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Assessing the Aquaculture Performance Indicators (APIs)

Evidence from Aquaculture Production Systems in Chile

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Assessing the Aquaculture Performance Indicators (APIs): Evidence from Aquaculture Produc[1]tion Systems in Chile

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Abstract

We evaluate the Aquaculture Performance Indicators (APIs) methodology by applying it to three aquaculture production systems in Chile. Our analysis considers the production of mussels, algae, and northern scallops. Our basic analysis model is a production function framework where the performance outcomes result from the available inputs. We measured all API categories (outcomes and input metrics) and then grouped the metrics into different dimensions suitable for analysis. We obtained the value of each metric from various sources using expert evaluation and secondary information to calculate aggregated measures for each production system. We compared the results for each production system and tested the equality of matched pairs of observations. Then, we evaluate the performance of the three production systems using the frame of a separable multiproduct production function. We found statistically significant differences in the aggregated performance and inputs between mussels and algae and mussels and northern scallops. However, we did not find statistical differences in the outputs. The results suggest that mussel production has a higher (average) level of sustainable inputs than the other production systems. This difference in inputs, however, is not fully reflected in output differences. We discuss possible explanations for our findings.

Keywords: Aquaculture Performance Indicators, production systems, triple bottom line, sustainable aquaculture.

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1. Introduction

Aquaculture has been one of the fastest-growing food sectors in recent decades, contributing to the supply of high-quality proteins at low cost worldwide (Asche et al., 2022, Garlock et al., 2020). Currently, aquaculture represents about 49% of global aquatic animal production, 66% of crustacean production, 75% of mollusk production, and 97% of algae production (FAO, 2022). Despite this trajectory, and like other natural resource-based production activities, the performance of aquaculture from economic, social, and environmental perspectives remains controversial as it faces several challenges to becoming sustainable (Naylor et al., 2009, Naylor et al., 2021).

Considering the current and expected global expansion of aquaculture, there is a demand to evaluate the performance of aquaculture production not only from an economic perspective but also from an environmental and social perspective. However, analyzing the performance of aquaculture could be particularly difficult when information is scarce, as in developing and transitional countries, where most of the future aquaculture growth is expected to occur (Garlock et al., 2020).

One example of the tools available to measure the performance of aquatic-based production is the Fisheries Performance Indicators (FPIs) (Anderson et al., 2015, Asche et al., 2018). A corresponding effort has been made to analyze the performance of the aquaculture production system through the Aquaculture Performance Indicators (APIs). The APIs are an innovative tool recently developed to evaluate the performance of aquaculture production systems in different countries around the world (Anderson et al., 2019). The APIs can be applied in developed countries (rich in data) or developing and transitional countries (poor in data) and used in a wide range of applications, such as comparing aquaculture production systems on a global scale or analyzing specific dimensions.

The APIs measure three key sustainability dimensions: the environmental dimension, the economic dimension, and the community dimension. These three dimensions are called the Triple Bottom Line (TBL).[1] The APIs are a new method to measure the performance of aquaculture farming, and how well it measures this performance has yet to be assessed. The assessment of a method is not simple, especially when the method, as in the case of the APIs, introduces several diverse dimensions. For this reason, our objective with this paper is to contribute to what we understand as an evaluation process that will take various forms, presenting a particular viewpoint. We use the fact that if we conceptualize the APIs tool as a separable multiproduct production function, the different input metrics should be associated with specific groups of output metrics at the dimension level, and we test whether the differences detected in the various inputs between other production systems are associated with the differences found in the output dimensions.

This paper analyses and compares three aquaculture production systems in Chile using Aquaculture Performance Indicators (APIs). Our analysis considers the cases of Chilean mussels (*Mytilus chilensis*), "pelillo" algae (*Gracilaria chilensis*), and northern scallops (*Argopecten purpuratus*). We apply the APIs to the production systems previously described by conducting fieldwork to interview key informants and using secondary

[1] There is a growing literature that proposes measuring aquaculture performance with different sets of indicators. See e.g., the Global Aquaculture Performance Index (GAPI) (Volpe *et al*., 2013), and the World Aquaculture Performance Indicators (WAPI) proposed by the FAO to provide quantitative information on the performance of the aquaculture sector at national, regional, and global levels. However, the GAPI is basically an environmental index of the species performance at the global level that does not include other sustainability dimensions, while the WAPI is an index that covers the performance of aquaculture species at the country, regional and global level, but does not include analysis of specific individual production systems at the country level, as the APIs does.

information. From this procedure, we obtain measures of these production systems' different input and output components. With these results, we analyze the correspondence of results between inputs and outputs of different production systems in a separable multiproduct production function framework. Our approach allows us to assess the APIs methodology by testing the general hypothesis that groups of input metrics in the APIs methodology should be associated with specific output dimensions across different production systems to be consistent with the production function framework. Thus, this assessment of the APIs can be understood as a consistency evaluation. Proposing a way to evaluate the APIs methodology is perhaps the main contribution of this paper to the literature. To the best of our knowledge, this type of assessment has not been made previously. A second contribution is analyzing the performance of three aquaculture production systems in Chile. The comparison of their performance allows us to assess their relative development and identify challenges that must be confronted to move these systems towards sustainable aquaculture.

The paper is organized as follows. In section 2, we present our case study. We describe each production system, location, and economic relevance. In section 3, we provide a brief description of the APIs methodology, how it was applied to our cases of study, and the method used to evaluate the performance of the APIs methodology. The results are presented in section 4. We discuss the results and conclude in section 5.

