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Stakeholder perceptions of enhancement opportunities in the Chilean small and medium scale mussel aquaculture industry

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ABSTRACT

The Chilean mussel aquaculture industry is a prime example of a thriving industry. However, the industry growth rate, aquaculture concessions and market prices have stabilized signalling a shift in the industry from exponential growth to, if handled correctly, economic stability. Here we used perception research, an efficient tool to inform on the implementation of management strategies, to provide policy makers with the tools necessary for the development of strategies that will aid in the sustainability of the industry through its current shift. We assessed the perceptions of four main small and medium scale stakeholder groups in the mussel industry (i.e. seed collectors, growing centres, processing plants and service providers) on the challenges, obstacles and improvements in the industry. This information was divided into five main domains, namely: (1) finance, (2) human resources, (3) knowledge, (4) management and policy and, (5) technology and infrastructure, and was used to determine the gaps and opportunities that impact the biologic and economic productivity of the industry. Stakeholders displayed significantly different perceptions on the challenges, progress and obstacles they face, suggesting that segregation among groups exists. Despite this heterogeneity, there are areas that can provide the greatest enhancement opportunities for the industry; these are mainly based within the seed collectors group and the collection and transfer of local and scientific knowledge among all stakeholders. Notwithstanding the aforementioned areas, the Chilean mussel aquaculture industry perceives it is working towards overcoming its current obstacles and displays important progress in the incorporation of technology and infrastructure, finance and management domains. Our results indicate that with targeted interventions a promising future for the mussel aquaculture industry in Chile is achievable.

Statement of interest: This study shows how perception research can be used to determine the gaps and enhancement opportunities in the productivity of developing aquaculture industries.

1. Introduction

Aquatic resources provide 15% of the protein intake for over 3 million people worldwide (Godfray et al., 2010). However, wild captures have become stagnant in the past decade (FAO, 2014) adding to the increasing threat to food security (McClanahan et al., 2015). Aquaculture, one of the fastest growing industries in the world, is emerging as a solution to the current and future food security risks faced by society (Duarte et al., 2009). Currently, aquaculture is responsible for the livelihoods and nutrition of millions of people (FAO, 2014).

The global mussel industry is particularly reliant on aquaculture, which supplies 90% of its total harvest (Carrasco et al., 2014). Mussel cultures have been a growing industry since the 1980s (Smaal, 1991). In Chile, the mussel aquaculture industry has undergone a rapid expansion for the past 20 years. It was initially developed in the 1980s

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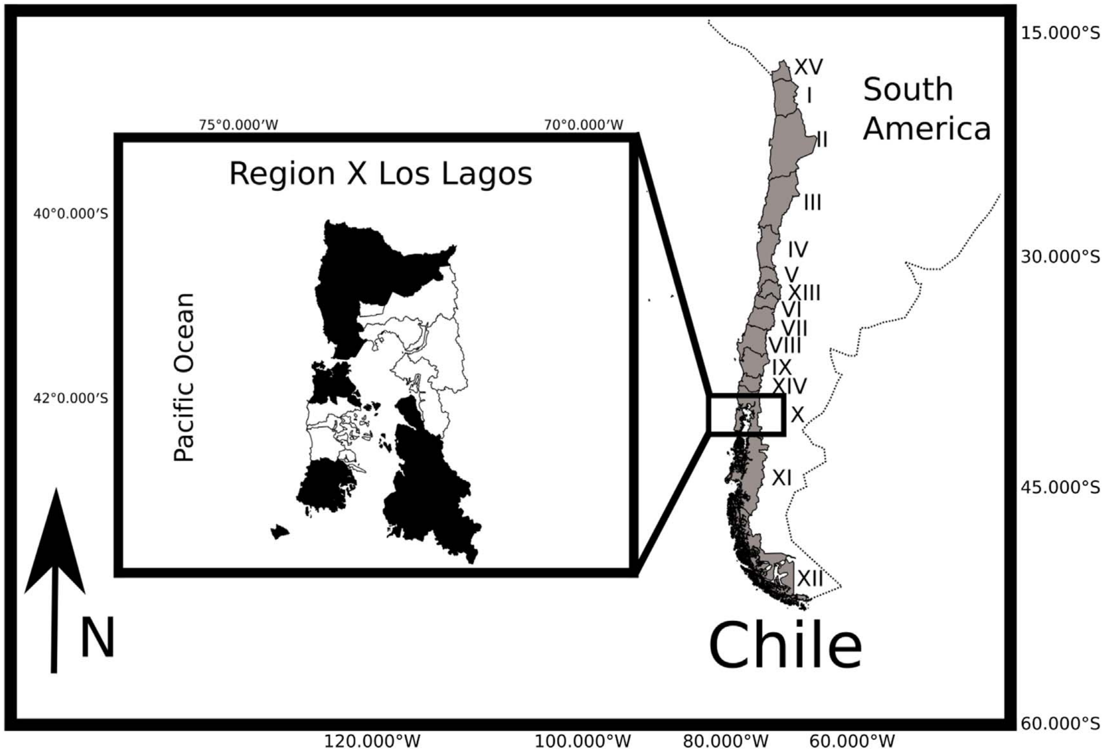

Fig. 1. Map of the study area. The roman numerals indicate the regions in Chile. Inset shows the Los Lagos (X Region) in Chile. Areas where surveys and questionnaires were carried out are coloured in white.

however its main expansion occurred in the 1990s, prompted by external market demand (Díaz, 2010). The continuous growth it has exhibited is unparalleled by any other industry in the country (Bagnara Vivanco and Maltrain Donoso, 2008). Its rapid growth can be attributed to the simplicity of the culture system (see Section 2.1), low initial investment and the existence of favourable oceanographic conditions (Díaz, 2010).

