RESEARCH ARTICLE

Sustainability Analysis of the Benthic Fisheries Managed in the TURF System in Chile

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Territorial use rights in fisheries (TURF) are considered to aid to the sustainability of small-scale fisheries, because they remove the perverse incentives, which sustain the tragedy of the commons. Nevertheless, a comprehensive evaluation of the implementation of TURFs is lacking. Chile offers a unique opportunity, because an extensive system for benthic fisheries has been implemented, with at present hundreds of TURFs along the coast. This study analyzes the sustainability of all the TURFs (109) along a stretch of 800 Km of coast, using population, productive, economic, social and institutional indicators. The information was obtained from the technical reports and monitoring each TURF has to prepare for the authority each year, databases the authority has and interviews with artisanal fishermen. Three states of TURFs were identified: unsustainable, poorly sustainable and sustainable. The resources exploited in the analyzed TURFs are the chilean abalon or “loco” (Concholepas concholepas), the key hole limpets “lapa negra” (Fissurella latimarginata), and “lapa rosada” (Fissurella cumingi), the kelps “huiro negro” (Lessonia berteroana), and “huiro palo” (Lessonia trabeculata), the surf clam “Macha” (Mesodesma donacium), the scallop “ostión del norte” (Argopecten purpuratus) and the seaurchin “erizo rojo” (Loxechinus albus). Results show general low performance for population, production and economic indicators, but good performance for social and institutional indicators. Overall the system shows a poor sustainability, which principally means unstable populations, landings and income in most of the TURFs. This result, which differs from most published analyses of the system, is explained mainly by the impossibility to reach a stable fishery through management of so small areas, given the natural variability of the species and the general environment. The good performance of some TURFs cannot be explained by a single factor, which is consistent with the complexity of the system, which makes it little amenable for proper management.

Keywords: TURF; benthic resources; community based management; performance; indicators; sustainability

1. Introduction

Fisheries worldwide are considered to exhibit increasing levels of overexploitation, with tendencies towards global collapse (Pauly, 2009; Watson & Pauly, 2013). Open access has been considered one of the most important responsible factors (Worm et al., 2009). Therefore new forms of governance have been implemented, assigning fishing rights and advancing to co-management, which seek to generate the necessary incentives to establish responsible and more sustainable fisheries. Nevertheless, sustainability as such is something rarely evaluated in its integrity for this new approaches (Nguyen Thi Quynh et al., 2017), as it needs multidimensional information (Robotham et al., 2019).

In open access fisheries exploitation pressure tends to exceed the productive capacity of the environment (FAO, 1992), thus ending with the overexploitation of resources (Bennett & Dearden, 2014). This has been considered by Hardin (1968) as an inevitable tragedy in the context of common property and open access, and resources should be converted into private property or strict government regulations should be instituted. Despite this has been a widely used argument in the literature in order to justify property right assignments, regulations and/or management strategies in fisheries and environmental issues (Zamora-Muñoz, 2019), it has been demonstrated by Ostrom (1990) that there are commons which are successfully managed by local
communities, without privatization and/or hierarchical regulations. Following nine basic principles by these communities, "the tragedy of the commons" are avoided (Ostrom, 1990). Territorial use rights in fishery (TURF), often being established as a common, are a good example. TURFs conform to most of Ostrom’s (1990) principles, and are considered to create the appropriate incentive to the protection for future benefits (Christy, 1982).

Chile has implemented an extensive TURF system for benthic fisheries (Stotz, 1997; Gelich, 2014), providing fishing rights to defined user groups, the resources being co-managed by the respective fisher organization and the state. The TURFs, as implemented in Chile, represent a good example of the importance of Ostrom’s (1990) principles for successful use of common resources, mainly because they have clearly defined boundaries, agreed rules, supervision, sanctions, mechanisms for conflict resolution, all recognized by the state administration in which the system is nested. There are diverse experiences in which fishing rights are an effective tool for the management of a sustainable and profitable fishery (Castilla & Defeo, 2001). Also co-management, based on agreements in which the decision power is shared between the State and the user of the resources (Carlsson & Berkes, 2005), managing them in a participatory way (Berkes et al., 1996) ads further on to attain sustainability. The most successful fisheries have involved local communities in a joint management agreement with government and non-government organizations (Worm et al., 2009). This form of fisheries management promotes social awareness in joint decision-making (Pomeroy et al., 2004; Pomeroy & McConney, 2007; Ayles et al., 2016), counteracting the dangers of the tragedy of the commons (Berkes et al., 2006).

Natural productivity given by upwelling within the Humboldt Current System makes Chile one of the most important fishery nations of the world (Thiel et al., 2007). But this has not prevented that the history of overexploitation observed for world fisheries has been also locally repeated, as it has been widely documented (Bacigalupo, 1994; Defeo et al., 2009; Marín & Gelich, 2012; Gelich et al., 2013; Robotham et al., 2019). In order to revert or prevent further overexploitation, diverse management strategies have been implemented, considering for artisanal fisheries the above-mentioned assignment of fishing rights, the regulation of user mobility and co-management (Castilla & Defeo, 2001; Defeo et al., 2009; Gelich et al., 2013; Gelich, 2014). The above mentioned TURF system has been decreed and implemented for artisanal fisheries in Chile in the nineties (General Fisheries and Aquaculture Law (GFAL, 1991), being considered a great contribution to the regulation of these fisheries (Zúñiga et al., 2008).

TURFs provide exclusive fishing rights (or privileges) in limited geographic areas (in the order of tens to hundred hectares) to defined artisanal fishermen organizations (Zúñiga et al., 2008; Gelich et al., 2010). The regulation explicitly states the aim of the TURFs as the conservation and maintenance of the local benthic resources and the achievement of a sustainable fishery. Sustainability is defined as “the responsible use of hydrobiological resources in order that the social and economic benefits derived from this use can be maintained over time to compromise opportunities for the growth and development of future generations” (GFAL, 1991). TURFs were initially implemented as an response to the claim of artisanal fishermen to recover the natural populations of benthic resources, mainly the chilean abalone locally called “loco” (Concholepas concholepas) (Stotz, 1997), as well as keyhole limpets (Fissurella spp.), sea urchins (Loxechinus albus), and other resources such as algae, crustaceans and tunicates, including to date about 60 species (Gelich et al., 2010).