2. The Chilean Cases: Aquaculture Production of Mussels, Algae, and Northern Scallops

Our research is based on the application of the APIs tool for three Chilean aquaculture production systems. First, the production of the Chilean mussel **(***Mytilus chilensis*), also known as the Chilean Blue Mussel, which is a bivalve that filters food (plankton) found floating in the water, forming dense aggregations on hard, muddy beds at a depth of up to 10 meters, although in exceptional cases, a depth of up to 25 meters has been observed (Lorenzen et al. 1979, Zagal et al. 2001). The Chilean mussel is currently the most commercially important mollusk in Chile. While extraction of this resource in the country dates to the 1930s, the development of large-scale commercial cultivation began in the 1990s (Plaza et al., 2005), with a current production that exceeds 400 thousand tons per year. Its geographic distribution includes the entire Chilean coast and part of the Argentinean coast, especially in the coastal communities of the fjords and channels of Southern Chile. However, its cultivation is concentrated in the Los Lagos Region in southern Chile (FIP 2014-57, 2016). (See Figure A.1 in the Appendix for a reference map with the geographical distribution of the production systems under analysis). Second, the “pelillo” (*Agarophyton chilensis,* also known as *Gracilaria chilensis*) is a native red alga found in the intertidal and subtidal strata up to 25 meters in depth. It lives on sandy or muddy sea floors and, in some cases, attached to hard substrates (Ávila et al., 2019). It is harvested from natural sea grasses and cultures. The excellent tolerance of this algae to changes in temperature and salinity allows it to be cultivated in saline and estuarine environments (FIPA 2015-02). Cultivation farms of pelillo range from the Atacama Region in northern Chile to the Aysén Region in Chilean Patagonia. Third, the northern scallop **(***Argopecten purpuratus*) is a species of native bivalve mollusk which inhabits the western Pacific coast from Panamá (10º N) to Valparaíso (33ºS). Natural populations are found from the Arica y Parinacota region (northern Chile) to Valparaíso (central zone) (see https://www.subpesca.cl/portal/616/w3-article-844.html#descripcion, for a description of resources and species). Populations are discontinuous along the coast, in natural banks on the sandy bottoms of the bays (Tongoy and Guanaqueros, 30° S; La Rinconada and Mejillones, 23° S). The production was originally extractive, performed by artisanal fishers in natural banks without regulation. However, overexploitation led the authorities to impose management measures for the species, banning its extraction from wild populations since 1986 (FIPA 2017-12, 2018), which led to the development of commercial cultivation of the northern scallop (SUBPESCA, 2002). Production of the species in Chile is currently done almost exclusively through farming. Cultivation of the species is widely developed, mainly in coastal marine ecosystems in the regions of Antofagasta, Atacama, and Coquimbo in northern Chile. However, there is also inland cultivation, mainly for the first (hatchery) stage (SUBPESCA, 2009).

These three species are cultivated in farms (production sites) which are managed by individuals, companies, or organizations of artisanal fishers holding aquaculture concessions. In mussel farming, the seed uptake and the growing stages are developed by three agent types: vertically integrated companies, individuals, and groups of artisanal fishers. This last group becomes more relevant in the seed uptake stage. The large companies in the Chilean mussel industry are vertically integrated, mainly in the growing and processing stages, although some also have their own seedbeds. Integrated companies supply their own farmed raw material but also buy from third parties. Most centers that cultivate northern scallops belong to companies, although there are also unions and cooperatives of artisanal fishers. Most of the pelillo cultivation farms belong to individuals, although they also have owners who are organizations of artisanal fishermen and companies.

The size and the number of farms for each production system differ. The average size of the approximately 274 pelillo production sites is 4.4 hectares (50 tons of average production per site). The average size of the more than 500 mussel farms is 10 hectares (490 tons of average annual production). The 34 scallop farms located in the north of the country are the largest, on average 42 hectares (with 356 tons of average annual production).

An important difference in the farming activity across these production systems is the level of organization of producers. No organizations currently bring together and coordinate pelillo and northern scallop producers, , although, these existed in the past,. Chilean mussel producers, on the other hand, have grassroots organizations and an association of small, medium, and large producers who cultivate about 60% of the national production. This organization also includes members who are exporters and suppliers. The objective of this organization is to work together in search of solutions to challenges in the sector, and to represent the industry's interests before the authorities, unions, and communities, generating public-private strategic alliances that benefit the mussel farming activity.

One of the similarities in the cultivation of these three species is that the seed or the food required for each production system is provided by the natural environment, a key element in the production chain. Farmers encounter difficulties in programming their cultures since they cannot be sure of the amount or quality of the seed that will be available.

The three species under analysis are cultivated in aquaculture concessions. Holders of aquaculture concessions have the right to use the portion of water and bed of the concession for farming. This right is for 25 years and is renewable for the same period. It is transferable and, in general, susceptible to legal transactions. Aquaculture concession holders pay annually for a single aquaculture patent. In the case of mussel cultivation, property rights are weaker in the seed uptake phase since its collection takes place in natural banks located in particular areas which are regulated through temporary seed collection permits.

The production of Chilean mussels and northern scallops is intended for human consumption, mainly through frozen and fresh refrigerated products. Both types of products mainly target foreign markets. Mussels is primarily sold to the United States, Russia, Spain, Italy, and France, while scallops are exported mainly to Spain, followed by Belgium, Germany, France, Italy, Portugal, Singapore, and Thailand. Pelillo algae are used primarily to produce agar-agar. Agar is used in many industries, but predominantly the food industry to make gelatins and as a thickening agent for ice cream, yogurt, soups, jellies, and a number of desserts. Agar is also used in the pharmaceutical industry as a laxative due to its high fiber content, in the cosmetic industry for producing face and body cream, and in cream makeup-removers, among others. Agar-agar is exported mainly to Japan and the USA.

The three aquaculture production systems are produced in different quantities and experience differences in trends over time. The growth in mussel production has been persistently high in the last 20 years, the. In 2000 harvests reached 20 thousand tons, and from 2010 production exceeded 200 thousand tons, with a record annual harvest above 400 thousand tons since 2020. The production of northern scallops has varied over time. In the year 2000, production reached almost 20 thousand tons, then decreased and reached a minimum in 2015 of just over 2 thousand tons. Between 2016 and 2017, it remained between 3 to 4 thousand tons, then in the years 2018-2019, the harvests increased considerably, reaching approximately 14 thousand tons in 2018. The production of pelillo also varied in the last 20 years. In 2002, production of just over 71 thousand tons was reached, which decreased drastically to 12 thousand tons in 2010 and stabilized at around 20 thousand between 2018 and 2020. In 2020, about 400 thousand tons of Chilean mussels, 18 thousand tons of pelillo and 4 thousand tons of northern scallops were produced.

The price at which the products from these species have been traded differs. The FOB sale price of Chilean mussels in the last decade has remained around 2 USD/kg, while the price of the northern scallop has decreased in recent years from 14 to 10 USD/kg, and the agar-agar price has increased from 16 to 22 USD/kg in the same period.

According to official information from SERNAPESCA, the total production of processed Chilean mussels in 2019 was 86,644 tons (5,726 tons of fresh refrigerated product and 80,918 tons frozen). The total production of processed pelillo in the same year was

15,869 tons (392 tons of agar-agar, 3,782 tons of colagar, and 11,695 tons of dry alga).[2] Processing plants produced 2,121 tons of elaborated northern scallops (fresh, refrigerated and frozen). Table 1 presents basic economic information for the aquaculture production systems under analysis for 2019.

The export value of Chilean Mussels was highest (US $202.3 million), followed by Pelillo (US $31 million) and Northern Scallops (US $14 million). While the FOB price (US $/ton) of Chilean mussels is significantly less than that of pelillo and northern scallops, the larger amount exported (76,700 tons compared with 1,966 tons of pelillo, and 1,304 tons of scallops), explains the higher value of production in this industry.

[2] Colagar is a patented intermediate product of Algas Marinas S.A. that is produced by treating the algae (making it alkaline and discolored). Colagar is used in the production of agar-agar.

