance, firms from ps1, ps2, and ps3 go to any of the three present clusters, but not the one associated with large firms (pr4).

In the case of large firms, despite their common pathway, not all of them are willing to pay for an early warning system. Although 57.2% of large firms that belong to ft4 are WTIad, there is also an important proportion of firms (42.8%) unwilling to invest in adaptation measures. We could explain these results through the prism of the different domains that build adaptive capacity (Cinner et al., 2018; Hughes et al., 2012; McClanahan and Cinner, 2012). Scientific literature has established key dimensions to build adaptive capacity: assets, flexibility, learning, social organization, and agency (Cinner et al., 2018). Most large firms are willing to invest in the early warning program could be closely related to the relevance of assets as a determinant to invest in anticipating changes (San Martin et al., 2020). Understanding assets as financial, technological, and service resources that firms have access to, and assuming large firms as a proxy of firms' assets, our results show that having more assets allows choosing them to help in times of need (Fenichel et al., 2016). Moreover, the fact of having more assets also implies more significant risks. Not investing is a high potential cost, probably because these firms have more to lose during an environmental crisis.

In the case of the large firms unwilling to invest, their response may be related to developing all the domains that build adaptive capacity and the trade-offs between them. As Cinner et al. (2018) mentioned, adaptive capacity is not just having access to resources and the willingness and ability to convert these into actual adaptive actions. The same authors highlighted that when other domains of adaptive capacity, such as agency, flexibility, and social organization, are insufficiently developed, learning (for instance, through the investment in building adaptive capacity to anticipate changes) by itself will not allow for adaptation. From

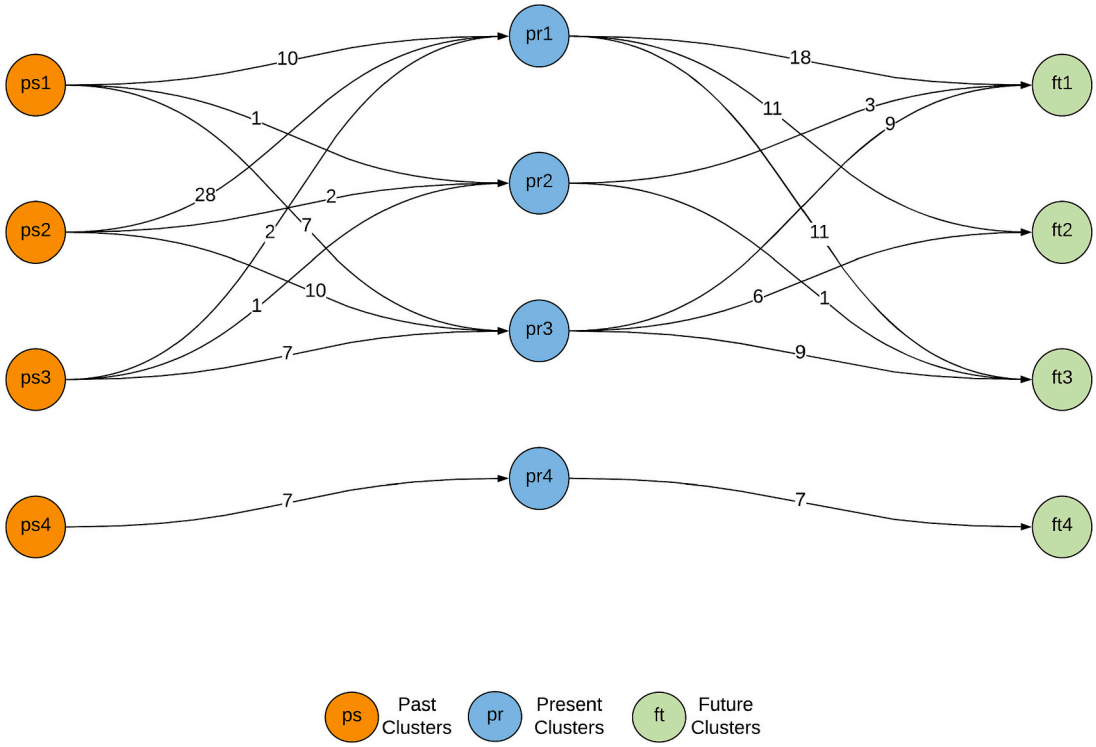

Fig. 4. Firm pathways considering their past, present, and future clusters.

another perspective, our results are consistent with what other authors indicate about the complexity of business adaptation and the number of variables that influence it (Gasbarro et al., 2019). In this case, it seems that the subjectivity of large firms' interpretation of environmental and social threats or past experiences affect their engagement in adaptation processes. This is consistent with other authors who associate the firms' subjective interpretation of vulnerability and awareness with the chance to take measures to face future events (Gasbarro and Pinkse, 2016).

