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Contribution to the study of sustainability of small-scale artisanal fisheries in Chile

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ABSTRACT

The present work aims to advance the study of sustainability in the small-scale fishing sector by exploring the relationships between the four pillars (economic, social, environmental and institutional) of sustainable development, based on a set of proxy indicators for each one. Faced with a lack of calibrated indicators for the artisanal fishing sector in Chile, the first stage was to identify a set of sustainability indicators that could be used to this end. Subsequently, using partial least squares structural equation modelling (PLS-SEM), the relationships of causality between the pillars were explored, and finally, from the scores obtained for each pillar through structural equation modelling, a sustainability index was determined for each fishing community. This index will provide an indicator with which to measure and compare the relative sustainability of the fishing communities found within three different zones. The results obtained show important differences between the sustainability indices of the three zones, with fishing communities in the northern zone having a lower sustainability index, while those in the central and southern zones have a higher sustainability index. Several causal relationships between the pillars were detected.

1. Introduction

The fishing communities that can be found along Chile's extensive coastline present a complex challenge for the sustainable management of the sea as and its resources. The diverse biological, territorial and sociocultural dimensions of these communities, together with the speed of changes that are being brought about by national and international economic drivers, has resulted in a lack of territorial management models that are sensitive to local context. The diversity of stakeholders and interests adds another level of uncertainty and complexity, with the potential to trigger conflicts of interest that are not conducive to the establishment of collaborative resource management regimes. Until now, scientific interest in these communities and fishing institutions [1] has been reduced to local interventions, and even when progress has been made in coastal planning, issues relating to knowledge gaps and poor or ineffective communication between stakeholders remain. As result, several daily practices are left out of development strategies for artisanal fisheries and the communities in which they are located.

The need to refocus territorial management approaches is evident, in order to achieve an integrated and interdisciplinary model that enhances sustainable development strategies. To advance in this direction, several studies propose the adoption of models centered around four integrated and interlinked pillars: economical, environmental, social and institutional [2–4]. For Chilean small-scale fishing sector, however, there are no studies that have analyzed how these pillars are related to sustainability, nor have the most appropriate sustainability indicators for each of the four pillars defined. Several possible reasons exist for the absence of studies of this nature, such as the complexity of marine ecosystems and the lack of sustainability indicators that can determine multidimensional information. Improving our understanding of the pillars that support the sustainable development, and the way in which they interact with one another, is a task that is still pending for the artisanal fishing sector.

This work aims to advance the study of sustainability in the small-scale fishing sector by exploring the relationships between the pillars, based on a set of proxy indicators for each one. Faced with a lack of calibrated indicators for the artisanal fishing sector in Chile, the first stage was to identify a set of variables that could be used to this end. Subsequently, using partial least squares structural equation modelling (PLS-SEM) [5], the relationships of causality between the pillars were explored, and finally, from the scores obtained for each pillar through structural equation modelling, a sustainability index was determined for each fishing community. This index will provide an indicator with which to measure and compare the relative sustainability of the fishing communities found within three different zones.

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2. Background

2.1. Sustainability

Questions regarding sustainability of human population and economic growth date at least as far back as the publication of the Limits to Growth (or Meadows) Report, commissioned at the end of the seventies to the Massachusetts Institute of Technology (MIT) by the Club of Rome, a group of philanthropists, scientists, politicians, and business leaders [6]. In this report, the idea of ecological limitations to growth, and the risk of overshooting these, along with the ensuing pressures this may place on natural resources was discussed. A subsequent version of the Meadows Report, titled Beyond the Limits of Growth confirmed that the global threshold for growth had been reached by the mid-1980s, just as had been predicted in one of the possible scenarios modelled by World3 in 1972.

The term ‘sustainable development’ was first coined in 1987 in the Our Common Future Report (also known as the Brundtland Report), which was commissioned by the United Nations, and created under the leadership of former Norwegian Prime Minister Gro Harlem Bundtland [7]. This document defined sustainable development as “development that satisfies the needs of the present without compromising the capacity for future generations to satisfy their own needs” [7]. With the passing of time, the concept would lose clarity, as different versions and variations of this definition began to accumulate.

In fisheries management, the idea if of sustainability of natural resources base has been present in the fundamentals at least since the 1950s. In the 1980s and 1990s, sustainability concepts that originally focused on resources and environmental protection developed to more explicitly include social and community concerns, and particularly the well-being of people in fisheries in general and in small coastal and riparian communities in particular [8]. The concept of sustainability in fisheries has latter been described in FAO [9] reports. A legal framework of principles for management of fisheries already exist in UNCLOS [10], the 1995 United Nations Implementing Agreement on Straddling Stocks and Highly Stocks (UNIA) and the FAO Code of Conduct for Responsible Fisheries [11].

In this article, the definition of sustainable development was taken from Agenda 21 and FAO and applied to the study of small-scales fisheries. Hence, if sustainable development is the one which satisfies actual needs without compromising future generation's possibilities and resources, it also needs to be analysed in a multi-dimensional perspective, including at least the following pillars: (1) ecological (the ecosystem, including biological resources and their environmental; (2) social; (3) economic; and (4) related to the institutions and governance system in which the fisheries operates.

2.2. Attempts at developing indicators and index of sustainability

A wide variety of mechanisms for estimating sustainability currently exist [12–14]. Singh et al. [15] offer a detailed review of many of these. They highlight the large number of sustainability reports, noting that most of them incorporate social, economic and environmental variables, some examples include the Global Reporting Initiative and the United States Commission on Sustainable Development; Singh et al. [15]. Another dominant tendency are ecosystem-based indices, such as the Sustainability Performance Index (SPI), which evaluates the area required for the incorporation of a complete process within the biosphere [16], the Eco-Index methodology, developed to calculate ecological footprints [17], the WWF's Living Planet Index [18], which has been used as a biodiversity indicator for the analysis of more than 2,000 populations and 1,100 species, and the Ecological Footprint, developed by Wackernagel and Rees [19], that uses equivalency factors to calculate the combined demand for natural resources in a real world area, and then transform that area into a standardized unit, known as the global hectare (gha).

