Ocean Acidification, Consumers' Preferences, and Market Adaptation Strategies in the Mussel Aquaculture Industry

Abstract

Ocean acidification (OA) is one of the largest emerging and significant environmental threats for the aquaculture industry, jeopardizing its role as an alternative for supporting food security. Moreover, market conditions, characterized by price volatility and low value-added products, could exacerbate the industry's vulnerability to OA. We use a literature review on the biological consequences of OA over marine commercial species attributes to inform the empirical assessment of consumers' preferences for those attributes affected by OA, and consumers' responses to a set of market adaptation strategies suggested by the industry. We found that OA will have a negative impact on consumers' welfare due to the effects on commercial attributes of aquaculture products. However, the main concerns for the industry are the market conditions. Thus, the industry's current adaptation strategies are focused on increasing their market share by offering new product assortments (with more value-added), regardless of the effect of OA on consumers' welfare. Despite this fact, the industry's strategies could eventually contribute to cope with OA since some specific segments of the market are willing to pay for new product assortments. This new market composition highlights the role of public institutions' reputation in issues related to food safety.

Keywords: ocean acidification; economic impacts; aquaculture; choice experiment; industry adaptation strategies; consumers' welfare.

1. Introduction

Current trends in emissions of carbon dioxide (CO_2) and human population growth are jeopardizing the possibility of achieving food security and nutrition targets for the human population (Golden et al., 2016). As a result, aquaculture has emerged as one the most important ways in which to support food security, mostly because it is an affordable source of protein in economically deprived regions (FAO, 2016). Unfortunately, increasing levels of anthropogenic CO_2 have dramatic consequences for oceans, causing widespread changes in seawater pH and carbonate chemistry (Caldeira and Wickett, 2003; Orr et al., 2005), known as ocean acidification (OA). OA threatens the potential of aquaculture to support food security (Gattuso et al., 1999) and the ways in which the industry can adapt to and/or mitigate the relative effects of this global stressor (Clements & Chopin 2017).

OA is a significant threat to the aquaculture industry, especially for marine shelled mollusks (Gazeau et al., 2013). These species are particularly vulnerable because they depend on carbonate concentrations to build their shells (Gazeau et al., 2013; Waldbusser et al., 2015). OA can significantly impair various physiological traits in marine mollusks such as scallops (Cooley and Doney, 2009; Schalkhausser et al., 2014; Talmage and Gobler, 2010), gastropods (Bednaršek et al., 2012; Wittmann and Pörtner, 2013), and mussels (Gazeau et al., 2013; Gazeau et al., 2007; Kroeker et al., 2010; Ventura et al., 2016; Waldbusser et al., 2015). OA also affects these species' mortality rates (i.e. larvae (Gibson et al., 2011)), calcification, and growth rates, as well as increasing their vulnerability to diseases and parasites (Gazeau et al., 2013; Mackenzie et al., 2014; Thomsen et al., 2013).

Research exploring the effects of OA on commercial attributes associated with mollusk quality, such as taste, appearance, and nutritional composition, is still in its infancy (Olsen 2003; Sveinsdóttir et al. 2009). As a result, the potential links between the impact of OA and consumers' preferences and well-being have not been studied sufficiently, with just a handful of papers analyzing the economic dimension of OA. Of these, Finnoff (2010) analyzes the impact of OA on the provision of ecosystem services, highlighting that welfare effects should be measured in terms of changes in consumer and producer surplus, rather than changes in gross revenue. Narita and Rehdanz (2017) evaluate the economic impact of OA on the production of mollusks in Europe. Using a partial-equilibrium model, they show that countries such as France, Italy, and Spain (the largest producers in Europe) are among those most affected by OA. Moore (2015) estimates the welfare effects of OA for four species of mollusks by estimating an inverse demand function and calculating the consumer surplus associated with a reduction in supply. Falkenberg and Tubb (2017) provide a review of studies on the economic impacts of OA, identifying the current state of knowledge, key gaps in its understanding, and promising methods and approaches for future research. Their results show that more (and better) inter-disciplinary work is needed to increase our understanding of the links between OA and human welfare.

In order to understand the impacts of OA on human welfare and to inform adaptation strategies for the aquaculture industry, it is crucial that we connect the effects of OA on market attributes and assess the roles of these attributes in human well-being. Unfortunately, evaluations of commercial attributes and adaptation strategies in the shellfish industry under OA scenarios have not received the attention they deserve (Mabardy et al., 2015). Here, we conduct a detailed analysis of the evidence identified in the literature related to the physiological, organoleptic, and nutritional consequences of OA in marine commercial species, focusing on mussels, in order to assess consumers' preferences for attributes affected by OA. We use discrete-choice experiments (DCEs) to evaluate consumers' responses to a set of market adaptation strategies aimed at reducing shellfish producers' vulnerability to OA, international prices variations, and other stressors. In doing so, we explicitly link the ecological and socioeconomic dimensions of climate change in the aquaculture socioecological system.