Focalizing on SMEs, Fig. 4 shows that firms willing to invest (ft1 and ft2) represent around 70% of SMEs (47 out of 68), whereas those SMEs unwilling to contribute (ft3) represent the remaining 30% (21 out of 68). SMEs willing to invest in adaptation came from different clusters, pr1 (61.7%), pr2 (6.4%), pr3 (31.9%), predominating clusters, pr1 and pr3 (93.6%), which represent firms with the highest risk perception of environmental factors. Additionally, more firms willing to invest, 41 out of 47, came from ps1 and ps2, where all firms were affected by the 2009/2010 crisis. Thus, our results seem to suggest the existence of a potential relationship between the perception of risk of environmental factors and past experiences with determining the contribution of SMEs. Most of the firms (93.6%) came from pr1 and pr3, and 87% were affected by the past 2009 crisis.

These results also seem to suggest the relationship between past experiences and present perceptions. Most of the SMEs belonging to those clusters that perceive environmental factors as the main threat to the industry (pr1 and pr3) - phytoplankton decline as one of the main- also come from clusters that were affected by the food crisis (phytoplankton decrease) that affected fattening in 2009/2010 (ps1 and ps2). This is in line with other studies that indicate that producers feel more vulnerable to possible environmental stress events if they have been previously affected (Adams et al., 2011).

The SMEs unwilling to contribute also came from pr1 (52.4%) and pr3 (42.8%), meaning they have a *high-risk perception* of the present environmental threats. Further, most of these firms (76%) were affected by one or two crises in the past. This mismatch between perceptions and willingness to invest in adaptation is in line with other studies that present a drop-in firms' responses to their willingness to implement adaptation measures despite their strong perception of environmental threats (Abid et al., 2015). Although this behavior could be interpreted as counterintuitive, it is commonly associated with various constraints and internal or external factors such as lack of information, lack of money, resource constraints, education, experience, or access to weather forecasting information (Abid et al., 2015; Adger et al., 2009). Commonly, due to these factors, more vulnerable firms work based on day-to-day priorities rather than for the longer term.

4.3. Firms' adaptation behavior profile

As observed from the previous analysis, there are no clear patterns between past experiences, present perceptions, and their WTIad. Thus, for identifying firms' adaptation profiles, we followed Gasbarro and Pinkse's (2016) approach. By doing this we proposed the use of different levels for past experiences ("non or low affected" and "Highly affected"); risk perceptions of an environmental factor ("low/moderate" and "High") and the willingness to invest in adaptation strategies ("yes" and "no"). Then, we developed two matrices combining the different levels of affection by past environmental perturbations and their WTIad (Fig. 5A) and the risk perception of environmental threats and their WTIad (Fig. 5B).

The main difference with Gasbarro and Pinkse's (2016) are: i) the factors that we consider as firms' drivers to undertake adaptation measures, and ii) the use of firm clusters previously constructed, where each one represents a range of characteristics, allowing the addition of more variables to a two-dimensional assessment.

Following Gasbarro and Pinkse's (2016) we proposed four possible adaptation behaviors: i) reactive (highly affected by past environmental perturbations but no WTIad; or a high-risk perception but no WTIad), ii) pre-emptive (highly affected by past perturbations or with a high-risk perception and willing to invest in adaptation), iii) deferred (non- or low-affected by past environmental perturbations and no WTIad; or low-risk perception and no WTIad), and iv) cautious (despite non be affected by past perturbations or have a low-risk perception they are willing to invest in adaptation).