Various methods seek to measure sustainable development by examining causal relationships. One of simplest and widely-recognized is the PSR (pressure-state-response) framework, developed by the OECD [20]. This model looks at the pressure that human activates plays on environment, the changes in state that are caused as a result, and the responses that are triggered in order to mitigate them. In an attempt to incorporate the social pillar, the OECD [21] developed the PSIR (pressure-state-impact-response) model. The key limitation of these models is their focus on unidirectional chains of causality, and the fact that they do not take into consideration the economic pillar. The European Environment Agency [22] developed the DPSIR (drivers-pressure-state-impact-response) framework, which incorporates the economic pillar. In this model, causal relationships are no long unidirectional, but can also be reciprocal [3]. An application for this model using an approach based on structural equations has been development by Sánchez and Ramajo [23].

Chesson and Clayton [24] have proposed a generic framework structure for sustainable development of fisheries known as Ecologically Sustainable Development (ESD). The framework divides the effects of fishing into the effects of fishing on humans and the effect of fishing on the environmental. Each of the two components is subdivided into six-subcomponents. The human component is subdivided into food, employment, income and life subcomponents; the ecology component is subdivided into commercial fish species, non-targeted fish species and other and other environment sub-component. An Australian example of their application has been provided by García et al. [25].

Despite the variety of possible definitions of sustainability, many of them comprise four pillars. For instance, sustainable development, as elaborated in Agenda 21 and confirmed later at the Word Summit on Sustainable Development, has three explicit pillars: social, economic and environmental. A fourth pillar, institutional, was included by the UN Commission on Sustainable Development (CSD); [3,26]. FAO's version of sustainable development - which can be considered a very general framework for fisheries sustainability - establishes five pillars: i) Resources; ii) People (social and economic human needs) iii) Institutions; iv) Environmental and v) Technology. In fisheries management, FAO adopted in 1995 the Code of Conduct for Responsible Fisheries, considered by fishing and coastal nations as the practical foundation on which to stablish sustainable fisheries in the future [8]. This specifically fisheries related framework offers a definition subdivided in the following operational dimensions: (1) Fishing operation, (2) Fisheries management, (3) Integration of fisheries into coastal area management, (4) Post-harvest practice and Trade, (5) Aquaculture development, and (6) Fisheries research.

Garcia et al. [25], maintain that in practice, it is not critical which framework is adopted, in many cases different frameworks will lead to the same or similar sets of indicators but will provide different ways of examining fisheries components (or criteria in FAO terminology) to be included in the sustainable development reference system.

In this study the UN Commission on Sustainable Development (CSD) framework, was adopted, which explicitly incorporate four pillars: economic, social, environmental and institutional. To design and develop an index of sustainability for small-scale fisheries based on causal model using structural equations, it is necessary to identify the pillars and their corresponding variables [27]. A list of fisheries components (criteria) for each one of the four pillars have been identified [28] from several workshop with local and regional actors of small-scale fisheries of Chile. Taking these criteria as general guideline for Chilean small-scale fisheries, a set of variables was formulated for each of the pillars. Each pillar highlights a particular aspect of the sustainability index and has its own index. The economic pillar reflects the extractive fishing capacity of the fleet as the fisherman's level of employability. The social pillar reflects the conditions of connectivity and health protection of the community. The environmental pillar reflects the ecological and environmental conditions expressed in the biodiversity of species and climate conditions. The institutional pillar reflects knowledge of norms and institutions that govern the artisanal fishing sector. The

Table 1
Variables defined by each pillar.

Pillar	Variables
Economic	Size of fleet (E1) on an ordinal scale (coded 1 to 3), from small to large.
	Logistic support (E2) on an interval scale that measures the number of supplies for the operation of the fishing vessels.
	Median weekly work hours (E3) on an interval scale measuring the average weekly work effort.
Environmental	Climatic conditions (A1) on an interval scale that measures mean annual percentage of days with fishing activity.
	Biodiversity (A2) on an interval scale measuring the number of species that are regularly caught within the fishing area.
Social	Connectivity (S1) on an ordinal scale (coded 1 to 3), from worst to best, measuring quality of access to the community.
	Health protection of artisanal fishermen (S2) on an interval scale measuring the percentage of fishermen with access to the public health system (Fonasa).
Institutional	Knowledge of fisheries institutions (I1) on an interval scale measuring the percentage of fishermen who know the institutions.
	Knowledge of the norms that govern the artisanal fisheries sector (I2) on an interval scale that measures the percentage of fisherman who knows the regulations of the artisanal fisheries sector.

sustainability index derived from the causal model is multidimensional, take in consideration the four pillars, all the pillars are inter-related.

2.3. The state of fisheries in Chile

Located in the southern cone of South America, Chile has a total of 83,850 km of coastline. The fishing sector in Chile, in keeping with patterns across the globe, suffers from a high level of socio-environmental risk, related to the deep historical ties of the people who work within the sector with the sea and its resources. The historical link between coastal populations and marine ecosystems, and the role of these ecosystems as a means of subsistence, date back to the earliest inhabitants of these areas. During the second half of the last century, a variety of factors, including: transformations in political and administrative structures, advancing technology, government-financed growth within the sector, increasing demand, and the commercial value that some species achieve in the international market, have led to many marine resources suffering from over-exploitation from the 1980's onwards [29]. As a result, many species that are highly-valued by Chilean small-scale fishermen, such as Chilean jack mackerel (*Trachurus murphyi*), Peruvian anchoveta (*Engraulis ringens*), pink cusk-eel (*Genypterus blacodes*), South Pacific hake (*Merluccius gayi gayi*) and southern hake (*Merluccius australis*), are either depleted or over-exploited. In total, over 49% of small-scale fishery resources now fall within these classifications [30]. The evidence points to the fact that small-scale fishing in Chile, as in the rest of the World, is in crisis, with over-exploitation seriously compromising important ecosystem services (e.g., conservation of biological and social diversity), social-economic performance and services (mitigation of poverty and vulnerability of coastal communities) and socio-cultural (food security, sense of territorial belonging, amongst others; [31,32]; seriously compromising important benefits of small-scale fishing such as ecosystem services. The degree of Chilean small-scale fishing sustainability, as evidenced by the current state of its key resources, appears to indicate a clear need for increased efforts to improve attempts to evaluate the socio-environmental behavior of small-scale fishing communities.

3. Materials and methods

3.1. Pillars and variables

Sustainability is the capacity of any system or process to maintain itself at a constant rate for an indefinite amount of time. Therefore, sustainable development is the development of social and economic systems that are able to maintain themselves indefinitely in harmony with the planet's biophysical systems [2]. Four integrated and interlinked pillars are considered to uphold the concept of sustainable development [2,26,33]: economic growth, environmental protection, social development and institutional viability.

The variables included in each pillar were selected in response to several problems that had been identified by González et al. [28] as a result of 17 regional workshops with local representatives of artisanal fisheries, public institutions, universities and NGOs. In relation to the economic pillar, marketing, insufficient investment in port infrastructure and low consumption of marine produce were mentioned. Resource overexploitation and the risk of environmental pollution were identified as issues relating to the environmental pillar. The most outstanding concerns regarding social development were the lack of relevant skills and knowledge, doubts about jobs and social security, and the absence of binding participation. In the case of the institutional pillars, inadequate support instruments, insufficiency and disparity of control, the absence of timely information and ongoing technical assistance, and divisions and weaknesses amongst the fishing organizations were mentioned.

Within this framework, a set of proxy variables for the economic, environmental, social and institutional pillars were defined [Table 1]: (1) In the economic pillar were included three variables (E1, E2 and E3): Size of the fleet (E1), to measure the operational capacity of the fleet; Logistic support (E2), to measure the physical supplies of the fleet; Median weekly hours worked (E3), to measure level of employability; (2) In the environmental pillar were included two variables (A1 and A2): Climatic condition (A1), to measure the annual fishing activity (in days) due to the effects of climate change and Biodiversity (A2), to measure the pressure of fishing activity on species; (3) In the social pillar two variables were included (S1 and S2): Connectivity (S1), to measure quality of access of the community and Health protection (S2), to measure the access to the public health system; (4) Two variables were included in the institutional pillar (I1 and I2): Knowledge of fisheries institutions (I1), to measure closeness of the fisherman with the fisheries institutions and Knowledge of the norms that govern the sector (I2), to measure the Fishermen's commitment of the fisherman to the control and regulation of the biological species.

These variables were selected with the criteria that they should be replicable and meet minimum standards of quality and robustness that guarantee their usefulness within decision-making processes [34]. These variables were selected with expert knowledge and when they satisfied the majority the following conditions or principles: (a) they are measurable; (b) they are statistically reliable and feasible; (c) accessible and (d) communicable. Not all variables always fully meet all these principles, however, they meet the majority. Other variables that were initially considered were discarded when the main principles for their selection were not met.

3.2. Study area and data collection

Chile is known for its territorial extension of more than four thousand kilometers from north to south, with a bio-geography that includes dry climatpe (Atacama Desert) in the northern part of the country, Mediterranean climate in the center and climate rainy in the south extending to Antarctic region. Northern and southern zones have a greater territorial length than central zone. The official register of small-scale fishing communities in Chile lists 450 coastal settlements,

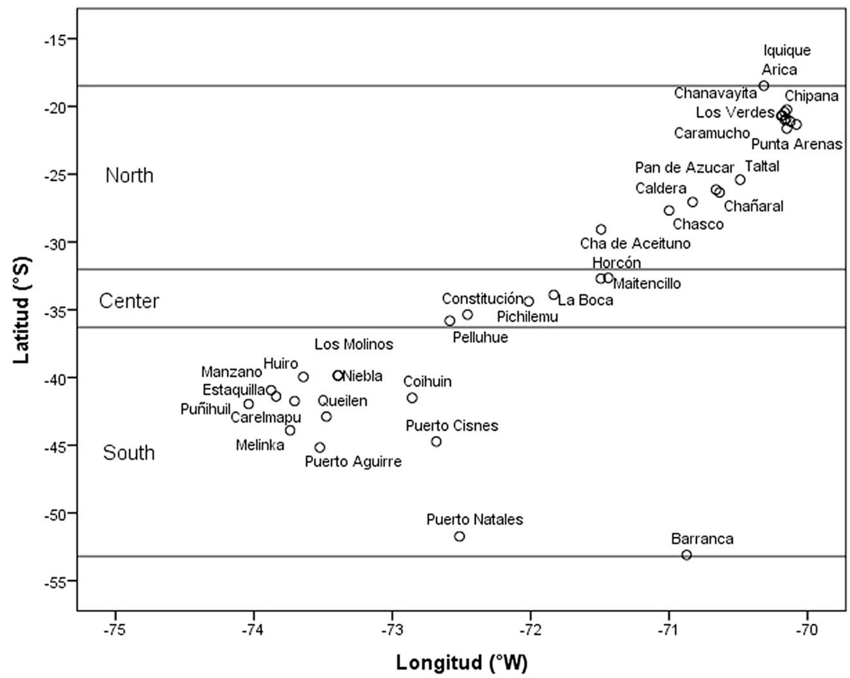

Fig. 1. Spatial distribution of fishing communities by zone (North, Centre and South).

20% came from the north zone, 10% from the central zone and 70% from the south zone. A total of 40 small-scale fishing communities were selected. However, only 36 of them have totally reliable data to be used in the causal model. A total of 15 communities (10 rural and 5 urban) were allocate in the northern zone, 6 communities (2 rural and 4 urban) in the central zone and 15 communities (10 rural and 5 urban) in the southern zone. The smaller number of communities in the central zone can be explained by their smaller territorial extension and smaller number of official records of small-scale fishing communities. The final distribution of the sample is not completely proportional with the official records, 42.5% came from north zone, 17% from central zone and 42.5% from south zone.

The sample of 36 communities was selected from three zones [Fig. 1]: a northern zone, located between 18°00′-29°00′ LS; a central zone between > 29°00′-35°00′ LS, and a southern zone between > 35°00' – 53°00′ LS. Data relating to the variables in Table 1 was obtained from a sample of 10 fishermen from each community, and a survey of local infrastructure was also carried out. Data of statistics on the fleet and species captured by fishing communities are obtained from the official statistical sources (Chilean National Fisheries Services (Sernapesca)). Data relating to the institutional pillar was obtained from Chile's first national fisheries census [35].

3.3. Structural equation modelling

Structural equation modelling (SEM) is a class of multivariate technique that combines factor analysis and regression, enabling the simultaneous examination of relationships among observable variables and latent variables (pillars, dimensions or domains), as well as between latent variables [5]. The available techniques of structural equation modelling include the CB-SEM approaches [36] and PLS-SEM [37]. The estimation procedure for PLS-SEM is an ordinary least squares (OLS) regression-based method, rather than the maximum likelihood (ML) estimation procedure for CB-SEM. The PLS-SEM-based approach was chosen because it allows a small number of samples to be used and does not require assumptions about the distribution of variables [5]; this is an important advantage over the CB-SEM approach [36], which generally requires a large sample size.

The structural equation method used (PLS-SEM) is composed of two types of different sub-models: a sub-measurement model and a structural sub-model [5]. The measurement sub-model specifies the relationships between observed variables and the latent variables (pillars, domains). The structural sub-model includes the effects of interaction (structural cause-effect relationships) among the structural variables (pillars). The specification of the model can be interpreted using path analysis. A graphic description is used to show the relationship that exists between variables.

3.4. Analysis procedure

The evaluation of the sub-measurement model involves the analysis of the individual reliability of indicators (outer loadings (λ)), composite reliability (ρ_c), convergent validity (AVE) and discriminant validity.

The individual reliability of the variables in the case of reflective observable variables must be highly correlated with the pillar that is being measured. The percentage of variance of the reflective observable variable explained by the pillar is measured by the square of the λ outer loadings (communality of an item). The most accepted rule is to consider a minimum threshold of $\lambda \geq 0.707$ [38,39], indicating that more than 50% of the variance of the observed variable is shared with the pillar. The composite reliability (ρ_c) is a measure of the internal consistency or reliability of the scale, which evaluates whether all the variables for a specific pillar measure that pillar with the appropriate rigor. The minimum acceptance rule, according to Nunnally and Bernstein [40], should be about 0.7. The average variance extracted (AVE) is a measure of convergent validity [41] that is equivalent to the communality of a pillar. It is the degree to which a latent variable (pillar) explains the variance of its indicators (observables variable). The acceptance criterion is that the AVE must be greater than 0.5, meaning that, on average, the pillar explains more than half of the variance of its indicators. According the rule of discriminant validity [41], the squared root of the AVE of each pillar should be higher than its highest correlation with any another pillar, which indicates that the pillar shares more variance with its associated indicators than with any other pillar [5]. Thus, establishing discriminant validity implies that a pillar is unique and captures phenomena not represented by other pillars in the model.

The most commonly-used measure to evaluate the structural model is the coefficient of determination (R^2). This coefficient is a measure of the model's predictive accuracy and is calculated as the square correlation between a specific endogenous pillar's actual and predicted values [5]. This coefficient also represents the amount of variance in the pillars explained by all of the pillars linked to it. The recommended minimum values have to be larger than 0.1 [5,42]. A second indicator of the structural model is the coefficients or standardized regression weights β or path coefficients that evaluate the significant relationships between the pillars. It is suggested that the coefficients should be greater than 0.2 for the relationship between the two pillars to be considered relevant [43]. The Bootstrap technique [44] is used to examine the stability of the estimates. The predictive relevance (Q^2 value [45,46]) of the model is determined using the Blindfolding technique, consisting of omitting one case at a time and re-estimating the parameters of the model, based on the remaining cases; it is considered that the model has predictive relevance if Q^2 value is greater than zero. The scores that were estimated for the pillars with the structural equation model were used as input to calculate the sustainability index from a unique factor of the factorial analysis (principal components) [27,47].

4. Results

4.1. Estimation results

The best adjusted model is presented in [Fig. 2], this shows the schematic representation of the causal relationships between the economic, social, environmental and institutional pillars of sustainability amongst 36 small-scale fishing communities. The path model shows how pillars and variables are related.

Several causal relationships can be derived from the results: positive causality from the economic pillar to the social pillar; positive causality from the environmental pillar to the economic and social pillars, and; positive causality from the institutional pillar to the environmental pilllar. Indirectly positive causality is present from the environmental pillar through economic pillar to social pillar and from the institutional pillar through the environmental and economic pillars to social pillar.

4.2. Measurement model evaluation

The measurement model for the study of causal relationships in the fishing communities was evaluated as adequate. The measures of analysis are in accord with standards criteria required for measurement model evaluation (PLS-SEM).

Most of the outer loadings (λ) of the pillars are near or above the threshold value, 0.707 [Table 2]. The variable s2 has the smallest indicator reliability, under the minimum acceptable level for outer loadings. However, this value can be considered as acceptable because the values of average variance extracted (AVE) and composite reliability are not negatively affected. All composite reliability values of the pillars are above 0.7, demonstrating that the model has high levels of internal consistency reliability. The variable of convergent validity (AVE) for each pillar is always above the required minimum level of 0.5 [41]. The results confirm that all variables that are supposed to measure the pillar are indeed measuring the pillar, and not another concept. As regards discriminant validity [Table 3], in all the cases the AVE is always higher than the square correlation between pillars, indicating that the pillars measure different concepts.

Table 2
Results summary for measurement models.

Pillar	Variable	Outer loadings	AVE	Composite reliability
Economic	E1_size of fleet	0.714		
	E2_logistic support	0.782	0.55	0.786
	E3_ work week hours	0.728		
Environmental	A1_climatic condition	0.835		
	A2_biodiversity	0.878	0.734	0.847
Social	S1_conectivity	0.506		
	S2_health protection	0.958	0.587	0.722
Institutional	I1_institutional knowledge	0.921	0.791	0.883
	I2_legislation knowledge	0.856		

4.3. Structural model evaluation

Having confirmed that pillar measurements are reliable and valid, structural model is evaluated examining relationship between the pillars and the model's predictive capabilities. The assessment procedures include coeficient of determination (R^2), structural model path coefficients (β) and predictive relevance (Q^2).

The t-values in [Table 4] show that all standarized regression coefficients (β) are significant at 5%. The path coefficients of the standarized regression measure the strengths of the relationship between the pillars or the proposal of some hipothesis of causality. For this index, desirable values are higher than 0.3. The significance levels were calculated using a bootstraping [44] procedure with 5,000 iterative processes. The coefficient of determination (R^2) of the pillars are all above 0.1 [Table 5], meaning that the pillars adequately capture the sustanaibility. The preference of this value must be over 0.2. The environmental pillar is located at the limit of the acceptable range. A method of blindfolding [43,45,46,48] was used to obtain the predictive relevance (Q^2). The results [Table 5] give values larger than zero, indicating that the environmental, economic and social pillars have a predictive relevant capacity.

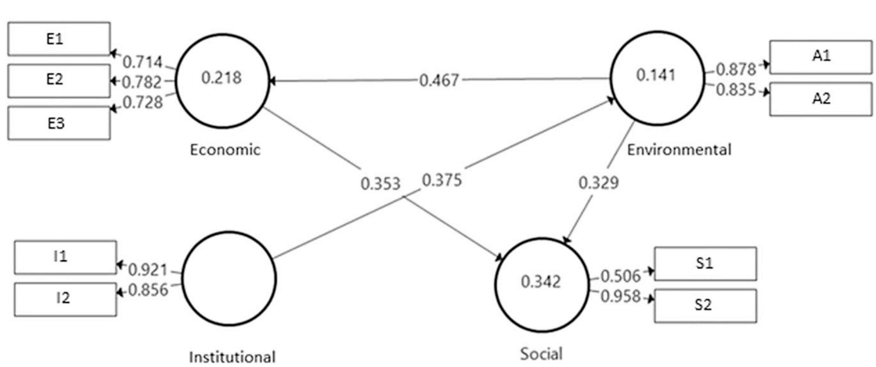

Fig. 2. Final model (PLS-SEM). The path coefficients represent standardized partial regression coefficients. Arrows between pillars (in circles) and indicators or observable variables (in boxes) represent the degree to which indicators are correlated with pillars.

Table 3
Discriminant validity.

Pillar	Economic	Environmental	Social	Institutional
Economic	0.742			
Environmental	0.467	0.857		
Social	0.507	0.494	0.766	
Institutional	0.112	0.375	0.345	0.889

Table 4
Significance of parameters (β) of the relationship between pillars.

Relation between pillars	B	t-value
Environmental ——— > Economic	0.467	3.89
Environmental ——— > Social	0.329	2.48
Economic ——— > Social	0.353	2.866
Institutional ——— > Environmental	0.375	2.755

Table 5
Coefficient of determination R^2 and predictive relevance Q^2.

Pillar	R^2	Q^2
Environmental	0.141	0.075
Economic	0.218	0.094
Social	0.342	0.139

4.4. Sustainability index

The estimated scores for the pillars [Table 6] were used as input for calculating the sustainability index through factor analysis, and the principal components method was selected to extract a unique factor. The sample is adecuate: the indicator of the Kayser-Meyer-Olkin (KMO) test was 0.676 (> 0.5), and Bartlett's Test of Sphericity confirms that the linear combination exists ($p < 0.0001$). The unique factor explains 54.5% of the total variance. The index shows a slightly negative skew and the Kolmogorov-Smirnov Test ($p > 0.097$) confirms the normality of the index.

The classification of the global score in quartile ranges was used by Ref. [49], to compare the status of Canadian fisheries under the Code of Conduct for Responsible Fisheries using the Rapfish technique, a non-parametric and multidisciplinary ordering technique. A similar criterion was used in this study. The sustainability indices of the fishing communities were classified into four quartile ranges: Very low (< -0.766 standard deviations); Low (−0.766 – 0.229 standard deviations); Medium (> 0.229–0.746 standard deviations) and High (> 0.746 standard deviations). The higher the sustainability index of a fishing community, as meausured in units of standard deviation, the greater the sustainability level of the community [Table 7]. Fishing communities in the northern zone scored mainly very low (VL) and low (L) quartile range; 75% scored VL. In the central zone, the communities scored mainly in the high (H) and medium (M) quartile ranges, with 66.7% scoring H. The communities in the southern zone scored in the H and M quartile ranges with 64% scoring M (42.9%) and H (21.4%). Results show that the sustainability indices highlight important differences between different areas [Fig. 3]. In northern zones there are mainly communities that have a lower sustainability index, while in the central zone there are mainly communities with a high sustainability index. The index in the southern zone has a similar distribution to the central zone.

To study the profiles presented by zones (north, center, south) with respect to the type of community (rural, urban), a chi-square statistical test was used, concluding that there are no significant differences ($p > 0.311$). Therefore, the three zones are homogeneous with respect to the type of community. On the other hand, in the first two quartiles ranges, 39% and 61% of the fishing communities were classified as rural and urban, respectively, while in the two lower quartile ranges were classified as 83% rural and 17% as urban. In the lowest quartile range, 100% of rural fishing communities were classified, 78% of them came from northern zone. The upper quartile range has a more heterogenous composition pattern, 56% is rural mainly from southern zone and 44% from the urban area. The results confirms that the composition pattern of the community type changes with the gradient of the quartile ranges.

Table 6
Indices by pillar and community from the causal model: ECP. (economic pillar), ENP (environmental pillar), SOP (social pillar), INP (institutional pillar).

Community	ECP	ENP	SOP	INP
Constitución	1.68	2.21	1.41	0.33
Manzano	0.01	2.02	0.81	2.57
Pichilemu	1.04	1.99	0.94	0.34
Los Molinos	1.50	0.11	0.91	0.87
La Boca	-0.78	0.69	0.65	3.30
Niebla	0.99	-0.13	0.99	1.17
Caldera	1.09	-0.02	0.57	1.25
Melinka	0.97	1.46	0.31	-0.51
Puerto Aguirre	1.76	0.64	0.25	-0.56
Barranca	0.50	1.05	0.64	-0.38
Pelluhue	0.28	-0.16	0.70	1.27
Puerto Cisnes	2.27	-0.24	0.42	-0.96
Taltal	0.85	0.87	0.52	-1.01
Queilen	0.27	-0.19	0.66	0.86
Chañaral	1.02	-0.29	0.55	0.04
Puerto Natales	0.49	0.39	0.39	-0.04
Horcón	0.11	0.78	0.29	-0.17
Arica	-1.04	1.40	-0.27	1.06
Huiro	-0.26	0.71	0.24	-0.59
Carelmapu	0.27	-0.23	-0.16	0.07
Pan de Azúcar	-0.50	-1.31	0.67	0.39
Iquique	-0.16	-0.22	-0.16	-1.00
Caramucho	-0.51	-0.09	-0.20	-0.92
Maitencillo	-1.24	-0.90	0.48	0.12
Coihuin	-1.63	0.41	0.12	-0.75
San Marcos	-0.07	-1.31	0.44	-1-00
Chanavaya	-1.14	-0.9	0.79	-1.02
Cha. de Aceituno	-0.35	-1.10	-0.47	-0.40
Puñihuil	-0.89	-0.16	-1.63	-0.17
Los Verdes	-1.14	-1.10	-0.18	-0.77
Chanavayita	0.04	-0.90	-1.98	-0.58
Chipana	-1.04	-1.10	-0.78	-0.71
Río Seco	-1.43	-1.31	-0.92	-0.73
Punta Arenas	-0.97	-0.90	-1.69	-1.02
Chasco	-1.12	-1.31	-2.12	0.16
Estaquilla	-0.85	-0.85	-3.18	-0.51

The estimated scores of each pillar with the structural equation modelling were also classified into four quartile ranges [Table 7]; this was compared with the global index. In some fishing communities, the specific clasification by pillar can rise or fall by at least two quartile ranges compared with the global index. Three of the communities that scored H on the global index [Table 7] dropped to L on the quartile range: La Boca Caleta in the economic pillar, Melinka Caleta in the social pillar, and Puerto Aguirre Caleta in the institutional pillar. Moreover, three communities that scored M on the global index [Table 7] dropped to VL on the quartile range: Arica Caleta in the economic and social pillars, Puerto Cisnes Caleta in the social pillar, and Taltal Caleta in the institutional pillar. On the other hand, three communities with VL on the global index [Table 7] went up to M on the quartile range: Chanvayita Caleta in the economic pillar, and Puñihuil Caleta and Chasco Caleta in the institutional pillar. Three communities that scored L on the global index [Table 7] rose to H on the quartile range: Huiro Caleta in the environmental pillar, Chanvayita Caleta and Pan de Azúcar Caleta in the social pillar, and the last community in the economic pillar [Fig. 4]. shows the zonal variation of the index of each pillar by type of community. The economic and social pillars indices have similar pattern regarding the type of community, but they differ in the score, being higher in urban communities. The environmental and institutional pillars show an inverted pattern regarding the type of community.

Table 7
Indices by community, type of community (Rural, Urban), zone and type of. Classification (Very Low (VL), Low (L), Medium (M) and High (H)). Index (global sustainability index values in standard deviation), GI (index global classification), classification by pillar: ECP (economic pillar), ENP (environmental pillar), SOP (social pillar), INP (institutional pillar).

Community	Type	Zone	Index	GI	ECP	ENP	SOP	INP
Constitución	Urban	Centre	1.97	H	H	H	H	M
Manzano	Rural	South	1.70	H	M	H	H	H
Pichilemu	Urban	Centre	1.51	H	H	H	H	M
Los Molinos	Rural	South	1.09	H	H	M	H	H
La Boca	Rural	Centre	1.08	H	L	M	M	H
Niebla	Urban	South	0.94	H	H	M	H	H
Caldera	Urban	North	0.88	H	H	M	M	H
Melinka	Rural	South	0.84	H	H	H	L	L
Puerto Aguirre	Rural	South	0.76	H	H	M	L	L
Barranca	Rural	South	0.69	M	L	H	M	L
Pelluhue	Rural	Centre	0.62	M	L	M	H	H
Puerto Cisnes	Urban	South	0.57	M	H	L	M	VL
Taltal	Urban	North	0.53	M	L	H	M	VL
Queilen	Urban	South	0.48	M	L	L	H	H
Chañaral	Urban	North	0.44	M	H	L	M	M
Puerto Natales	Urban	South	0.44	M	L	M	M	M
Horcón	Urban	Centre	0.38	M	L	H	L	M
Arica	Urban	North	0.34	M	VL	H	VL	H
Huiro	Rural	South	0.12	L	L	H	L	L
Carelmapu	Urban	South	-0.04	L	M	L	L	M
Pan de Azúcar	Rural	North	-0.30	L	L	VL	H	H
Iquique	Urban	North	-0.45	L	L	L	L	VL
Caramucho	Rural	North	-0.51	L	L	M	L	VL
Maitencillo	Urban	Centre	-0.53	L	VL	VL	M	M
Coihuin	Rural	South	-0.53	L	VL	M	L	VL
San Marcos	Rural	North	-0.60	L	L	VL	M	VL
Chanavaya	Rural	North	-0.68	L	VL	VL	H	VL
Cha. de Aceituno	Rural	North	-0.80	VL	L	VL	VL	L
Puñihuil	Rural	South	-1.00	VL	L	L	VL	VL
Los Verdes	Rural	North	-1.04	VL	VL	VL	L	VL
Chanavayita	Rural	North	-1.20	VL	M	L	VL	L
Chipana	Rural	North	-1.22	VL	VL	VL	VL	L
Río Seco	Rural	North	-1.48	VL	VL	VL	VL	L
Punta Arenas	Rural	North	-1.54	VL	VL	L	VL	VL
Chasco	Rural	North	-1.59	VL	VL	VL	VL	L
Estaquilla	Rural	South	-1.90	VL	L	L	VL	L

5. Discussion and conclusions

According to Parris and Kates [50], there are no universally accepted sustainability indicators. For this simple reason, designing and implementing indicators and sustainability indices still has a long way to go; it is an open and dynamic challenge, which encounters additional complexities according to the scale and the area being measured. This article has attempted to contribute to this unfinished task, laying the foundations for the interdisciplinary and multidimensional modelling of a sustainability index for artisanal fishing settlements in Chile.

The global index was calculated for each community. using factor analysis (principal components) [51]. Different techniques have been used to combine indicators into a single index and measure sustainability in fisheries. For instance, the multi-criterion techniques were used in the case study of South East Trawl Fisheries (Australian example) to standardize, weight and aggregate indicators [24,25]. Multi-criterion analysis provides a convenient method for explicitly dealing with subjective weights and hierarchical structure of the framework allows aggregations to whatever level is necessary or desirable. Liu et al. [52], on the other hand, used factor analysis to gain objective weights. Non-parametric multi-dimensional scales (MDS) [53], is an ordination method has been employed to compare different fisheries [49]. Charles [54] suggest two methods of aggregation, one is to use the average weight and the other is to use de geometric average weigh. Despite any possible demerits of these aggregations indicators they also certainly have the advantages of providing straightforward communication, warning signal, policy guides, flexibility and straightforward control [55].

Faced with the lack of calibrated indicators for the artisanal fishing sector in Chile, the first stage of the work was to identify a set of variables for the four pillars of sustainable development. The process of selecting variables for each pillar sought to identify those which were conceptually equivalent to existing applications, but in this case, appropriate to the context of small-scale fishing communities. Eventually, nine variables were selected for the four pillars, upon which the results are based. The adjusted measurement model presents an acceptable evaluation, which validates the estimation of the proposed pillars; the same happened with the structural model, validating the causality

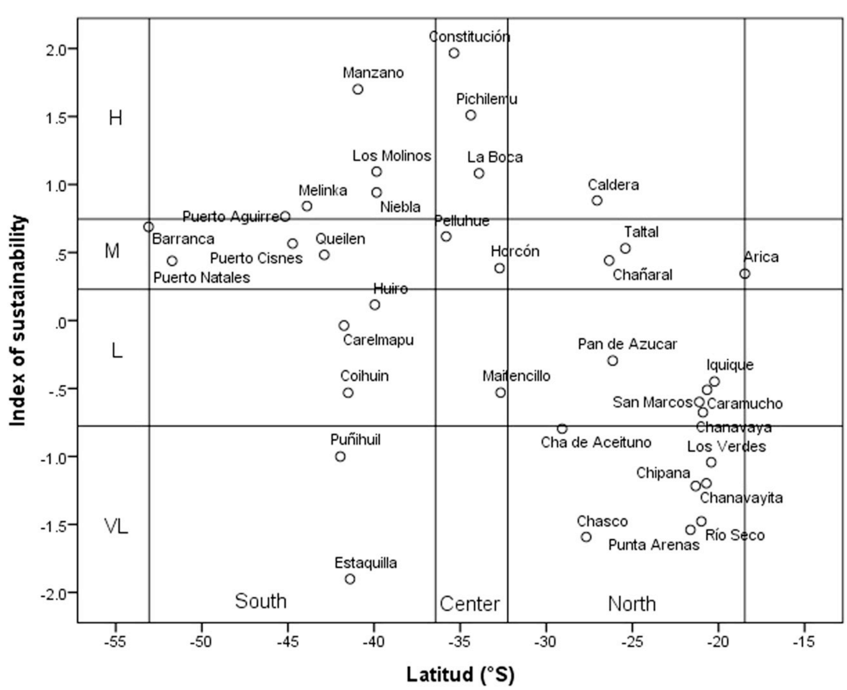

Fig. 3. Global sustainability index by community (circles) and zone (North, Center, South). Quartile range classification: (Very Low (VL), Low (L), Medium (M) and High (H)).

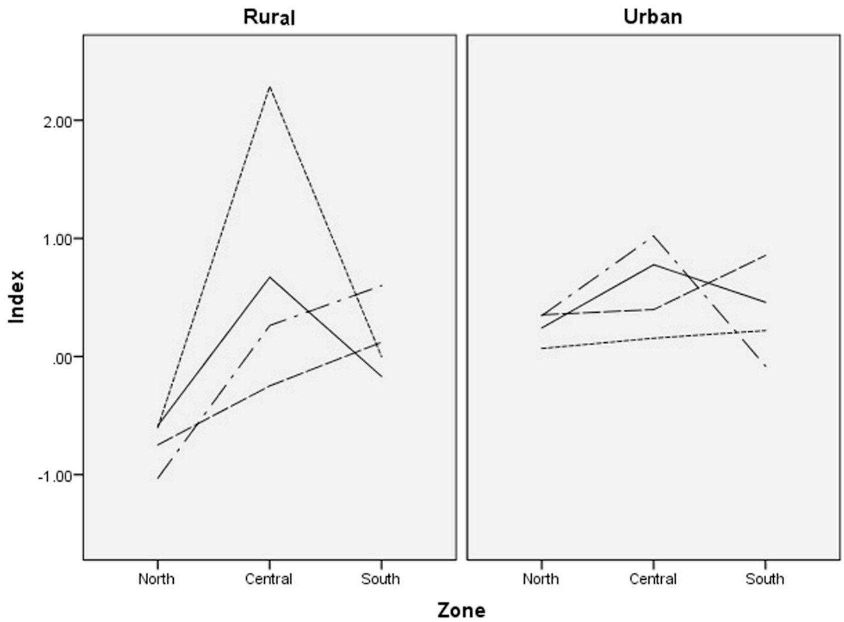

Fig. 4. Rural and Urban, index by zone for economic, environmental, social and institutional pillars. ECP: economic pillar (————); ENP: environmental pillar (— · — · —) ; SOP: social pillar (————); INP: institutional pillar (—————).

relationships between the pillars. In the measurement model, the lowest individual reliability was found in the social pillar, where the variable (S2), with a value equal to 0.506, is below the threshold level of 0.7 [56]. This result demonstrates the need to consider improving this variable, or to find another alternative. We suggest reviewing of the explanatory variables I1 and I2 of the institutional pillar, since they are based on information derived from the 2008 census, which would imply proposing new and updated explanatory variables.

The structural model shows that relationships between the pillars are all positive, the strongest was between the environmental and the economic pillars (0.467), demonstrating that environmentally favorable conditions positively influence economic activity in an artisanal fishing community, thus facilitating its development. A similar, but smaller effect can be found between the environmental and the social pillars (0.329). The economic pillar is positively related to the social pillar (0.353), suggesting that if the community undergoes positive economic development, this will positively impact on social conditions. The institutional pillar has a direct and positive effect on the environmental pillar (0.375); therefore, the application of policies that improve the level of knowledge of fisheries institutions and legislation will improve conditions for implementing policies that benefit the environment. The institutional pillar indirectly impacts on the economic and social pillar. On the other hand, the environmental pillar indirectly impacts on the social pillar. Consequently, the total effect of the environmental pillar on the social pillar has a value of 0.494, while the value of the institutional pillar's effect is 0.185. The institutional pillar's total effect on the economic pillar is of 0.175. The social pillar does not present any direct or indirect impacts on the other pillars. We recommend exploring new observable variables for this pillar.

The 36 small-scale fishing communities analyzed in this study had an unbalanced zonal distribution: the number of communities in the central zone is smaller than those in northern and southern zones. The smaller number of communities in the central zone can be explained by their smaller territorial extension and smaller number of official records of small-scale fishing communities**.** The sample size used in the study was small, but within the limits allowed by the PLS-SEM approach [5], however, it is necessary to expand the coverage of fishing communities. It is possible to conclude that the sustainability index captures the multidimensional causal relationship between the four pillars, allowing to use it as a comparative ranking approach of their performance that in the future may serve as a support tool for sustainable development policies. In this context, an important result was to detect that the communities with the lowest level of sustainable development (VL and L) are located mainly in the northern zone and those with the highest level (H and M) are in the central and southern zones, keeping in mind that the central zone consisted of a smaller sample.

By analyzing the pillar index, it was possible to detect increases and decreases in the classification of the communities compared to their classification on the global development index; this facilitates identifying specific differences between the pillars and the overall sustainability of each community and each zone. The communities that scored L and VL represent the lowest level of sustainable development, and therefore any public policy development should consider them among their priorities. The presence of gaps between global sustainability performance and the pillars is nothing other than a specialized reading of these differences, which in turn facilitates the understanding of territorial performance in terms of sustainability. Results show that the global index captures some patterns by type of community, which are modified with the gradient presented by the quartile ranges. It was possible to detect a significant concentration of rural communities in the northern zone with a low level of the global index. The economic and social pillars indices have similar pattern regarding the type of community, meanwhile the environmental and institutional pillars show an inverted pattern.

The construction and proposal of sustainability indicators and the study of causal relationships have been addressed under various approaches in the literature. Mirshojaeian and Kaneko [4] claim that all of the pillars may be integrated and inter-related in different directions at once. Through analysis based on Granger's causality test [57], they identify three schematic representations that represent different causal relationships between the pillars of sustainable development amongst countries. In this study we have chosen a model based on structural equation modeling (PLS-SEM) [4]. To develop a more robust model, it will be necessary to redefine and agree fisheries criteria with the participation of the community and other relevant stakeholders, and to significantly increase the sample size, as well as paying closer attention to locality-specific effects on causality, for example in rural vs. urban communities. Improving our understanding of the pillars, and the ways in which their interactions affect the sustainable development of a productive sector, such as artisanal fisheries, is a task that is yet to be developed. The current state of the artisanal fisheries suggests the need for an urgent refocusing of the way in which territorial management has been approached, incorporating integrated and interdisciplinary strategies that will guide sustainable local development through the participation and effort of the communities themselves.

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