Table 1. Basic Economic Information of Aquaculture Production Systems: Chilean Mussels, Pelillo Algae, and Northern Scallop 2019

	Chilean Mussels	*Algae (Pelillo)*	*Northern Scallops*
Harvest (tons)	379,000	21,841	11,313
Production (tons)[a]	86,644	15,869	2,121
Exports (tons)[b]	76,676	1,966	1,304
FOB Price (US$/tons)[c]	2.710	21.974	10.976
Value of exported production (millions of USD)	US$ 202.3	US$ 31.3	US$ 14.1
Number of cultivation sites (farms)[d]	553	274	34

Source: Own calculations using data from the National Fisheries and Aquaculture Service (SERNAPESCA in its Spanish acronym).

[a] Production corresponds to processed products. In the case of pelillo, production includes raw material from the cultivation centers and natural seagrasses, and the production corresponds to 74% dry seaweed, 24% colagar and 2% agar-agar

[b] Not all annual production is exported in the same year. Exports of pelillo are composed of agar (67%) and dry pelillo (33%). Of all the agar produced in 2019, 32% was exported. In the case of northern scallops, from a total of 11,313 tons harvested, about 50% was processed, and the rest was sold fresh domestically. The processing plants produced 2,121 tons of elaborated product (fresh, refrigerated and frozen); 1,304 tons were exported. 89% of the total mussels processed in plants were exported.

[c] FOB prices correspond to the weighted average price of exported products obtained from processed mussels, pelillo, and northern scallops. The export value of Chilean mussels includes frozen mussels (94%) and canned mussels (6%). The export value of pelillo products considers agar-agar (94%) and dry algae (4%). The total value of exported scallop processed products includes frozen (93%) and fresh refrigerated (7%) products.

[d] Mussel cultivation farms are owned by 321 firms (data for 2016), and the cultivation sites for northern scallops are owned by 34 firms. The number of firms that cultivate pelillo was 274.

3. Brief Description of the APIs Methodology, its Application to Three Aquaculture Production Systems in Chile, and Testing Procedures

The APIs considers a total of 154 metrics which are grouped into inputs and outputs. The input factors, or enabling conditions, contribute to the process of encouraging the socio-ecologically sustainable use of aquaculture resources. The enabling conditions are composed of 66 metrics which are scored from one to five. The outputs are indicators that identify and measure whether the aquaculture system is delivering economically viable and socio-ecologically sustainable results and measuring community performance. The outputs are comprised of 88 metrics, also scored from one to five. In this group of metrics, a score of five represents the best performance, while a score of one represents the poorest performance.

Similar to the Fishery Performance Indicators (Anderson *et al.*, 2015), each of the APIs measures were rated by an expert evaluation team according to a subjective evaluation of their quality, which in turn, attempts to reflect the degree of certainty for each assigned score. An “A” rating was given if the scorer team was highly confident that the score was correct, a “B” if the scorer was highly confident that the true score was within one bin of the given score, and a “C” if the scorer made an educated guess but felt highly confident with that score (Asche *et al*., 2019). The value of each metric was obtained by expert evaluation and secondary information, including scientific reports, official statistics from SERNAPESCA, the Undersecretariat for Fisheries and Aquaculture (SUBPESCA in its Spanish acronym), export statistics, environmental performance indicators, World Bank information, and the Heritage Index, among others. We also conducted interviews in 2020-2021 with experts in the production of Chilean mussels (between December 2020 and March 2021), algae (pelillo) (March to July 2021), and northern scallops (July to November 2021. A total of 24 interviews were conducted[3], mostly by two members of the research team, using a questionnaire translated into Spanish from the original English APIs metrics, instructions, and manuals.

The quality of the metrics obtained varied slightly between aquaculture production systems. In the case of mussels, 98.6% of the metrics were rated as “A”, 0.7% as “B” and 0.7% as “C”. In the case of algae (pelillo), 98.1% of the metrics were rated as “A”, 0.7% “B” and 1.3% “C”. Finally, for northern scallops, 94.1% of the metrics were rated as “A”, 5.9% as “B” and 0% as “C”. To sum up, the quality of the metrics is similar across the production systems under analysis.

The metric scores were averaged across input and output dimensions. For the purposes of analysis, APIs metrics can be aggregated in different ways. Following the APIs methodology, the 66 input and 88 output metrics can be aggregated into two levels: dimensions and components. Six dimensions were identified that grouped all input metrics: Macro Factors, Property Rights, Co-management, Management, Supply Chain, and Production. The 17 components are an intermediate aggregation which in turn are contained

[3] The details are: Mussel interviewees: two scientists, one SERNAPESCA representative (monitoring/ enforcement), three producers (small, medium, and large-scale), and two representatives of processing and marketing plants. Northern scallop interviews: one scientist, one fisheries administrator (SUBPESCA), one enforcement representative (SERNAPESCA), two producers, one marketing representative, and one processing plant representative. Algae - Pelillo: one scientist, one monitoring/enforcement representative (SERNAPESCA), one fisheries administrator (SUBPESCA), five producers, and one processing plant representative. Due to the COVID-19 pandemic, all the interviews were conducted via video calls.

in these six dimensions. In turn, the 88 metrics of the outputs are also aggregated into 15 (or 19) components (intermediate aggregation) and by dimension. However, the outputs allow for two types of aggregation by dimension. The first is by sector, which includes the sectorial dimensions: Environmental, Production Sector, and Post-production sector (in this type, the metrics are aggregated into 15 components). The second form of aggregation is by dimension and is known as the Triple Bottom Line (TBL), which includes the dimensions: Environmental, Economic, and Community (the dimension metrics are aggregated into 19 components). We used the metric scores of each dimension as different realizations of these dimensions. To measure the equality of matched pairs of observations we used the Wilcoxon matched-pairs signed-rank test (Wilcoxon 1945) to analyze if there exist significant differences in the score of these dimensions between the different production systems.[4]

A basic way to view the APIs´ framework is in terms of a separable multiproduct production function where the various inputs included in the metrics should condition the different outputs obtained with these metrics (Diewert, 1973; Lau, 1976). We do not have the required information to estimate such a framework, but conceptualizing the problem can tell us what we should expect from the results. Specifically, we should expect that input variability (between production systems) should be translated into variability (of the same sign) in the outputs. In the Methodological Appendix, we briefly present this framework. We show that the difference between the output performances of two production systems can be related to differences between the marginal effects of the same type of inputs in different production systems, differences in input endowments in the production systems, and differences in the inputs used in the various production systems. The possibility of separability leads us to the possibility of interactions between restricted sets of inputs and outputs. More concretely, we should expect that we can separate inputs by their contribution to different output dimensions, and the differences detected in these dimensions between the different production systems should be related to differences in their inputs. For example, one should expect that differences in the outputs of the triple bottom line's environmental,

[4] The Wilcoxon signed-rank test is a non-parametric statistical version of the paired t-statistics used to compare two or more observation units based on one or more shared characteristics (in our case, the same country and the same institutional framework governing the different production systems for the three resources analyzed). The null hypothesis is that the two distributions are the same.

economic, and community dimensions (TBL) should be positively correlated with differences in the inputs related to these dimensions. Likewise, this relation should be evident in the results for the environmental, production sector, and post-production sector dimensions. This allows us to test if the APIs methodology is generating plausible results.