Both panels of Fig. 5 show that large firms (cluster ft4) present two types of adaptation behaviors. In particular, with past experiences, Fig. 5A shows that all large firms highly affected, triggered on the one hand a reactive adaptation behavior, and, on the other, a pre-emptive adaptation behavior. This pattern is repeated when the assessment is made with the present perceptions (Fig. 5B). A reactive adaptation behavior is related to an after-the-fact response in the presence of a future environmental perturbation. At the same time, pre-emptive firms commonly adopt an anticipatory posture about environmental threats as they learn from their high exposure to past experiences. These results show that despite the common features of large firms regarding experiences and perceptions, they take different adaptation behaviors, which could be explained by the individual subjective interpretation of adaptation or even of their present risk perception and past experiences.

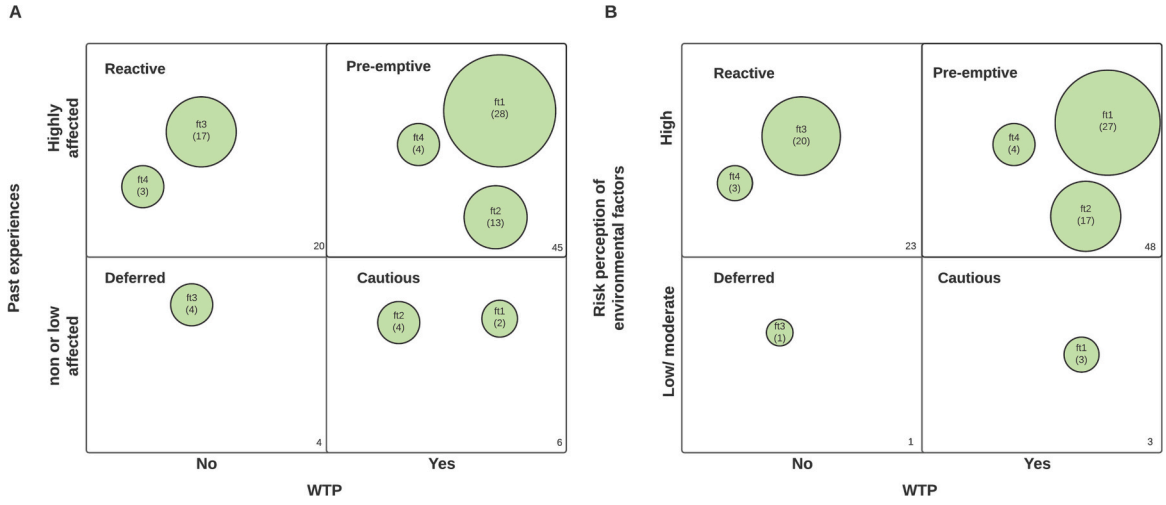

Fig. 5. Adaptation behavior profile matrices. 5A) Profiles based on degrees of affection by past environmental perturbations and their WTIad. 5B) Profiles based on risk perception of environmental threats and their WTIad. The size of bubbles represents the number of firms belonging to that profile and content in the specific cluster. The number at the right-bottom corner of each quadrant represents the total number of firms related to the specific profile.

These results are in line with different studies that indicate that despite the insights of firm typologies could provide, they do not reflect how the subjectivity of a firm's interpretation of physical climate impacts affects the adaptation process it engages in (Gasbarro and Pinkse, 2016; Linnenluecke et al., 2012).

Unlike large firms, SMEs present four different profiles that, at the same time, move on depending on their perceptions and past experiences. Regarding past experiences (Fig. 5A), considering those firms that are willing to invest in anticipating changes (ft1 and ft2), most of them present a pre-emptive adaptation behavior (87% of firms from ft1 and ft2). In comparison, a few firms (13% from ft1 and ft2) present a cautious adaptation behavior. Regarding the pre-emptive adaptation behavior, our results suggest the potential relevance of past experiences on the tendency to adopt it - through the willingness to invest in anticipating change. Our results seem to indicate that the learning incorporated by SMEs after living a crisis made them more willing to invest in anticipating changes in the future. This would probably relate to the role of past experiences in informing the firms about their vulnerability (which already faced the cost of a past environmental crisis), triggering a pre-emptive adaptation behavior. This has been mentioned previously in the literature, where has been highlighted the role of past experiences with a specific event in the adaptation response to that type of event (Berkhout et al., 2006; Linnenluecke and Griffiths, 2010; Pinkse and Gasbarro, 2019), as also in triggering the adaption process in response to other environmental risks (Gasbarro et al., 2019).