Many benefits are attributed to TURFs, including a significant increase in the abundances of the main fisheries resources compared to sites with free access (Castilla & Defeo, 2001; Navarrete et al., 2010), as substantial instruments for conservation (Gelich et al., 2012) as well as an effective resource management option, as shown for Concholepas concholepas (San Martín et al., 2010). Nevertheless, the performance of TURFs has been shown to be heterogeneous (Marín & Gelich, 2012; Biggs et al., 2016), observing good, as well as bad, cases, but there is a general consensus that this system has its advantages (Rosas et al., 2014). Despite the beneficial results in some aspects (Zúñiga et al., 2008; San Martín et al., 2010), the implementation showed different dynamics. Some TURFs have managed to recover their populations, achieving success in the co-management of species (Castilla & Defeo, 2001), but others have shown economic problems (Zúñiga et al., 2008). Results vary according to the particular dynamics of each TURF or the species exploited in it. But there exist no comprehensive analysis of the sustainability of the system in its integrity.

Among the diverse information published regarding TURFs, usually conceptual works and perceptions of the performance of this system predominates, and there are few publications that analyze their trajectory based on indicators. Or when using indicators, generally, biological, economic or social indicators are analyzed separately, rarely together. And when this happens, it is only done for some specific TURFs without considering a larger number of them. In general there is a rich literature about TURFs, but few studies doing an integral analysis (Table 1). There are no studies that have analyzed the economic, environmental, social and institutional ambitions together, relating it to sustainability (Robotham et al., 2019). Sustainability, in its wider sense, has not been analysed. Chile offers a good study case, because there are a great number of TURFs, there are some fisheries that are exclusively allowed within TURFs, and they already have a history of almost
20 years since their implementation. The objective of this study is to evaluate the TURF system in Chile after 20 years of operation, analyzing its performance in two regions, comprising ca 500 Km of the Chilean coast, and including the regions in which the system mainly started in the nineties. Both regions at present include TURFs as its most important management tool for benthic fisheries. The study seeks to get a general view through the integration of population, productive, economic, social and institutional indicators.

2. Methods

2.1. Study area
All 109 TURFs in operation according to the register of the fisheries authority in the Atacama and Coquimbo regions were analyzed (Figure 1), comprising ca 500 Km of the Chilean coast. Coquimbo region was one of the first ones to start with the system in the beginning of the nineties, even before the system was formalized in 1997 (Stotz, 1997). Atacama region has 33 TURFs distributed in 21 coves or “caletas” and Coquimbo region has 76 TURFs distributed in 31 “caletas”. “Caletas” are official recognized sites on which fishery resources are landed, some including a village, some having just port infrastructure and fisher live

Table 1: Review of studies in the literature about TURFs. There are few studies that provide analysis based on data regarding stocks, production, income, etc. describing its performance through integral analysis. Studies analyzed N = 123, period from 2000 to 2019.

| Characteristics of the Studies reviewed | Number |
|----------------------------------------|--------|
| Studies containing reviews without own data | 123 |
| Studies in Chile with own data | 63 |
| Studies in the world with own data | 60 |
| Case Studies | 58 |
| Studies containing a sample of TURFs for some area | 58 |
| Studies containing a census of TURFs for some area (as our study) | 7 |
| Conceptual studies, without specific data analysis | 12 |
| Studies including the analysis of indicators for one or some ambits | 100 |
| Studies containing an integral analysis for diverse indicators (as our study) | 23 |

Figure 1: Study site. Each TURF is shown by a point (black) in the regions of Atacama and Coquimbo.
elsewhere, and some just are a cove with a beach on which fisher can land with their boats, without any infrastructure nor associated village. The number of TURFs per “caleta” ranges between 1 and 4 in the Atacama region and between 1 and 7 in Coquimbo region. A total of 6527 fishermen are associated to the 109 studied TURFs; 1254 and 5273 fishermen respectively in the Atacama and Coquimbo regions. This numbers nevertheless contain a great number of fishermen associated to more than one TURF, thus the actual different persons associated to the system in both regions is lower, but unknown for us. We estimate that the real number for Atacama region is between 878 and 1254 and for Coquimbo region between 2179 and 5273, given the average number of TURFs per “caleta”. The average fishermen per TURF are 42 for Atacama region and 70 for Coquimbo region, ranging respectively between 12 and 107, or 16 and 227. These numbers vary between years, some years accepting new people, others some leaving some TURFs.

2.2. Benthic fisheries resources included in the study
Species that appear in the greatest number of TURFs were considered: Loco (chilean abalone, *Concholepas concholepas*), Lapa negra (black key-hole limpet *Fissurella latimarginata*), Lapa rosada (pink key-hole limpet, *Fissurella cumingi*), Huiro negro (kelp, *Lessonia berteroana* and *L. spicata*), Huiro palo (kelp, *Lessonia trabeculata*) and Erizo rojo (sea urchin, *Loxechinus albus*). All former are in areas of rocky bottom (Figure 2). The Macha (surf clam, *Mesodesma donacium*) and Ostión del norte (scallop, *Argopecten purpuratus*) were part of the few TURFs with soft bottoms, which were not included in this study (Figure 2). The 109 studied TURFs exploit a range from 1 to 7 species within a single TURF, the average being 3,5 resources for the Atacama region and 4,1 resources for Coquimbo region.

The fishermen organization responsible for each TURF has to deliver to the fishery authority each year a report containing a direct stock assessment for each species, including abundance and size structure, the weight-size relation, the estimated allowable catch quota based on that stock assessment, as well as the actual captures done in that year. Sampling is mostly done by fishermen, supervised by a professional or consultant, which prepares the report with all required data and estimates. This reports are revised and summarized by the fishery authority. From these reports was the necessary information for the diverse analysis obtained.

2.3. Population, productive, economic, social and institutional situation of the TURFs of Atacama and Coquimbo
2.3.1. Indicators analyzed
The indicators represent the best possible use of all available information – their definition was adjusted to what was available. For each TURF, the population, productive, economic, social and institutional ambits were analyzed. The detail of indicators considered in each ambit is described in Table 2.

![Figure 2](image-url): Number of TURFs by species declared as target species in the regions of Atacama (III) and Coquimbo (IV). The dotted line indicates the total number of TURFs in each region of analysis.
**Population indicators**

The population health was analyzed through three main indicators, the abundance, condition index and sizes structures (Table 2). Abundance should be maintained in time. The condition index was obtained from individuals of commercial size (Table 3) and tells us about the relation between abundance and food. If the abundance exceeds the availability of food, the condition index diminishes, the individuals will have little biomass accumulated in relation to their size. And vice versa, if there is plenty of food, the condition index will be high. The size structure tells us about recruitment and mortality. A healthy population maintains its structure along the years, the individuals dying being replaced by new recruits, while the rest grows, thus maintaining the average size and the same size range.

**Table 2: Indicators analyzed by each ambit and their meaning.**

| Ambit          | Indicator               | Variables                                                                                                                      | Equation or value estimation                                                                                                                                                                                                 |
|----------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Population     | Abundance               | Number of individuals in the TURF Surface area of the TURF                                                                    | \( a = N^*ha^{-1} \) Where \( N \) stands for the total number of individuals in the TURF, and \( ha \) for the surface area of the TURF expressed in hectares.                                                                                      |
|                | Condition index         | Individual sizes and weights of each individual above commercial size (Table 3)                                              | \( CI = \text{Weight/Length}^b \) Where \( b \) is the exponent of the potential equation of the height-weight relationship obtained from the annual monitoring reports.                                                  |
|                | Sizes structures         | Average size, Percentile 95% of the population size structure, Percentile 5% of the population size structure                  | Average size = \( \Sigma \text{sizes/number of individuals analized.} \) \( \% \text{of 95\% = size above the 5\% of biggest individuals of the population are.} \) \( \% \text{of 5\% = size below the 5\% of smallest individuals in the population are.} \) |
| Production     | Captures                | Number of individuals or kilos extracted per hectare                                                                        | \( C = N^*ha^{-1}; Kg^*ha^{-1} \) Where \( N \) stands for the total number of individuals captured and \( Kg \) the total weight of the all the individuals captured. \( ha \) is the surface area of each TURF in hectares. |
|                | Yield                   | Number of individuals necessary to produce one Kg (1000g) of product                                                        | Yield = \( 1000/P \) Where \( P \) is the average weight (in grams) of commercial size individuals. To obtain that average weight, the length-weight relationship of population sampled each year was used, using the following equation: \( P = a^*(LT)^{-b} \) |
|                | Capture/Quota ratio     | Capture/Quota                                                                                                                 | Ratio = Capture/Quota Represents the proportion of the allowed quota that is extracted of each species each year, which fluctuates between 0 and 1.                                                                                 |
| Economic       | Number of users         | Formally inscribed users                                                                                                      | Number of artisanal fishermen formally associated with each TURF according to the official register.                                                                                                                         |
|                | Total income            | Value per individual or per Kg of each species captured Number of individuals or Kg captured of each species                  | Total Income = \( \Sigma \text{of the total value of each species captured each year, summed over all species in each TURF ($).} \)                                                                                                    |
|                | Per capita income       | Total annual Income Number of users, Per capita Income = \( (\text{Total income-Total cost})/\text{Number of users} \)         |                                                                                                                                                                                                                  |

(Contd.)
Arias and Stotz: Sustainability Analysis of the Benthic Fisheries Managed in the TURF System in Chile

| Ambit       | Indicator          | Variables                                                                 | Equation or value estimation                                                                 |
|-------------|--------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Social      | Schooling          | Years of formal education of fishermen                                     | Schooling = Σ years in formal education of fishermen/Number of fishermen interviewed.           |
|             | Housing quality    | Housing type of artisanal fishermen associated to each TURF.               | See Table 4.                                                                                  |
| Institutional| TURF activity     | Years since TURF creation (age of the TURF) Years with extractive activity | Activity= (Active years)/(Total years TURF)*100 Where 'Active years' was estimated as number of years with extraction activity. “Total years TURF” was number of years that TURF has existed since the baseline study (ESBA) was made: Total years TURF = 2015- year of completion of ESBA. |
|             | Commitment         | Number of annual meetings of the organization in charge of the TURF       | Commitment= Σ meeting held in 12 months informed by different fishermen asked/Number of fishermen interviewed |
|             | Compliance         | Years since TURF creation (age of the TURF) Number of annual reports      | Compliance= (Number of annual reports)/(Total years TURF)*100 Where number of reports represent the amount of annual monitoring reports, which have been formally delivered to SUBPESCA by each organization. “Total years TURF” represents the age of the TURF since formal creation. |
|             | Shared responsibilities Existence of commettees in the organization associated to each TURF Actual activity of each committee | This indicator was categorized. There are commettees and they work = 3; There are commettees but mostly do not function = 2; There is no committee =1. Shared responsibilities = Σ of categorical numbers given to each answer given by fishermen asked/Number of fishermen interviewed. |

Table 3: Minimum commercial size of TURF main fisheries resources.

| Main resource                                      | Minimum size                     |
|----------------------------------------------------|----------------------------------|
| Loco (*Concholepas concholepas*)                   | 100 mm peristomal opening length |
| Lapa negra (*Fissurella latimarginata*)            | 65 mm shell length               |
| Lapa rosada (*Fissurella cumingi*)                 | 65 mm shell length               |
| Erizo rojo (*Loxechinus albus*)                    | 70 mm diameter                   |
| Mачa (*Mesodesma donacium*)                        | 60 mm shell length               |
| Ostión del norte (*Argopecten purpuratus*)         | 90 mm shell length               |
| Huiero negro (*Lessonia berteroana*)               | 20 cm adhesive disc              |
| Huiero palo (*Lessonia trabeculata*)               | 20 cm adhesive disc              |

Productive indicators

The production, in terms of what is assumed to be of interest for fishermen, was analysed, considering as indicators the captures, the yield and the capture/quota ratio (Table 2). These indicators tell us about how much (captures) and of what quality (yield) is this production. The fewer individuals you need to produce a Kg, the bigger the captured individuals are, the better the price. This is what the yield tells us. The Capture/Quota ratio tells us about what they have been really able to extract, considering the estimated (or desired) quota. The less the ratio, the less the production compared to what they estimated, telling about possible productive problems.
Economic indicators
The value gained through annual production, in terms of what is assumed to be of interest for fishermen, is analyzed using the number of users, total income and per capita income as indicators (Table 2). Stable income is expected. The changes in number of users represent the interest to own that TURF. If it diminishes, it tells us about losing the interest – probably related to individual income, which is observed through the per capita income. The three indicators are expected to keep stable over time. Frequent variations over time would mean unstable income for fisher, thus losing the attachment to that particular TURF.

Social indicators
The social benefits or increase in human capital produced through the income gained in the TURF is analyzed using schooling and housing quality as indicators (Table 2). The better the housing quality, the higher are the social benefits produced by the TURF. As there is just one value, not knowing how it behaves in time, it is compared to average values for the general population of the country. Values for comparison are shown in Table 4. For housing quality the access to basic public services (electricity and water) was considered as standard. For schooling the 8 obligatory years established in Chile were used as standard. Values below the standard were considered unsustainable.

Institutional indicators
The health of the organization managing the TURF was analyzed using the TURF activity, commitment, compliance, shared responsibilities as indicators (Table 2). This indicators tell us about how good they are organized by the years they have been able to maintain the activity of the area, and how well they comply with regulations, delivering their yearly report to authority. Shared responsibilities refers to how well structured is the organization, the more committees they have, the more people participate, telling about a healthier organization.

2.3.2. Information sources
Abundance, condition index, capture, yield, capture/quota ratio, size structure, total income, per capita income and number of users were obtained from the Monitoring Reports and Technical Reports prepared annually by Subsecretariat of Fisheries and Aquaculture (SUBPESCA). These reports were requested from the consultants that work with the TURFs of the Atacama and Coquimbo regions. TURF activity and compliance were obtained from SUBPESCA online data (www.subpesca.cl) and requested through the Transparency Law (Transparency Law, 2008). Housing quality, schooling, commitment and shared responsibilities, were collected through semi-structured interviews of the artisanal fishermen associated with each TURF in the regions of study. A total of 286 interviews were conducted (107 in Atacama and 179 in Coquimbo between August and September 2015). The interviews were conducted to all artisanal fishermen housing quality. Access type to basic services of electricity and drinking water: if they were provided by public network or by an alternative system. Housing situation: if one or several families lived in the same house. Housing type: if it is owned or not. If it was owned, a distinction was made between owning the land or not.

| Access to basic service | Housing situation | Type of property | Category |
|------------------------|-------------------|-----------------|----------|
| With basic service by public network | Particular | Own | 12 |
| With basic service by public network | Particular | Own on private land | 11 |
| With basic service by public network | Particular | Not own | 10 |
| With basic service by public network | Collective | Own | 9 |
| With basic service by public network | Collective | Own on private land | 8 |
| With basic service by public network | Collective | Not own | 7 |
| No basic service by public network | Particular | Own | 6 |
| No basic service by public network | Particular | Own on private land | 5 |
| No basic service by public network | Particular | Not own | 4 |
| No basic service by public network | Collective | Own | 3 |
| No basic service by public network | Collective | Own on private land | 2 |
| No basic service by public network | Collective | Not own | 1 |
fishermen, which could be found in each visited “caleta”, including in the analysis only those TURFs for which at least three persons could be interviewed. These interviews consisted of questions that referred to the age of the fisherman, place of work, associated “caleta”, TURF in which he works, place of residence, housing type, housing situation, access type to basic service (electricity, drinking water) that has his house, schooling level, number of meetings that the organization to which he belongs does every year, existence of work commissions within the organization to which he belongs and if they are active, participation in the TURF system, compliance with the operation of their TURF.

2.3.3. Situation of TURFs
The TURF’s situation was classified into 3 categories according to the behavior of each indicator (Table 5) and it was averaged for each ambit. The codification was done dividing in each case the continuum between sustainable and not sustainable according to the criteria in Table 5 of each indicator in 3 equal parts. In each case the criterium was to consider sustainable the most desired behavior of the variable, as not sustainable the most undesired behavior. As poorly sustainable was considered any behavior of the variables being in between these two extremes. The sustainability of the TURFs as a dependent variable was derived from the behavior of the independent variables described in Table 5. In the case of abundance,

| Indicator | Criteria | TURF situation | Value |
|-----------|----------|----------------|-------|
| Abundance | Tendency to be maintained over time | Sustainable | 3     |
| 95% Percentile | | | |
| 5% Percentile | | | |
| Average size | Tendency to increase or fluctuate over time | Poorly sustainable | 2     |
| Condition index | Tendency to decrease over time | Unsustainable | 1     |
| Captures | | | |
| Capture-Quota ratio | | | |
| Total income | | | |
| Percapita income | | | |
| Number of user | | | |
| Yield | Tendency to be maintained over time | Sustainable | 3     |
| | Trend towards better performance | Poorly sustainable | 2     |
| | Trend towards worse performance | Unsustainable | 1     |
| Schooling | Greater than 8,8 years – obligatory schooling in Chile is 8 years | Sustainable | 3     |
| | Between 4 and 8,7 years | Poorly sustainable | 2     |
| | Less than 4 years | Unsustainable | 1     |
| Housing quality | Greater than 7 according Table 4 | Sustainable | 3     |
| | Between 4 and 7 according Table 4 | Poorly sustainable | 2     |
| | Less than 4, according Table 4 | Unsustainable | 1     |
| TURF activity | Greater than 90% | Sustainable | 3     |
| | Between 60% and 90% | Poorly sustainable | 2     |
| | Less than 60% | Unsustainable | 1     |
| Commitment | Greater than 9 meetings | Sustainable | 3     |
| | Between 4 and 9 meetings | Poorly sustainable | 2     |
| | Less than 4 meetings | Unsustainable | 1     |
| Compliance | Greater than 90% | Sustainable | 3     |
| | Between 60% and 90% | Poorly sustainable | 2     |
| | Less than 60% | Unsustainable | 1     |
| Responsibilities's distribution | There are commettee and they work | Sustainable | 3     |
| | There are commettee but mostly do not function | Poorly sustainable | 2     |
| | There are no commettee | Unsustainable | 1     |
size structure, condition index, captures, capture/quota ratio, total income, per-capita income and number of users, their trends over time were analyzed with the statistic: General Linear Model (General Lineal Model: GLM) that uses the annual information of each TURF and adjusts it to some pattern of temporal evolution, if it is change or permanence (Puig et al., 2005; López-González & Ruiz-Soler, 2011). To catalog the degree of sustainability in each area, the criterion used was arithmetic, dividing the continuum between sustainable and not sustainable into 3 equal parts. As some of the indices were averages, when decimal values were obtained, the number was approximated with arithmetic criteria to the entire. To compare the performance of the TURFs in each ambit between study regions, t-tests for independent samples, Mann-Whitney and t-test for independent samples with unequal variances were used.

2.5. Characterization of the performance of the benthic fisheries managed in the TURF system of the Atacama and Coquimbo regions

The performance of each TURF was standardized using the decostand function in R®, available in the vegan library (https://cran.r-project.org/web/packages/vegan/index.html). Euclidean distance was calculated and to eliminate the noise of the indicators that did not have available information (NA), the NA were replaced by the average values of the data series. The TURFs were grouped according to similarity using a UPGMA-type cluster analysis (cophenetic correlation index = 0.74 and Gower distance = 18.60), which is a method that uses the average values of the distances (Núñez-Colín & Escobedo-López, 2011). Finally, the multivariate descriptive technique of Principal Component Analysis (PCA) was applied to reduce the information to only some main components (Almenara-Barrios et al., 2002).

3. Results

3.1. Situation of TURFs of Atacama and Coquimbo by ambit

3.1.1. Population situation

The 93 TURFs of the Atacama and Coquimbo regions with available data for the analysis, presented population performance indices ranging from 1.1 to 2.4, with most between 1.3 and 2.1 (Figure 3A). This means that most populations show a decreasing trend or very variable trend of their stock size structure and

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**Figure 3:** Population indices of the TURFs of the Atacama and Coquimbo regions, based on the abundance, size structure and condition index of their main resources. The n represents the TURFs with available information for the analysis in each case. **A)** Frequency distribution of the different indices. Horizontal bars represent the mean, standard deviation and range of indices for each region **B)** Proportion of TURFs (%) in the different states.
condition index. While in the Atacama region there was only 1 TURF with an index above 2, in Coquimbo there were 8 TURFs above that level (Figure 3A), which means that there are few stocks, size structures or condition indices which stay stable in time. The average performance in the Coquimbo region was slightly higher than that of the Atacama region (1.72 versus 1.63), however, this difference was not statistically significant (t-test, p > 0.05, Table 6). According to the values of the indices, no TURFs were found stable in either the Atacama or Coquimbo region, and the majority was classified as poorly sustainable. It is interesting to note that a very similar pattern is observed in both regions (Figure 3B).

3.1.2. Productive situation
The 85 TURFs with available data for the analysis presented performance indices between 1.1 and 2.5 in the productive ambit. This means that most exhibit decreasing or very fluctuating captures, mostly not being able to capture the allowed quota, and the yield decreasing, which means catching increasingly smaller individuals. In the Coquimbo region, 6 TURFs reached performance levels higher than 2.0, while in Atacama there were only two cases (Figure 4A). The average performance of both regions was very similar (1.67 to 1.68 for Coquimbo and Atacama respectively), with no significant difference between them (t-test, p > 0.05, Table 6) (Figure 4A). Most of the TURFs of Atacama were classified as poorly sustainable or unsustainable, generally coinciding with that observed for Coquimbo, where, however, 2% of TURFs were found to be sustainable (Figure 4B).

Table 6: Statistics used to assess the performance of TURFs in each ambit, using the t-test for independent samples when appropriate.

| Ambit        | Test          | p   |
|--------------|---------------|-----|
| Population   | t             | 1.9864 | 0.1701 |
| Productive   | t             | 1.9890 | 0.9316 |
| Economic     | Mann-Whitney  | 3.7500 | 0.0002 |
| Social       | t             | 1.9966 | 0.2996 |
| Institutional| Mann-Whitney  | 0.5883 | 0.5563 |

Figure 4: Productive situation of the TURFs of Atacama and Coquimbo regions, based on the capture, capture/quota ratio and yield of their main resources. The n represents the TURFs with available information for the analysis of this aspect. A) It shows the number of TURFs regarding their performance in Atacama and Coquimbo. Horizontal bars represent the mean, standard deviation and range of indices for each region. B) Shows the proportion of TURFs (%) that presented the different states.
3.1.3. Economic situation
The 96 TURFs with available data in both regions showed slightly better performance than the previous
ambits, with index values ranging from 1.1 to 3. In the region of Coquimbo 8 TURFs reached the highest
level of the performance index (Figure 5A). The TURFs of Coquimbo had a higher average performance
index (1.97) than Atacama (1.70); the difference is statistically significant (Mann-Whitney, p < 0.05,
Table 6) (Figure 5A). There were no sustainable situations in Atacama, while in Coquimbo 16% of the
TURFs presented this state. Despite this, most TURFs in both regions were classified as poorly sustainable
or unsustainable (Figure 5B). This means, that most TURFs show decreasing or very fluctuating total and
per-capita income.

3.1.4. Social situation
The 88 TURFs with available data showed social performance indices ranging from 1.41 to 3, with the
majority of them in levels between 2.41 and 3 (Figure 6A). The average of the Atacama region (2.71) was
slightly higher than that of the Coquimbo region (2.63), but the difference was not statistically significant
(t-test, p > 0.05, Table 6) (Figure 6A). Globally the social situation of the TURFs of both regions appears
to be good, with 93% and 85% classified as sustainable (Figure 6B). The proportion of TURFs with regular
performance was higher for Coquimbo (15%) than for Atacama (7%) (Figure 6B). This means that most
fisher related to a TURF have improved their schooling, housing and access to electricity and drinking water.

3.1.5. Institutional situation
In this ambit, the 109 TURFs with available data show performance indices between 1.1 and 3; most were
between 2 and 3 (Figure 7A). In both regions, highest performance values were achieved by 3 TURFs
in Atacama and 9 TURFs in Coquimbo (Figure 7A). The average performance for the two regions was
almost identical (Table 6). The institutional situation in both regions was generally good, with 70% of
the TURFs in Atacama and 78% in Coquimbo in that situation. In spite of this, there was a fraction of
TURFs classified as poorly sustainable, with very similar values in the two regions (Figure 7B). This means,
that most organizations having a TURF, deliver regularly the annual report and have active committees in
charge of different duties related to the TURF.
Figure 6: Social situation of the TURFs of the Atacama and Coquimbo regions, based on schooling and housing quality of artisanal fishermen associated with this management system. The n represents the TURFs with available information for the analysis of this aspect. A) Shows the number of TURFs with different performances in Atacama and Coquimbo. Horizontal bars represent the mean, standard deviation and range of indices for each region. B) Shows the proportion of TURFs (%) that presented the different states.

Figure 7: Institutional situation of the TURFs of Atacama and Coquimbo regions, based on their activity, compliance, commitment and shared responsibilities. The n represents the TURFs with available information for the analysis of this aspect. A) Shows the performance levels of TURFs in Atacama and Coquimbo. Horizontal bars represent the mean, standard deviation and range of indices for each region. B) Shows the proportion of TURFs (%) that presented the different states.
3.2. Sustainability of benthic fisheries managed in the TURF system of Atacama and Coquimbo regions

TURF performances indices of Atacama and Coquimbo showed low average levels in the population, productive and economic ambits, and the opposite in the social and institutional ambits (Figure 8). The great similarity in averages in each ambit in the two regions of study, and also in the general result is notable. The values of general sustainability (average of 5 ambits) were 2.05 in Atacama and 2.11 in Coquimbo, indicating that the TURF system is in general classified as poorly sustainable (Figure 8).

3.3. Characterization of the performance of the benthic fisheries managed in the TURF system of the Atacama and Coquimbo regions

The cluster analysis showed that the TURFs were separated into 7 statistically distinct groups (ANOSIM, p < 0.05; Figure 9). The largest number of TURFs was concentrated in 3 main groups and the other groups were integrated only by 1 TURF each (Figure 9). The groups that contained the most TURFs were 1, 2 and 5. Group 1 was characterized by better performance in the population, social, productive and institutional ambits, while group 2 was broader and its performance was intermediate in all analyzed ambits. Group 5 was characterized by better economic and social performance (Figure 10).

In most groups the TURFs were classified as poorly sustainable, especially group 2 that contained the most TURFs. So the majority of TURF had intermediate results. Despite this, within this group, 12% of the TURFs were sustainable (n = 10 TURFs). Group 3 with only 1 TURF was the only one that turned out to be unsustainable (Figure 11).

It should be noted that the sustainable TURFs had information in few areas of analysis and there were only 2 sustainable TURFs that had information from all areas of study. As more information was integrated, that is, as the scope of analysis increased, the TURFs became increasingly classified as poorly sustainable (Figure 12).

4. Discussion

The result that TURFs show a poor performance in most ambits, with decreasing or heavily fluctuating stocks, captures and income, but better performance regarding social and institutional indicators, could explain why the system is maintained regardless of not being sustainable overall, and not doing what would be expected from a fisheries management perspective: maintain a sustainable production and income for user. The governance produced by the system, for which mainly social and institutional factors are important, generates a state of general satisfaction or perception of success by users, administrators and in the scientific community, regardless of its poor productive indicators. This general perception is documented so by Gelcich et al., (2016), who conducted an analysis of the state of TURFs, based on the perception of artisanal fishermen, showing that TURFs in Chile have not achieved their conservation objective, but do manage to satisfy the social objectives. This may be explained by a good operation of Ostrom’s (1990) principles, generating a good functioning institution around the commons, which nevertheless has no influence on nature and its variability, on which production depends. But the question
is how long this may last, considering its overall poor sustainability, but specially the poor sustainability or unsustainability of what is supposed to sustain the livelihood of fisher, the natural production base. In fact, the observation that the number of TURFs which are not any more delivering the annual report (thus formally abandoning the area, as this is cause of caducity of a TURF), and the increase of reported illegal not reported catches (Oyanedel et al., 2017) of what was the flagship species of the system, the Chilean abalone, shows the first signs of decay.

Could this result, different from what was expected, be influenced by the characteristics of the information analyzed? It is necessary to examine the information on which the analysis of the present study is based. For example, a difficulty, which this study found was that the monitoring reports, did not always contain all the required information. This implied that not all the indicators were based on the same number of

Figure 9: Cluster analysis of the TURFs of Atacama and Coquimbo regions: 7 groups were found and each number corresponds to a TURF of the analysis.
Figure 10: Principal Component Analysis with the 7 groups established by the cluster analysis. Four components (PC1; PC2; PC3 y PC4) were analyzed. A: Shows components PC1 and PC2. B: Shows components PC3 and PC4. Most TURFs belong to group 2, which was characterized by intermediate performance in all areas of study.

Figure 11: TURFs sustainability groups in Atacama and Coquimbo regions. The number inside each bar indicates the number of TURFs in each group.
TURFs, but each indicator analyzed a sample of the total, using only those for which the information was complete for the indicator. However, the worst-case sample included $n = 85$ TURFs of the total universe of 109 TURFs, which is a very high value. For those TURFs that did not contain information on some indicators, especially in the population and productive ambits, it actually reflects their inactivity, that is, a situation that could be classified as a malfunction. Therefore, if not including them influenced, it did so in the direction of considering a proportion of unsustainable TURFs lower than what actually exist. Thus if there is influence, it has been in generating a more conservative result, which given the general result of the study does not have great relevance for the overall conclusion. Another difficulty in this study were the indicators for the social ambit, since they measure not only what is related to the TURF, but also include the integral development of people or coves, and can be attributed to other factors and not exclusively to the TURF. This can mean that there is not always a direct relationship between the good behavior of social indicators and the overall performance of the TURFs. In this ambit, representativeness of the sample is more for the general evaluation of the system, not so much regarding individual TURFs. This because of the number of interviews per TURF, even so only TURFs with more than three interviews were considered for the analysis, may not be representative of that given TURF. So, the 286 interviews, distributed over the two analyzed regions are considered globally representative for the system in both regions. Thus the finding that the TURFs do not work according to proposed sustainability objectives in the population, economic and productive ambits, but have worked from the social point of view must be considered with some caution, at least at the individual TURF level. However, the best possible approximation was made in this area according to the available information existing up to that moment and what could be gathered through the interviews. It gives us a general picture, which should not be tried to be interpreted too strictly in terms of individual TURFs.

The low performance of TURF in the population ambit may be related to the fluctuating behavior of natural production, given the ecological characteristics and life cycles of the exploited resources (Aburto et al., 2016). Life cycle characteristics may influence how these species respond to the dynamics of the environment, considering the biological, physical and chemical processes to which they are exposed (Castilla & Defeo, 2001; Molinet et al., 2008). The species exploited in TURFs are generally species of short life cycles, with larvae developing and being dispersed within a naturally fluctuating environment, which generates temporal variability in recruitment. Duration of life cycles fluctuate between 2 years (macha) (Riascos et al., 2009) and 5 or 6 years (loco) (Bustos & Navarrete, 2001). All these species have larval periods ranging from weeks (Fissurella spp.) to 2–3 months (loco) (Bustos & Navarrete, 2001). For the majority, variable recruitment has been described between years and between sites (Riascos et al., 2009; Parada et al., 2013). This variability is due to the characteristics of the Chilean coast, which is in general very exposed, with fluctuating winds that generate upwelling periods in localized foci, which together generate variability in circulation and temperatures (Moraga et al., 2001). This affects the populations of invertebrates mainly in the processes of larval development and recruitment, which is then reflected in variations in abundance,
biomass, age structure, and distribution patterns of fisheries resources (Parada et al., 2013; Defeo et al.,
2014). These characteristics of great environmental variability and consequent dynamics of species together
explain what happens within the TURF dynamic. This is mainly because in the TURFs, when harvesting most
of the individuals that are above the minimum size of capture, it depends mainly on what enters each year
as an exploitable fraction, which basically implies that the fishery is based on almost only one cohort every
year. Thus, the variability of the recruitment is transmitted directly to the captures. The effects of this great
variability have largely overcome the impact of the management measures implemented to recover the
populations (Defeo et al., 2014).

The TURFs as management strategy seek to maintain exploitation over time, however this does not consider
the variability to which they are exposed and how sensitive the species exploited are to that variability. It
should be noted that all the TURFs analyzed have a management plan in which they collect biological and
fishing data annually, and these are the data that show variability in the system. The variability is due to
factors that go far beyond the effect of management and fishing (Ríascos et al., 2009). Processes such as
recruitment, natural mortality and the abundance of species that generate variability in populations are
processes that vary on a large scale, far beyond what happens within the TURF, so they cannot be controlled
by the management imposed by this administrative system in such small areas (Aburto et al., 2014). Within
a TURF there is only a small part of a metapopulation, which depends on what happens in the rest of the
system over which the holders of a TURF have no influence. Other TURFs may contribute to recruitment,
which have their own management and their own variability, conditioned to the particular physical factors
that affect the distribution and abundance of the species (Castilla & Defeo, 2001). Recruitment in areas close
to the TURFs is very important, since they can benefit the connection between them, contributing with new
recruits due to the dispersion of larvae in the environment (Aburto et al., 2013). This high dynamic in the
environment and in the same TURF, makes what happens in it and its consequent success not guaranteed
(Aburto & Stotz, 2013).

The productive aspect, that is, what can be extracted of fisheries resources at a given moment, depends on
the available biomass of the species of interest. If that biomass fluctuates over time, so will the biomass that
can be extracted. Although the prices obtained with the resources captured in a TURF are generally higher
than those of open access areas (Bandin & Quiñones, 2014), since they do not vary greatly between years,
the fluctuation in production is directly reflected also in the economic performance of each TURF. Therefore,
if the population aspects are unstable, the productive and economic aspects are directly affected, behaving
also in an unstable manner. As explained in the previous paragraph, the species currently exploited in TURFs
present naturally fluctuating biomasses, which results in fluctuating production and income and generates
the diagnosis of poor performance also in these ambits. The capture/quota ratio can be interpreted as an
expression of that low performance perceived by the fishermen. Because the quota expresses expectation,
while capture expresses what is really there. Probably the direct stock assessment, often done by the own
fishermen under technical supervision tend to inflate (because of their high expectations) and thus to
overestimate abundances, resulting in a higher quota than really exists.

Another relevant point to consider is what it means for a fisherman to live with a fluctuating income,
as shows the per-capita income for most TURFs. The fishermen, to avoid being subject to the economic
fluctuations of this system, do no live exclusively from the income of their TURF (Gelich et al., 2016). Most of
the TURFs have been transformed over time into an exceptional activity, different from their regular fishing
activities, since the total annual income produced by a TURF is not enough to sustain the fisher taking care
of it (Cereceda & Czischke, 2001). The economic performance of the TURFs is lower than expected, and in
most cases the TURFs represent just a fraction of the income on which fishermen relay and constitute only a
complement to their regular fishing activities carried out outside the TURFs (Zúñiga et al., 2008), at present
mainly sustained by the exploitation of kelps. Although the prices of TURF’s products are higher than for
the same resources of open access areas (Bandin & Quiñones, 2014), they are not reflected in better income
for the individual, as also revenues became distributed among more and more fishermen who were attracted
by the system, especially for the extraction of the loco (Aburto et al., 2013). The low economic performance
is also affected by poaching, a very important problem TURFs are facing (Gelich et al., 2016), which may
rest biomass from the TURFs. Oyanedel et al. (2017) reported that clandestine fishing is common and that
many syndicates are authorizing their members to also fish informally within their TURFs, because the
economic income from the quota assigned to the resources of TURFs is not enough and the informal fishing
can provide important economic benefits. Examples of poaching have been reported mainly for the Chilean
abalone (C. concholepas) (Bandin & Quiñones, 2014), and to a lower extent for the surf clam Mesodesma
donacium (Aburto et al., 2016).
Good social performance contrasts with poor productive and economic performance, which suggests that there is no direct relationship between the functioning of organizations and the general development of fisher, and the TURFs. Good social performance may not be attributed exclusively to the TURFs, however there are many elements that allow us to affirm that the TURFs make a contribution. The study by Gelcich et al. (2016), based on the perception of users rather than on data of productive or economic performance, confirms the social contribution that is granted by the TURFs. These have contributed to the quality of life of artisanal fishermen in terms of ownership or territorial empowerment and the ability to negotiate with other interest groups, becoming negotiation tools, especially when facing economic problems (Gelcich et al., 2016). In addition, the TURFs give the artisanal fishermen who takes care of them a sense of security, that they will not be expelled from their activities within the cove which are often within private property, the owner of which trying to expel them (Aburto et al., 2013). The TURFs are a very important negotiation tool for organizations, allowing them to improve their “caletas” (cove) through diverse projects, including infrastructure, implementation of new technologies, improve their selling capacity, etc. all financed by the government, especially when they face socio-environmental problems (Gelcich et al., 2016).

The fact that most of the TURFs show good performance in the institutional ambit can have a direct relationship with a legal condition posed by the system, since in order to access a TURF, the respective regulation establishes that they must be legally constituted as a organizations (Gelcich et al., 2013). Thus any fisherman or group of fishermen that want to administer a TURF necessarily has to be organized. The simple fact of wanting to apply for TURF has contributed to improving the organizational capacities of artisanal fishermen (Zúñiga et al., 2010), reinforcing existing institutions in cooperative practices within the fishermen’s organization (Gelcich et al., 2013). But the institutional ambit is instrumental to the system, rather than a consequence. The process of forming a TURF involves a series of steps that organizations must comply with (Aburto et al., 2014), including that organizations must have a legal structure as backup to work properly. Organizations must be able to assume responsibilities, fulfill commitments (Cereceda & Czischke, 2001) and also meet the demands that management plans require, even if they are prepared with technical assistance (Gelcich et al., 2012). The fact of having an active organization can also generate other benefits, mainly access to investment projects and repopulation of benthic resources in addition to having support in initiatives to improve production, so that fishermen take advantage of the multidimensional benefits of the TURFs and also make connections between them even in other matters of interest in their daily lives (Gelcich et al., 2016).

The fact that the multivariate analysis had difficulty to establish common characteristics of TURFs within defined groups, not allowing to identify clear patterns, is consistent with the complexity of the system. Each TURF works according to a combination of factors related to the place, the resources and the people, all of which generates diversity, which shows the heterogeneity of the system. Each TURF is a case, so there is no single reason for a particular performance, which shows that there are no general formulas or recipes to be applied indistinctly of location or situation for the success of this co-management system (Marín & Gelcich, 2012). The success or good performance within this administrative system cannot be explained by a single factor. It should be noted that in this analysis, the only group that presented a fraction of sustainable TURFs had intermediate performance in all ambits as a result of the interaction of all the indicators analyzed. Performance depends on the interaction of many factors, being of a multidimensional nature rather than depending on a specific field (Epstein et al., 2015). TURFs are complex systems, forming part of a diverse, extensive and complex co-management network (Marín & Gelcich, 2012). Each TURF is a separate system and works according to its own characteristics. Therefore, predicting their overall behavior is difficult and it is a challenge to identify which factor or attribute of this system can contribute more importantly to its success (Epstein et al., 2015). The current state of artisanal fisheries suggests the need for an urgent refocusing of the way territorial management was approached initially (Robotham et al., 2019), considering the described complexity of the system. Good performing TURFs should be maintained, but because of those, the rest should not be artificially maintained, the entire small scale fishery being trapped within a system which is causing new problems and conflicts, whose first symptom is an increasing informal fishery happening along the Chilean coast.

5. Conclusion
This comprehensive analysis shows that after almost 20 years of operation, the TURFs of the Atacama and Coquimbo regions have not achieved their objective of sustainability, with the majority of the TURFs appearing with low sustainability and only a very minor proportion showing good results. This fact can be attributed to their design, since the basic problem of variability is related to the size of the TURFs, which does not adjust to the scale in which the natural variability occurs. Although the TURFs do generate a good
institutional framework, as would the implementation of Ostrom’s principles predict, but the variable dynamics of natural production, which cannot be managed, generates productive and economic problems to the fisher, which are incentives for informal behavior and causes finally a poor performance of the entire system. However, this varies along the coast, TURFs being successful in some places and failing in others. This calls for caution regarding the possible replication of this same system to other regions or countries without considering properly the natural local dynamics of nature, the resources and how fisher have adapted to it in the past (Stotz, 2019).

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Competing Interests
The authors have no competing interests to declare.

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