To test a more robust evaluation of the method, in the second stage, we grouped the inputs and outputs into three categories according to the degree of generality of each metric. With a degree of generality, we mean the level of validity that the metric has outside the domain of the specific production system. Some of the metrics used in the APIs´ methodology are specified at the country level and therefore show the same value for the different production systems independent of their geographic location, while others are specific for each culture and therefore vary. For example, the *Environmental Performance Index* is a nationwide environmental index that measures general environmental conditions in the country and, thus is not specific to any of the cultures analyzed. In contrast, the *Proportion of Production with Property or Lease Rights* is specific to each management system.[5] We identified three potential degrees of generality for each metric: general, medium-general, and specific to each resource. For each output dimension, we classified by degree of generality the metrics of the inputs that potentially produce these output dimensions. The objective was to identify whether the differences were detected (or not detected) with the analysis that included all metrics for the three resources held when tested, including only the more specific metrics, controlling for the degree of generality of the inputs. One drawback of this robustness check is that the number of observations for testing is decreased when we reduce the level of generality of inputs and outputs.

4. Results and Discussion

In this section, we first present the results of the APIs and compare the differences between production systems using the Wilcoxon matched-pairs signed-rank test. Second, we evaluate

[5] Specifically, in the inputs, we identify five metrics that are the same for the three resources because they measure the country's performance in some areas (and the base year is the same). These metrics are Environmental Performance Index (EPI); Governance Quality (Average of four indicators in the World Bank's Governance Indicators: Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption); Governance Responsiveness (Average of two indicators in the World Bank's Governance Indicators: Voice and Accountability, and Political Stability); Index of Economic Freedom (Heritage: Index of Economic Freedom); and Gross Domestic Product (GDP) per capita.

the performance of the three production systems under the previously described separable multiproduct production function approach. Third, as a robustness check, we analyze the performance across the aquaculture production systems according to our classification with respect to the degree of generality of the metrics included in the APIs.

4.1 APIs Across Production Systems in Chile

The aggregate performances of Chilean mussels, algae (*pelillo*), and northern scallops are presented in Table 2. The performance is measured as the simple average of all metrics. The average APIs score for each of these production systems is 3.85, 3.68, and 3.64, respectively, suggesting a slightly better performance for mussels than for algae and northern scallops. In the case of outputs, the corresponding average scores are 3.97, 3.91, and 3.90, while for inputs, the figures are 3.68, 3.38, and 3.31, respectively. In general, the APIs values are similar among the production systems. The results show higher and more homogenous values for outputs than inputs.

Moreover, variability in the importance of the different metrics is higher in inputs than outputs for all production systems. Of course, all these results are aggregated average performance measures, which may involve differences in the performance by TBL dimensions and input components within and across the production systems under analysis. We present and discuss disaggregated performance results later in this section.

Table 2. Aggregate Performance of Chilean Mussels, Algae (Pelillo), and Northern Scallops According to the APIs

	Mussels	Algae (Pelillo)	N. Scallops	*p-value* Mussels – Algae	Mussels – N. Scallops	Algae (Pelillo) – N. Scallops
Total APIs						
Mean	3.85	3.68	3.64	0.0725*	0.0075***	0.6676
SD	1.19	1.34	1.36			
# Metrics	152	152	152			
Outputs						
Mean	3.97	3.91	3.90	0.4950	0.4652	0.8757
SD	1.06	1.19	1.19			
# Metrics	87	88	88			
Inputs						
Mean	3.68	3.38	3.31	0.0461**	0.0008***	0.6257
SD	1.34	1.47	1.51			
# Metrics	65	65	65			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively. Some metrics are not applicable (N/A). These include, for mussels, the “Proportion of feed ingredients sourced from socially responsible sectors.” and “Traceability of feed inputs” and, for Northern scallops, the metric “Traceability of feed inputs” .

We performed a mean comparison test to analyze if there exist differences in metric scores between the different production systems. Table 2 (right) shows the p-values of the Wilcoxon matched-pairs signed-rank test differences. We found statistically significant differences in the total APIs and inputs between mussels and algae and between mussels and northern scallops, suggesting that mussel production has a higher (average) input performance than the other production systems. However, we did not find statistical differences in the outputs. This result confirms higher dispersion between average scores for inputs than for outputs across the production systems under analysis.

Although the three production systems exhibit similar average APIs, some differences are revealed when analyzing disaggregated results. Table 3 presents the outputs by TBL. The outputs by TBL involve three key dimensions: environmental, economic, and community. Comparing the different production systems, shows slightly higher environmental dimension scores for mussel production, economic dimension scores for algae production, and community dimension scores for northern scallops. However, these differences are not statistically significant. At the component level, all the cultures perform well at the feed-related impacts, water use and effluents, and local labor indicators. However, at the same time, we observe very low performance in the degree of production certified across production systems and larger variations in performance for the cases of trade conditions, supply chain performance and career opportunities for farm workers (see Table 3, Figure A.2, and Table A.2 in the Appendix).

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Table 3. Outputs by TBL: Chilean Mussels, Algae (Pelillo), and Northern Scallops.

Dimension	Component	Mussels		Algae (Pelillo)		Northern Scallops	
		Average Score	Dimension Score	Average Score	Dimension Score	Average Score	Dimension Score
Environmental	Feed	5.0	4.15	5.0	3.91	5.0	3.94
	Water use and effluents	5.0		5.0		5.0	
	Impacts to wildlife	4.6		4.6		4.7	
	Environmental compliance	4.2		4.0		4.0	
	Certification	2.0		1.0		1.0	
Economic	Production Performance	3.3	3.82	3.2	3.95	3.2	3.59
	Production Assets	3.7		2.9		2.9	
	Risk	4.3		4.3		3.0	
	Product Form	3.8		4.1		4.1	
	Trade	3.8		4.8		3.3	
	Supply Chain Performance	3.5		4.3		4.7	
	Post Harvest Assets	4.3		4.0		4.0	
Community	Managerial Returns	4.4	4.04	3.2	4.10	4.3	4.40
	Labor Returns	3.9		3.2		3.3	
	Health & Sanitation	4.3		4.0		4.6	
	Community Services	4.2		4.5		4.5	
	Local Ownership	4.2		4.5		4.8	
	Local Labor	5.0		5.0		5.0	
	Career	2.3		4.3		4.3	

Table 4 presents the input scores by components for each production system and the score differences of production systems for each component (see also Figure A.3 and Table A.3 in the appendix). According to the APIs methodology, inputs are subdivided into 17 components. Some differences exist in the inputs between the three aquaculture production systems under analysis. In general, all three production systems show high values in governance and general economic conditions, as well as in leadership and cohesion. At the same time, they are all monoculture production systems. In general, the northern scallop and algae production systems are similar in inputs, except for the components contracts and production scale within the production dimension. In contrast, mussel production scores show differences from the other systems in these components as well as the co-management components, such as participation, leadership, and social cohesion.

