



Territorial Use Rights for Fisheries (TURF) in central-southern Chile: Their sustainability status from a transdisciplinary holistic approach

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ARTICLE INFO

Keywords:

TURF
Artisanal fishery
Survey
RAPFISH
Sustainability
Multidimensional approach

ABSTRACT

The Territorial Use Rights for Fisheries (TURF) system are a kind of marine property where user rights are assigned to collective entities of artisanal fishers' organizations. But their effectivity continues to be limited, which demands a comprehensive evaluation of their social, economic, and ecological performance. Consequently, the practical integration and application of these aspects continue to be a significant challenge for their management. The "RAPFISH" multidimensional scaling technique was applied to assess the sustainability status of 19 TURFs of the Biobío Region (Chile), using 51 transdisciplinary attributes relating to ecological, economic, social, among other dimensions. The results obtained in the two-dimensional arrangement presented a sustainability gradient, due to the marked variations among the different TURFs, and only four cases had very weak sustainability scores. Broadly speaking, this study determined that the social dimension (score: 61.37%) had a "high" influence on the best performance of the TURF system, while the ecological, ethical, and institutional dimensions were rated from 'regular' to 'bad'. Overall, results indicate an average performance in the "medium" sustainability range (score: 54.68%), and these results generated questions about the TURFs' viability, mainly in those that have not reached their sustainability objectives. Therefore, more local studies are needed on the social dimension of this system, in order to define the effective participatory tools and social management plans in TURFs, which will contribute to improve their performance.

1. Introduction

In recent decades, sustainable development has been a goal for those responsible for fisheries policies. Such policies, drawn up by governments that usually have a monopoly based only on biological knowledge when taking decisions, have rarely been sufficient to make fishing sustainable. In spite of excellent and detailed guidelines for fisheries policy in the form of a Code of Conduct for Responsible Fisheries [1], compliance with the code has been deficient [2]. Researches such as Pitcher et al. [3] and Coll et al. [4] have shown that compliance with the code in many countries of the world is still poor or very poor. Despite the results obtained, considerable international efforts continue to be made

to achieve sustainable development [5].

In 2015, the 193 member states of the United Nations approved 17 sustainable development goals (SDG) and 169 targets aimed at addressing worldwide concerns about poverty, inequality, peace, justice, economic growth, climate change and marine resources, among other challenges described in 2030 Agenda [6,7]. The SDG provide a new opportunity to progress towards sustainable development, since fishing is compatible with these goals. Various researches have demonstrated its close relationship with SDG 14, as well as with other SDG [8–11]. However, changes in a number of variables (not only ecological, as sustainability is multidimensional) show that we are still far from reaching the SDG targets [12–14]. In many cases, major

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challenges facing the planet (destruction of resources, climate change, intensive aquaculture) endanger the economy, livelihoods, safety and even identity of people living in fishing communities [7]. Unfortunately, few management plans have resulted in sustainable coastal fisheries and this failure is also associated with inadequate management tools and incoherent policies for the fishing sector [15–17]. The chosen management strategies also commonly create conflict and argument [18].

Different strategies and/or management tools have been used in recent decades to progress towards sustainability. One of the oldest and most popular is Territorial Use Rights for Fisheries, or TURF [19–26]. TURFs are intended to assign exclusive rights and privileges to specific areas for certain users to make rational use of their marine resources [27, 28]. The importance of TURF is shown by SDG 14, specifically target 14.4 “to restore fish stocks in the shortest time feasible” [29]. Nevertheless some TURFs have not produced the results expected of them for a variety of reasons: i) resource conservation and protection, ii) fair distribution of the benefits obtained from the activity, (iii) maintaining social cohesion and preserving cultural values and iv) scarce administrative, human and financial resources for policing illegal fishing and [30–32] the geographic variability of the results achieved. On the one hand, efficient conservation of the ecosystem and on the other a fair distribution of the benefits of using natural resources [30]. Many of these occupied spaces are owned, shared and, indeed, disputed [31]. There is a persistent problem of illegal fishing and even a risk that the resources will disappear as a result of uncontrolled fishing for immediate profit [32].

In recent years researchers and those responsible for fisheries have concentrated on improving this system of territorial use rights for fishing. One of the world’s most important programs contributing to sustainable fishing is the Chilean TURF system, known as “Áreas de Manejo y Explotación de Recursos Bentónicos - AMERB”. This system was created due to overfishing of the Chilean abalone or ‘loco’ (*Concholepas concholepas*), one of the most economically valuable benthic shellfish, which since 2000 can only be taken within the TURFs [17,33]. The TURFs thus play a vital role as the principal tool for managing and extracting this species and other high-commercial-value benthic resources in Chile.

In 2017 around 803 legally established TURF had been registered on the Chilean coast and the Los Lagos, Coquimbo and Biobío regions contain the largest number of TURFs [34]. TURFs have become particularly important, their main aims are not only to protect the principal benthic resources and allow them to recover, but also to improve empowerment and social cohesion among artisanal fishers’ organizations [35,36]. Despite their increasing popularity, earlier research has shown that their management is still limited, because the necessary importance is not given to the social aims and because of [37–44] regulatory compliance problems [17, 45–48]. It has also been shown that “the current situation of artisanal fishing communities is unfavorable because of unsustainable fishing methods and failed governance” [49]. There have been challenges affecting territorial use rights and little attention has been paid to the complexity of the coastal environment where artisanal fishing takes place [36, 50–53].

According to research by Fulton et al. [54], Máñez et al. [55], Arias-Schreiber and Linke [56], Benson and Stephenson [57] and Arias-Schreiber et al. [58] our current understanding of the state of the fisheries is limited and we require better knowledge of their complexity, dynamism and diversity. It is therefore essential that we understand the different agents affecting them due to interactions between the social and ecological systems that make up each fishery. Different studies underline the importance of fishers’ traditional knowledge in addressing the problems of sustainability and creating opportunities in an uncertain environment. Although integral management of inshore waters is an internationally established ideal, decisions taken in practice are not properly planned because the management model is imperfect [59]. Consequently, a multidisciplinary and multidimensional study of the fisheries is essential as a contribution to sustainable development and

thus to obtaining a greater, integrated, understanding of the system from a local perspective [2].

In this document we evaluate and compare the sustainability status of fisheries in 19 TURFs managed by different artisanal fishers’ organizations in Biobío region. It should be noted that each TURF sector has different geographic characteristics, to which management methods have to be adapted to ensure sustainable development of the fisheries. In order to identify the factors affecting the sustainability of the chosen TURFs and to understand their condition, this study uses multivariate statistics and a multidimensional analytical approach. The study used the Rapid Appraisal for Fisheries – RAPPFISH methodology, which consists in transforming multidimensional attributes into a simpler dimension. RAPPFISH is described in detail by Pitcher and Preikshot [60] and Pitcher et al. [61], and its statistical basis by Alder et al. [62] and Kavanagh and Pitcher [63].

This is the context in which we suggest the hypothesis of a sustainability gradient in the TURFs in Biobío region. The purpose of this research was to compare selected TURFs and determine whether their sustainability is weak or strong, as well as to identify attributes in the different dimensions that require improvement. To achieve this objective we interviewed fishers belonging to organizations with TURFs, which were grouped according to coastal characterization in the region. The results will thus provide valuable information for policy makers and fishers when taking decisions and future specific actions. The document structure is as follows: This section contains background information on the case under study. Section 2 explains the quantitative variables used as indicators adapted to the TURFs and the RAPPFISH methodology that integrates the different variables. Section 3 concerns interpretation of the results for each dimension and a determination of how the indicators influence each other. The results discussed in Section 4 and the final section make up a general overview of the TURF system.

1.1. Background to the study zone

The integral analysis of the different dimensions of sustainability will be carried out in Biobío region, particularly TURFs administered by artisanal fishers’ organizations. This region has a coastline approximately ~598 km long, where multiple activities are carried out (forestry, fishing and others) principally in its bays and gulfs. The region consists of 15 coastal communities and includes three inhabited islands: Quiriquina, Santa María and Mocha (<https://vdocuments.mx/embed/v1/politica-sobre-borde-costero.html>).

There are around 76 fishing coves or ‘caletas’ on the coast, of which 69 are on the mainland and 7 on islands (the Islands of Santa María and Mocha). 67% of the villages in the region are rural and 33% urban (<http://mapas.subpesca.cl/visualizador/>). Although the ‘caletas’ in this region experienced economic growth in the middle of the 20th Century, this has not been the case in recent decades. Some of them have suffered high social costs in terms of employment, incomes and the viability of small businesses and this has meant that ever fewer people can make a living in these maritime areas. Other ‘caletas’ however have developed further based on the social and economic benefits provided by artisanal fishing and the presence of natural benthic resources, as well as pelagic and demersal fish (anchovies, sardine, hake and others) [64]. These conditions give them an advantage, although many inhabitants feel the future to be uncertain and do not see work associated with the fishing industry as being sustainable. Nevertheless, they have employed a variety of strategies to preserve their lifestyles and identity and the work that enables both [65]. Geographic differences also affect the impact of sustainable fishery management measures and these require further study.

Two momentous events in this region were the earthquake and tsunami on the 27th of February 2010 (27/F), which caused important and significant changes its topography [66]. These events had a significant effect on the distribution of marine species in the coastal area and the islands. Furthermore, the loss of low intertidal and shallow sub-tidal

habitats meant the reduction or disappearance of certain species of algae, such as ‘pelillo’ *Gracilaria chilensis*. As far as economic activity was concerned, they caused enormous damage to coastal property, including that used by artisanal fishers, ports, industry and health infrastructure [67,68].

The Biobio region is home to a significant number of artisanal fishers and gatherers, including indigenous peoples: approximately twenty thousand fishers (14,533 men and 5273 women). More than half of whom belong to artisanal fishers’ organizations. The region has the second largest number of fishers and registered vessels in the country after Los Lagos region [69]. In 2017 there were a total of 127 TURFs in the region, 78 had been legally confirmed and 31 rejected, while 18 applications were pending. They are administered by 47 organizations representing the users of fishery resources, including labor unions, fishers’ associations, indigenous communities and cooperatives [34,69].

Landings from TURFs throughout Chile during 2017 were 43% higher than in the previous year (Table 1). Between 2010 and 2017 (Table 2), the main species recorded in Biobio region were the Chilean abalone ‘loco’ (62%) and razor clam ‘huepo’ (7%), both mollusks; while the macroalgae group, such as chicorea de mar, pelillo and huiro, made up 25% of total landings (Sernapesca 2010–2017, <http://www.sernapesca.cl/informes/estadisticas>). Recent years have seen an increase in macroalgae extraction, but ‘loco’ continues to be the most economically important mollusk in Chile, it is relatively easy to catch, is produced exclusively by the TURFs and generates significant income (mainly from export sales) [70]. For that reason, extraction continues in certain TURFs of the region despite low catch volumes; it also enables the organizations benefiting from the TURFs to earn seasonal income in addition to other means of earning a living in the area, such as restocking the algae or small-scale aquaculture. At present however, very few organizations are involved in this latter activity.