An important segment of the mussel aquaculture industry in Chile could be labelled as "small-scale", it is comprised by small-medium sized producers, with limited technological developments (Díaz, 2010), who rely heavily on the environmental conditions (Uriarte, 2008). In fact, 89% of the mussel aquaculture industries are either small or medium scale producers (Infyde, 2015). However, the industry in Chile appears to be shifting from small producers to larger more mechanized companies (Bagnara Vivanco and Maltrain Donoso, 2008). This shift is reasonable, considering that for industries to continue to grow they must not only focus on expanding their production but also on increasing their productivity, i.e. increasing their output/input ratio (Farrell, 1957). In fact, one of the main appeals of aquaculture is its ability to increase outputs from selected inputs (Muir and Young, 1998). Thus, to support these small-scale producers it is important that management guidelines and policies identify new opportunities to increase the sector's economic and biologic productivity. The current challenges, progress and obstacles facing the Chilean mussel aquaculture industry must continually be assessed to achieve this goal.

The success of natural resource management and conservation is dependent on the degree of support received by the stakeholders (Gelcich et al., 2008). Thus, perception research is emerging as means to assess legitimacy and effectiveness of management strategies (Gelcich and O'Keeffe, 2016; Mabardy, 2013). In data-deficient situations perceptions can help determine the current context of socio-ecological system to aid in its planning and monitoring (Bennett, 2016). Additionally, perception research can be used at a broad scale to provide insight on national or international policies (Bennett and Dearden, 2014). Here we used perception research theory (Gelcich and O'Keeffe, 2016) to gauge the current gaps and opportunities in the Chilean mussel aquaculture industry. Despite the ample use of stakeholder perceptions in fisheries management (Dimech et al., 2009; Gelcich et al., 2009; Gelcich et al., 2005) their implementation in the aquaculture sector is not as widespread and has mainly focused on social acceptability or environmental impacts of aquaculture (for examples see Bacher et al., 2014; Chu et al., 2010; Kaiser and Stead, 2002; Mazur and Curtis, 2008; Salgado et al., 2015). Through perception research theory we hope to obtain insights into the key issues, priorities and concerns of the stakeholders (Banks et al., 2010; Salgado et al., 2015).

Through perception research we assessed the areas that display the most enhancement opportunity in the mussel aquaculture industry in order to aid policy makers in the transition process from exponential growth to an economically, biologically and socially stable state. In the first section we will introduce the methods used in this paper to assess the perceptions of the four stakeholder groups directly involved in the Chilean mussel aquaculture industry (i.e. seed collectors, growing centres, processing plants and service providers). Next, we will present the results from the perception analysis on the challenges, progress and obstacles of the Chilean mussel aquaculture industry. Finally, we will use perceptions to illustrate the gaps, needs and progress of the industry.

2. Methods

2.1. Setting: the Chilean aquaculture industry

Three mussel species are harvested in Chile: *Mytilus chilensis* (Hupé, 1854), *Aulacomya ater* (Molina, 1782) and *Choromytilus chorus* (Molina, 1782). The species with the highest economic and social importance is *Mytilus chilensis* (Uriarte, 2008), by 2014 it comprised 98% of the total mussel harvests. Over 99% of the mussel aquaculture industry in Chile is located in the administrative region X (Los Lagos region; Fig. 1). The mussel production process consists of 4 main steps, each carried out by a specific group of stakeholders (i.e. seed collectors, growing centres,

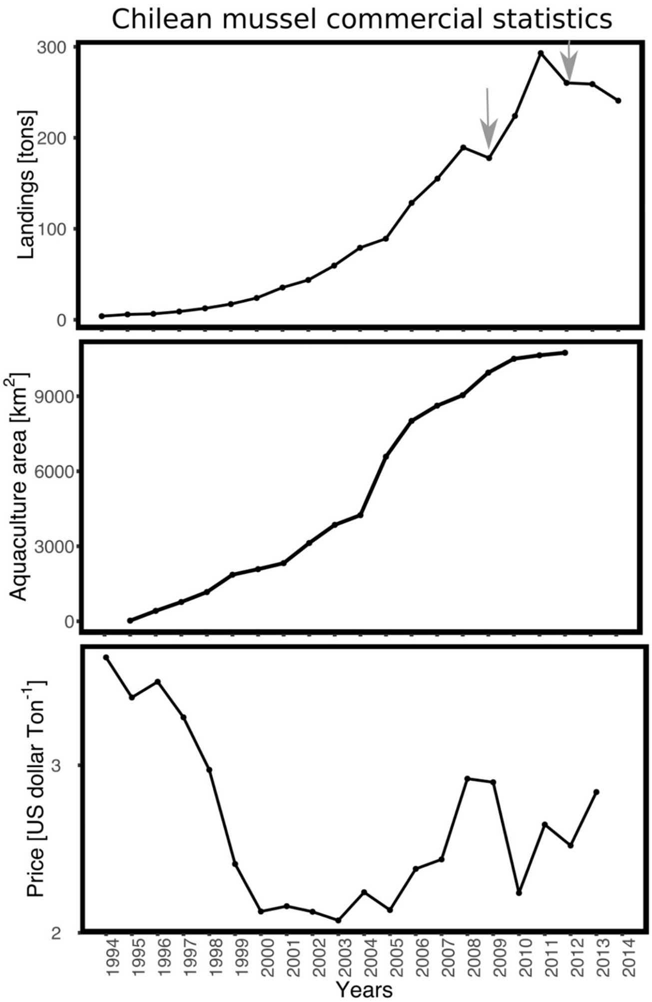

Fig. 2. Chilean mussel commercial statistics. Landings from 1994 to 2014, mussel aquaculture area (concessions) from 1994 to 2012 and price ton^{-1} from 1994 to 2013 for exported mussels.

processing plants and service providers). The industry relies mainly on natural spatfall, thus the first step to harvesting the resource is collecting the spat or seed. Mussel farms can obtain seeds from their own concession or outsource to independent seed collectors. The seeds are then transported to the growing centres, where mussels are placed in culture systems until they reach their market size (approximately 5 cm). The main culture system in Chile is the long-line, where mussels are attached to vertical ropes that hang from a floating mainline rope strung across the culture area (Serramalera, 2015). Once mussels reach their market size, they are harvested, generally by hand, and sent to processing plants. Processing plants are responsible for washing, declumping, debyssing, and classifying mussels. The final product can be sold fresh or processed depending on the market (local or international). Stakeholders who are not part of a growing centre or processing plant that develop harvesting plans, carry out environmental impact analyses and ensure the utmost quality of the resource throughout the production process are considered service providers.

Mussel landings increased exponentially from 1990 to 2011 (Fig. 2). After 2011 landings appear to decrease. In fact, landings are 18% lower in 2014 than those registered in 2011. A similar exponential growth was observed in the area used for mussel aquaculture. In an 8-year time-period the aquaculture area expanded over 900%, from 804 km^2 to 8413 km^2 (1994–2012; Fig. 2). On the contrary, prices for exported mussels exhibited a sharp decrease from the 1990s to mid 2000s (Fig. 2). After 2005 mussel prices begin to increase and remain relatively stable for the rest of the time-series (2013), with the exception of a price drop in 2010.

2.2. Stakeholder perceptions

To assess stakeholders' perceptions on the challenges, progress and obstacles faced by the industry in the past two years (2013–2014) 3 specialists administered questionnaires from May to August 2015 in the Los Lagos Region, mainly in the island of Chiloé (42° 40′ 36″ S; 73° 59′ 36″ W; Fig. 1). The four different groups of stakeholders were interviewed -seed collectors, growing centres, processing plants and service providers-. The selection of interviewees depended on the stakeholder group being assessed. Owners and managers were selected for the seed collector group and growing centres and quality control officials were selected for processing plants and service providers. All stakeholders had at least 5 years of experience in the industry. To obtain a 95% confidence level we applied 86 questionnaires to different stakeholders. Questionnaires focused on small and medium size producers (annual sales up to 1 million USD) because they comprise 89% of the stakeholders in Chile's mussel industry (Infyde, 2015). Nevertheless, it is important to consider that from an economic standpoint the large scale producers might have an impact on the industry, which is not contemplated in this analysis. Interviewees were consulted on three subjects: (1) challenges faced by the aquaculture industry, (2) progress in innovations and processes in the past two-years and, (3) main obstacles.

To obtain a general perception of the challenges faced by the aquaculture industry and minimize framing effects the first question of the survey was: "What are the first words that come to mind when you think about gaps in the mussel aquaculture industry in Chile?" Responses were then grouped into 5 domains: (1) Finance, (2) Human resources, (3) Knowledge, (4) Management and policy and (5) Technology and infrastructure. The domains were selected a priori and corroborated with the stakeholders general perceptions. The finance domain includes challenges on production costs, price reduction, financial capital, added value and commercialization. Human resource challenges include staff training and lack of qualified personnel. The knowledge domain considers challenges regarding scientific or local knowledge; among these we can highlight information on seed dynamics, oceanography and resource quality. The management and policy category includes challenges in bureaucracy, foreign markets, communication, competitiveness and linking different groups of stakeholders throughout the production process. Finally, the technology and infrastructure category includes machinery, laboratories, optimization procedures, software, transportation and automation. The word automation refers to the mechanization and increased efficiency of technologic processes. For a further description on the subjects encompassed by each domain see indicators in Tables 1 and 2.

Next, stakeholders were asked to use a scale from 1 (not important) to 5 (very important), to rank the main challenges (n = 35), progress or improvements (n = 13) and obstacles faced by the industry (n = 14). Interviewees only considered the improvements for the last two years because these are the most likely to have an effect on the current challenges faced by the industry. Significant differences among stakeholder groups for each indicator were assessed using Kruskal-Wallis one-way analysis of variance by ranks and Dunn's test for post hoc comparisons.

The challenges, progress and obstacles faced by the industry were divided into the five aforementioned domains (i.e. human resources, knowledge, management and policy and, technology and infrastructure). We calculated the mean and standard error for each user group and domain. Average values equal to or above 3 were deemed important for the group of stakeholders. Gaps in innovation were determined by subtracting the mean progress score per stakeholder group and domain from the mean challenge score. We used a Kruskal-Wallis one-way analysis of variance by ranks to detect differences in gaps among stakeholder groups.

Finally, to determine the domains and stakeholder groups with the

Table 1
Average score and standard error per user group for the main challenges faced by the industry. Significant differences (p) among stakeholder groups were determined using Kruskal-Wallis test. Statements that are not significantly different among stakeholder groups, according to Dunn's test, share the same letter.

Domain	Indicator	Seed collectors	Growing centres	Processing plants	Service providers	P-value
Finance	Developing added value	1.63 ± 0.30	2.16 ± 0.25	3.4 ± 0.75	2.54 ± 0.46	0.06
	Reducing cost in production	3 ± 0.45	3.45 ± 0.24	3.4 ± 0.81	3.62 ± 0.37	0.94
Human resources	Qualified workforce	2.84 ± 0.46	3.16 ± 0.25	3.4 ± 0.98	3.08 ± 0.43	0.92
	Staff training	2 ± 0.40	3.14 ± 0.26	3.2 ± 0.92	3.38 ± 0.45	0.12
	Obtaining expert technical support for the production process	1.53 ± 0.29	2.53 ± 0.26	2.8 ± 0.92	2.46 ± 0.50	0.1
Knowledge	Seed dynamics	3.84 ± 0.41[a]	3.69 ± 0.24[a]	2.2 ± 0.80[b]	2.54 ± 0.45[b]	0.04
	Nourishment factors	3.05 ± 0.44[a]	4.14 ± 0.21[b]	2.2 ± 0.80[a]	2.92 ± 0.47[a]	0.01
	Quality factors for raw materials	2 ± 0.37[a]	3.45 ± 0.24[b]	4 ± 0.55[b]	2.38 ± 0.49[a]	0.01
	Epidemiology	2 ± 0.40	2.29 ± 0.24	1.6 ± 0.40	1.92 ± 0.45	0.79
	Harmful algal blooms	2.26 ± 0.40	3.02 ± 0.26	2.8 ± 0.49	3 ± 0.55	0.39
	Oceanography	1.63 ± 0.30[a]	3.02 ± 0.25[b]	2.2 ± 0.49[a,b]	2.38 ± 0.49[a,b]	0.02
	Carrying capacity	2.05 ± 0.38	2.86 ± 0.25	3.4 ± 0.75	2.85 ± 0.45	0.25
	Environmental impact	1 ± 0[a]	2.73 ± 0.25[b]	2.8 ± 0.73[b]	2.08 ± 0.49[b]	< 0.01
	Improve the product quality	1 ± 0[a]	3.41 ± 0.26[b]	3 ± 0.71[b]	3.38 ± 0.49[b]	< 0.01
	New raw material sources	3.63 ± 0.43[a]	2.39 ± 0.24[b]	1.2 ± 0.20[b]	2 ± 0.42[b]	0.01
Management and policy	Interactions with other industries	2.63 ± 0.45	3.06 ± 0.25	1.6 ± 0.60	2.23 ± 0.47	0.16
	Production management	1.68 ± 0.32[a]	2.84 ± 0.27[b]	3.4 ± 0.81[b]	3.15 ± 0.42[b]	0.03
	Improve the management of the company	1 ± 0[a]	2.39 ± 0.25[b]	2.6 ± 0.81[b]	2.77 ± 0.48[b]	< 0.01
	Commercialization management	1.68 ± 0.30[a]	2.84 ± 0.24[b]	2.6 ± 0.75[a,b]	3.54 ± 0.43[b]	0.01
	Establish quality standards	2.32 ± 0.38	2.92 ± 0.26	3.2 ± 0.80	3.92 ± 0.40	0.09
	Residue management	2.32 ± 0.37	3.39 ± 0.25	2.6 ± 0.60	2.62 ± 0.49	0.08
	Obtain third-party certifications (e.g. ISO norms)	1 ± 0[a]	2.02 ± 0.22[b]	2.4 ± 0.60[b]	1.77 ± 0.41[b]	0.02
	Legal framework	1.63 ± 0.32[a]	2.8 ± 0.26[b]	2.6 ± 0.60[a,b]	1.69 ± 0.38[a]	0.03
	Surveillance program	1.53 ± 0.29[a]	3.1 ± 0.26[b]	1.2 ± 0.20[a]	2.08 ± 0.45[a]	< 0.01
	Traceability	1.21 ± 0.21[a]	2.2 ± 0.25[b]	2 ± 0.45[b]	2.38 ± 0.4[b]	0.04
	Increase the productivity of the company	2.58 ± 0.45	3.49 ± 0.27	2.4 ± 0.75	3.77 ± 0.47	0.22
	Improve environmental management	2.58 ± 0.44	3.08 ± 0.27	2.2 ± 0.80	2.62 ± 0.40	0.56
Technology and infrastructure	Access to more efficient productive systems	2.68 ± 0.43	3.1 ± 0.26	2.8 ± 0.92	2.23 ± 0.50	0.52
	Automation	2.26 ± 0.40[a]	3.63 ± 0.25[b]	3.6 ± 0.75[a,b]	3.46 ± 0.46[b]	0.04
	Improve the energetic efficiency	1.11 ± 0.11[a]	2.18 ± 0.25[b]	3.2 ± 0.80[c]	2.23 ± 0.43[b,c]	0.01
	Hatcheries	1.05 ± 0.05	1.92 ± 0.22	1.2 ± 0.20	1.77 ± 0.36	0.12
	Logistics and infrastructure	3 ± 0.43	3.67 ± 0.25	2.4 ± 0.51	2.69 ± 0.50	0.1
	Modelling	1.21 ± 0.21	1.84 ± 0.20	1 ± 0	1.77 ± 0.32	0.06
	Harvesting systems	2.89 ± 0.43[a]	3.49 ± 0.25[a]	1 ± 0[b]	1.62 ± 0.35[b]	< 0.01
	Access to new technologies	4.63 ± 0.22	4.02 ± 0.20	3.2 ± 0.80	3.54 ± 0.46	0.09

greatest need to improve we analysed the relationship between mean current progress and obstacles in the industry using Linear Regression Analysis. All values below the fitted regression line indicate domains and groups whose progress is below what is expected from the corresponding obstacles they face. Thus, these areas require the most attention and must be considered in management frameworks.

All questionnaires and interviews were administered in the Los Lagos region (region X, 41°28′18″S, 72°56′12″W; Fig. 1). Data analyses were carried out in R computing software (R Core Team, 2015) using the *ggplot2* package (Wickham, 2009) for graphical displays.

3. Results

3.1. Global perceptions of challenges

We surveyed a total of 86 stakeholders from May to August 2015 distributed along the 4 user groups in the region X (Los Lagos) Chile. 19 seed collectors, 49 growing centres, 5 processing plants and 13 service providers comprised the samples. Stakeholders' response to the challenges facing the mussel aquaculture industry that first came to mind differed among groups (Fig. 3). Seed collectors and growing centres are mainly concerned with challenges in technology and infrastructure,

Table 2
Average score and standard error for the perceived progress in the Chilean mussel industry for the past two years. Significant differences (p) among stakeholder groups were determined using Kruskal-Wallis test. Statements that are not significantly different among stakeholder groups, according to Dunn's test, share the same letter.

Domain	Indicator	Seed collectors	Growing centres	Processing plants	Service providers	P-value
Finance	Restructuring or production processes	1.79 ± 0.33	2.41 ± 0.24	2.83 ± 0.76	2.26 ± 0.47	0.56
	Energy management	1.21 ± 0.21[a]	1.27 ± 0.13[a]	2.97 ± 0.84[b]	1.87 ± 0.46[a]	0.01
Human resources	Staff training	1.69 ± 0.32[a]	2.39 ± 0.24[a,b]	3.86 ± 0.29[c]	3.23 ± 0.39[b,c]	0.02
	External technical advisors	1.65 ± 0.31	2.16 ± 0.22	1.66 ± 0.66	2.55 ± 0.42	0.4
	New highly qualified personnel	0.98 ± 0.02[a]	1.6 ± 0.19[b]	2.31 ± 0.84[b]	1.7 ± 0.38[b]	0.05
Knowledge	Access to technical information	1.62 ± 0.29	2.35 ± 0.24	2.31 ± 0.80	2.82 ± 0.50	0.21
	New techniques for production processes	1.1 ± 0.10	1.4 ± 0.16	1.66 ± 0.66	1.25 ± 0.25	0.7
Management and policy	Environmental management	1.5 ± 0.23[a]	3.16 ± 0.24[b]	3.11 ± 0.87[b]	1.68 ± 0.36[b]	< 0.01
	Quality management systems and third-party certifications	1 ± 0[a]	1.52 ± 0.17[a]	3.77 ± 0.74[b]	2.93 ± 0.52[b]	< 0.01
	Security and risk prevention systems	1.16 ± 0.17[a]	2.85 ± 0.25[b]	3.2 ± 0.61[b]	2.97 ± 0.47[b]	< 0.01
	Logistics and traceability	1.35 ± 0.24	1.8 ± 0.21	1 ± 0	1.87 ± 0.46	0.39
Technology and infrastructure	Acquisition of new machinery for production processes	3.58 ± 0.33	3.43 ± 0.24	3.49 ± 0.71	3.19 ± 0.50	0.96
	Acquisition of new platforms and software for production processes	1.14 ± 0.14	1.69 ± 0.21	2.31 ± 0.80	1.96 ± 0.42	0.2

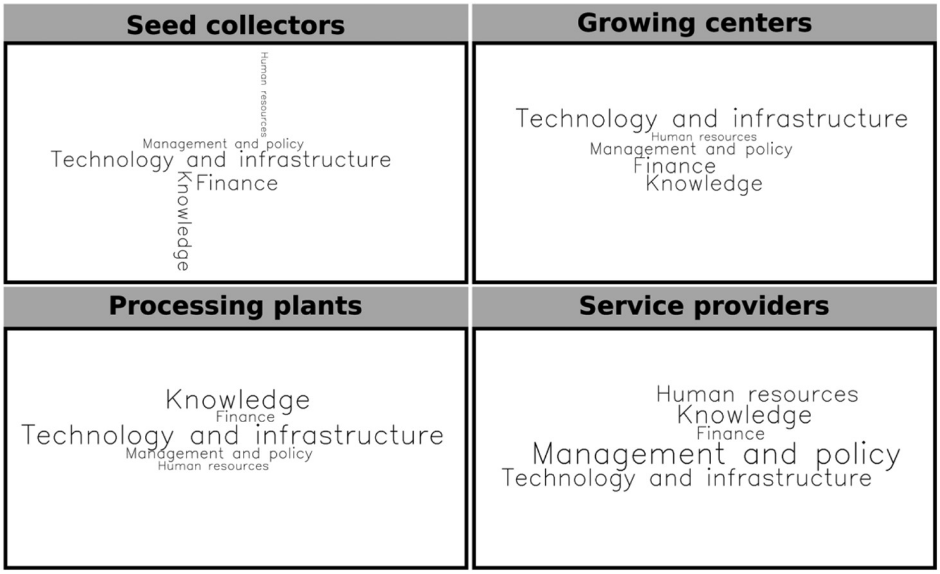

Fig. 3. Word cloud of stakeholders' general perceptions on the challenges facing the mussel aquaculture industry in Chile.

finance and knowledge. Similarly, processing plants perceive the main challenges to be centred in technology and infrastructure and knowledge. On the contrary, service providers believe the industry's main challenges are found in management and policy.

3.2. Challenges

Of the 35 challenge indicators assessed by the stakeholders, 25 were considered a priority (average values above 3) by at least one group of stakeholders and 17 displayed significant differences among stakeholder groups (Table 1). Nonetheless, when the challenges were averaged by domain, the seed collector group did not consider any of the challenges to be above the 3 limit. On the contrary, growing centres, processing plants and service providers all perceived that the industry faced important challenges in the finance, human resources and knowledge domains (Fig. 4).

The main challenge detected in the finance domain, ranked as important by all three groups of stakeholders, was the reduction of production costs. As for the human resources domain, the challenges were mostly focused on staff training and obtaining qualified work force (Table 1). The challenges were more widespread in the knowledge domain, where significant differences among stakeholders were observed (Table 1). Seed collectors were more concerned with challenges at the beginning of the production line, such as biological knowledge on seed dynamics, nourishment factors and new raw materials. Growing centres and service providers also perceive biological challenges to be important, such as seed dynamics, nourishment, algal blooms and oceanography (Table 1). In contrast to the seed collectors group, all other stakeholders place significant importance on knowledge further down the production line, for instance processing and quality of the resource.

On average the management and policy domain was not a priority by any of the stakeholder groups (Fig. 4). Nevertheless, the indicators displayed significant differences among stakeholders (Table 1). Growing centres consider residue management, surveillance programs and interactions with other industries to be important challenges. Also, processing plants and service providers both ranked production management and quality standards as priorities (Table 1).

Significant differences among stakeholder groups were also found in the technology and infrastructure domain. Growing centres perceive this domain as an important challenge (Fig. 4). In particular, this group considers the access to new technologies, production and harvest systems to be priorities for the industry. They also ranked the improvement of automation, logistics and infrastructure as challenges. Once again, the other groups did not consider this category as a whole as a priority but several individual challenges were highly ranked such as access to new technologies (> 3 for all stakeholder groups) and automation (> 3 for processing plants and service providers; Table 1).

3.3. Progress

Despite the challenges perceived by the stakeholders they have also had several improvements in the past two years. Six of the indicators displayed significant differences among groups of stakeholders. All of the 13 possible improvements were implemented in the past years by at least three of the user groups. Nevertheless, the seed collector group perceived the lowest progress of all user groups. When the assessed improvements were grouped by categories only the progress in the technology and infrastructure domain carried out by processing plants was ranked as significant (Fig. 4).

Some progress indicators in the human resources domain were ranked as important by the processing plants and service providers groups of stakeholders; these were mostly focused on staff training. Processing plants and growing centres also invested in the management and policy domain through environmental management and risk prevention systems, such as carrying capacity studies and HABs detection mechanisms. Additionally, the service providers group considered they had achieved significant progress in risk preventions (Table 2).

All stakeholder groups perceive the incorporation of new machinery and software in the production process indicator to be the most important progress in the technology and infrastructure domain (all average values > 3.19; Table 2).

3.4. Obstacles

We analysed 14 obstacle indicators that might hinder the progress in the mussel aquaculture industry. Of these, four indicators found within the finance and knowledge domains displayed significant differences among stakeholders (Fig. 4). The only domains that were not perceived as important obstacles for the development of the mussel industry were the technology and infrastructure domain for all stakeholders and the knowledge domain for service providers.

Seed collectors, growing centres and service providers, considered all 3 indicators for the finance domain important. However, processing plants only considered the high technological costs an obstacle (Fig. 4). In the human resources and management and policy domains, most

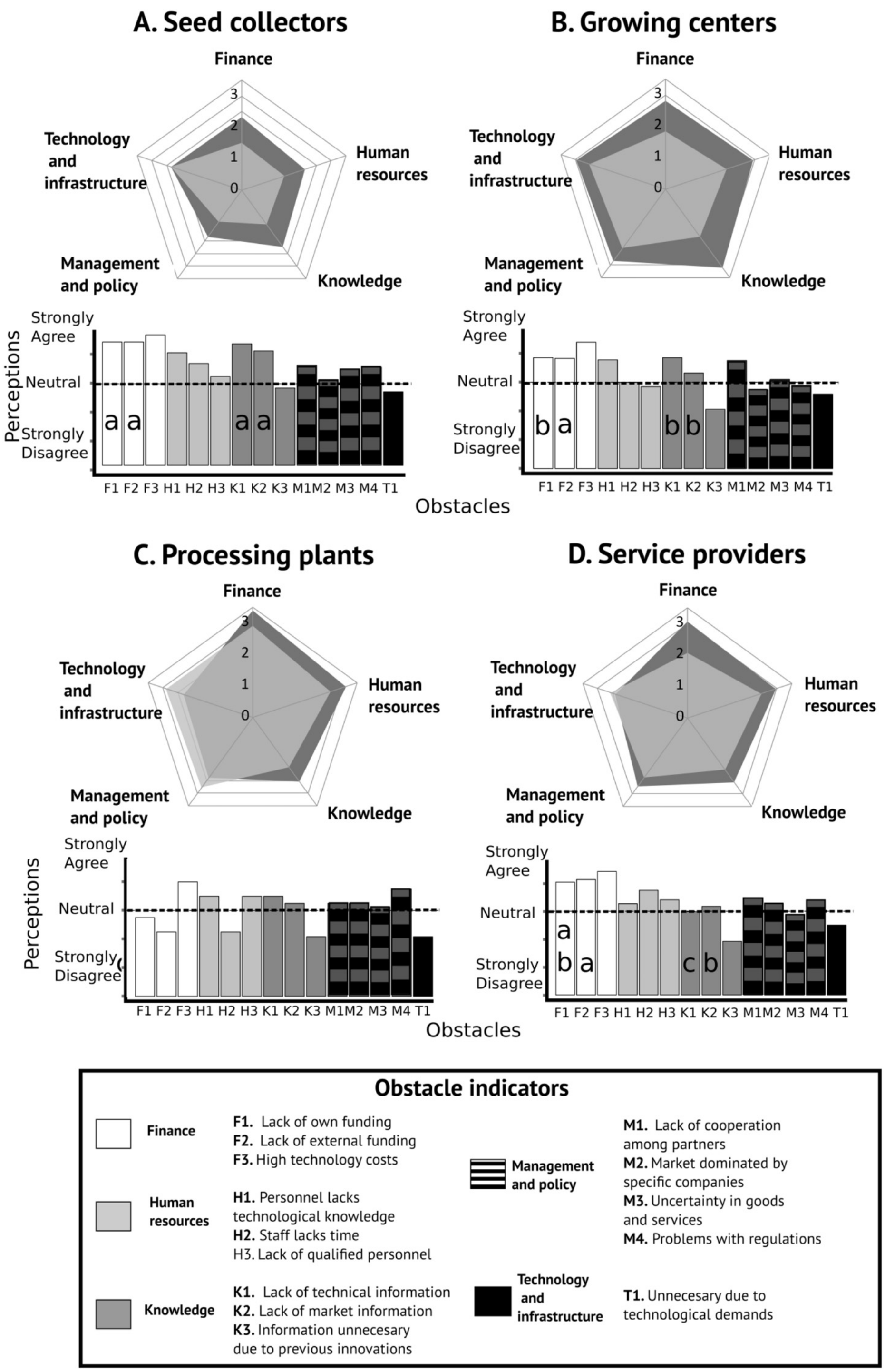

Fig. 4. Gaps and obstacles in the mussel aquaculture industry in Chile for seed collectors (A), growing centres (B), processing plants (C) and service providers (D). Gaps are determined by the differences in mean challenges per domain and stakeholder group (dark grey pentagon) and mean progress per domain and stakeholder group (light grey pentagon). The bar graphs display the users' response to each of the obstacle indicators. The indicators are detailed in the legend and colour coded by domain. Significant differences in indicators (**) among stakeholder groups were determined using Kruskal-Wallis test. Groups that are not significantly different share the same letter.

groups perceive all indicators to be obstacles for the industry. In the knowledge domain, all stakeholders perceive the lack of technical and market information to be important obstacles. However, the seed collectors group perceived these obstacles to be significantly higher than the other groups.

3.5. Gaps in the mussel aquaculture industry

We analysed the gap between the challenges and progress in the past few years for all stakeholders and domains. Statistically significant differences in gaps among user groups were found (Kruskal-Wallis test, $p = 0.02$). Seed collectors face gaps in the human resources, knowledge and management domains (0.85, 1.14 and 0.68, respectively). Nevertheless, the progress carried out in the technology and infrastructure category surpasses the challenges. Growing centres perceived important challenges for most of the domains but the improvements were not highly ranked, leading to gaps ranging from 0.63 to 1.62 in all categories (Fig. 4). Processing plants perceived the most progress of all stakeholder groups. They only display gaps in the human resources and knowledge domains (0.66 and 1.05, respectively). Finally, service providers display gaps between 0.71 and 0.85 for the human resources, knowledge and management domains. Additionally, this group also perceives a slight gap (0.02) in the technology and infrastructure domain (Fig. 4).

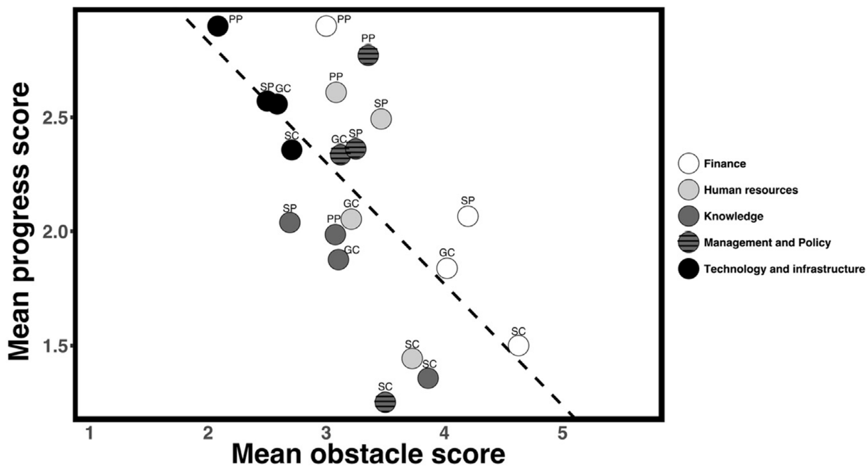

Fig. 5. Linear regression between average perceived progress and obstacles for each stakeholder group and domain. Dashed line indicates the regression line or efficiency line for the expected progress at the displayed obstacle level. SC indicates seed collectors, GC growing centers, PP procesing plants and SP service providers.

3.6. Enhancement opportunities

We analysed the linear relationship between the perceived progress in the past two years and the obstacles faced by the industry. The regression line represents the average progress achievable to date given the current level of obstacles. The regression line between mean progress and obstacles per stakeholder group and domain had a slope of − 0.53 and an intercept of 3.9 (Fig. 5). This indicates that the average perceived progress in the absence of obstacles would be a 3.9. Thus, there is still an opportunity for enhancement in the progress carried out within the mussel aquaculture industry in Chile.

All values below the regression line indicate areas that are inefficient, and thus require more attention and can be viewed as areas that need to be enhanced, whereas the values above the regression line indicate efficient domains. The seed collector group perceived the lowest progress and greatest obstacles out of all stakeholders (Fig. 5). Four out of five domains for this group are below the efficiency line, finance being the only exception. Additionally, the knowledge domain was also below the efficiency line for all stakeholders. Therefore, the knowledge domain and the seed collector group are the areas with the most enhancement potential in the Chilean mussel aquaculture industry.

4. Discussion

Chile is experiencing a standstill in mussel landings coupled with a stabilization of aquaculture concessions and market prices (Fig. 2). The industry is in need of new developments and innovations to maintain its position as one of the most important aquaculture industries in the country. This concurs with previous studies in the area that observed a shift from traditional small producers to larger companies with high technological development (Bagnara Vivanco and Maltrain Donoso, 2008). Considering no industry can grow indefinitely and the recent halt in the increasing trend in landings, it appears that the mussel aquaculture in Chile industry is currently at an inflection point, triggering the need to assess current challenges, progress, gaps and obstacles in order to identify new opportunities to revitalize the industry.

The aquaculture industry in Chile is composed by a heterogeneous group of users with distinct views on the challenges, progress and obstacles of the industry (Tables 1 and 2; Fig. 4). It is common for stakeholders to have different values and needs, which leads to different way of framing problems and solutions (Jentoft and Chuenpagdee, 2013). Many of the difference in perceptions among stakeholders are caused by the different roles in the supply chain they carry out (Fleming et al., 2014; Lim-Camacho et al., 2015). For example, processing plants and service providers do not consider technological advances in harvesting systems or knowledge on seed dynamics to be important challenges for the industry whereas seed collectors and growing centres do (Table 1). This could highlight a lack of cooperation among stakeholders, were resource users are only concerned with the issues that directly affect them (Fleming et al., 2014; Lim-Camacho et al., 2015). Studies have observed that collaboration can lead to greater quality and safety in the production of aquatic products (DongDong et al., 2012). Thus, for management strategies to be successful cooperation must exist among all stakeholders.

These differences among stakeholders can make governance particularly challenging since policies cannot be generalized (Jentoft and Chuenpagdee, 2013). Thus, policies and management strategies must be flexible and adapt to the individual needs of each group of stakeholders (Mahon et al., 2008). We observed significant differences in the gaps faced by each of the stakeholder groups (Fig. 4) as well as ample variation in the efficiencies for each domain and stakeholder group (Fig. 5). Stakeholders in the processing plants and service providers groups perceived the smallest gaps between the challenges and the progress carried out. Furthermore, when we analysed the efficiency of the stakeholder groups per domain (Fig. 5), seed collectors displayed the lowest efficiency in all areas. This might indicate that the improvements made by seed collectors in the past years might not be up to par with those made by other groups of stakeholders. Thus, the seed collector group has the most opportunity to enhance. The main challenges for this group are the incorporation of new technologies, access to new raw materials and knowledge on seed dynamics (Table 1). The best way to understand and control seed dynamics is through the incorporation of hatcheries. Hatcheries provide a reliable seed supply and facilitate the genetic selection of the resource (Davis, 1969; Paquet et al., 2011). Moreover, hatcheries could aid in the sustainability of the industry by reducing the effects of environmental impacts on the spat, such as ocean acidification, as has been observed in other shellfisheries (Barton et al., 2015). Considering costs for implementing mussel hatcheries in Chile are high and the social consequences a rapid shift towards hatcheries could have, management strategies should work towards a co-existence of natural and sustainable seed collection coupled with the development of economically efficient hatcheries (Carrasco et al., 2014). Our current research provides a first step in understanding the heterogeneity in stakeholders present in the Chilean mussel aquaculture industry. The information presented here can serve as a basis to develop the adaptive markets hypothesis (Lo, 2004) in the Chilean mussel industry. This can help us understand the industry's response to the current changes it is experiencing and to external effects such as climate change.

Understanding heterogeneity is critical to influence support mechanisms for specific industries and their sub-groups. Further research on this subject, such as cluster theory (Hamdouch, 2011; Kuah, 2002) and social network analysis (Barnes-Mauthe et al., 2015; Marín and

Gelcich, 2012), can shed light on the heterogeneity of the subsectors present in the system particularly in the seed collectors group, which requires the most attention. Understanding the values and needs of stakeholders and incorporating them in aquaculture management promotes the sustainability of the industry (Hugues-Dit-Ciles, 2000).

Despite the heterogeneity present in the Chilean mussel aquaculture industry, all stakeholders perceived gaps in three domains: finance, human resources and knowledge (Fig. 4), suggesting that joint development efforts should be focused in these areas. Users agree that one of the main challenges in the industry is the reduction of production costs (Table 1). The most common way to reduce costs is through the introduction of productivity enhancing innovations (Asche et al., 2008). Considering that the technology and infrastructure domain displays the smallest (and in some cases negative) gaps (Fig. 4), it appears the mussel industry is already working towards the reduction of costs. This can be observed in the efficiency of the finance domain, where most values are above the efficiency line (Fig. 5). The same can be said for the human resources domain, which displayed important progress in staff training (Table 2).

Perception values for the knowledge domain were below the efficiency line (Fig. 5), making it one of the key areas to invest in. Stakeholders perceive a lack of access to biological and economic information (Table 1 and Fig. 5). The generation of knowledge is crucial for this sector considering its vulnerability to natural impacts. According to Lopez et al. (2008) harmful algal blooms, encrusting species and pathologies are the main problems affecting shellfish culture. In fact, in the past year (2016) harmful algal blooms caused losses of US$ 800M in Chilean aquaculture (Hallegraeff, 2016). These problems can begin to be tackled by increasing collaboration among researchers, policy makers and stakeholders, which facilitates the transfer of scientific and local knowledge (Cvitanovic et al., 2015; Rivera et al., 2017). It is possible that the small and medium size stakeholders surveyed in this study disregarded certain indicators highlighted in previous studies (Enriquez et al., 1992; Lopez et al., 2008), such as harmful algal bloom, epidemiology and climate change, because they were beyond their scope. Thus, it is essential that local research laboratories and Universities promote public outreach programs to make new information easily digestible (Smith, 1994) for all stakeholders in the mussel aquaculture industry. Furthermore, the collaboration among sectors and disciplines could aid in the introduction and acceptance of new technological and social innovations in the industry (Agbayani and Toledo, 2008). The generation and exchange of knowledge should be considered a priority in the mussel aquaculture industry in Chile.

Through perception research theory we have generated a description of obstacles, gaps and opportunities in the Chilean mussel aquaculture industry. Furthermore, we have uncovered the specific user groups and study domains that require immediate attention and which exhibit the greatest opportunity for enhancement. These findings have a direct applicability to the management of this developing industry, which appears to be in need of new innovations and policies for it to continue to be economically and ecologically sustainable. The Chilean mussel aquaculture industry is a prime example of a thriving industry that is currently working on overcoming the necessary obstacles to increase its productivity. Here we synthesize the main obstacles and opportunities of the Chilean mussel aquaculture industry as perceived by the stakeholders. However, it is important to consider that only 5 processing plants were surveyed and therefore this could lead to a bias in results for this stakeholder category. Furthermore, perceptions are not fixed and can evolve in time. Thus, the challenges, progress and obstacles of the industry must continue to be closely monitored and should be complemented with quantitative data on its productivity. Nevertheless, based on the progress and efficiency perceived by the stakeholders, in the finance, technology and infrastructure, management and policy and human resources domains, we can conclude that the Chilean mussel aquaculture industry is working towards improving its biologic and economic productivity. This suggests that despite the standstill in the growth of the industry, with enhancements in the knowledge and technology areas, its future appears to be promising.

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