Table 4. Inputs by Component Chilean Mussels, Algae (Pelillo), and Northern Scallops

Dimension	Component	Average Score		
		Chilean Mussels	**Algae (Pelillo)**	**Northern Scallops**
Macro Factors	National Environment	4.00	4.0	4.00
	Exogenous Factors	3.71	4.0	4.10
	Governance	4.50	4.5	4.50
	Economic Factors	4.50	4.5	4.50
Property Rights	Land Rights	4.50	4.5	3.83
Co-Management	Collective Action	2.67	2.3	1.50
	Participation & Support	4.00	3.0	2.50
	Leadership & Cohesion	5.00	4.0	4.00
	Gender	2.63	2.8	2.13
Management	Management Inputs	3.67	2.9	3.56
	Data	2.00	2.0	2.00
	Management Methods	3.80	3.9	3.60
Supply Chain	Markets & Market Institutions	3.14	2.4	2.93
	Infrastructure	4.29	3.9	3.43
Production	Scale	4.00	2.0	3.00
	Integrated Culture	1.00	1.0	1.00
	Contract Farming	3.02	1.0	3.00

4.2 The Performance of the Production Systems in Terms of a Separable Multiproduct Production Function

Our conceptualization of the APIs approach is in terms of a production function framework, where the performance outcomes result from the available inputs. A fundamental way to check if this view is consistent with the results is to control if the differences found in the inputs between the production systems are reflected in differences between the outputs of the same sign, since all inputs were defined to positively affect the output dimensions. This was done in the preceding section at the more aggregated level, and the results were presented in Table 2. The results indicated that the statistical differences found in inputs between different production systems are not fully reflected in significant differences between the outputs. However, both inputs and outputs in this framework are heterogeneous, so perhaps a more suitable way to conceptualize the APIs is in terms of a separable multiproduct production function, where various outputs exist, and they are separable and related to some of the specific inputs. In this section, we review the results using this approach.

First, we consider outputs disaggregated at the dimension level. We present the results of the mean comparison test at the intermediate disaggregation for the outputs in Table 5, using the Triple Bottom line division, and Table 6, using the sectorial division. When we consider the results of this test for outputs by TBL in Table 5, we find that the only significant results are those between the outputs for algae and northern scallops in both the economic and community dimensions. The northern scallops' output has a much higher value for the community dimension than the algae. On the other hand, the algae output has a higher value in the economic dimension than that for northern scallops. We do not find significant results between production systems for any sectorial dimension, as shown in Table 6.

Table 5. Outputs by TBL - Chilean Mussels, Algae (Pelillo), and Northern Scallops

Outputs by TBL		Mussels	Algae (Pelillo)	N. Scallops	*p-value* Mussels - Algae	Mussels – N. Scallops	Algae (Pelillo) – N. Scallops
Environmental	Mean	4.52	4.44	4.50	0.4375	0.6250	1.0000
	SD	0.90	1.08	1.05			
	# Metrics	15	15	15			
Economics	Mean	3.72	3.77	3.45	0.5868	0.1915	0.0480**
	SD	1.17	1.30	1.34			
	# Metrics	42	43	43			
Community	Mean	4.05	3.85	4.23	0.3045	0.4878	0.0385**
	SD	0.89	1.03	0.75			
	# Metrics	30	30	30			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively. The means reported in Table 5 are calculated by dimension, which is slightly different from those presented in Table 3, where means are calculated by components.

Table 6. Outputs by Dimension - Chilean Mussels, Algae (Pelillo), and Northern Scallops

Outputs by Dimension		Mussels	Algae (Pelillo)	N. Scallops	*p-value* Mussels - Algae	Mussels – N. Scallops	Algae (Pelillo) – N. Scallops
Environmental	Mean	4.52	4.44	4.50	0.4375	0.6250	1.0000
	SD	0.90	1.08	1.05			
	# Metrics	15	15	15			
Production Sector	Mean	3.71	3.49	3.44	0.3923	0.1569	0.5158
	SD	1.18	1.33	1.23			
	# Metrics	40	40	40			
Post-Production Sector	Mean	4.05	4.18	4.18	0.6369	0.6227	0.6443
	SD	0.88	0.88	1.01			
	# Metrics	32	33	33			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively.

However, this comparison is performed for all types of inputs and different dimensions of outputs. But different inputs might be more related than others to some types of outputs. Therefore, in the second stage, we identified most of the input metrics with the TBL outputs to evaluate the three production systems in terms of a separable production function. We identified groups of input metrics that we associated with environmental, economic, and /or community outputs (The details of this identification are in Table A.1. in the appendix). Table 7 shows results of the evaluation regarding a separable production function.

Table 7. Inputs Allocated by TBL Outputs - Chilean Mussels, Algae (Pelillo), and Northern Scallops

Inputs allocated by TBL		Mussels	Algae (Pelillo)	N. Scallops	*p-value* Mussels – Algae	Mussels – N. Scallops	Algae (Pelillo) – N. Scallops
Environmental	Mean	3.86	3.99	3.85	0.7305	0.9062	0.4219
	SD	1.35	1.46	1.44			
	# Metrics	17	17	17			
Economics	Mean	3.84	3.35	3.38	0.0067***	0.0025***	0.6923
	SD	1.17	1.47	1.48			
	# Metrics	37	37	37			
Community	Mean	3.61	3.14	2.79	0.3359	0.0078***	0.3281
	SD	1.30	1.03	1.35			
	# Metrics	14	14	14			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively.

The results are that the selected inputs do show several significant results. Specifically, there are statistical differences in the production systems between mussels and algae and mussels and scallops in the economic. dimension and mussels and scallops in the community dimension. Moreover, when the inputs are selected between TBL outputs, the statistical difference previously found in Table 5 between algae and scallops in the community dimension vanishes (see Table A.4 in the Appendix).

4.3 Robustness Check

As a robustness check, we propose a more specific approach to measuring the relationship between inputs and outputs. Particularly, we classify each input metric according to three degrees of generality, i.e., general, medium-general, or specific, as previously discussed. For the output dimensions of the TBL, we classify the metrics as the inputs that produce the output that comes from some degree of generality. Our approach considers that a more stringent test of the relationship between inputs and outputs is attained when we use only the restricted set of inputs directly related to each production system. Thus, we repeat the test presented in Table 7 with the restricted set of specific inputs. The results are presented in Table 8.

Table 8. Inputs Allocated by TBL – Chilean Mussels, Algae (Pelillo), and Northern Scallops. (Degree of Generality = Specific)

Inputs allocated by TBL (Specific)		Mussels	Algae (Pelillo)	N. Scallops	*p-value* Mussels – Algae	Mussels – N. Scallops	Algae (Pelillo) – N. Scallops
Environmental	Mean	3.9	4.1	3.9	0.7500	1.0000	0.5000
	SD	1.5	1.7	1.6			
	# Metrics	10	10	10			
Economics	Mean	3.8	3.3	3.3	0.0125**	0.0040***	0.8434
	SD	1.2	1.5	1.5			
	# Metrics	34	34	34			
Community	Mean	3.3	2.9	2.4	0.5312	0.0156**	0.1719
	SD	1.3	0.9	1.2			
	# Metrics	11	11	11			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively.