The TURF case study in Biobio region proved ideal for our sustainability analysis for a number of reasons. Firstly, because the system has not been free from problems, including heterogeneous distribution of benthic resources: some areas have acceptable levels while others do not. This was reflected in landings of the main species between 2010 and 2017, which amounted to less than 2% of total national landings (<http://www.sernapesca.cl/informes/estadisticas>). Furthermore, the number of fishers belonging to the different organizations that manage the TURFs varies due to low incomes and unsustainable management. There is wide variety in the contributions made by the system, some TURFs have incomes of less than US\$ 300, amounting to less than 10% of family incomes [71]. Secondly, an inescapable latent problem all over the country is illegal fishing (poaching) of the principal resources such as Chilean abalone or ‘loco’. In 2017, illegal fishing was estimated to amount to 79–100% of quotas assigned to fishers’ organizations [70]. This illegal activity seriously affects the operation of the system as it

threatens conservation of benthic resources (invertebrates and algae) and makes fishers even poorer. In the region this illegal activity is carried out not only from boats but also by people who enter the TURF without boats [70]. Finally, we must also take into account human effort, technology and certain socioeconomic and institutional standards as prerequisites for maintaining the TURFs over the long term.

2. Materials and methods

2.1. Study zone

In order to meet the aims of this study we chose 19 TURFs in different parts of Biobio region (Fig. 1), distributed as follows: 02 are in bays, 07 along the shoreline, 03 in the gulf and 07 around islands, both Santa María Island (Fig. 2) and Mocha Island (38°22′17.76″S; 73° 54′ 44.24″W). Table 3 lists the TURFs chosen for this research, as well as the codes established for illustration purposes.

2.2. Selection of TURFs and respondents

The 19 chosen TURFs were grouped into four geographic zones: bay, gulf, coastline and island. The main species fished in these TURFs (i.e the Chilean abalone or ‘loco’) was the factor common to them all. Nevertheless, landings were different for each one; as were the commercial distribution centers in each TURF, especially for those in island zones far from the coast (Table 4). Furthermore, the examination of their status used information on different criteria, such as productivity in terms of abundance, or harvest per effective area of the commercially-important species (Franco et al. - unpublished results).

In the chosen TURFs, we identified the fishers’ organizations that contribute to their management. Visits were made to the 19 selected TURFs during the following period: November 2018 to March 2019, in order to obtain qualitative and quantitative data on the organizational component, as well as the attributes of the six dimensions of the RAP-FISH method. We used 7–10 attributes for each dimension, 51 attributes in total (see Appendix A). We compiled this information by using a semi-structured questionnaire. The questionnaire was completed by 76 members and 27 leaders of the organizations, and took approximately 45 min. Interviews were face to face after we had obtained the consent of the interviewees (CEBB 747–2020). We used random sampling to select the interviewees from each TURF (as indicated in Franco et al. - unpublished results), with a sample of 7 fishers (5 members and 2 leaders) per organization, except for organizations responsible for more than two TURFs, in which case we interviewed an average of 5 participants. This was because they belonged to the same organization and consequently the same participants were involved; getting people to take part voluntarily was also one of the difficulties we faced during the

Table 1

Total landings (in tons) from TURF system by region, period 2010–2017.

Region	2010	2011	2012	2013	2014	2015	2016	2017	% 2017	Var (%) 2017–2016
Arica y Parinacota (XV)	0	7	0	0	0	0	0	0	0.0	–
Tarapacá (I)	1279	469	699	705	728	587	276	281	1.2	–
Antofagasta (II)	266	114	160	479	584	496	380	623	2.6	63.9
Atacama (III)	932	768	610	1523	631	2692	2753	3963	16.4	44.0
Coquímbo (IV)	7649	5192	6790	9512	10,640	13,126	10,034	15,379	63.5	53.3
Valparaíso (V)	1534	466	287	66	340	497	459	507	2.1	10.5
Libertador O’Higgins (VI)	20	25	35	55	10	49	83	188	0.8	126.5
Maule (VII)	5	5	13	18	10	14	49	18	0.1	-63.3
Biobio (VIII)	335	384	249	215	168	118	142	222	0.9	56.3
La Araucanía (IX)	0	0	0	0	19	2	2	0	0.0	-100.0
Los Lagos (X)	3649	3003	1617	2135	1904	2512	2206	2700	11.1	22.4
Aysén (XI)	17	27	0	40	345	0	239	19	0.1	-92.1
Magallanes (XII)	0	0	0	0	0	0	0	0	0.0	–
Los Ríos (XIV)	233	200	243	295	424	611	360	327	1.3	-9.2
Total	15,919	10,660	10,703	15,043	15,803	20,704	16,983	24,227	100.0	42.7

Source: SERNAPESCA

Table 2
Landings (in tons) of the main resources harvested from TURFs in the Biobío region, period 2010–2017.

Group	Specie	2010	2011	2012	2013	2014	2015	2016	2017	Total	%
Shellfish	Chilean abalone	182	262	180	152	137	92	89	49	1143	62.4
	Razor clams	10	13	21	14	19	17	14	16	124	6.8
	Limpets	–	3	4	2	–	–	3	6	18	1.0
	Clams	–	–	–	–	–	–	9	–	9	0.5
	Mussels	–	–	–	–	–	–	–	6	6	0.3
Seaweed	Chicorea	53	54	43	44	12	4	27	51	288	15.7
	Bull kelp	–	–	–	–	–	5	–	13	18	1.0
	Chilean kelp	–	–	–	–	–	–	–	81	81	4.4
	Black luga	48	–	–	1	–	–	–	–	49	2.7
	Gracilaria seaweed	42	52	–	–	–	–	–	–	94	5.1
Others	Sea urchin	–	–	1	2	–	–	–	–	3	0.2
Total		335	384	249	215	168	118	142	222	1833	100.0

Source: SERNAPESCA

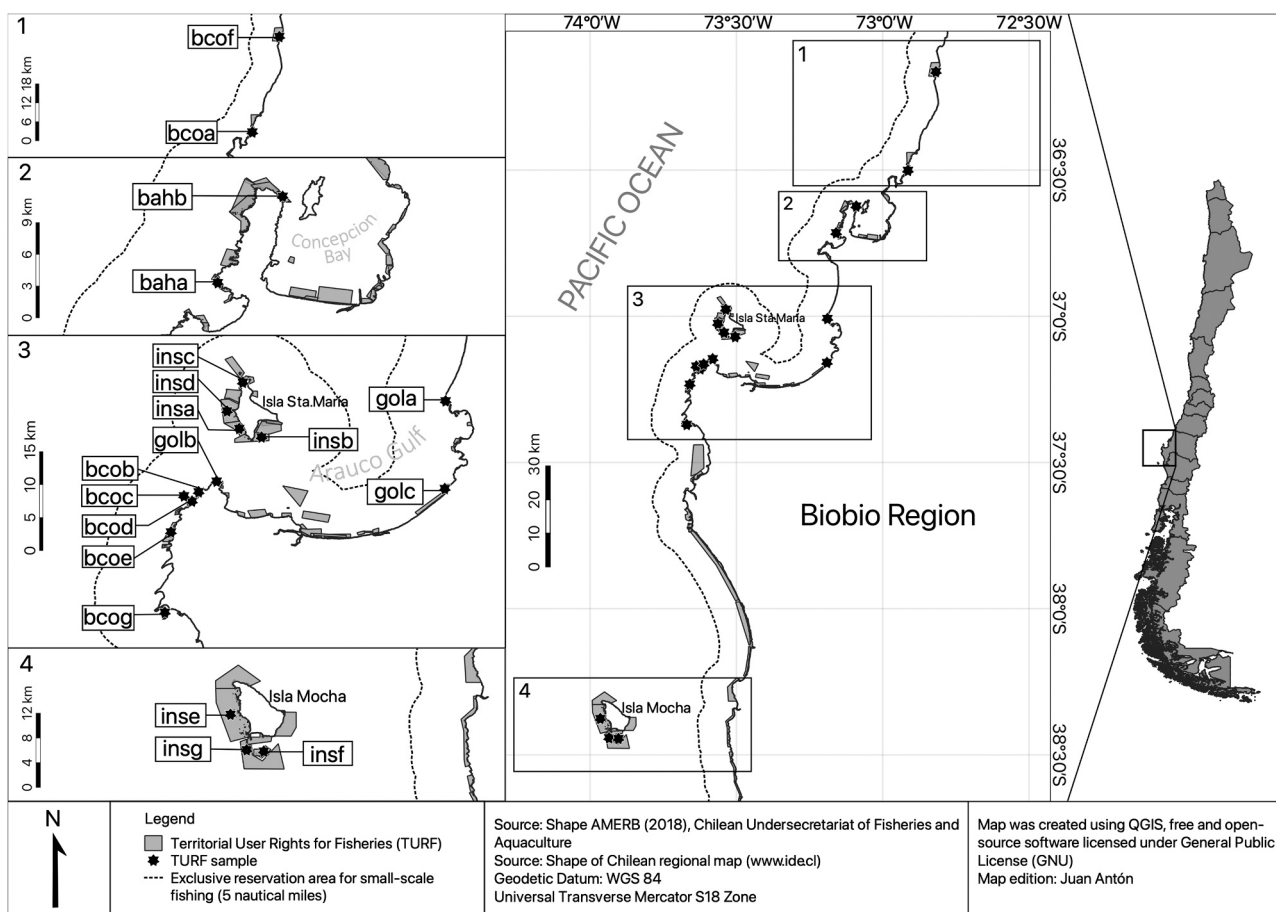


Fig. 1. Map of the study area in the Biobío region, Chile. Study locations are indicated by black stars according to Territorial use rights in fisheries (TURF) sampled, their names are displayed in codes. TURF Codes description: baha=San Vicente, bahb=Candelaria-Cantera, bcoa=Dichato, bcob=Punta Raimenco, boc= Bajo Rumena, bcod=Rumena, bcoe=Los Piures, bcof=Cobquecura sector A, bcog=Puerto Yana, gola=Maule, golb=Punta Lavapie, gold=Laraquete, insa=Los Partidos, insb=Puerto Sur, insc=Pueblo Norte sector B, insd=Punta Cadena, inse=Weste Isla Mocha, insf=Quechol, insg=Quechol Sur. Organized by the author and map edited by J. Antón using QGIS software, 2021.
Source: Shape AMERB (2018), Chilean Undersecretariat of Fisheries and Aquaculture.

interviews (Table 3). The interviewees included adults (women and men) involved in fishing as boat owners, divers, gatherers and assistants. Finally we examined statistics and documents containing secondary data on the chosen TURFs, which were used to give complementary context.

2.3. RAPFISH technique

RAPFISH is a rapid and practical multidisciplinary evaluation technique using limited data, to determine the level of sustainability of the

fisheries by assigning scores in a semi-quantitative manner [72]. It has been used for more than a decade as a fisheries management tool. We used this technique because it enables us to integrate simultaneously a set of transdisciplinary attributes for 6 dimensions (ecological, social, economic, technological, ethical and institutional). The empirical technique is considered useful for analyzing the status of the TURF system on a spectrum ranging from ideal (“good”) to worst case (“bad”).



Fig. 2. View of the Pueblo Norte pier, Santa Maria Island. Biobio region-Chile (credit: MFM).

2.3.1. Criteria

RAPFISH was adapted for the TURFs using the following considerations: Firstly, most worldwide studies using the technique have been used to measure sustainability in open-access fisheries (whether for commercial purposes, subsistence or artisanal and industrial fishing). There are few studies, however, that measure the effectiveness of management for those where exploitation of live marine resources is restricted, such as Marine Protected Areas - MPAs [73] of for those that are jointly managed, such as the TURFs. The technique, as a measurement of the effectiveness of TURF administration, should be practical and cost-effective, so that decision takers and administrators can easily understand what is being measured. According to the General Law on Fisheries and Aquaculture - LGPA (S.D. N° 355, 1995), TURFs tend to produce three positive effects: biological, economic and socio-organizational. An evaluation should therefore address ecological, social, economic and institutional questions, among other management aims. To apply this methodology therefore, we will define a new set of attributes that reflect the TURF system through different sustainability

Table 3

19 TURFs selected in the RAPFISH analysis for the Biobio region, Chile.

TURF name	TURF code	Zone	Established ^γ (year)	Age of TURF* (years)	TURF total extensión (ha)	Total no. of fishers	No. of surveys (total n = 103)
San Vicente	baha	Bay	1997	20	91.66	34	3 ^δ
Candelaria-Cantera	bahb	Bay	1997	20	69.91	61	5
Dichato	bcoa	Coast	1997	20	191.58	48	6
Punta Raimenco ^ψ	bcob	Coast	1997	20	48.83	40	5
Bajo Rumena ^ψ	bcoc	Coast	1997	20	11.50		5
Rumena	bcod	Coast	1997	20	74.48	72	6
Los Piures	bcoc	Coast	1997	20	271.64	34	6
Cobquecura sector A	bcof	Coast	2001	16	452.50	28	1 ^δ
Puerto Yana	bcog	Coast	1997	20	112.50	36	7
Maule	gola	Gulf	1998	19	59.90	27	7
Punta Lavapie	golb	Gulf	1997	20	68.48	27	6
Laraquete	golc	Gulf	1998	19	48.88	42	7
Los Partidos [†]	insa	Island	2004	13	416.00	125	6
Puerto Sur [†]	insb	Island	1997	20	552.79		6
Pueblo Norte sector B	insc	Island	1997	20	239.61	89	6
Punta Cadena	insd	Island	2004	13	947.20	88	6
Weste Isla Mocha ^φ	inse	Island	1999	18	3870.81	86	5
Quechol ^φ	insf	Island	2003	14	277.94		4
Quechol Sur	insg	Island	2003	14	2376.77	31	6

*until 2017.

^γ availability decree (approved by the Ministry of Economy-MINECON).

^ψTURF manage by the same artisanal fisher organization, called: "Sindicato de Trabajadores Independientes, Pescadores Artesanales, Buzos Mariscadores y Actividades Conexas de Caleta Punta Lavapie".

[†]TURF manage by the same artisanal fisher organization, called: "Cooperativa de Pescadores Pelilleros, Isla Santa Maria Limitada".

^φTURF manage by the same artisanal fisher organization, called: "Organización Comunitaria Funcional de Pescadores Artesanales y Buzos Mariscadores de Isla Mocha".

^δTwo fisher organizations, only less than five respondents agreed to be surveyed.

dimensions.

Secondly, as TURFs are zones with exclusive access for exploitation they must meet the requirements of the RAPFISH methodology: the proposed attributes can be applied coherently to different areas, which should be spatially independent of each other at macro-zone, regional and even local levels. In this study we decided to group the TURFs according to their geographic location in Biobio region.

Thirdly, the physical characteristics of each TURF did not limit application of the methodology. However, differences of scale could be important, as in the case of the MPAs, due to connectivity and buffering [73]. Some TURFs cover large areas while others are small. Nevertheless, accessibility and the level of exposure of the TURFs should play an important role, because the more exposed and less accessible may be favored, though this does not prevent illegal incursions and poaching.

2.3.2. TURF attributes: identification, definition and quantification

Applying the RAPFISH concept to TURFs requires us to identify and define appropriate attributes within the dimensions of sustainability. These attributes are defined by positive effects on the TURFs, as we have

Table 4

Some characteristics in each group of TURFs according to geographic zones in the Biobio Region. Period 2001–2017.

Zone (No. TURF)	Harvest, only loco (ton)	Harvest, total* (ton)	TURF average extension (ha)	Distance from 'caleta' to TURF in km, min and max (mean)
Bay (2)	89.53	1535.02	80.78	0.38 – 3.30 (1.84)
Coast (7)	321.59	601.22	175.85	0.68 – 5.42 (2.42)
Gulf (3)	76.33	228.62	59.09	0.23 – 1.50 (0.72)
Island (7)	1059.06	1525.12	1240.16	1.52 – 35.57 (9.92)
Total (19)	1546.51	3889.98	539.52	0.23 – 35.57 (4.85)

Source: SERNAPESCA; SUBPESCA; A. Hernández

(*) correspond all invertebrates (Chilean abalone 'loco', razor clams, limpets, clams, mussels, sea urchin among others) and seaweeds (Chicorea, Gracilaria seaweed, bull kelp, among others)

already mentioned. Pitcher and others [61] propose evaluating the sustainability of fisheries based on multiple dimensions: ecological, economic, ethical, social, technological and institutional. Some elements of these dimensions are important attributes in the evaluation of a TURF. Nevertheless management objectives for the TURFs include other aspects, for example: participation and level of compliance with landings, consolidation of fishers' organizations, as well as their management capability, leadership, cooperation networks and coordination, among others.

Consequently new sets of attributes were drawn up to evaluate the performance of the TURFs in Biobio region. The proposed sustainability dimensions were also defined:

- i. Ecological-fishing: Guarantee that the extraction of commercially important benthic resources within the TURF are sustainable, so that future generations can obtain economic and social benefits.
- ii. Economic: Ensure that the TURFs and their resources are properly valued in the market.
- iii. Ethics: Comply with the principle of justice in fishing inside the TURF, which should be fair to the ecosystem and society as a whole.
- iv. Social: Satisfy the expectations of those involved and local communities concerning the benefits of maintaining these rights of use, but also to value them as preservation zones.
- v. Technological: Stimulate proper use of technology in order to reduce risks to the ecosystem.
- vi. Institutional: Ensure that TURF management and implementation programs function efficiently and effectively.

Within these dimensions we classified the attributes that demonstrate the degree of sustainability of the TURFs. The R Studio program and ggplot2 library [74] were used to explore the quantitative data deriving from available secondary information. The aim of this was to adjust these attributes to understand the different actors, principally the direct users (fishers). In general terms, the attributes came from different local sources [42], [75,76], as well as case studies from other fisheries [2, 77–81].

As a first approximation, 51 attributes were drawn up based on the six proposed dimensions, subdivided into: 09 for the ecology-fishing dimension, 07 for the technological dimension, 07 for the ethical dimension, 09 for the economic dimension, 09 for the social dimension and 10 attributes in the institutional dimension. Scoring for each attribute was determined from the secondary and primary sources (interviews). Each attribute was scaled and values specified, taking into account the system proposed by RAPFISH. The list of attributes, values assigned and a description are given in the [Appendix A Supporting information](#).

2.3.3. Applying the technique

The scores obtained from the secondary information and interviews with fishers were combined for the RAPFISH analysis. The technique is described in detail by Pitcher and Preikshot [60], Alder et al. [62] and Kavanagh and Pitcher [63]. Each attribute was valued using an ordinal scale from zero to ten (representing bad or good - with assignments able to be mixed between attributes if necessary). The technique uses MDS (multi-dimensional scaling) for ordination of objects chosen in a space (the x-axis) from bad to good, for each one of the six dimensions. The other dimension of the MDS (the y-axis), represents other factors unrelated to sustainability. We used the RAPFISH software version 3.1 for ordination in the MDS in R application (available at <http://www.rapfish.org/software>).

The RAPFISH functions include a leverage (or influence) analysis and Monte Carlo techniques to account for aspects of uncertainty [60]. Leverage analysis determines how much each attribute influences the general scoring of values in the ordination. Values lower than 10% and relatively similar, will be interpreted as showing that no single attribute

dominates the analysis. Monte Carlo techniques create statistical simulations to evaluate the effects of random error in a process, and estimate the "true" value of a statistic of interest [63]. Generally speaking, the analyses were applied to the attributes of the six dimensions used in this study and the set of attributes made up different results.

As far as the assignment of points for sustainability was concerned, we use the classification described by Cissé et al. [79], with 3 categories: (i) "High", with scores greater than 70% where the TURF may be considered as "very sustainable"; (ii) "Medium", with scores between 50% and 70% where the TURF is considered "sustainable or acceptable" but need to improve, and (iii) "Low", with values under 50%, where the TURF is considered "almost unsustainable". To determine whether the ordination is good for all dimensions, we applied Kruskal's non-metric scaling using the isoMDS function in the MASS library [74]. Kruskal's non-metric MDS uses only ordinal information on proximity and is described by Jacoby and Ciuk [82]; stress values below 0.2 are good. The isoMDS function uses a lower or complete triangular distance matrix and the resulting stress values are expressed as a percentage.

To determine the status of this system and evaluate sustainability conditions, the mean indicators in each dimension were used to generate Kite graphs. These graphs enable different dimensions to be included in a single entity [73], thus permitting decision-makers to decide which TURF or TURFs need attention. The results were also grouped to enable comparison according to their geographic location: bay, coastline, gulf or islands.

3. Results

3.1. Sustainability in each field of evaluation

Evaluating the sustainability of the TURFs requires integrating data from different transdisciplinary attributes, such as the economic, social, technological and ecological dimensions, among others. The fishers classify the performance of the TURFs in accordance with a large set of proposed attributes grouped in different dimensions, such that sustainability can be considered from a more holistic point of view. The Kruskal non-metric stress values obtained were acceptable for all the dimensions (stress <0.05 provides an excellent representation), except for the economic dimension. Dimension reached nearly 98% of the variance explained by the model (Table 5), enabling us to explore which attributes influence each dimension.

The results of the sustainability analysis are shown in Fig. 2 (A-F) for the six dimensions of RAPFISH. The sustainability scores (described in the figure as the 'Sustainability Index') are distributed along the X-axis under the level of sustainability for each dimension described. The sustainability scores are distributed around two reference points, a "best" point (100%) and a "worst" point (0%). Vertical distribution along the Y-axis shows differences that are unrelated to sustainability.

Table 6 compares sustainability scores between the TURFs. We can see from these results that the social dimension received the best score (61%) and the ethical dimension received the lowest average scoring (44%). Breaking the X-axis down into shows us which TURFs were under or above the mid-point (50%), between "Low" and "Medium" categories in the bidimensional RAPFISH ordination. The table shows that 15 of the 19 TURFs were between 52.85% and 59.19% mean sustainability points,

Table 5

Statistical indices of MDS analysis. Kruskal non-metric stress and RSQ for the different RAPFISH dimensions.

Dimension	Kruskal's Non-metric stress	Squared correlation RSQ
Ecology	0.00095	0.982
Economics	0.06398	0.979
Ethical	0.00008	0.976
Institutional	0.00008	0.980
Social	0.02354	0.977
Technological	0.00000	0.986

Table 6
Sustainability scores (%) by each TURF sector according to RAPFISH ordination.

TURF name	TURF code	Ecol	Econ	Ethi	Inst	Soci	Tech	Reord. TURF code	Mean
San Vicente	baha	51.06	49.85	34.56	41.79	59.15	60.64	insg	59.19
Candelaria-Cantera	bahb	55.40	61.32	44.56	43.41	71.28	57.37	bcod	58.70
Dichato	bcoa	48.34	52.42	42.02	50.10	71.64	61.54	bcof	58.41
Punta Raimenco	bcob	54.98	61.21	46.98	65.95	59.37	61.85	bcob	58.39
Bajo Rumena	bcoc	51.76	56.42	39.61	53.76	57.28	60.64	golb	58.25
Rumena	bcod	53.06	65.45	55.21	57.94	59.19	61.37	insf	57.87
Los Piures	bcoe	46.60	53.89	38.02	38.93	58.32	62.82	inse	57.52
Cobquecura sector A	bcof	58.67	60.43	57.14	52.74	69.26	52.22	insa	56.09
Puerto Yana	bcog	59.18	58.39	43.29	49.60	60.03	62.42	bahb	55.56
Maule	gola	48.84	53.64	42.59	51.99	65.94	55.02	bcog	55.48
Punta Lavapie	golb	57.94	65.12	48.30	53.57	62.06	62.49	insb	54.94
Laraquete	golc	41.02	56.98	44.80	50.27	56.51	49.55	bcoa	54.34
Los Partidos	insa	56.42	54.75	42.83	52.05	67.53	62.95	bcoc	53.25
Puerto Sur	insb	58.63	56.04	38.38	54.68	59.11	62.82	gola	53.00
Pueblo Norte sector B	insc	59.64	52.90	42.73	37.39	58.16	66.29	insc	52.85
Punta Cadena	insd	55.65	51.47	33.36	42.94	56.37	57.03	golc	49.85
Weste Isla Mocha	inse	59.69	64.77	48.58	55.43	58.28	58.33	bcoe	49.76
Quechol	insf	53.41	63.22	57.52	58.12	57.33	57.62	baha	49.51
Quechol Sur	insg	58.70	67.33	47.99	58.68	63.70	58.71	insd	49.47
total		53.86	58.07	44.05	50.91	61.37	59.81	mean= 54.68	

Ecol=ecology; Econ=economic; Ethi= ethical; Inst=institutional; Soci=social; Tech=technological

the maximum value being given to the Quechol Sur ('insg'), which is an island zone. Despite not exceeding the 70% threshold, 15 TURFs were considered with "Medium" sustainability that is, acceptable but need to improve. Meanwhile the four remaining TURFs: Laraquete ('golc'), Los Piures ('bcoe'), San Vicente ('baha') and Punta Cadena ('insd'), attained values below 50%, with "Low" sustainability, verging on unsustainability, and the worst case was observed in Punta Cadena ('insd'). This results support our hypothesis of a sustainability gradient of the TURFs in Biobio region. In general, the sustainability analysis achieved an average "Medium" sustainability value of less than 60%, being highly sensitive to the choice of attributes as some were more influential than others; none of the TURFs was truly sustainable.

3.1.1. Ecological-fishery dimension

Fig. 3A shows the distribution of the TURFs in the bidimensional ecological ordination, with a large number of them forming a central group. Scorings for the ecological dimension are relatively low compared to the 70% threshold, varying between 41.02% and 59.69%. Laraquete ('golc') was the TURF with the lowest score, tending towards ecological unsustainability, while the island TURFs such as Weste Isla Mocha ('inse') and Pueblo Norte sector B ('insc') produced values around 60%, which were considered "Medium". However the 'total' scoring of the TURFs is below 70%, in other words between the "Low" and "Medium" level. Only 4 TURFs have confidence limits below 50% (Fig. 4A).

3.1.2. Economic dimension

Distribution of the TURFs in the economic bidimensional ordination shows relatively high grouping with scores fluctuating between 49.85% and 67.33%. The TURF with the lowest score in the economic valuation is San Vicente ('baha'), which is a bay zone. However, eight TURFs obtained values above 60% including Quechol Sur ('insg'), which produced the best performance (Fig. 3B). The general economic sustainability value was 58.07%, below the "High" 70% threshold. This dimension of the chosen TURFs, being below the threshold and in the 50%–60% range, also needs to be improved. Only 7 TURFs have confidence limits that exceed 60% (Fig. 4B).

3.1.3. Ethical dimension

Grouping of the TURFs was relatively high in the ethical bidimensional ordination (Fig. 3C), with values fluctuating between 33.36% and 57.52%, but a large number of TURFs were below 50%. The TURFs with the highest values were Quechol ('insf') (a southern island zone), which

achieved the highest value (57.52%), followed by Cobquecura sector A ('bcof') with 57.14% and Rumena ('bcod') with 55.21%, both on the coast. The total value for all the sectors was 44.05% (below "Medium" 50% thresholds), therefore "Low" not ethically sustainable. This is corroborated by the confidence limits illustration, where the three TURFs mentioned are above 50% (Fig. 4C).

3.1.4. Institutional dimension

In this dimension (Fig. 3D) the TURFs were relatively scattered, with institutional sustainability values between 41.79% and 65.95% and two outstanding groups. Firstly, 13 TURFs had values above 50%, except for one TURF that exceeded 60% in the Punta Raimenco ('bcob') TURF, located on the coast. Group 2 consists of 6 TURFs: Pueblo Norte sector B ('insc'), Los Piures ('bcoe'), San Vicente ('baha'), Punta Cadena ('insd'), Candelaria-Cantera ('bahb') and Puerto Yana ('bcog') were institutionally "Low" with scores between 37.39% and 49.59%. In general, the mean value for all TURFs ('total') was 50.91%, below 70% and therefore with a "Medium" level of institutional sustainability for the TURFs evaluated in this region. Fig. 4D shows that the 'bcob' TURF sector has the highest confidence limit, above the "Medium" level, and the 6 TURFs already mentioned with lower confidence limits (< 50%).

3.1.5. Social dimension

In the social bidimensional ordination, three groups of TURFs (Fig. 3E) have social performance scores between 56.37% and 71.64%. Group 1, with two TURFs that obtained "High" values > 70% such as Dichato ('bcoa'), on the coast and Candelaria-Cantera ('bahb'), in the Bay of Concepcion. Group 2 consists of six TURFs: Cobquecura sector A ('bcof'), Puerto Yana ('bcog'), Los Partidos ('insa'), Maule ('gola'), Quechol Sur ('insg') and Punta Lavapie ('golb'), whose "Medium" values lied in the 50–70% range. Group 3 contains ten TURFs that obtained "Low" values below 50%. The TURFs as a whole ('total') achieved a value of 61.37%, which is considered "Medium", but improvements are required for the sectors with the lowest values. The 'bcoa' and 'bahb' TURFs have the highest confidence limits, above 70% (Fig. 4E).

3.1.6. Technological dimension

The two-dimensional ordination plot of the technological dimension (Fig. 3F) shows that the distribution of values among the TURFs was relatively concentrated in groups with scores that fluctuated between 49.55% and 66.29%. The TURF with the highest score was Pueblo Norte sector B ('insc'), in the island zone. The set of all TURFs ('total'), was "Medium" above 50%, which means that the technological progress

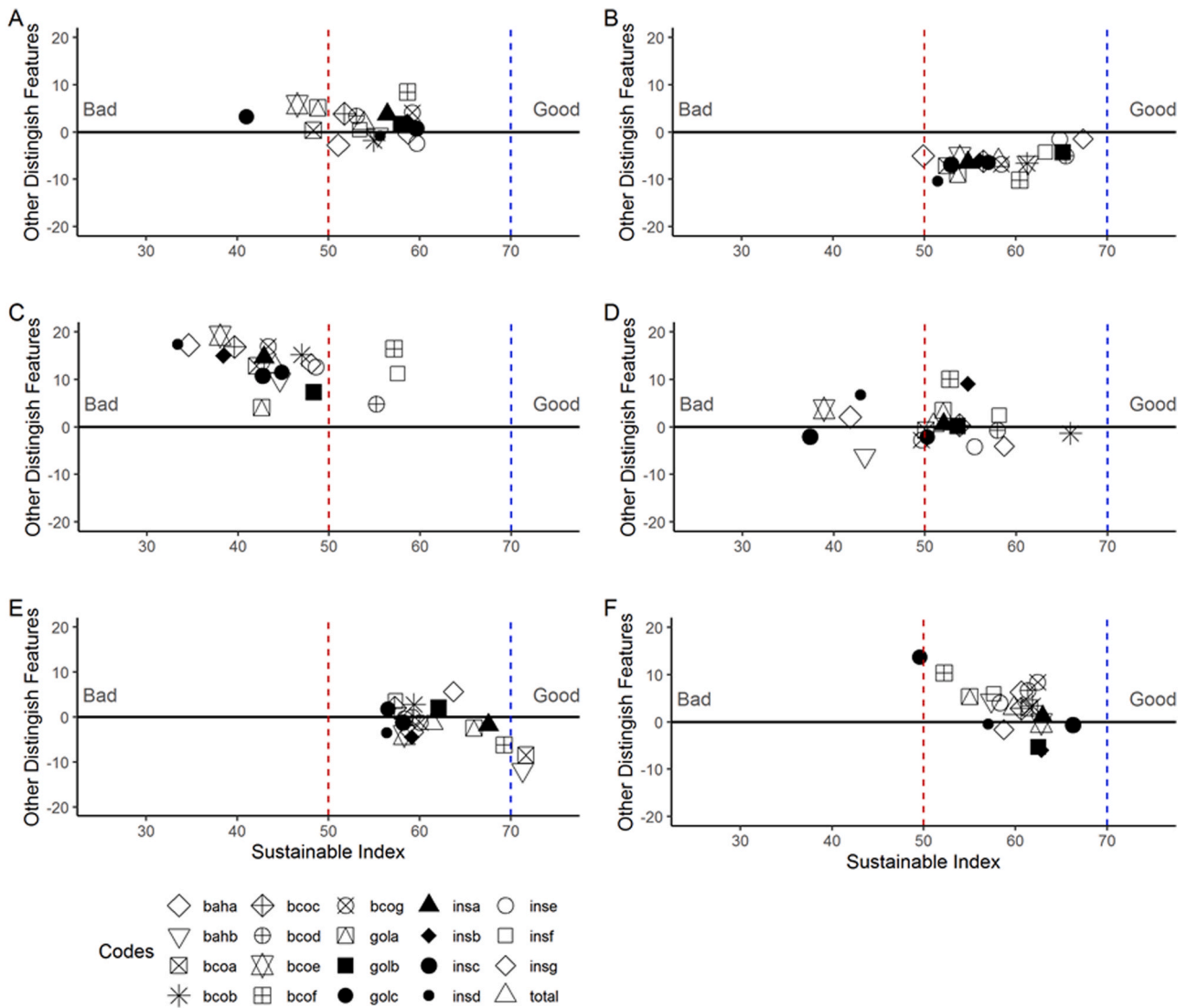


Fig. 3. Two-dimensional RAPFISH ordination plots of the TURF system in each dimension (A=ecology, B=economics, C=ethical, D=institutional, E = social and F=technological) and in an interdisciplinary analysis. The horizontal axis is the sustainability scores from zero (“worst”) to one hundred percent (“best”). The vertical scale expresses differences among TURFs, derived from the ordination of scores, that are not related to sustainability (the codes represent the TURFs as given in Table 6). Performance score: “High”, with scores greater than 70% (blue dashed line) and “Low” less than 50% (red dashed line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article)

adopted is insufficient to guarantee sustainability in the study area. None achieved values over 70% and the lowest confidence limit is that of the Laraquete (‘golc’) TURF (Fig. 4F).

3.2. Leverage (influence) analysis of attributes

Fig. 5 (A–F) shows an analysis of the influence of the different individual attributes for each dimension. This analysis shows that the most influential attributes correspond to the social, institutional and technological dimensions. But the lowest values of the standard error (S.E), below 2%, are observed in attributes of the ecological dimension. According to Tesfamichael and Pitcher [83], if all the attributes have a S.E lower than 10% and are relatively similar, this indicates that no individual attribute dominates the analysis, therefore all have approximately the same importance and none can be discounted for statistical reasons. We can thus see that there is no dominant attribute in this analysis as all of them have a S.E lower than 10%. Nevertheless, some of them still stand out in each dimension.

To complement the bidimensional ecological classification, we can see that all attributes were homogeneous and the most representative

were the following: level of abundance of the target species (‘Abund_Level’) and stability of abundance (‘Stab_Abund’) with standard error (S.E) of 1.70% and 1.62%; respectively (Fig. 5A). We may assume that the low sustainability values in this dimension were associated with the productivity of the TURF, due to a reduction in levels of abundance of the target species and, consequently, low landings (harvests).

Of the 9 attributes in the economic dimension, the leverage analysis results show that average wage (‘Average_Wage’) attribute has the greatest influence (S.E of around 2.85%), followed by cost per kilo (‘Cost_Kilo’) and economic productivity (‘Econ_Production’), as can be seen in Fig. 5B. Attributes closely linked to production and incomes provided by the TURF.

In Fig. 5C the attribute with the greatest influence in the ethical dimension was damage mitigation ‘Mitigation’ (S.E 3.30%), followed by illegal fishing ‘Evol_Poach’ (S.E 2.16%) and cultural value ‘Cult_Value’ (S.E 2.04%). Surprisingly, the ‘Mitigation’ attribute has hardly ever been included in the management plans, which require actions to restore damage to the TURFs, whether caused by nature or provoked by unsuccessful restocking or pollution, among other reasons. As far as the second attribute is concerned, it should be noted that poaching is

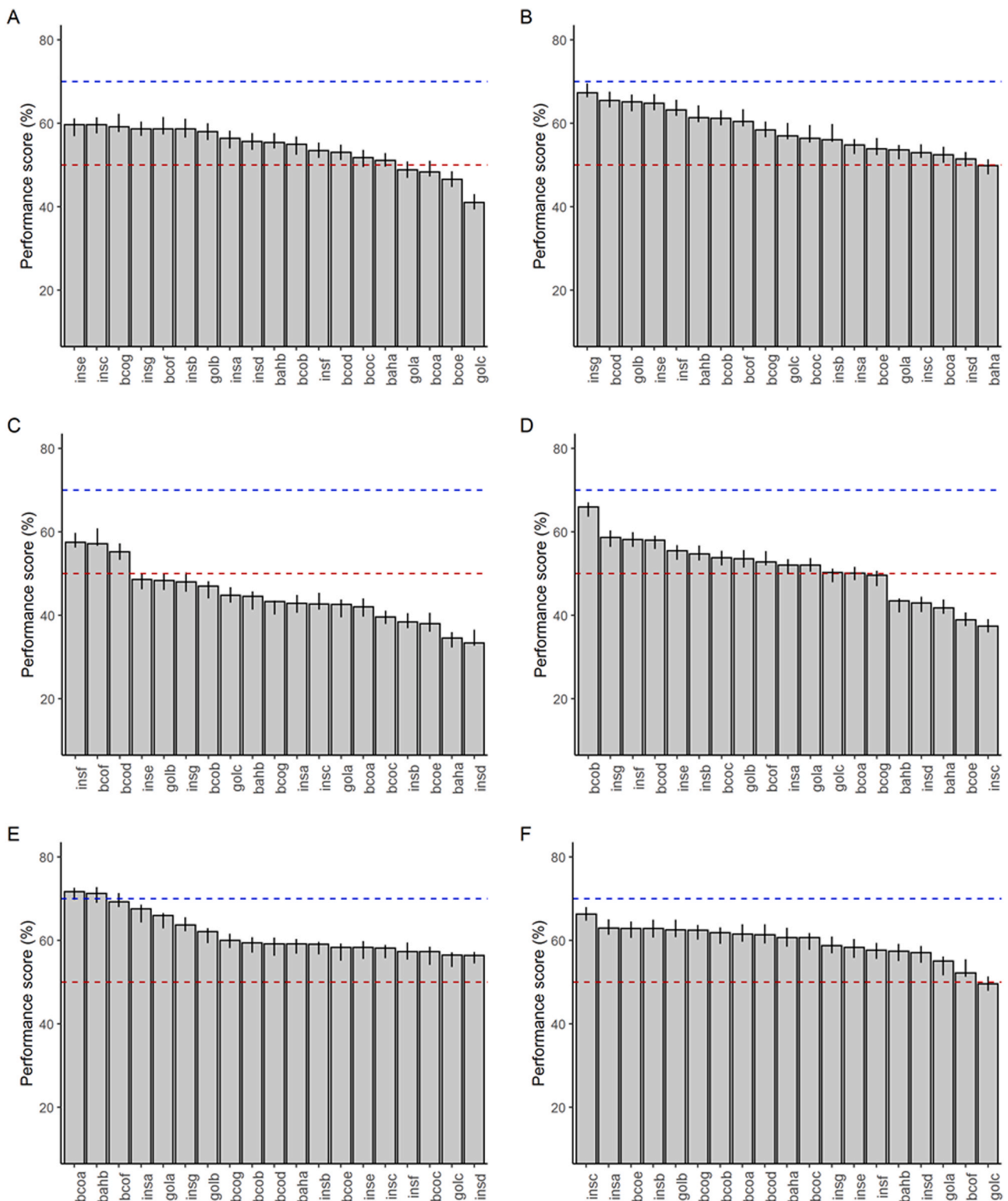


Fig. 4. Sustainability performance rating for TURF system in the Biobio region. Upper and lower limits assigned to individual scores as each score is evaluated in ecology (A), economics (B), ethical (C), institutional (D), social (E) and technology (F) dimensions. TURFs are shown in order of performance rating from left to right. For 100 Monte Carlo simulations (the codes represent the TURFs as given in Table 6). Performance score: “High”, with scores greater than 70% (blue dashed line) and “Low” less than 50% (red dashed line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article)

common among fishers in the study zone. Several studies mention this problem [17,36,46,48,70] and because this activity is undeclared or inaccurately declared, it makes official data on landings, fishing effort and biomass estimates unreliable, thus preventing adequate policies from being designed.

Regarding institutional sustainability (Fig. 5D), access to communications or how it is transmitted (‘Acces_Comic’) and the presence of monitoring authorities (‘Presen_Advice’) were the attributes with more influence on the analysis, with S.Es of 3.41% and 3.31%, respectively. These attributes are closely linked to interactions within the

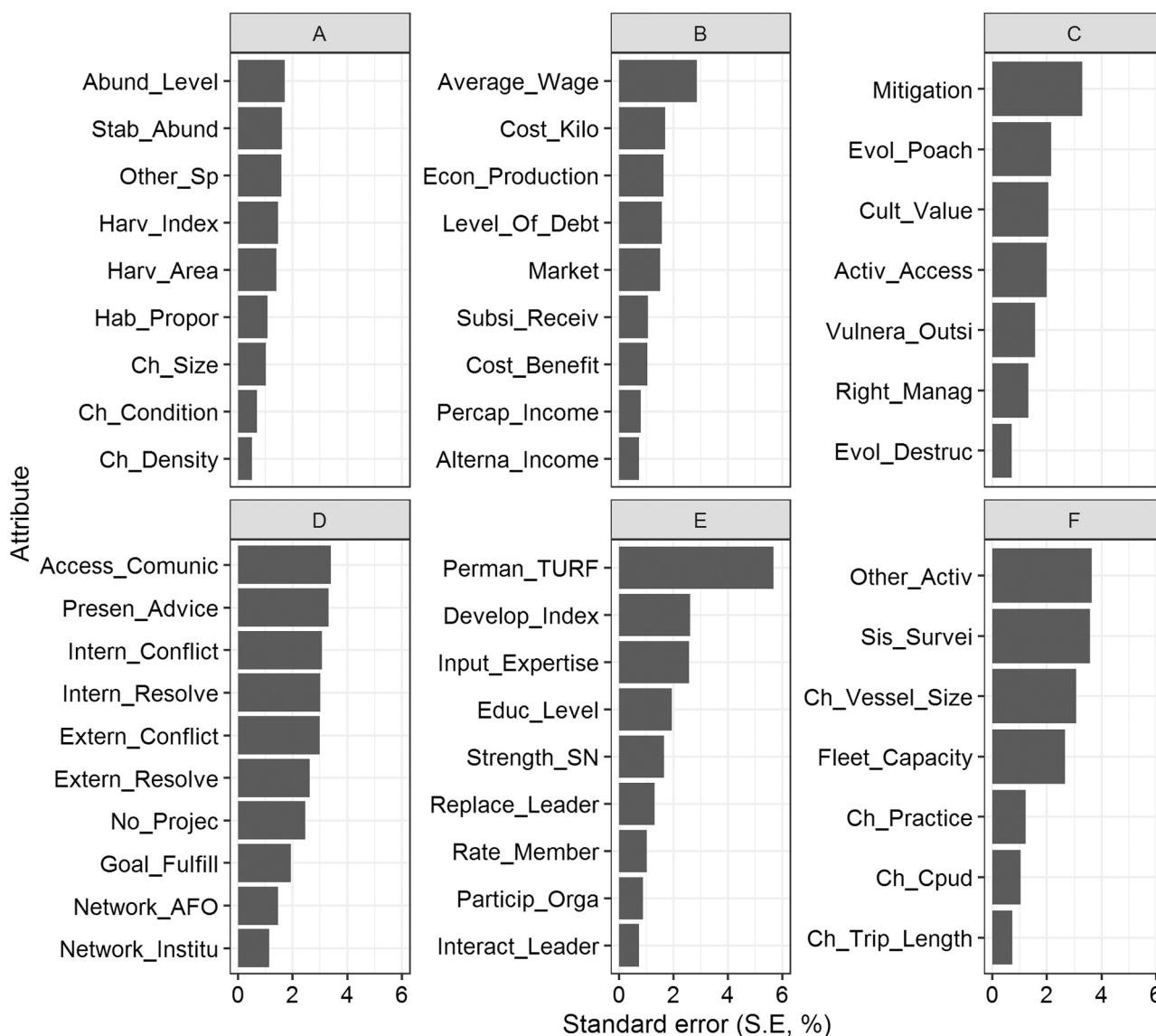


Fig. 5. Leverage (sensitivity) analysis in the RAPFISH ordination for TURF system in ecology (A), economics (B), ethical (C), institutional (D), social (E) and technological (F) dimensions, based on the standard error in percent (S.E., %)The length of each bar shows the percent difference that removing that attribute has on the ordination value along the sustainability axis. It is roughly the average radius of the leveraging scatter for the sustainability dimension. The longest bar indicates the attribute which seems to have more influence on the ordination, each graph results is independent (see [Appendix A supporting information](#) for the description of the attributes in each dimension).

organization and outside it. Despite such interaction as might exist, conflicts and deficient mechanisms for resolving them are very frequent.

The attribute with more influence on the sustainability dimension was the permanence of the TURF ('Perman_TURF'), followed by two more attributes such as the fishery development index ('Develop_Index') and the practical knowledge acquired by fishers ('Input_Expertise') (Fig. 5E). The 'Perman_TURF' attribute was a characteristic in each chosen TURF as it involves the time in years that the activity has been taking place and not only for studies of the segment but also the permanent fishing activity based on established landing quotas.

In the technological dimension (Fig. 5F), the attributes with more influence were those activities involving care and extraction methods within the TURF: secondary effects associated with other activities ('Other_Activ'), the monitoring system ('Sis_Survei') and changes in vessel size ('Ch_Vessel_Size'). Secondary effects on areas surrounding the TURF, such as purse seine fishing and trawling among others and within it, such as crab traps, are common in the majority of cases. Furthermore, incursions by non-local boats near the TURF are poorly controlled,

therefore protection is limited and inefficient and poaching is frequent.

The "kite diagrams" resulting from a combination of all the RAPFISH dimensions grouped by geographic zone are shown in the attached plot (Fig. 6). This plot shows that in almost all dimensions, the island TURFs have more acceptable values of sustainability, except for the social and ethical dimensions, in which they are less sustainable or "unsustainable". In contrast, the coastal TURFs had low values in the ecological and social dimensions. Despite the slight similarities in the scores obtained by coastal and island zones, it is important to note that this is due only to "acceptable" results in the technological dimension (with values that exceed 60% but are below the 70% threshold). Consequently these results offset the values obtained in the other dimensions, which indicates low multidimensional sustainability. Generally speaking, the low ecological, ethical and institutional performance by the region's TURFs is explained by the limitations described by fishers. Some of these have been noted in previous studies and were observed during this one: lack of management strategies adapted to the geographic characteristics of the region and responsible use of the resource, poor cooperation and

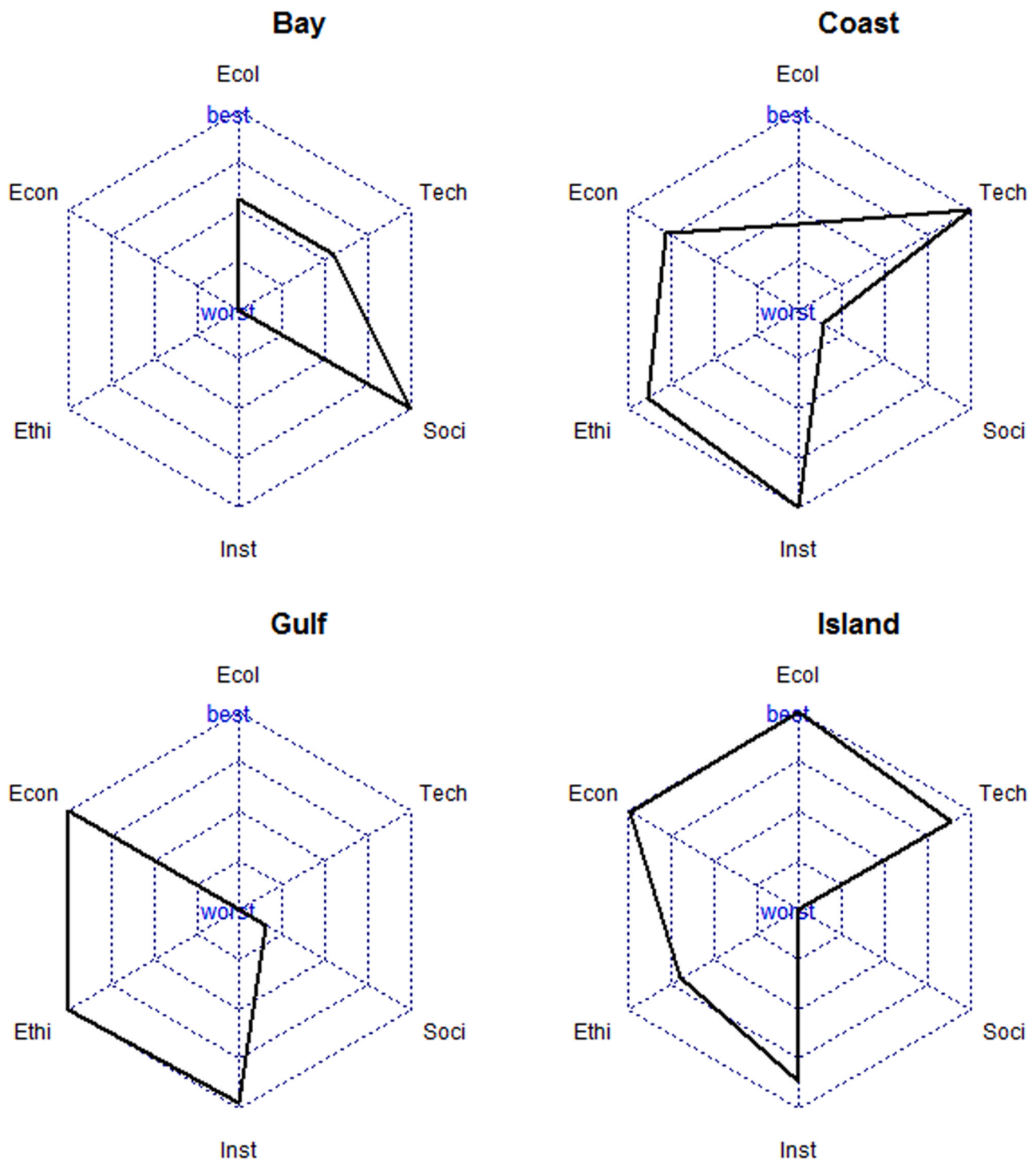


Fig. 6. Kite diagram representing the TURF system sustainable scores in the six dimensions, grouped by zones: bay, coast, gulf and island. The black empty polygons show the maximum value scores reached in each dimension respect to others. Dimension codes description: Ecol=ecology, Econ=economics, Ethi=ethical, Inst=institutional, Soci=social and Tech=technological.

lack of commitment to preserving the species that they themselves manage. Furthermore, little importance is given to the institutional role, meaning that the TURFs become centers for illegal fishing practices.

4. Discussion

Artisanal fishing is complex, dynamic and contains several coexisting bio-ecological and human aspects; several studies have tried to connect these and interact with them in order to improve our understanding.

However, the integration and practical application of both aspects continue to present a significant challenge for good performance and are also frequently ignored [48,49,84]. The results of our RAPFISH-based research are encouraging and suggest that the application of this technique has considerable potential for the management of TURFs. It is important to emphasize that RAPFISH cannot replace conventional procedures for evaluating stocks, but it is an important tool for evaluating the relative sustainability of fisheries [85]. As far as sustainability is concerned, the results show that the TURFs under analysis are far from

that ideal condition in which they can be exploited over the long term. Nevertheless, they are also a long way from being “unsustainable”. This analysis can therefore be considered as a first step towards improving the six dimensions of sustainability in the study zone, taking into account its findings in each dimension.

4.1. Ecological-fishery dimension

In ecology-fishing terms, most of the TURFs evaluated in Biobio region were classified as “regular” to “acceptable”. In this study, the ecological dimension obtained one of the lowest values (53.86%) compared with the others. The results described in the previous section show that the island sectors tended to be more sustainable: Weste Isla Mocha (‘inse’), Pueblo Norte sector B (‘inse’), Quechol Sur (‘insg’) and Puerto Sur (‘insb’) (Table 6; Fig. 7). According to this, zones noted for the exploitation of Chilean abalone (‘loco’), among other invertebrates, have historically been fishing areas and remain so today. Nevertheless, the TURF system has not been able to meet the needs of those who rely on these benthic resources for their living [67]. The regulations regarding minimum size and density for the main species of invertebrates in the management plan remain the same. Earlier studies also show that the Chilean abalone and limpet populations, among others, are decreasing and also have highly variable size and wellness trends [84]. These studies agree with our empirical analysis of variations

in abundance, densities and harvest figures from technical reports (Fig. 7) and even the perception of local fishers. When there is a lack of scientific data, as in our case and in many artisanal fisheries, the perception of the fisher involved is potentially important as an alternative source of information [2,86].

Attributes such as reorientation to other species (‘Other_Sp’), size variation (‘Ch_Size’) and area proportion (‘Hab_Propor’) push ecological-fishery sustainability towards the positive end of the scale. As far as the first attribute is concerned, other species have frequently been incorporated into management plans in recent years due to an increase in the extraction of macroalgae in the region. Nevertheless, the Chilean abalone is still the most valuable resource and as such is targeted by illegal fishing [87]. Our results also show that attributes such as levels of abundance ‘Abund_Level’ and harvests ‘Harv_Index’ result in weak sustainability in this dimension, associated with the productivity and the TURF’s inability to guarantee ecological sustainability in the long term.

4.2. Economic dimension

According to Schumann [88] the TURF system creates important economic benefits in the form of financial security, stable employment and viable small enterprises that enable fishers to make a living out of fishing. These economic strengths have enabled fishers in the study area to support the implementation of the system. The reality, however, is

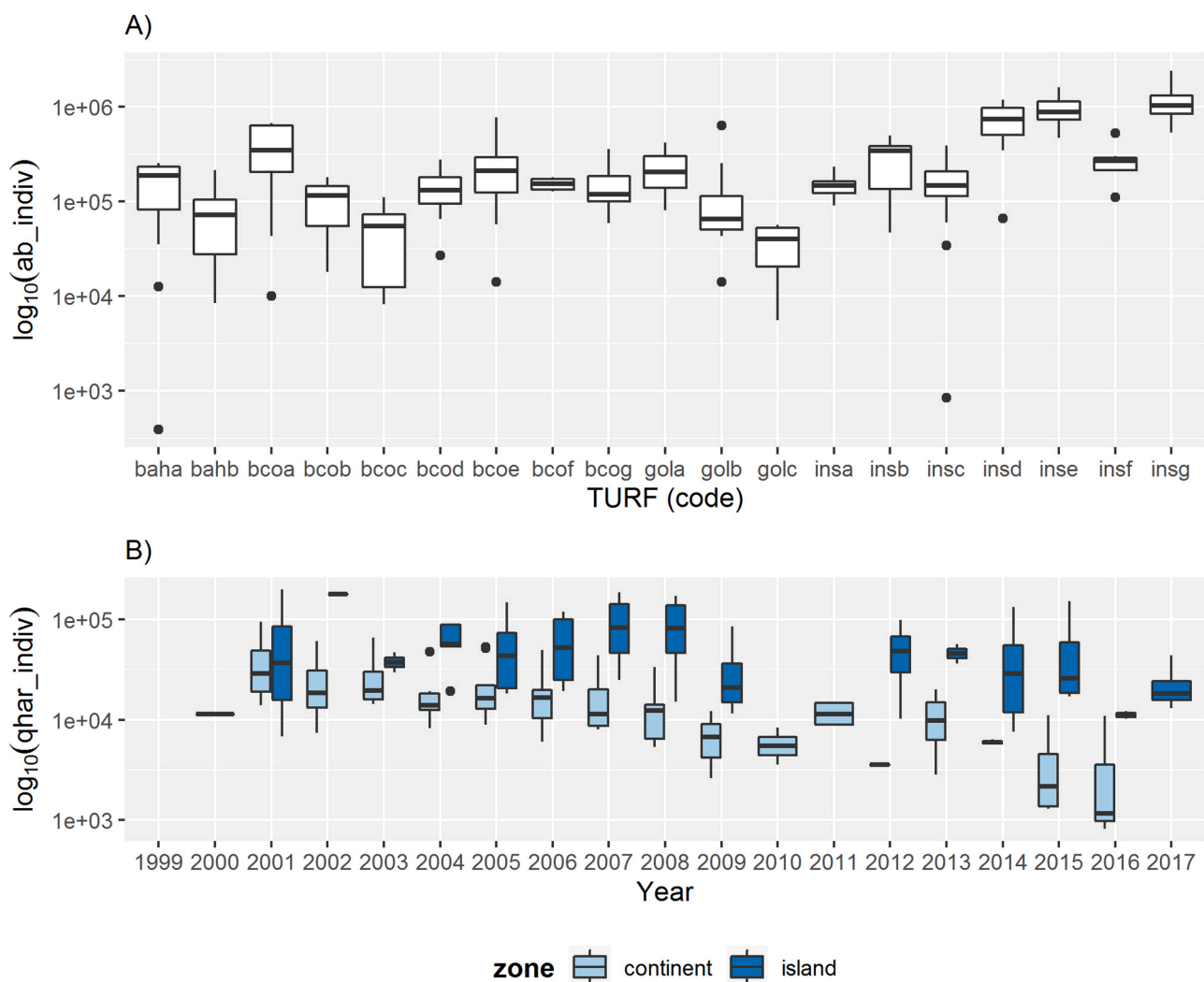


Fig. 7. Local patterns of Chilean abalone’s *Concholepas concholepas* productive situation. Based on: A) abundance of individuals by TURFs and B) yearly capture ‘harvest’ of individuals by zones, both variables with log transformation. Note the different scales in the y-axis between panels A and B.

different as the economic results did not live up to expectations [42]. Our study shows that the economic performance of the TURFs needs to improve, except for a small number of TURFs in which economic sustainability is slightly higher: such as those TURFs located in the Mocha island zone, another on the coast (Rumena, 'bcod') and one in the gulf zone (Punta Lavapie, 'golb') where fishers say that production depends on the available abundance of the commercially important species. Consequently, production variations are reflected in the economic performance of the TURF [70,84]. It is notable that international demand for the Chilean abalone or 'loco' may have reduced legal catches within the TURFs, thus creating perverse incentives to increase illegal fishing and serious under recording of landings [33,36].

In this study, the distribution of the different TURFs in the bidimensional economic ordination (Fig. 3B) shows an orientation towards the positive end, influenced by some attributes. Particularly those related to economic benefits. According to the information compiled in this case study, the average wage ('Average_Wage') and alternative incomes ('Alterna_Income') are included in profitability. This result confirms the findings of Zúñiga et al. [42] who argued that the TURFs are not an economic solution for fishers, but do constitute a complement to traditional fishing [89]. Our results show that attributes such as market type ('Market') and cost-benefit ('Cost_Benefit') reduced the economic sustainability of the TURF due to deficient sales channels and high maintenance costs (e.g., surveillance, monitoring studies and others). Ortiz and Levins [90], concluded that the fishing dynamic in the TURF is not economically sustainable and, therefore, proposed the application of new methods to control access to the resources, such as an "environmental" tax to cover management costs.

4.3. Ethical dimension

In the ethical ordination (Table 6; Fig. 3C), many of the TURFs show reduced sustainability values because many attributes trend towards the bad end of the scale ("weak sustainability"). This dimension also had the lowest value for sustainability (44.05%) compared to the other dimensions. We understand that ethical issues arise, for instance concerning welfare, autonomy and justice relating to the ecosystem, its conservation and sustainability [91] which are necessary for making responsible decisions about the fisheries. To do so the knowledge held by those affected by such decisions and fisheries management must be integrated, taking into account the uncertainties and risks involved [92]. Many actors with their own interests, responsibilities and tasks are present on this stage and this makes it difficult to harmonize economic and conservation considerations with the need for people to make a living [93]. Consequently, one of the common problems affecting TURFs is poaching ('Evol_Poach') of the Chilean abalone, among other invertebrates. Almost all the fishers, whether from outside the area or, indeed, members of organizations participating in the management of the TURF, have caught and sold immature specimens of this mollusk. Even in the close season many fishermen have continued to fish, either clandestinely or with the consent of their leaders [17,38]. It is evident that illegal fishing is one of the biggest challenges to the managers of the TURFs and few investigations have been able to quantify it.

Low variation in ethical sustainability showed by the analysis suggests that a lack of regulatory control is one of the problems of the TURF system. A large number of the TURFs were assigned values below 50%. We have emphasized some of the attributes that bias these values towards the negative end of the sustainability scale, one of these being damage mitigation ('Mitigation'). This is thought to be due to a lack of initiatives to reduce the environmental damage caused by activities such as unsuccessful restocking, pollution, small-scale aquaculture and others. We further note that none of the TURF management organizations reported any damage-mitigation measures in their management plans. Another aspect with a negative influence on the ethical sustainability of TURFs is access to the activity or access to the land by artisanal fishers ('Activ_Access'). Many of the TURFs cover shared spaces and at

times face confrontations as a result, such as the expansion of private concessions in TURFs that were traditionally worked by artisanal fishers, as well as tensions between fishers' unions and indigenous coastal communities where the physical, social and cultural contexts are different [93,94]. In this regard, ownership of coastal land is fundamental for the development of the TURFs. Nevertheless, much of the region is rural and, therefore, there are few opportunities for fishers to negotiate with others or to acquire infrastructure.

4.4. Institutional dimension

Our analysis of the institutional dimension (50.91%) shows that the majority of the TURFs in the region are classified as "regular" to "less sustainable" (Table 6; Fig. 3D). This is the result principally of negative factors in the internal management of the fishers' organizations, as well as deficient communication with other local organizations, both governmental and private (Franco et al., unpublished results). The TURF system, as an example of co-management, is based on the ability of users to manage and self-regulate the use and extraction of resources [95]. Despite highlighting the responsibility and authority of local artisanal communities, the particular social, economic and cultural circumstances of the coastal villages have been ignored [20]. Consequently, possible solutions have mainly exacerbated the original problems or given rise to new difficulties within the system. As a result, Marin and Gelcich [96] carried out an analysis of social networks to try to find the type of relationship that exists between the different actors. In line with their results, we have been able to complement the conceptualization of the system and identify relationships that both facilitate and hinder cooperation between the fishers and other actors. TURFs such as Pueblo norte sector B ('insc'), Los Piures ('bcoe'), San Vicente ('baha'), Punta Cadena ('insd'), Candelaria-Cantera ('bahb') and Puerto Yana ('bcog') obtained the worst values due to frequent problems, including conflicts, the deficient interchanges between members and members of other organizations.

In this context, the RAPFISH results show that some of the attributes have a negative influence on the sustainability of this dimension. Parts of them relate to social networks, principally the channeling of information, and the existence of conflicts either within the organization or outside it. Deficiencies within an organization derive from the manner and frequency with which information is facilitated between fishers ('Access_Communic'). Surprisingly, we found that the TURFs with low scores have a highly centralized management structure with little interaction between their members and other organizations. These results corroborate the ideas of Gutiérrez et al. [97] and Crona et al. [44] who suggest that leadership and better social cohesion between members are fundamentally important for the successful management of benthic fisheries. On the other hand, the lack of commitment and compliance inside or outside an organization has generated the "conflicts" that we see today. This attribute, in the form of internal ('Intern_Conflict') and external ('Extern_Conflict') conflicts, implies the "moderate sustainability" that is found in the majority of the TURFs in the region. The principal conflict reported by fishers is with illegal fishing ('poaching') by outsiders fishing in their TURFs, and even by these fishers themselves. This, of course, affects cooperation and creates tension and even violence among organizations and with coastal communities.

4.5. Social dimension

From a social perspective, the RAPFISH results were favorable for this dimension (61.37%) since a large number of the TURFs are located towards the positive end of the axis (Fig. 3E). Therefore the attributes tend towards "sustainability". TURFs such as Candelaria-Cantera ('bahb') and Dichato ('bcoa'), obtained scores above 70% and the rest of the areas exceeded 50%. We can attribute the social benefits of the TURF system to different variables, such as cohesion among members of

the organization, territorial empowerment and the ability to negotiate with other stakeholders [36]. Our results are consistent with those of Zúñiga et al. [42], Gutiérrez et al. [97] and Arias and Stotz [84] who contrasted the social benefit of TURFs with the poor economic results obtained all over the world. Our multivariate comparative analysis of chosen TURFs in the region revealed a need for different management measures depending on the sector in question.

The good classification in the social dimension may be because of the combined influence of the 'Perman_TURF' and 'Develop_Index' attributes (Fig. 5E). Both complement each other: one corresponds to the functionality of the TURF and the other concerns the physical environment in which it operates. Another attribute that contributed to social sustainability was fishers' practical knowledge ('Input_Expertise'). Neither does the result of this dimension negate the role of the fishers in the TURF as those responsible for making decisions within the space granted to them, although a lack of autonomy in management decisions can be seen, due to scant participation in fishery management activities. Furthermore, fishers' groups could share experiences to improve their abilities if institutional changes were made with a view to strengthening organizational matters. It is important to point out that participation by fishers in the organization ('Particip_Orga') and their level of education ('Educ_Level') made a negative contribution to social sustainability. One unexpected finding was that strengthening of social networks ('Strength_SN') obtained a low score, despite the fact that one of the aims of the TURFs is to generate greater cohesion through networking. Thus many members of the organizations have little or no communication with other local artisanal organizations or even among themselves (Franco et al., unpublished results).

4.6. Technological dimension

The performance of the TURFs was heterogeneous, with some sectors on the region's coastal and island zones achieving higher values (>60%) (Table 6; Fig. 6). Nevertheless, our results show that technological sustainability needs to be improved in most of the TURFs due to problems associated with defective surveillance systems and, consequently, more frequent poaching. To correct these deficiencies, small improvements are continually being made that have little to do with the security of the TURFs. These include the acquisition of boats, motors and/or other items such as diving equipment, but none of the changes have a substantial impact on the activity. Furthermore, capacity (i.e. the number of divers) has varied over the years principally because few retired divers have been replaced by members of their organizations.

The short duration of fishing trips to the TURF ('Ch_Trip_Length') and minimal changes in fishing practices ('Ch_Practice'), are the attributes that have made a positive contribution to each individual TURF. The majority of TURFs are in zones close to the coast, although navigation depends on sea conditions, particularly for more distant ones. The technological aspects of fishing practices have changed little over time, as the activity continues to be a small-scale fishery. On the other hand, secondary effects associated with other activities ('Other_Activ') and the surveillance system ('Sis_Survei') are the attributes that vary the most. This may be explained by the fact that their scores are at the poor end of the scale of attributes. However, the most interesting finding was the difference in surveillance systems ('Sis_Survei') between TURFs, even those managed by the same groups of fishers. TURFs such as Cobquecura sector A ('bcof'), Laraquete ('golg'), Puerto Yana ('bcog') and Punta Cadena ('insd') gave the worst results for this attribute. Care should therefore be taken when interpreting these results. Earlier work suggests that surveillance, productivity and the costs of self-administration tend to be more efficient in TURFs that are closer to the fishing coves [31,48,98]. So, improvements in the internal surveillance system and greater external monitoring could make a substantial contribution to better technological sustainability of the TURFs.

4.7. Sustainability gradient

Thanks to the transdisciplinary approach of the RAPFISH technique, this investigation provided some useful information and enabled us to identify the TURFs that require greater attention. Although the results of the bidimensional ordination (see Fig. 3A-F) show a certain dispersion due to the marked variations between different TURFs in the region, almost all obtained a medium sustainability rating with the exception of four with low ratings (Fig. 8). Furthermore, most of the TURFs proved to have "Low" scores at the ecological, ethical and institutional levels compared with the other dimensions. These results partially coincided with the findings of Arias and Stotz [84] who, using available secondary sources, classified the population, production and economic indicators with "low performance". In contrast, the social and institutional levels were classified as having "High" scores, due to the satisfaction or success perceived by stakeholders. Curiously, the results showed by Gelcich et al. [36] based on the perceptions of the fishers themselves, show that managed areas satisfy the social dimension in particular. This aspect is related to the role of the TURFs, which influence territorial empowerment and cooperative relationships between fishers belonging to the same organization or external organizations or other TURFs. Nevertheless, not all of the sustainability goals were fully met, resulting in a certain dissatisfaction among fishers. It is important to recognize that previous studies were designed with different aims but their findings reflect how the communal system operates. In our surveys, fishers identified various aspects influencing the performance of the TURFs, giving us a better understanding of how they function at the local level. The results of this preliminary investigation, consequently, may be used to identify and improve such characteristics.

Our findings showed that there are TURFs that have managed to maximize the bio-ecological and human factors, however raising the level of sustainability of the different TURFs in the region will be a challenge. We have shown that the TURF system is not just a means of administration, it is also complex and not homogeneous. The estimated sustainability of the TURFs in our RAPFISH analysis showed how TURFs are socially important to fishers, as they provide 'empowerment' to people. To this we can add the permanence of the TURFs, which is the result of a number of ecological, social, economic and ethical factors, among others influencing the system. Some of these dimensions obtained low scores, so TURFs need to strengthen their organizational level, leadership capacity and social networks. The RAPFISH analysis proposes to maintain the surveillance system because it will improve the performance of the attributes, as well as to compare the sustainability changes between the coastal and the island TURFs in the region. In this context the authority should engage in a more effective dialog with fishers who participate in the management of the TURFs for example, by means of periodic consultative workshops. Future works should aim to understand the current situation of the region's TURFs, how they could be improved and which (TURFs) could be viable in the next decades.

5. Conclusions

We conclude from the integrated evaluation of the TURFs system in the Biobio region that there is a relative sustainability gradient, between "Low" and "Medium" sustainability status, that enables us to determine where interventions are more necessary. This study used the RAPFISH technique with transdisciplinary attributes adapted to the TURF system and others deriving from a number of different studies. Among the lessons learned from the application of future RAPFISH analyses, we can recommend that at least the same set of attributes and value definitions should be used, in order to get comparable results and to monitor changes in the sustainability of the TURFs over time. This study provide us with an integral classification of the sustainability status of the TURFs at a local level, however, it should be remembered that the small number of fishers interviewed in certain TURFs limits how far the results can be extrapolated.

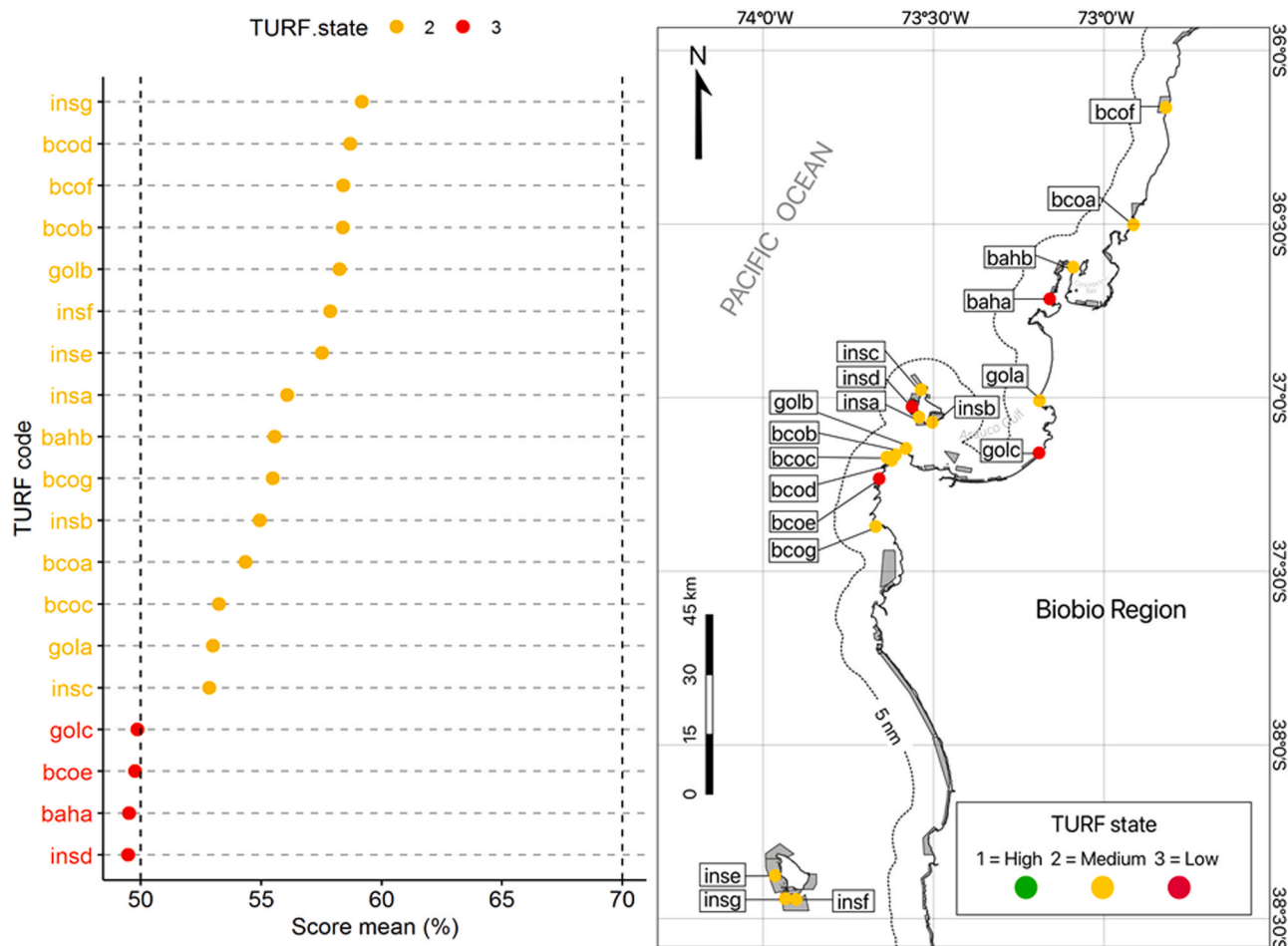


Fig. 8. Reordering to sustainability mean scores by each TURF based on RAPFISH, grouped by status of sustainability (Turf state: 1 = ‘High’, 2 = ‘Medium’ and 3 = ‘Low’) and their spatial distribution. A score of more than 70% indicates a “high” score, 50–70% indicates a “medium” score, and less than 50% indicates a “low” score. TURF codes description: baha=San Vicente, bahb=Candelaria-Cantera, bcoa=Dichato, bcob=Punta Raimenco, bcoc=Bajo Rumena, bcod=Rumena, bcoe=Los Piures, bcof=Cobquecura sector A, bcog=Puerto Yana, gola=Maule, golb=Punta Lavapie, gola=Laraquete, insa=Los Partidos, insb=Puerto Sur, insc=Pueblo Norte sector B, insd=Punta Cadena, inse=Weste Isla Mocha, insf=Quechol, insg=Quechol Sur.

Our results showed that the social dimension had the highest influence on the good performance of the TURFs. Fishery policies should place more emphasis on the social component due to their importance for the sustainability of fishing communities, however, the most challenging dimensions will be the ecological, ethical and institutional dimensions, which were classified from “Medium” to “Low”. In order to ensure the sustainable development of the TURFs it is essential to consider transdisciplinary indicators of the system and in particular to use the vast knowledge possessed by fishers and other stakeholders. Such knowledge will enable us to deal with the complexity of the socio-ecological relationships and to apply responsible practices on coastal TURFs. We recommend to use the six dimensions proposed in this study to monitor and improve the performance of any socio-ecological system and consequently, guarantee the sustainability of the TURFs. This will not only improve governance through greater participation and commitment from fishers, coastal communities, advisers, private and government entities involved in the TURFs, but also will enable the adoption of more environmentally-friendly practices to achieve the sustainability of both the resources and the environment.

CRedit authorship contribution statement

Milagros Franco-Meléndez: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **Luis Cubillos:**

Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing - review & editing. **Jorge Tam:** Conceptualization, Supervision, Validation, Writing - review & editing. **Simón Hernández Aguado:** Conceptualization, Supervision, Validation, Writing - review & editing. **Renato A. Quiñones:** Writing - review & editing. **Aldo Hernández:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank the leaders and members of the artisanal fishers’ organizations in the TURFs of Cobquecura sector A*, Dichato, Candelaria-Cantera, San Vicente, Maule, Laraquete, Bajo Rumena, Punta Lavapie, Punta Raimenco, Rumena, Los Piures, Puerto Yana, Los Partidos, Puerto Sur, Punta Cadena, Pueblo Norte sector B, Weste Isla Mocha, Isla Mocha Sector Quechol and Isla Mocha Sector Quechol Sur for their trust and commitment in sharing their valuable knowledge about the management areas in the Biobio region. We also thank the students and professionals who volunteered their support during the field trips. This work was partially funded by Centro de Investigación Oceanográfica,

COPAS Sur-Austral (ANID PIA APOYO CTCE AFB170006) and the postgraduate scholarship from the Universidad de Concepción provided to MFM.

The authors would like to thank J. Antón for his assistance regarding the map elaboration for the creation of Fig. 1 and Fig. 8.

(*) From 2018, this management area became part of the Ñuble region (Ley Nro. 21.033).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2021.104644](https://doi.org/10.1016/j.marpol.2021.104644).

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