This study contributes to the literature on the economic impacts of OA by (i) linking the effects of OA to consumers' preferences using stated-preference methods, and (ii) assessing the effectiveness of the market adaptation strategies identified by the industry. Unlike a cost–benefit analysis, which focuses on average net benefit, we examine market segmentation based on consumers' preferences as an adaptation strategy to cope with OA. Our study is novel in two ways: i) we examine OA effects on multiple product attributes; and ii) we offer suggestions to the industry on adaptation strategies by product form.

2. Materials and Methods

Mussel aquaculture production includes four stages: 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; iii) industrialization in processing plants; and iv) marketing to national and international markets (Rivera et al., 2017). The greatest exposure of mussel production to OA occurs during the first two stages, but its consequences are found throughout the supply chain.

To gain insight into the industry’s adaptation opportunities and challenges under OA scenarios, we follow a two-stage approach. In the first stage, using a literature review, we identify the impacts of OA on mussels’ market attributes (i.e., shell appearance, shell size, and nutritional composition). In the second stage, we conduct participatory activities with industry representatives to assess their awareness of OA and to examine current and expected market adaptation strategies aimed at increasing value and adaptive capacity. The literature review and participatory activities are used to design a DCE that investigates consumers´ responses to changes in mussels’ market attributes and to the adaptation strategies suggested by the industry, enabling us to identify the attributes consumers find most valuable. As such, we evaluate whether the proposed industry strategies will be accepted by the market (or by certain segments within the market).

2.1 Literature review of the impact of OA on market attributes

We conduct a systematic literature review of the impact of OA on mollusks’ market attributes, such as shell size, meat color, shell appearance, texture, taste, and nutritional composition (lipid and protein content, Vitamin B12, and fatty acid). These attributes are selected based on previous surveys on seafood consumption preferences (e.g., Cardoso et al. 2013, Sveinsdóttir et al. 2009). Here, we search the databases of Scopus, Science Direct, Web of Knowledge/Science, and Google Scholar. In our literature analysis, we consider only original research papers and review papers, but exclude conference proceedings and other non-peer-reviewed publications. However, we include unpublished information from ongoing experiments by the authors of the present study on evaluating the impact of OA on mussel color.

2.2 Industry awareness

Participatory activities (interviews and seminars) are used to understand both the industry's awareness of OA and the current and expected market situation (prices, production levels, main markets). We conducted 20 semi-structured interviews with key industry representatives between June and August 2014. These interviews examined the cost structure, production, main threats, future expectations about activities, and market adaptation strategies, among other topics. Using this information, and collaborating closely with the Chinquihue Foundation (private non-profit organization that promotes artisanal fisheries and small-scale aquaculture sectors) and the Chilean mussel industry association (AmiChile), we designed and administered surveys to 87 of 148 firms in the industry between November 2014 and January 2015.[1] This survey analyzes participation in various stages of the value chain (seed producer, feeder, processing, and commercialization), main industry threats (production, environment, market), and market characteristics (main markets served, product assortment offered[2]). With regard to industry threats, the survey included 10 potential threats to the industry, grouped into the following categories: environmental (lack of knowledge about the environment, water pollution, red tide, environmental standards); production (seed shortages, labor shortages), market (dependency on international prices, input-market concentration, fixed-capital replacement, and environmental certification).

We included specific questions related to environmental issues, asking the interviewees whether they were familiar with OA, global warming, anoxia, phytoplankton decrease, eutrophication, water pollution by antibiotics, and water pollution by other compounds. In each case, we also inquired about the potential threat to the industry and the level of relevance they assign to each issue.

Finally, we held two seminars (May 2015 and July 2016) in which we discussed the results of the industry survey and designed the DCE consumer survey. In these seminars, we discussed the market adaptation strategies, including information related to potential changes in product presentation (product assortments). The seminars were targeted at industry

[1] The remaining 61 firms did not participate owing to various constraints (time, geographical, and budget).
[2] Product assortment refers to the number of different product presentations available for commercializing the product.

representatives responsible for the marketing/management and production/processes in their respective organizations.

2.3 Consumer preferences

DCEs are widely used in the fields of marketing and environmental economics (Louviere et al., 2000) to assess the relative relevance of different attributes for consumers. The method is grounded in both the theory of value (Lancaster, 1966) and random utility theory (McFadden, 1974).

The utility level obtained by individual n selecting alternative j from among $j = 1, \dots, J$ alternatives in choice situation t, for $t = 1, \dots, T$, is given by:

$$U_{njt} = V_{njt} + \varepsilon_{njt}, \quad [1]$$

where V_{njt} is the observed component of the utility of individual n when choosing alternative j in choice situation t, and ε_{njt} is an unobserved random component. The model assumes that people choose the alternative that provides the highest utility (McFadden, 1974; Train, 2009).