When we control for the degree of generality, the significant differences related to different dimensions found in the previous results are maintained (see Table A.5 in the Appendix). Thus, the considerable differences between inputs found in the production systems are not reflected as significant differences in the outputs.

5. Discussion and Conclusions

The APIs are a relatively new instrument to gather information that can be used to assess the performance of aquacultural production systems by diverse dimensions. The APIs can be applied in countries rich and poor in data and cover various applications. Therefore, it is crucial to assess how well this instrument works. In this paper, we have proposed a method for this evaluation and applied it to three aquaculture production systems in Chile. We considered a production function framework to conduct our analysis, where performance outcomes result from the available inputs.

Our results indicate that the three production systems under analysis exhibit good performance. The average APIs score for each production system under analysis is above 3.6 in all cases. We observe a slightly better performance for mussels than for algae and northern scallops. The mean output performance is close to 4.0 in each production system under consideration. Also, we found differences in the aggregated performance and inputs across some of the production systems. However, with only minor exceptions, we did not find differences in the outputs.

The results suggest an inconsistency between tests across outputs that generally tend to show non-significant differences between output dimensions across production systems and the ones between inputs that encounter significant differences between these systems. Moreover, if a statistical difference in outputs is found (the community dimension between algae and scallops measured by the TBL), this difference is not found in the inputs, which is further evidence of inconsistency of differences between outputs and inputs.

There could be different potential explanations for our findings. We mention a few of them. First, the observed differences in inputs across production systems may not translate into detectable differences in outputs because there could be differences in how sensitive the different production systems under analysis are with respect to inputs. In other terms, the marginal effects of the inputs could be different between different production systems. However, obtaining the result of a significant difference between inputs and zero output differences requires a particular constellation of marginal effects. The difference in marginal effects between production systems would have to cancel the input differences. A full-fledged estimation could test this hypothesis if the data to estimate production systems were available.

Second, another possibility is that the APIs data used in this case may not consider all the relevant inputs for the aquaculture production systems under analysis. As reported in section 3, the experts' subjective evaluation showed high confidence in the data delivered. In this case, we assume that this explanation considers the possibility of omitted inputs relevant to the case study. It is unclear to us what these inputs might be or why they should countervail the positive significant differences in inputs. However, the APIs instrument should be reviewed if this is the case.

Finally, another possible explanation for our results is that there could be potential measurement errors when collecting API metrics. Once again, explaining the results obtained requires that the mentioned errors be systematic between inputs and outputs. Considering the protocols used to gather the necessary information for allocating the scores to each metric, we doubt this could drive our results. It is more likely that the alternative explanations previously discussed –differences in the marginal productivity of inputs and the possibility of omitted inputs- are behind our results. Unfortunately, a thorough evaluation of them is beyond the scope of this work. This could be a fruitful extension of this research.

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Methodological Appendix

Conceptual Model: A Separable Multiproduct Production Function Model

Our basic conceptual model is that outputs and inputs are related through a separable multiproduct production function model[6] (Diewert, 1973; Lau, 1976). We assume that we have Q^j production functions for j different aquaculture systems. Each production depends on a vector of inputs, X, where some are common (X_c) to all aquaculture systems, and some are specific (X_s) for each system. We model a linear model, where the β's reflect the marginal impact of each input on the respective output. Selecting one output from two different production systems, we obtain,

$$(1)\ Q^{j1} = \beta_c^{j1'} X_c^{j1} + \beta_s^{j1'} X_s^{j1}$$

and

$$(2)\ Q^{j2} = \beta_c^{j2'} X_c^{j2} + \beta_s^{j2'} X_s^{j2}$$

$$\text{where } j = j1, \ldots, J.$$

The difference between output performance between production system 1 and 2 can be decomposed in the following way,

$$(3)\ Q^{j1} - Q^{j2} = \left[\beta_c^{j1} - \beta_c^{j2}\right]' X_c^{j1} + \beta_c^{j2'}\left[X_c^{j1} - X_c^{j2}\right] + \left[\beta_s^{j1'} X_s^{j1} - \beta_s^{j2'} X_s^{j2}\right]$$

Three sources of differences can be identified: differences between the marginal effects of the same type of inputs in different production systems, differences in input endowments in the production systems, and differences in the inputs used in the various production systems. A fourth source of empirical differences appears when we introduce randomness in this deterministic system: measurement errors can generate differences in the outcomes of the production systems.

[6] We discuss formally our view based on a single production function instead of using a transformation function, which is the usual way for treating multiproduct functions. This is done to transmit our perspective in the simplest way. The extension to a multiproduct function, in this setting, should be straightforward.

Appendix: Figures and Tables

Figure A.1. The Chilean Cases: Aquaculture Production of Mussels, Algae, and Northern Scallops

Figure A.1. Outputs (by Components). Chilean Mussels, Algae (Pelillo), and Northern Scallops