Firms adopting a cautious adaptation behavior are represented by firms with non/low exposure to past crises and are willing to invest in adaptation capacity. This would probably be related to the awareness of these firms regarding the impacts of past environmental stresses on other similar or nearby firms. This means that although not affected by the past crises, they know about the effect that it has on the industry, so they are willing to invest in an early warning system to improve their adaptation capacity.

SMEs unwilling to invest (ft3) present a deferred and reactive, adaptive behavior. The firms adopting a deferred adaptation behavior (19% of firms from ft3) are characterized to postpone adaptation measures and do not intend to do so anytime soon. This is explained by their low awareness of environmental-induced physical changes (the firms indicate they were not affected) and their low vulnerability self-assessed (Gasbarro and Pinkse, 2016). In this context is not surprising their unwillingness to invest. In the case where firms adopt a reactive adaptation behavior (81% of firms from ft3), it could be explained by two issues previously mentioned in the corporate adaptation behavior literature. First, constantly dealing with a specific environmental event may become a routine (firms understand their vulnerability). This implies a learning process from previous experiences that may trigger a low-risk awareness (for our case, translated in the unwillingness to invest in the anticipating of change). However, this routine can still catch a firm by surprise when a climate event is more intense or not anticipated (Gasbarro and Pinkse, 2016). Second, like larger firms, the subjective interpretation of SMEs about environmental events and their impacts affects the adaptation process they engage in. Despite operating in extreme events but having a high sense of control, firms see their existing routines as sufficient. These specific behaviors must be considered with caution since it is expected that natural hazards with their related environmental events increase in frequency, severity, and duration due to climate change.

Through the present perception perspective (Fig. 5B), the distribution of clusters and firms within the adaptation behaviors matrix remains practically the same. However, the number of firms changes in some of them. When considering past experiences, the number of firms within the pre-emptive profile was 45, including 28 firms in ft1, 13 in ft2, and 4 in ft4. Considering present perceptions, firms increased to 48, considering an increase in ft2 (from 13 to 17) and a decrease in ft. 1 (from 28 to 27) on the pre-emptive quadrant. As we previously mentioned, these results are probably related to the awareness (i.e., the risk perception of environmental threats) that firms already have about likely environmental impacts.

Regarding the other two adaptation behavior related to their unwillingness to invest in future adaptation actions (deferred and reactive), we observe changes in their adaptation profile of SMEs when considering the present risk perception of environmental factors. Our results are in line with other studies that have mentioned the past experiences on particular events as drivers of change in the adaptation behavior (Gasbarro et al., 2019). In this case, the high-risk perception of environmental factors seems to be a further determinant driver (to the past experiences), that helps to change from deferred to reactive adaptation behavior.

5. Conclusions

This study identified different adaptive behaviors of mussel producers in the Los Lagos Region in Chile by an innovative approach. These behaviors are represented by different pathways constructed based on both firms' productive and economic features and past, present, and future adaptive behaviors. This exploratory approach looks to shed some light on the different drivers that might be influencing the willingness to invest in future adaptive strategies. Understanding these drivers could be an essential input to delineate future adaptation strategies to the mussel industry in the Los Lagos region, considering firms' structural characteristics and past context and present perceptions about social and environmental threats.

Like past experiences, current mussels firms' perception of environmental threats is an important driver to change and improve adaptive capacities. Future policies looking for a significant industry engagement in adaptation, independent of their productive and economic characteristics, should consider addressing these perceptions through training and educational strategies about current and future environmental threats that will be detrimental to the sector.

Adaptation strategies must be planned so that the interrelated nature of factors, including social behaviors that limit adaptation, must be considered. When adaptation planning is addressed to heterogeneous primary sectors, such as the mussel industry, where small, vulnerable firms represent a significant share of it, such a plan must consider the adaptive profile of those involved through bottom-up approaches.

Our findings represent the basis for future studies about how an adaptive profile, based not only on economic and productive features and their social behavior regarding environmental threats, influences future adaptive behavior. It is important to highlight the exploratory condition of the present study, whose results do not allow to establish causalities. In this sense, more studies are needed considering a more significant sample of producers, improving the characterization of firms' adaptive profile, and identifying better-focalized adaptation strategies.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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