Assuming a linear specification for V_{njt} and an identical and independent Gumbel-distributed stochastic component, the probability that individual n makes a sequence of independent T choices, conditioned on coefficients α_i and β_n, is given by:

$$L_{ni}(\alpha_i, \beta_n) = \prod_{t=1}^{T} \left[\frac{e^{\alpha_i + \beta_n' x_{nit}}}{\sum_j e^{\alpha_i + \beta_n' x_{njt}}} \right], \quad [2]$$

where x_{njt} represents the attribute levels; α_i is an alternative specific constant (ASC), independent of the attribute levels we use to model the utility of the “opt-out” option; and β_n is a random parameter vector associated with the attribute levels, with distribution function f ($\beta \mid \mathbf{b}, \mathbf{W}$), in which **b** corresponds to the vector of means and **W** indicates the covariance matrix. We use a random parameter specification (mixed logit model) because the standard conditional logit model does not allow the random error to be correlated between alternatives and observations and suffers from the independence of irrelevant alternative (IIA) property (Train, 2009). Because we cannot obtain an analytical expression for the unconditional probability, we develop a simulation method that allows us to assess the integral of the probability. Values for β are generated from the distribution f ($\beta \mid$ **b, W**), called β^r, which in turn allows us to calculate a value according to the probability $L_{ni}(\alpha_i, \beta^r)$ given in [2]. The simulated unconditioned probability of choosing alternative i, $\check{P}_{ni}$, is obtained as the average of R simulations:

$$\check{P}_{ni} = \frac{1}{R}\sum_{r=1}^{R} L_{ni}(\alpha_i, \beta^r). \quad [3]$$

The simulated maximum-likelihood estimator corresponds to the values of α_i, **b**, and **W** that maximize the likelihood function constructed with the simulated probabilities $\check{P}_{ni}$ (Train, 2009).

2.3.1 Experiment design

We developed a face-to-face survey that we conducted from October to December 2016 in two Chilean cities: Santiago (Chile's capital) and Concepción (the second-largest city). As mentioned above, the design of the final survey was the result of close collaboration with the industry, and the final DCE was presented in two seminars with industry representatives. After the seminars, we conducted four focus groups (two each in Concepción and Santiago) to explore people's reactions to specific aspects of the experiment and to identify wording problems or misleading sections in the survey. Then, we conducted 125 pilot surveys to field-test the design of the instrument (with 25, 50, and 50 observations, respectively).

We rely on a socioeconomic sampling process based on the National Socioeconomic Household Survey (CASEN), using a probabilistic polietapic sampling design, in which we randomly select neighborhoods and blocks. Next, we systematically select the households to be interviewed. Here, we select one household in each block, starting in the northern corner. If there is no answer from that house, we skip the next four houses and try the fifth. The sampling process yielded a useful sample of 1,278 individuals, each of whom were presented with six decisions, with three alternatives for each choice. This yielded a final sample of 7,668 useful observations.

The final questionnaire consists of four parts. The first part provides information about mussels' characteristics, the second explains the relationship between mussel production and OA as an environmental stressor. Here, we also evaluated respondents' trust in public institutions on issues related to food safety. In the third section, we explain the choice exercise, the attributes of the alternatives, and the levels for each attribute. We provide an example of a choice to the interviewees to ensure their understanding of the cognitive task. After this explanation, we applied the final choice question. The final part focuses on socioeconomic characteristics (age, educational level, income, and household size).

The interviewees were presented with six choice sets, each with three alternatives: two mussel profiles and one opt-out alternative. Through the interviews, seminars, focus groups, and pilots, we identified eight main attributes (see Table 1). We classified the attributes into five categories: physiological, organoleptic, nutritional, product assortments, and price. Physiological attributes include shell size, meat color, and shell appearance; organoleptic attributes include texture and taste; and the categories of nutritional composition, product, and price contain one element only.

Physiological, organoleptic, and nutritional attributes are included in the DCE because all are affected by OA. The relationships between these categories and OA were identified from previous studies on the effects on shell appearance, shell size, meat color, texture, and nutritional composition. The last column of Table 1 shows the total number of studies reviewed, supporting the presence of each attribute category.[3]

The product attributes were defined after close discussion with the industry on both current product assortments (fresh and frozen formats) and new product assortments they wished to offer in future (bagged and dressed formats) in order to enhance their market performance. Finally, we also include six values for price. The ranges of prices vary according to the product assortment. These ranges were identified through focus groups, and were tested and adjusted after pilot surveys.

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[3] We provide detailed information about these studies in the supplementary material.

After the focus groups and pilot surveys, we decided to reduce the levels of most of the attributes (physiological, organoleptic, and nutritional) from three to two, given the complexity of the original choice exercise. We decided to retain the complexity in the product assortment attribute (10 levels) because the assortments represent both the current and the future options identified by the industry as the main market adaptation strategies available. To make prices comparable between different presentations of the product, we adjust the prices to represent the same weight (250 g of meat).

Table 1. Attributes and levels used in the choice sets and references to studies which justify their inclusion.

Category	Attributes	Levels	Group	Number of Studies	Total studies
Physiological	shell size	Small (5 cm) Large (7 cm)	Mussel	23	52
			Oyster	13	
			Clam	4	
			Snail	2	
			Scallop	2	
	Meat color	Yellow White	Oyster	4	
			Fish	1	
	Shell appearance	Acidified (decolorated) Not acidified (shinny)	Snail	2	
			Mussel	2	
			Oyster	3	
Organoleptic	Texture	Soft Hard	Snail	1	4
			Fish	1	
	Taste-sea scent	Intense Moderate	Shrimp	1	
			Oyster	1	
Nutritional composition	Nutritional composition	High Low	Mussel	6	9
			Oyster	2	
			Seafood	1	
Product	Product depth/assortment	Fresh with shell Fresh only meat Frozen with shell	Mussel	2	2

		Frozen only meat Canned in oil or water Canned in hot sauce Canned in green sauce Bagged with shell, in butter and garlic dressing Bagged with shell, in white wine dressing Bagged with shell, in tomatoes dressing			
Price	Price (250 g)	Six prices per product assortment ranging from [US$1.3- US$5]	Mussel	1	1

When appropriate, we used pictures to help interviewees understand the outcomes of each alternative (e.g., physiological attributes (shell size, meat color, and shell appearance), with and without impacts of OA). Based on secondary information, we informed interviewees about the nutritional characteristics (omega 3, omega 6 and Vitamin B12) of mussels by comparing them with other food with similar nutritional characteristics perceived as healthy by the Chilean population (olive oil, avocados, salmon, and mackerel). We also used pictures to illustrate the different product assortments, where we informed respondents (before the choice question) that 250 g of meat is approximately equivalent to 45 mussel units. An example of a choice set is shown in Figure 1.

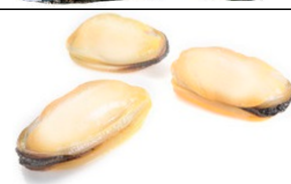
	Option 1	Option 2	Not Buying
Shell Size	Small (5 cm.)	Large (7 cm.)	
Texture	Hard	Soft	
Taste – sea scent	Intense	Moderate	
Nutritional composition	High	Low	
Product depth/assortment			
Shell appearance			
Meat Color			
Price (250 gr)	$1.700	$1.000	$0
Your choice			

Figure 1. Choice-set example

We include a constant opt-out alternative, representing a non-purchase choice. This is a standard design in choice experiments (Hanley et al., 2001; Meyerhoff and Liebe, 2009; Veldwijk et al., 2014). This opt-out alternative may be associated with elements of utility derived from characteristics that differ from those already included in the options (Bahamonde-Birke et al., 2017; Hanley et al., 2001; Hess et al., 2014; Kontoleon and Yabe, 2003; von Haefen et al., 2005; Zijlstra et al., 2015). This design offers several advantages. For example, it provides a more realistic choice scenario, the possibility of estimating an unconditional demand model rather than a conditional model, and correct estimates of welfare measures (Bateman et al., 2002; Batsell and Louviere, 1991; Kontoleon and Yabe, 2003; Louviere et al., 2000; Ortuzar and Willumsen, 2011; Zijlstra et al., 2015).

The choice sets are defined following state-of-the-art practices in the choice-modeling literature (Goos et al., 2010; Louviere et al., 2000; Scarpa et al., 2005; Street and Burgess, 2007; Street et al., 2005). Because the number of treatment combinations (full factorial) may be too costly in terms of data collection, we defined a subset of this design using an efficiency criterion. In the pilot surveys, we used an orthogonal design (Louviere et al., 2000; Street and Burgess, 2007) of 36 choice situations, divided into six blocks, each with six choice questions. For the final survey, we constructed a D-efficient design (Street and Burgess, 2007) using prior coefficients retrieved from the pilot regressions,[4] assuming a mixed logit model (Kuhfeld, 2005; Vermeulen et al., 2008) and using the Ngene software package (Quan et al., 2011). The final design consisted of 60 choice sets, each with two alternatives and an opt-out option, divided into 10 blocks of six choice questions. The final sample was fairly balanced, with about 10% of the sample in each block. The final distribution is shown in Appendix A.

To estimate the welfare measures, we adapted the classical welfare log sum expression to our profiles, following Bockstael and McConnell (2007). The baseline utility has only the opt-out alternative. However, in the choice situation, respondents face a new profile that includes the non-purchase option. Therefore, the willingness to pay (WTP) for a new mussel profile is given by:

$$WTP = -\frac{1}{\gamma} \cdot \ln\left[\frac{e^{v_0}}{e^{v_0} + e^{v_1}}\right].$$

Here, v_0 is the utility level at the opt-out alternative, and v_1 is a predefined profile. A marginal WTP (MWTP) for an increase in quality of one attribute only is calculated as:

$$MWTP = \frac{1}{\gamma} \cdot [v_1^M - v_0^M],$$

where v_0^M is the utility level of the baseline profile, represented by the lowest levels of the physiological, organoleptic, and nutritional composition categories. These are the levels we expect to find in a mussel affected by OA (labeled as "with OA"). This profile is completed by including the reference level for the product assortment (fresh with shell) and the lowest price. Then, v_1^M is the utility achieved by incrementing one level of one attribute only.

Finally, for the OA scenario, we rely on the RCP 8.5 scenario, which predicts around 1000 μatm of pCO_2 for 2100 in the open ocean (i.e. high seas). Although the timing assumed in this scenario is far in the future, living organisms in coastal zones could already be facing ocean acidification values in that range, owing to the natural variability in upwelling and

[4] We estimate a conditional logit (CL) model from the pilot responses.

river flows which are part of Chile's complex coastal system (Vargas et al., 2017). In fact, in situ studies show that in some places along the coast, the levels of pCO_2 reach 1800 µatm. This implies a pH level of between 7.4 to 7.6, which are the values predicted for 100 years from now (Vargas et al., 2017).

3. Results

3.1. Literature review on the impact of OA on market attributes

We identified 49 papers on the impact of OA on the market attributes of the main commercial marine species. Of these, only 24 papers (49% of the total) focused on mussels. Note that these studies, despite examining species of commercial importance, focus only on the effects on physiological responses, such as growth rate, size, and shell appearance. Similarly, only two studies examine the variation in organoleptic characteristics under OA scenarios (shrimp and oysters, respectively). However, these studies do not link their findings to consumers' preferences or how these preferences might vary if products with different attributes are made available.

Our analysis shows that OA can significantly impair attributes such as shell size, shell appearance, nutritional composition, and organoleptic characteristics (see Supporting Information, Table S1). The studies identified typically consider the response of Mytilus species to low pH/high pCO_2 conditions. Furthermore, our unpublished information shows that OA can impair shell color in both juvenile and adult mussels (Mytilus chilensis), with a 48% reduction in shell color in adult organisms and a 9% reduction in juvenile individuals (data not shown).

3.2 Industry awareness

Only 10.1% of the firms participate in all stages of the value chain (seed supply, feeding, processing, and commercialization). Considering the overall sample, the largest share (58%) participates in feeding, followed by seed supply (27%), and commercialization (8%). Firms perceive that the greatest threats relate to red tide events (95%), followed by seed shortages

(92%), and a dependency on international prices (86%).[5] A lack of environmental knowledge is recognized as a threat by 68% of respondents.

With regard to the specific environmental issues included in the survey, 94% of respondents indicated that they were familiar with water pollution from antibiotics, 91% with the phytoplankton decrease, and 89% were familiar with global warming. At the same time, 89% of respondents viewed the phytoplankton variability as a threat to the industry, as did 21% for the direct effects of OA. Figure 2 shows the results for all of the environmental categories, including the familiarity and perceived threat level in each case.

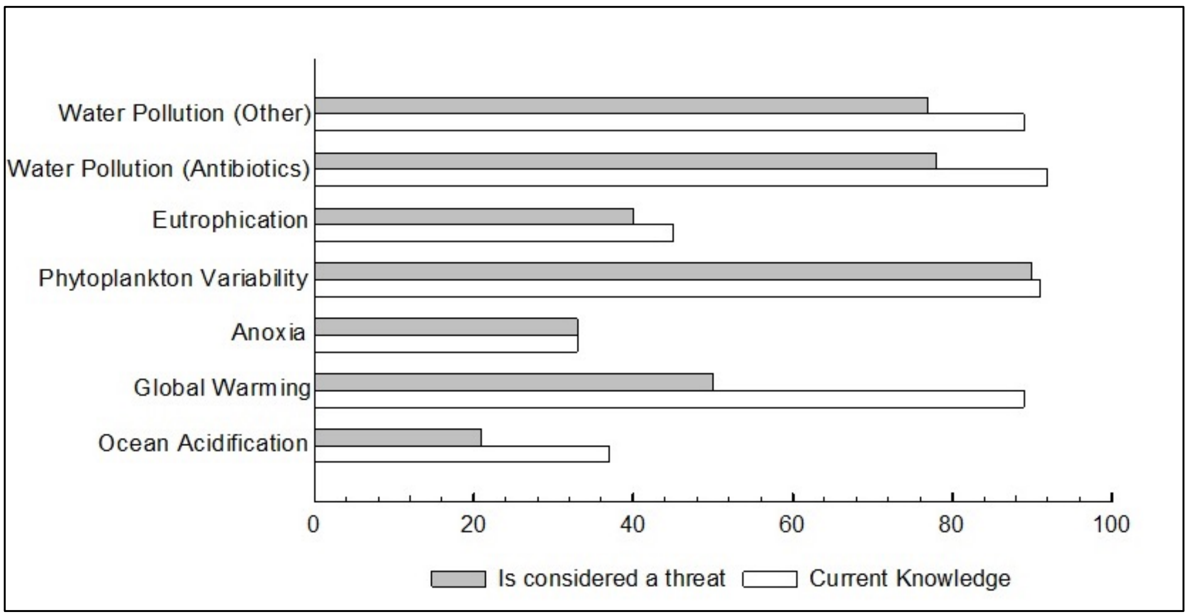


Figure 2. Environmental knowledge and level of threat perceived by mussel firms

All firms that participate in all stages of the value chain produce individual quick-freezing (IQF) meat, 75% produce whole-shell IQF, 63% produce half-shell fresh meat, 50% produce canned meat, and 13% produce other formats. All formats are characterized as low value-added. Firms sell almost all of their products to international markets (Spain, France, Italy, USA, and China), with a small share devoted to the domestic market (3%–5%), which increases their vulnerability to international price variations. Given the dependence on the

[5] These categories are not mutually exclusive; that is, respondents could select more than one option.

international market with low value-added products, the respondents stated that they would like to increase the share of the domestic market by offering new product assortments.

3.3 Consumer preferences

Table 2 presents the estimates of the mixed logit model. Here, we include all attributes from Table 1 and the sociodemographic variables interacting with the opt-out option. We report only the significant results for the demographic variables (trust in institutions and household size).

The table presents the mean and standard deviation for each attribute (columns 3 and 5, respectively). For the physiological attributes, the means of meat color and shell appearance are statistically significant. The mean of nutritional composition is also significant, indicating that consumers prefer mussels with yellow meat, without evident color changes in the shell (not acidified) and with a high nutritional level. The aforementioned attributes also have statistically significant standard deviations. Despite the other attributes (shell size, texture, and taste) of mussels not being statistically significant, all have a statistically significant standard deviation, suggesting strong heterogeneity across consumers' preferences. In other words, for some consumers, these attributes reduce welfare, while for others, they have positive effects from an economic perspective.

Table 2. DCE results/social valuation of the attributes and marketing format. Distribution of heterogeneity of preferences for mussel attributes and product assortment under normally distributed random coefficients.

Category		Mean	Std. Err	SD	Std. Err	% Negative	% Positive
		Random Coefficients					
Physiological	Shell size (large)	0.057	(0.05)	0.659***	(0.087)	46.58%	53.42%
	Meat color (yellow)	0.269***	(0.061)	1.349***	(0.082)	42.10%	57.90%
	Shell Appearance (not acidified)	0.828***	(0.065)	1.322***	(0.076)	26.57%	73.43%
Organoleptic	Texture (soft)	0.044	(0.049)	-0.596***	(0.085)	47.03%	52.97%
	Taste – sea scent (moderate)	0.058	(0.051)	0.742***	(0.08)	46.90%	53.10%
	Nutritional Composition (high)	0.306***	(0.055)	1.033***	(0.073)	38.35%	61.65%
Product assortment	Format: Fresh - Only Meat	-0.045	(0.117)	-0.793***	(0.26)	52.25%	47.75%
	Format: Frozen - With Shells	-0.079	(0.127)	-0.998***	(0.237)	53.17%	46.83%
	Format: Frozen - Only Meat	-0.409*	(0.128)	1.276	(0.214)	-	-
	Format: Canned – Oil or water	0.155	(0.12)	1.342***	(0.258)	45.40%	54.60%
	Format: Canned - Hot Sauce	-0.420**	(0.13)	-1.607***	(0.206)	60.31%	39.69%
	Format: Canned - Green Sauce	-0.170	(0.137)	1.613***	(0.23)	54.19%	45.81%
	Format: Bagged with Shell – Butter and garlic	-0.628***	(0.125)	0.926**	(0.284)	75.11%	24.89%
	Format: Bagged - White Wine	-0.619***	(0.124)	0.474	(0.348)	-	-
	Format: Bagged - Tomato	-0.881***	(0.124)	0.780***	(0.224)	87.05%	12.95%
		Fixed Coefficients					
	Price	-0.362***	(0.052)				
Opt-out and interactions	opt-out	-1.346**	(0.129)				
	opt-out*Trust	-0.309**	(0.107)				
	opt-out*Household Size	-0.103**	(0.03)				

Standard errors in parentheses. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

With regard to product assortments, the means of fresh-only meat, frozen with shells, canned (oil or water), and canned (green sauce) are not statistically significant. However, the means of frozen-only meat, canned (hot sauce), bagged with shell (butter and garlic), bagged (white wine), and bagged (tomato) are statistically significant. Notably, all of these product assortments have a negative sign, indicating that they reduce consumers' welfare (compared with choosing the "fresh with shell" option). However, in most cases, there is heterogeneity across consumers' preferences, meaning that some consumers do prefer these formats. Note that the standard deviations are not statistically significant for bagged (white wine) and frozen-only meat, indicating that these attributes are negative for consumers.[6]

Columns 7 and 8 of Table 2 present the percentages of the sample that have positive or negative signs for the "individual parameter" of the attribute (i.e., these values represent the probability that the coefficient is greater than or less than zero, respectively). For the physiological, organoleptic, and nutritional composition attributes, we find that the means are positive and that the heterogeneity among consumers is significant and, broadly speaking, evenly distributed between the negative and positive parts of the distribution. For those cases with significant means (meat color, shell appearance, and nutritional composition), the distribution leans toward the positive side of the distribution, with shell appearance and nutritional composition having the highest proportion of consumers in this area.

For bagged with shell (butter and garlic) and bagged (tomato), the percentage of negative signs is larger than 75%, suggesting that the majority of consumers do not value these presentations. For each of the five remaining assortments, the share of positive values is greater than or equal to 40%, suggesting that the industry can reach at most 40% of the market using this differentiation strategy. Thus, the results suggest that a market differentiation strategy (offering different product assortments) is appropriate for different market segments.

With regard to socio-economic characteristics, consumers can increase their welfare by selecting any of the available alternatives (the opt-out constant is negative and statistically significant). In other words, there is a preference for the purchasing option. The interaction of opt-out and trust, which is also negative and statistically significant, shows that greater trust in institutions related to food safety is associated with a larger probability of buying the product (i.e., consumers are less likely to choose the opt-out alternative). Furthermore, the larger the size of a family, the lower is the probability of choosing the opt-out alternative. Lastly, as expected, the price coefficient is negative and statistically significant.

[6] Note that they do not have an interval in columns 7 and 8 in Table 2.

Table 3 presents the assessment of OA on consumers' welfare. The first column presents three products assortments: the baseline case (fresh, with shells; frozen-only meat; and canned (standard)), which are the current options offered by the industry. Columns 2 and 3 present the total WTP for a profile with and without OA. Profiles "with OA" are small in size and have discolored shells, white meat, and a hard texture (the lowest levels of each attribute, except price and assortment).

Table 3. Consumers' WTP. Results for each profile, with and without OA effects.

	With OA	Without OA
Frozen - Only Meat	2.88	7.15
	(1.01 ; 4.75)	(5.28 ; 9.01)
Canned - Standard	3.41	8.02
	(1.78 ; 5.04)	(5.9 ; 10.13)
Fresh - With Shells	3.05	7.44
	(1.3 ; 4.81)	(5.47 ; 9.41)

Confidence intervals in parentheses.

For the currently marketed products, the WTP decreases between 41% and 43%, depending on the profile analyzed. The largest impact is observed for the canned (standard) offering.

An analysis of the MWTP is presented in Table 4. The second column shows the MWTP for the whole population, which is a standard indicator used in cost–benefit analyses. Nevertheless, from a marketing perspective, we are more interested in the MWTP for the proportion of the population who are willing to buy the product (i.e., those on the positive side of the distribution). This is because the differentiation strategies identified by the producers can target different segments of the market in order to decrease their vulnerability.

Table 4. MWTP for attributes (USD).

Attribute	MWTP	MWTP (positive only)
Shell size (from small to large shells)	0.259	2.512
	(-0.198 ; 0.717)	(0.102 ; 6.936)
Meat color (from pale to yellow)	1.23	5.402
	(0.612 ; 1.848)	(0.223 ; 14.69)
Shell appearance (without acidification)	3.784	6.517
	(2.623 ; 4.945)	(0.329 ; 16.429)
Texture (softer)	0.203	2.235
	(-0.242 ; 0.648)	(0.092 ; 6.225)
Taste – sea scent (lighter taste)	0.264	2.804
	(-0.196 ; 0.723)	(0.113 ; 7.772)
Nutritional composition (from low to	1.4	4.322
high composition)	(0.778 ; 2.021)	(0.197 ; 11.587)
Product Assortment (Baseline: Fresh with shells)		
Fresh - only meat	-0.205	2.825
	(-1.244 ; 0.834)	(0.116 ; 8.065)
Frozen - with shells	-0.364	3.512
	(-1.519 ; 0.792)	(0.135 ; 9.985)
Frozen - only meat	-1.888	
	(-3.143 ; -0.634)	-
Canned – oil or water	0.709	5.18
	(-0.37 ; 1.789)	(0.221 ; 14.268)
Canned - hot sauce	-1.921	5.2
	(-3.283 ; -0.559)	(0.194 ; 15.165)
Canned - green sauce	-0.776	5.573
	(-2.061 ; 0.51)	(0.217 ; 15.877)
Bagged with shell – butter and garlic	-2.871	2.525
	(-4.201 ; -1.541)	(0.087 ; 7.765)
Bagged with shell - white wine	-2.83	
	(-4.291 ; -1.369)	-
Bagged with shell - tomato	-4.027	1.773
	(-5.598 ; -2.456)	(0.058 ; 5.665)

95% confidence interval indicated in parentheses.

For the physiological, organoleptic, and nutritional attributes, the MWTP values are all positive. The highest MWTP is shown for an improvement in shell appearance (from small shells to large shells; USD 3.7). In contrast, the lowest MWTP is related to an improvement in meat softness (from a hard to a soft texture; USD 0.2). The MWTP values for the product attributes need to be compared with those of the baseline product assortment (fresh, with shell). For example, consumers' MWTP will increase by USD 0.71 when changing from "fresh, with shell" to "canned (oil or water)." As expected, the MWTP will decrease when changing from the "fresh, with shell" format to any of the other product assortments.

If we restrict our analysis to the positive side of the distribution, focusing on those consumers who are willing to buy the different assortments, the attribute "bagged with shell (butter and garlic)" is valued similarly by consumers to the attributes taste, texture, and shell size (approximately USD 2.5). For the remaining product attributes, the MWTP of the canned formats are similar (approximately USD 5). This is a promising result, because it tells us that producers can compensate for the loss due to OA by offering these product assortments to at least one segment of the market.

4. Discussion

The literature review showed that OA has a direct impact on mussels' physiological characteristics and nutritional content. Previous studies have suggested that shell appearance is decisive in terms of informing consumption decisions (Alfnes et al., 2006; Azpeitia et al., 2016; Batzios et al., 2003; Brenner et al., 2012; Grabacki, 2011). Furthermore, as shown by Colombo et al. (2016), a decrease in nutritional quality indicates a higher content of proteins and lipids in specimens that have not been exposed to environmental stress (i.e., temperature, habitat, and air exposure). Our results show a strong link between these biological/physiological consequences of OA and human welfare. Similarly to Batzios et al. (2003) and Batzios et al. (2002), we find that the nutritional content of shellfish is an important and significant attribute for consumers. In addition, we find that consumers consider both the appearance and the color of the meat.

Market price is highly dependent on both the quality of the meat and mussels' appearance (Brenner, Buchholz, Heemken, Buck, & Koehler, 2012). Thus, any variation in these attributes due to OA will have implications for the mussel industry and, thus, will affect the local economy and consumers' welfare. The industry has identified market segmentation as a strategy to cope with the low value-added products, price volatility, and producers' dependency on international markets by creating new product assortments. However, our results show that these strategies will only help for specific segments of consumers. Unlike Batzios et al. (2003), who found that shellfish packaging is not a relevant criterion in consumers' purchasing decisions, our results show that, on average, consumers place a low value on these new and innovative assortments (i.e., different bagging and dressing options).

The heterogeneity analysis of the WTP for different attributes identified segments of the population that could be targeted using these strategies. Despite the proposed product assortments having a negative sign, thus reducing consumers' welfare, a significant segment of the population (40%) is willing to pay for them. Discrete-choice models can help to identify these market segments in order to increase producers' revenue. Our results complement those of other studies, showing that OA affects mussel production and, thus, prices (Moore, 2015). However, we go beyond the price (quantity) effect by considering other mussels attributes affected by OA that consumers find relevant. In other words, OA not only affects prices (by affecting quantities), but also affects other relevant attributes of the products, thus exacerbating the impact of OA.

Based on our results, it is possible to inform future scenarios for the industry by considering the interplay between market adaptation strategies, such as that between offering new product assortments and the traditional mussel attributes preferred by consumers. Implementing these adaptation options will require that the industry educate consumers about the characteristics (i.e., nutritional quality) of the new product assortments in order to inform the buying process. As our results show, greater trust in institutions leads to a higher probability of buying the products. Therefore, there is space to build a fruitful private–public partnership with regard to food safety. This is a highly relevant result, because public policies rely heavily on providing information to consumers (McDowell, 2006).

Our results can be extended in three ways. First, it would be worth including foreign consumers and conducting a similar analysis for the main markets of Chilean mussels (Spain, China, France, and the United States). This new information would enrich our results with regard to the most valuable attributes. Another possible extension of the study would be to empirically test the organoleptic characteristics under different OA scenarios in order to compare consumers' perceptions to the laboratory results. Finally, our results could be complemented with information about the industry's adaptive capacity, which would enable an assessment of whether the aquaculture industry can face the burden of climate change.

5. Conclusion

In this study, we explicitly link the expected impact of OA on physiological, organoleptic, and nutritional characteristics of commercial mussel species with consumers' preferences. Our results suggest that OA will affect biological and physiological characteristics that are highly valued by consumers and, thus, will affect their welfare. The attribute analysis suggests that the product assortment that mussel producers would like to offer does not meet consumers' expectations, on average. However, a heterogeneity analysis shows that different product assortments would meet the expectations of a significant share of the market. This point reveals the effectiveness of the adaptation strategies developed by the industry.

OA is not identified as a main threat by the industry, where producers are more concerned about their vulnerability to international market price volatility and would like to increase their domestic market share by introducing new product assortments (with higher value-added). However, these strategies could also contribute to coping with OA because reductions in physiological, organoleptic, and nutritional attributes can be compensated for, at least for some segments of the market, by introducing new product assortments.

The greatest challenge the aquaculture industry is going to face when confronted by OA is, arguably, preserving the attributes of appearance and nutritional composition. This is because the industry has less adaptive capacity in the first stages of the value chain, when organisms are more exposed to environmental oceanographic conditions. Thus far, industry efforts have focused on adaptation strategies such as using hatcheries, nurseries, artificial seawater, alternative food supplements, long-line systems with photosynthetic species, among others, which are costly and imply changes to production processes. Our results reveal the complexities and opportunities of using adaptation strategies in subsequent value-chain stages, such as labeling, product assortments, and market differentiation. Identifying the roles of these adaptation measures is critical to informing future strategic investments of the industry along the supply chain.

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Appendix A. Distribution of blocks in the sample

Table 1: Distribution of blocks in the sample

Blok	individuals	decision occasions	Percent	Cum.
1	129	774	10.09	10.09
2	125	750	9.78	19.87
3	132	792	10.33	30.20
4	129	774	10.09	40.30
5	128	768	10.02	50.31
6	130	780	10.17	60.49
7	126	756	9.86	70.34
8	127	762	9.94	80.28
9	124	744	9.70	89.98