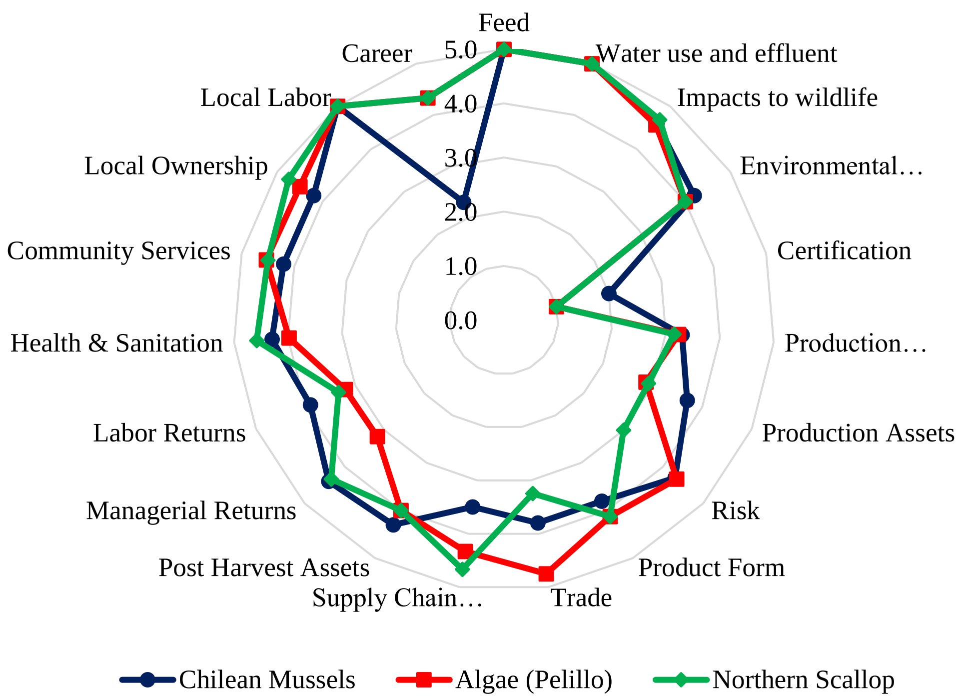

Figure A.2. Inputs. Chilean Mussels, Algae (Pelillo), and Northern Scallops

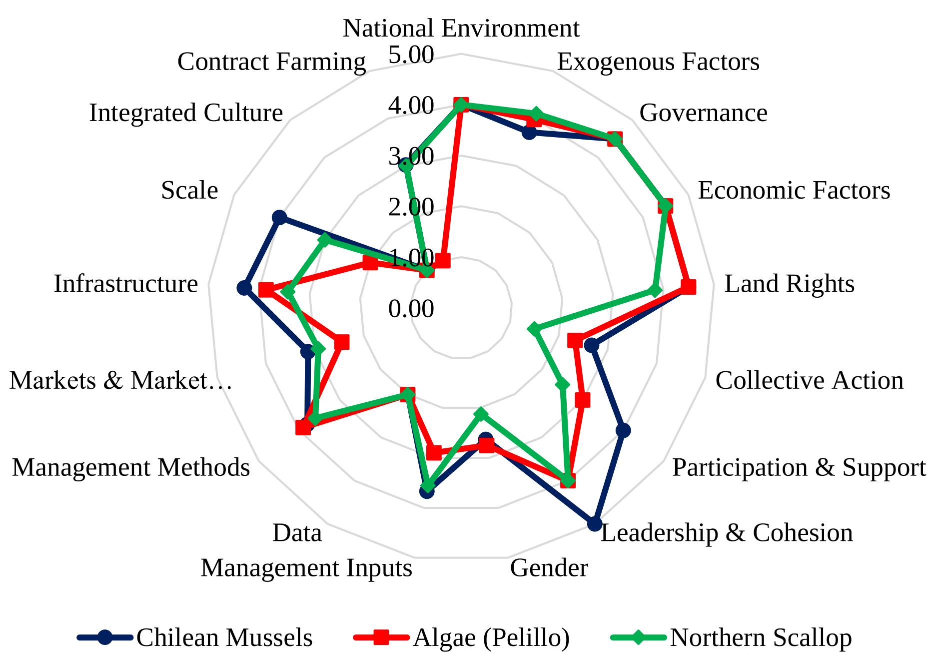

Table A.1. Assignment of Inputs to the Triple Bottom Line Output Indicators

Environmental:	Input
Environmental Performance Index (EPI)	2
Natural Disasters and Catastrophes	3
Drought	4
Pollution Shocks and Accidents	5
Level of Chronic Pollution - Production Effects	6
Level of Chronic Pollution - Consumption Effects	7
Percentage of marine ingredients	35
Traceability of feed inputs	36
Regional disease control	41
Genetic management	42
Discharge/effluent control	43
Antibiotic use	44
Antibiotic use practices	45
Food safety services	46
Animal welfare/handling practices	47
Damage compensation/management	48
Access to Water	49
Land or water zoning/management	50
Economic:	
Governance Quality**	8
Governance Responsiveness**	9
Index of Economic Freedom	10
Gross Domestic Product (GDP) Per Capita	11
Proportion of Production with Property or Lease Right	12
Transferability Index	13
Security Index	14
Durability Index	15
Flexibility Index	16
Exclusivity Index	17
Proportion of Farmers in Industry Organizations**	18
Farmer Organization Influence on Management**	19
Farmer Organization Influence on Business & Marketing**	20
Industry Financial Support for Management**	22
Management Expenditure Compared to Farm-Gate Value	29
Enforcement Capability	30
Management Jurisdiction	31
Coordination of regulatory authorities**	33
Level of Subsidies	34
R&D	37
Private R&D	38
Transparency of Farm-gate price	51

Availability of Farm-gate Price & Quantity Information	52
Number of Buyers	53
Degree of Vertical Integration	54
Level of Tariffs	55
Level of Non-tariff Barriers	56
Contribution to Economy	57
International Shipping Service	58
Road Quality Index	59
Technology Adoption in Production	60
Technology Adoption in Processing	61
Extension Service	62
Reliability of Utilities/Electricity	63
Access to Ice & Refrigeration	64
Scale of farm	65
Production under contract farming	76
Community:	
Governance Quality**	8
Governance Responsiveness**	9
Proportion of Farmers in Industry Organizations**	18
Farmer Organization Influence on Management**	19
Farmer Organization Influence on Business & Marketing**	20
Days in Stakeholder Meetings	21
Industry Financial Support for Management**	22
Leadership	23
Social Cohesion	24
Business Management Influence	25
Resource Management Influence	26
Labor Participation in Production Sector	27
Labor Participation in Processing Sector	28
Coordination of regulatory authorities**	33
No Identifier	
Generations separated by selective breeding	32
Biological data collection	39
Market and economic data	40
Integrated culture	66

Note: ** denotes metrics identified in both economic and community categories of TBL.

Table A.2. Outputs by Component - Chilean Mussels, Algae (Pelillo), and Northern Scallops

Outputs by Component			Mussels	Algae (Pelillo)	N. Scallops	*p-value* Mussels - Algae	Mussels – N. Scallops	Algae – N. Scallops
Environmental	Feed	Mean	5.00	5.00	5.00	-	-	-
		SD	0.00	0.00	0.00			
		# Metrics	2	2	2			
	Water use and effluent	Mean	5.00	5.00	5.00	-	-	-
		SD	0.00	0.00	0.00			
		# Metrics	3	3	3			
	Impacts to wildlife	Mean	4.58	4.57	4.69	0.9773	0.4310	0.6968
		SD	0.73	0.61	0.46			
		# Metrics	8	8	8			
	Environmental compliance	Mean	4.15	4.00	4.00	-	-	-
		SD	-	-	-			
		# Metrics	1	1	1			
	Certification	Mean	2.00	1.00	1.00	-	-	-
		SD	-	-	-			
		# Metrics	1	1	1			
Economics	Production Performance	Mean	3.27	3.24	3.15	0.9362	0.7092	0.7661
		SD	1.43	1.42	1.42			
		# Metrics	13	13	13			
	Production Assets	Mean	3.73	2.86	2.92	0.2967	0.2010	0.9553
		SD	1.00	1.61	1.36			
		# Metrics	6	6	6			
	Risk	Mean	4.33	4.33	3.00	1	0.0429**	0.0103**
		SD	1.21	0.82	1.26			
		# Metrics	6	6	6			
	Product Form	Mean	3.81	4.13	4.13	0.095*	0.3884	1
		SD	1.25	1.36	1.46			
		# Metrics	8	8	8			
	Trade	Mean	3.75	4.75	3.25	0.0917*	0.4950	0.1027
		SD	0.50	0.50	1.26			
		# Metrics	4	4	4			
	Supply Chain Performance	Mean	3.50	4.33	4.67	0.5	0.5	0.4226
		SD	0.71	0.58	0.58			
		# Metrics	2	3	3			
	Post Harvest Assets	Mean	4.33	4.00	4.00	0.4226	0.4226	-

		SD	0.58	0.00	0.00			
		# Metrics	3	3	3			
Community	Managerial Returns	Mean	4.36	3.18	4.33	0.0197**	0.9448	0.0565*
		SD	0.60	0.98	0.41			
		# Metrics	6	6	6			
	Labor Returns	Mean	3.86	3.20	3.33	0.3394	0.2003	0.8278
		SD	0.96	1.17	0.61			
		# Metrics	6	6	6			
	Health & Sanitation	Mean	4.26	3.77	4.33	0.2162	0.8038	0.0239**
		SD	0.42	0.77	0.75			
		# Metrics	6	6	6			
	Community Services	Mean	4.23	4.53	4.50	0.5711	0.4233	0.9272
		SD	0.83	0.50	0.50			
		# Metrics	5	5	5			
	Local Ownership	Mean	4.25	4.50	4.75	0.5	0.4936	0.7952
		SD	0.35	0.71	0.35			
		# Metrics	2	2	2			
	Local Labor	Mean	5.00	5.00	5.00	-	-	-
		SD	0.00	0.00	0.00			
		# Metrics	2	2	2			
	Career	Mean	2.33	4.33	4.33	0.0742*	0.0742*	-
		SD	0.58	1.15	1.15			
		# Metrics	3	3	3			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively.

Table A.3. Inputs by Indicator - Chilean Mussels, Algae (Pelillo), and Northern Scallops

Inputs by Indicator		Mussels	Algae (Pelillo)	N. Scallops	*p-value* Mussels - Algae	Mussels – N. Scallops	Algae – N. Scallops
National Environment	Mean	0.00	0.00	0.00	-	-	-
	SD	-	-	-			
	# Metrics	0	0	0			
Exogenous Factors	Mean	3.71	3.98	4.10	0.7824	0.2484	0.8679
	SD	1.56	0.98	1.08			
	# Metrics	5	5	5			
Governance	Mean	0.00	0.00	0.00	-	-	-
	SD	-	-	-			
	# Metrics	0	0	0			
Economic Factors	Mean	0.00	0.00	0.00	-	-	-
	SD	-	-	-			
	# Metrics	0	0	0			
Land Rights	Mean	4.50	4.50	3.83	-	0.025**	0.025**
	SD	0.84	0.84	0.75			
	# Metrics	6	6	6			
Collective Action	Mean	2.67	2.33	1.50	0.7418	0.0198**	0.3701
	SD	0.58	1.15	0.50			
	# Metrics	3	3	3			
Participation & Support	Mean	4.00	3.00	2.50	0.50	0.50	0.50
	SD	1.41	0.00	0.71			
	# Metrics	2	2	2			
Leadership & Cohesion	Mean	5.00	4.00	4.00	0.50	0.50	-
	SD	0.00	1.41	1.41			
	# Metrics	2	2	2			
Gender	Mean	2.63	2.75	2.13	0.8915	0.1817	0.4309
	SD	1.25	0.50	1.03			
	# Metrics	4	4	4			
Management Inputs	Mean	3.67	2.90	3.56	0.1388	0.7599	0.1038
	SD	1.32	1.60	1.74			
	# Metrics	9	10	9			
Data	Mean	2.00	2.00	2.00	-	-	-
	SD	0.00	0.00	0.00			
	# Metrics	2	2	2			
Management Methods	Mean	3.80	3.90	3.60	0.7807	0.3749	0.1934
	SD	1.42	1.79	1.71			
	# Metrics	10	10	10			
Markets & Market Institutions	Mean	3.14	2.44	2.93	0.1368	0.1996	0.2 131
	SD	1.86	1.81	1.92			

	# Metrics	7	7	7			
Infrastructure	Mean	4.29	3.86	3.43	0.2894	0.1428	0.5891
	SD	0.76	1.21	1.72			
	# Metrics	7	7	7			
Scale	Mean	4.00	2.00	3.00	-	-	-
	SD	-	-	-			
	# Metrics	1	1	1			
Integrated Culture	Mean	1.00	1.00	1.00	-	-	-
	SD	-	-	-			
	# Metrics	1	1	1			
Contract Farming	Mean	3.02	1.00	3.00	-	-	-
	SD	-	-	-			
	# Metrics	1	1	1			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively.

Table A.4. Comparative for Outputs by TBL and Assignment of Inputs to the TBL Output Indicators

Component	Resource		Outputs by TBL	Inputs assigned to the TBL outputs	Difference	p-value
Environmental	Mussels	Mean	4.52	3.86	0.66	0.1105
		SD	0.90	1.35		
		# Metrics	15	17		
	Algae (Pelillo)	Mean	4.44	3.83	0.61	0.1999
		SD	1.08	1.58		
		# Metrics	15	18		
	N. Scallops	Mean	4.50	3.85	0.65	0.1552
		SD	1.05	1.44		
		# Metrics	15	17		
Economic	Mussels	Mean	3.72	3.84	-0.11	0.6653
		SD	1.17	1.17		
		# Metrics	42	37		
	Algae (Pelillo)	Mean	3.77	3.35	0.42	0.184
		SD	1.30	1.47		
		# Metrics	43	37		
	N. Scallops	Mean	3.45	3.38	0.08	0.8138
		SD	1.34	1.48		
		# Metrics	43	37		
Community	Mussels	Mean	4.05	3.61	0.44	0.2664
		SD	0.89	1.30		
		# Metrics	30	14		
	Algae (Pelillo)	Mean	3.85	3.14	0.71	0.0433**
		SD	1.03	1.03		
		# Metrics	30	14		
	N. Scallops	Mean	4.23	2.79	1.45	0.0017***
		SD	0.75	1.35		
		# Metrics	30	14		

Note: Two-sample t-test with unequal variances. *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively.

Table A.5. Inputs - Chilean Mussels, Algae (Pelillo), and Northern Scallops

Inputs				Mean Differences (p-value)		
	Mussels	Algae (Pelillo)	Northern Scallops	Mussels – Algae (Pelillo)	Mussels – Northern Scallops	Algae (Pelillo) – Northern Scallops
1 = very general						
Mean	4.44	4.33	4.44	0.6811	1.000	0.3466
SD	0.73	0.71	0.53			
# Metrics	9	9	9			
2 = medium general						
Mean	4.15	3.92	4.15	0.5854	0.9953	0.5675
SD	1.20	1.19	1.20			
# Metrics	10	10	10			
3 = specific						
Mean	3.43	3.04	2.90	0.0493**	0.0005***	0.2852
SD	1.39	1.56	1.52			
# Metrics	46	47	46			

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively.