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Does the Chilean TURFs achieve the sustainability of its fisheries? Evaluation of its performance considering the administrative, biological, and economic dimensions of this fisheries regime

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The management based on the allocation of Territorial Use Rights for Fisheries (TURF) is a mechanism used to achieve the sustainable development of the activity and its fisheries. In Chile, the measure began in the late 1990s, and after 30 years, it remains uncertain whether its implementation has achieved this goal. The objective of the present study is to evaluate the historical performance of the MEABR regime across biological, economic, and administrative dimensions. To achieve this, objectives for each dimension were defined in collaboration with the administrative professionals of the regime, leading to the identification of eight evaluation indicators. The performance results indicate that, in general, during the period from 1998 to 2020, the MEABR regime has met institutional objectives at an "acceptable" level in the biological, economic, and administrative dimensions. Specifically, regarding resource performance, it is observed that species such as loco, sea urchin, and the macroalgae kelps have seen increased initial densities within the areas; however, ecological conditions remain below acceptable levels, generating uncertainty about the future state of these resources. The study identifies the level of success of the regime and proposes strategies to reduce gaps to achieve sustainability objectives.

KEYWORDS

MEABR, TURF, performance evaluation, benthic resources, institutional management

1 Introduction

Fisheries are a cornerstone of global food security, providing a critical source of protein for millions of people worldwide. However, overexploitation, habitat degradation, and climate change have placed numerous fish populations at significant risk, jeopardizing the livelihoods of communities that depend on them (Angel et al., 2019; Panudju et al., 2023). Over recent decades, achieving sustainable development has become a central goal for fisheries management (Franco-Meléndez et al., 2021). To support this objective, various frameworks and guidelines have been established, including the *Code of Conduct for Responsible Fisheries* (FAO, 1995) and the *Ecosystem-Based Fisheries Management Guide* (Garcia et al., 2003), among others. These frameworks address the complex interconnections between fishing activities, marine and coastal ecosystems, and socioeconomic dimensions, aiming to ensure the long-term provision of ecosystem services for humanity (Estévez et al., 2020).

Despite these efforts, the implementation of such approaches has proven insufficient in many cases (Defeo and Vasconcellos, 2020; Coll et al., 2013; Pitcher et al., 2009). As result, countries continue to face the challenge of translating conceptual frameworks into actionable strategies and applying effective administrative mechanisms to achieve sustainable fisheries (Estévez and Gelcich, 2021).

Globally, various management strategies have been implemented to ensure the sustainable administration of fisheries. In the mid-20th century, rights-based fishery management (RBFM) models emerged as a promising approach for promoting the sustainable use of marine resources (Cancino et al., 2007; Uchida et al., 2012). These models achieve sustainability by granting exclusive rights to access and extract marine resources (Wilen et al., 2012). Among the most widely adopted of these approaches is the Territorial Use Rights for Fisheries (TURF) model (Franco-Meléndez et al., 2021; Quynh et al., 2017; Auriemma et al., 2014; Uchida et al., 2012; Gelcich et al., 2010; Hilborn et al., 2005). TURFs provide resource users, such as fisher organizations, with the capacity to co-manage activities within clearly defined spatial boundaries. This model promotes the rational use of marine resources by integrating conservation objectives with the economic and social needs of stakeholders (Franco-Meléndez et al., 2021; Charles, 2011; Beitl, 2017).

Integrated management is widely acknowledged as an ideal framework at the international level (Anderson et al., 2015). However, practical decision-making in public resource management frequently faces shortcomings due to inadequate planning and poor coordination (Alencar et al., 2020). Overcoming these challenges necessitates the development of multidisciplinary and multidimensional evaluation models that support the achievement of sustainable development objectives. Such models are crucial for providing a comprehensive understanding of socio-ecological systems, particularly when analyzed from localized perspectives (Franco-Meléndez et al., 2021; Hernández Aguado et al., 2016). In this context, the Performance Evaluation (PE) emerge as an invaluable tool for evaluating the benefits derived from fisheries. The PE models offers critical insights into the interactions between management regimes, external resources, and community dynamics. By doing so, it helps elucidate the distribution of benefits among stakeholders, thereby enhancing the understanding of fisheries' socio-economic and ecological performance (Anderson et al., 2015).

In Chile, the management of marine resources through Territorial Use Rights for Fisheries (TURF) models is operationalized under the Management and Exploitation Areas for Benthic Resources (MEABR) regime, as established by the Chilean General Fisheries and Aquaculture Law. This framework has significantly transformed resource management approaches. However, the outcomes of its implementation have elicited divergent opinions regarding its contribution to the sustainability of hydrobiological resources. Gelcich et al. (2008) via comparative subtidal surveys comparing the abundance of targeted benthic species within MEABR and outside them evidenced a positive effect of the MEABR in central Chile. Arias and Stotz (2020) conducted an integrated analysis by implementing a set of economic, biological, social, and institutional variables across 109 areas located in the Coquimbo and Atacama regions, resulting in generally poor performance for biological and economic dimension but good performance in social and institutional aspects. Franco-Meléndez et al. (2021) analyzed 19 areas in the Bio Bío region using the RAPFISH methodology, demonstrating the success of the administrative measure. In contrast, as well, in Chilean Patagonia, Hamamme and Ortiz (2022) observed no positive effect of MEABR on different indicators (e.g. size, density and weight) of commercial species. Regardless of the results obtained, these studies primarily focus on comparative analysis, defining levels of success based on their own experiences and expectations, which makes it difficult for these results to be considered in decision-making process regarding the management of the administrative measures. These opposing views stem from the absence of explicit objectives and indicators set by the fisheries administration to guide the vision and interpretation under which the achievement of administrative measures should be evaluated. The lack of institutional objectives and indicators has led each study to present different evaluation methods, models, and variables, a situation that does not ensure the generation of appropriate knowledge for management (Bennett et al., 2021).

Development programs and policies are typically designed to change outcomes. Knowing whether these changes are achieved is a crucial question for public policy. Evaluations are part of a broader evidence-based policy-making agenda focused on achieving outcomes, and they are useful in designing and making decisions oriented towards the objectives pursued by the policy or program (Gertler et al., 2016). In this sense, performance evaluation is considered a management tool aimed at providing systematic and continuous information on the achievement of set objectives, whether for a regime, program, or other predefined actions. The purpose is to support decision-making strategies to achieve better efficiency and effectiveness in the use of public resources (Bonnefoy and Armijo, 2005).

The aim of this study is to conduct a comprehensive assessment of the management areas for the exploitation of benthic resources regime in Chile, focusing on their principal benthic resources and

aligning with the expectations of decision-makers. By integrating biological, economic, and administrative dimensions into the performance evaluation of fisheries management measures, this study introduces a novel framework for multidimensional analysis. Finally, as this framework was developed in collaboration with fisheries managers, this approach serves as a valuable tool for decision-makers to evaluate progress toward sustainability objectives and to provide actionable recommendations for enhancing fisheries governance.

1.1 Research setting

Over the past 30 years, the governance of Chilean artisanal fisheries has progressively transitioned toward a collaborative governance model through the adoption of a polycentric system. This framework is characterized by the coexistence of multiple decision-making centers, each operating with a degree of autonomy and implementing self-regulation measures (Gelcich, 2014; Gelcich et al., 2010). The establishment of self-regulation measures in Chile began in 1991 with the implementation of a co-management model aimed at managing benthic resources. This policy granted artisanal fisher organizations exclusive territorial user rights for fishing through the Management and Exploitation Areas for Benthic Resources (MEABR) regime (Gelcich et al., 2012).

The allocation and governance of the MEABR regime are governed by the Chilean General Law of Fisheries and Aquaculture (1991 and subsequent modifications) and further supported by the MEABR Regulation Manual (Supreme Decree N° 355). These regulations require fisher organizations to undertake preparatory studies, including a Base Situation Study (BSS), and submit a management and exploitation plan proposal for the designated area before obtaining usage rights. Once MEABRs are assigned by the Undersecretariat of Fisheries and Aquaculture (SSPA), organizations must produce a Technical Report (TR) annually or biennially. These reports document the biological and fisheries status of the target species, along with socioeconomic and organizational information, and are typically prepared by external consultants. The TRs and their accompanying databases are reviewed and evaluated by the SSPA. These reports are critical for assessing activities within the MEABRs and provide essential data for calculating extraction quotas for subsequent management periods.

Since its inception, the MEABR regime has encompassed a total of 1,459 areas requested by fisher organizations. Of these, some areas remain operational while others have expired. By 2019, the regime included 601 operational management areas, covering approximately 126,000 hectares and benefiting around 7,780 artisanal fishers (Arenas et al., 2021). The MEABR system is recognized as one of the largest co-management experiments globally (Leiva and Castilla, 2002; Prince, 2005; Hilborn et al., 2005). Although 45 benthic species can be included in MEABR management plans, efforts have predominantly focused on the extraction of the "loco" (Concholepas concholepas, Bruguière, 1789) as the primary target species (Castilla, 2006). However, in the last decade, kelps (Lessonia trabeculata, L. berteroana, and L. spicata) have experienced significant growth in harvesting volumes, becoming the most exploited resources under this regime, as reported in annual fisheries statistics (Servicio Nacional de Pesca y Acuicultura (SERNAPESCA), 2023).

After three decades since the MEABR regime's implementation, evaluating its performance is essential for advancing sustainable fisheries along the Chilean coastline. This study assesses its performance from the fisheries administration's perspective, focusing on the administrative, biological, and economic dimensions of the regime.

2 Materials and methods

The historical Performance Evaluation (PE) considered the total universe of 630 management areas that have reported BSS and TR from 1998 to 2020. Evaluations were conducted at the individual MEABR level and grouped at the national level through the normalization and aggregation of information for each area of interest.

Any evaluation process aims to verify the achievement of objectives, expectations, or actions that are intended to be measured (Bonnefoy, 2006; Anderson et al., 2015; Bennett et al., 2021). The Fishery Performance Indicators (FPI) on the other hand, requires a clear understanding of the key factors that best represent the achievement of the proposed objectives and the design of output variables that adequately meet the evaluator's needs (Anderson et al., 2015).

The general methodology for establishing evaluation indicators adopts a structured approach to ensure the consistency, relevance, and reliability of the metrics used to assess performance. This methodology is rooted in principles of scientific rigor and is designed to address the multifaceted nature of evaluations across biological, economic, and administrative dimensions. PE follows a cyclical process, enabling the assessment of progress toward achieving predefined objectives while supporting evidence-based public decision-making to attain a desirable state within the framework of the administrative regime (Figure 1).

2.1 Collaborative workshop

To ensure an accurate assessment of the MEABR regime, a collaborative effort was conducted with public administrators, specifically professionals from the Unit of Benthic Resources within the Chilean fisheries administration under the Undersecretariat of Fisheries and Aquaculture (SSPA). This collaboration aimed to identify administrative objectives across three key dimensions: (i) biological, (ii) economic, and (iii) administrative. The process involved four telematic workshops held between January and February 2021, during which objectives, indicators, reference points, and administrative challenges were discussed. Open-ended questions were utilized in a general panel format to foster dialogue and achieve consensus regarding the MEABR regime's scope as defined by the law.

Objectives: The definition of the MEABR regime's scope was proposed based on a review of legislative information. Institutional

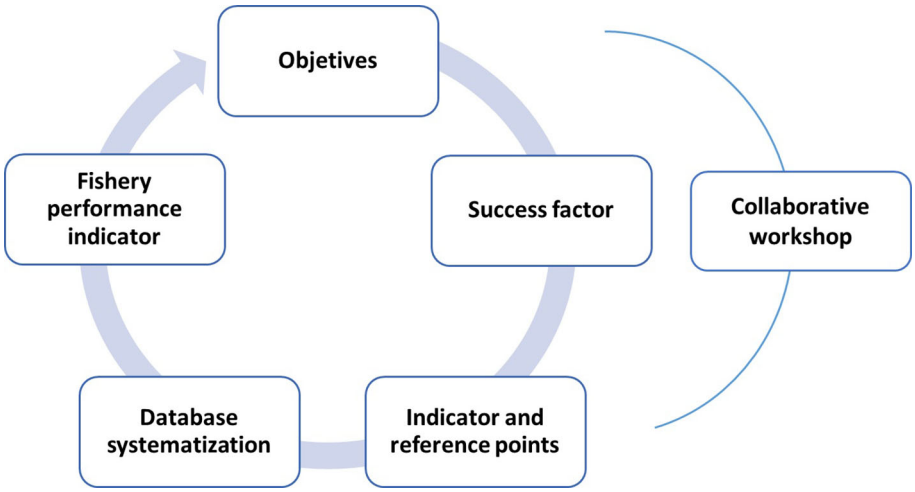

FIGURE 1
General methodology for establishing performance evaluation using fishery performance indicators.

objectives for the regime's evaluation were derived from two primary sources. The first source includes the legislative purposes articulated in the Chilean Fisheries Law (No. 21,134). The second source comprises the perspectives of executive public actors within the administrative regime, who serve as decision-makers. However, these institutional objectives are often formulated broadly, using general concepts open to various interpretations, which introduces ambiguity into the evaluation process (Bonnefoy and Armijo, 2005). To address this issue, the institutional objectives were refined into specific, actionable targets, referred to as "success factors" (Beltrán, 2013). These success factors define the precise conditions that must be met to demonstrate that an objective is being achieved. In collaboration with professionals from the Unit of Benthic Resources, these success factors were identified, reflecting the expected effects for each area of interest from an institutional perspective. To ensure focus and feasibility, the number of success factors considered for evaluation was limited to a maximum of three per area of interest.

Indicators: Based on the definitions of the "objective" and its "success factors", we defined indicators that most accurately reflect the success factors for each objective. For the biological and quality of information indicators, the presence of multiple species necessitated the use of dimensionless indicators to facilitate comparison and aggregation across species. Dynamic comparisons were made, with a focus on the temporal evolution of density. The selection of these indicators was guided by a set of criteria designed to ensure their applicability throughout the evaluation process, including: i) availability of data; ii) ease of use; iii) temporal consistency; iv) data accuracy; and v) relevance to the objective.

Reference points: The expected levels for each indicator were established based on the definitions of the "success factors", and based on prior knowledge of each indicator, and the expectations of public evaluators regarding the level of satisfaction. This approach allowed for the definition of thresholds and goals, serving as benchmarks for evaluating the degree of achievement, thereby ensuring objectivity in the evaluation process (Beltrán, 2013).

2.2 Database systematization

The data used to assess MEABR performance was derived from official reports submitted to the Undersecretariat of Fisheries and Aquaculture, associated to the BSS and TR, which are mandated annually or biennially to sustain the MEABR. Only MEABRs with complete information for all proposed indices were included in the analysis.

The data associated with the biological dimension comes from the direct evaluations of the species within each MEABR, as reported in the BSS and TR. The biological indicators use data sampled to estimate the density and length-weight of individuals of each species within the MEABR. In total, we have 15,525 observations of biological data. For the economic dimension, information was obtained from the TRs, which recorded resource extraction levels, sale prices, general income, and operating costs for each area. Of the 4,865 TRs available, 3,300 included economic data, as the reporting of this information ceased to be required by the state over time. Administrative information was provided directly by the Undersecretariat of Fisheries, comprising 3,769 observations concerning processing times and decisions on the acceptance or rejection of data. Regarding data quality information, this is constructed based on a review of the quality standards provided in the technical reports, focusing on the representativeness of the sample, standard deviations, presence of outliers, and consistency in the reported information.

2.3 Fishery performances indicator

The overall performance evaluation was conducted by considering the biological, economic, and administrative areas, consolidating the information from these areas through the indicators agreed upon in collaboration with the URB-SSPA. The determination of an aggregated performance level required the normalization of the results obtained for each indicator.

Normalization of the indicators was achieved by assigning a scoring scale to the Reference Points, thereby determining the degree of satisfaction associated with the individual fulfillment of each indicator. The scoring scale used ranged from 1 to 3, where 1 represented "below acceptable" reference points, 2 indicated an "acceptable" level, and 3 corresponded to a "desired" level.

The normalized evaluation was derived by summing the scores assigned to the Reference Points (p) for each indicator and comparing them with the maximum attainable value for each within its respective domain. This evaluation covered a time "t" from 1998 to 2020.

$$PE_{MEARB_t} = 100 * \sum_{k=1}^{3} \sum_{p=1}^{N_k} \left(\frac{V_{p,k,t}}{3 * n_{p,k,t}} \right), \ \forall \ t \in \{1998 \ , \ 2020\}$$

Where:

V: Score of the p-th indicator for the k-th evaluation dimension.

n: Number of indicators "p" associated with the k-th evaluation dimension.

Based on the above, a normalized evaluation score was obtained for each dimension, with the evaluation score ranging from 33 to 100 points, where 33 represents the minimum performance value and 100 the maximum. From these scores, and maintaining equidistant ranges, three performance levels were established.

$$PE_{AMERB} \begin{cases} 79 \leq ED \leq 100 & \text{Desirable} \\ 56 \leq ED \leq 78 & \text{Acceptable} \\ 33 \leq ED \leq 55 & \text{Below acceptable} \end{cases}$$

The performance evaluation (PE) is structured into three primary components: (1) an annual performance estimation, which averages the performance of all MEABRs to provide an annual assessment of the regime's performance at the national level; (2) a geographic evaluation (spatially explicit analysis), wherein the annual performance of each MEABR is averaged over time, allowing the identification of spatial clusters in performance; and (3) a species-specific performance analysis, focusing on the most significant species harvested under the MEABR regime. This analysis incorporates both annual performance and geographic evaluation within the biological dimension of the performance assessment. The species considered include *loco* (Chilean abalone, *Concholepas concholepas*), brown Chilean kelps (various species of the genus *Lessonia*), keyhole limpet (*Fisurrella* spp.), *sea urchin* (*Loxechinus albus*), and *Chilean surf clam* (*Mesodesma donacium*).

3 Results

3.1 Collaborative workshop

Based on meetings with decision-makers of the MEABR regime, three overarching objectives were identified, corresponding to the biological, economic, and institutional dimensions. From these objectives, eight indicators were developed (Table 1).

The indicators within the biological dimension are categorized into two key areas. The first focuses on assessing whether the MEABR regime supports the long-term sustainability of biomass, consistent with resource extraction and conservation objectives. Two indicators are utilized: the Historical Density Trend (HDT), which compares current abundance to baseline levels to evaluate changes relative to initial conditions, and the Temporal Density Ratio (TDR), which contrasts current biomass with that of preceding periods. The second area addresses the ecological and spatial conditions necessary to sustain marine species and their food supply. For this purpose, the Area Quality Index (AQI) is employed, linking the biological condition of the resource to the system's carrying capacity.

In the economic dimension, three indicators are employed to address key success factors. To evaluate the economic profitability generated by the MEABR regime, the Benefit-Cost (BC) ratio is used, with reference levels derived from previous studies (Romero et al., 2016) and aligned with public sector expectations. Given the regime's contribution to supplementing fishers' income, the Gross Profit per Partner (GPP) indicator assesses its contribution relative to the national minimum income, with a threshold of 15% used as a benchmark to reflect the activity's income-generating significance (Romero and Melo, 2021). Additionally, the MEABR regime aims to increase resource sale prices compared to open-access (OA) conditions, with a 15% income increase identified as a desirable target.

The administrative dimension pertains to two primary areas of interest: the delivery times (T) of BSS and TR studies submitted to URB-SSPA, and the quality of the information they provide. Regarding delivery times, managing professionals accept delays of up to three months in the submission of BSS and TR studies, while delays exceeding one year are deemed unacceptable according to the authority's standards. The quality of the information was evaluated using a General Quality Information Index (GQII), developed as an aggregate measure of five distinct variables to assess whether the TR and BSS meet the required standards of information quality. These variables include: the sample size of the size structure sampling and its length-weight relationship, which compares the observed sample size to the minimum expected (*i.e.* 150); the size range representation in length-weight sampling and assessing the fitness of the model of the length-weight relationship, assessing the representativeness of the samples collected. Additionally, the density estimation error was evaluated by comparing the study's error margin to the regulatory threshold of 30. A further description of the indicators considered for the GQII is found in the Supplementary Material.

3.2 Performance evaluation

3.2.1 Annual performance

The historical Performance Evaluation covered a total of 630 MEABRs that provided information between 1998 and 2020. The annual evaluation depends on the number of MEABRs that reported data during this period, which ranged from 7 reports in the first year to a maximum of 266 reports in 2018 (Figure 2). It is important to note that, starting from 2019 and continuing through

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TABLE 1 Objectives, indicators and reference points for the evaluation of the performance of the MEABR for the biological, economic and administrative dimension.

Dimension	Objective	Success factor	Indicator	Reference point
Biological	To achieve extraction levels that allow the maintenance or an increase in the biomass of the hydrobiological resources, safeguarding their biological condition and the ecosystem	To maintain or present an upward historical trend in density (HTD) for the main species, based on the fourth follow-up of the first study,	$HTD_{bo} = \left(\frac{1}{S}\right)\sum_{s=1}^{S}\frac{1}{T}\ln\left(\frac{D_{ts}}{D_{0s}}\right)$ HTD: Historical trend in density D: Mean density on year t D_0: Base time density (year 0) T: Accumulated time years (year T- year 0) S= number of species evaluated within the MEABR	HTD >= 0 -0,1<= HTD< 0 HTD< -0,1
		Population density should be greater than or equal to the historical average density of the main resources in the MEABR	$TDR = \left(\frac{1}{S}\right)\sum_{s=1}^{S}\frac{D_{ts}}{\hat{D_{Ts}}}$ TDR: Temporal density ratio D_t: Density on year t D_T: Moving average density on T previous year S= number of species evaluated within the MEABR	TRD > = 1 0,5<= TRD< 1 TRD< 0,5
		Safeguard that the condition index and resource density are maintained or increased over time.	$AQI = \left(\frac{1}{S}\right)\sum_{s=1}^{S}IA_{Es} + IC_{Es}$ AQI: Area Quality index $IC_E = IC_t/IC_{t-1}$; if >=1, IC_E=1, if not, IC_E=-1 $IA_E = D_t/D_{t-1}$; if >=1 IA_E=1, if not, IA_E=-1 IC: Condition Index IA: Abundance (or density) index D_t: Mean density on year t D_t: Mean density on year t-1 S= number of species evaluated within the MEABR	AQI > 0,1 AQI=0 AQI<-0,1
Economic	That the MEABR generates profits for its users through the sustainable use of resources	Annual income is 5 times greater than the costs.	$BC = \frac{IT}{CT}$ BC: Benefit-Cost ratio IT: Total Income CT: Total Cost	BC >= 5 1<= BC< 5 BC< 1
		That the economic contribution of the MEABR is 15% greater than the median national income.	$GPP = \frac{(IT - CT)}{NS}$ GPP: Gross profit per partner NS: Number of partners	730.000 >= GPP 0<= GPP< 730.000 0< GPP
		Obtain the best beach price for each resource, compared to other MEABRs	$TCP = \left(\frac{1}{S}\right)\sum_{s=1}^{S}\left(\frac{pp_s}{\hat{ppr_s}}\right)$ TCP: Beach price ratio pps: Beach price per species pprs: Beach price per region (r) and species (s) S= number of species evaluated within the MEABR	10%<= TCP -10%<= TCP< 10% TCP< -10%
Administrative	Requested Information reported in a timely and appropriate manner for decision-making	Report arrives within the established period, with a tolerance of 3 months	$T = FE - FR$ T: Time FE: Report delivery date FR: Expected delivery date	T ≤ 3 3< T ≤ 12 T > 12
		Information meets the expected quality standards	$GQII = \left(\frac{1}{S}\right)\sum_{s=1}^{S}\left(\frac{1}{Q_s}\right)\sum_{q=1}(PC_{qs})$ GQII: General Quality Index of Information Q= Evaluated quality section PC= normalized quality score S= number of species evaluated within the MEABR	GQII>80% 60%≤ GQII≤ 80% 60%< GQII

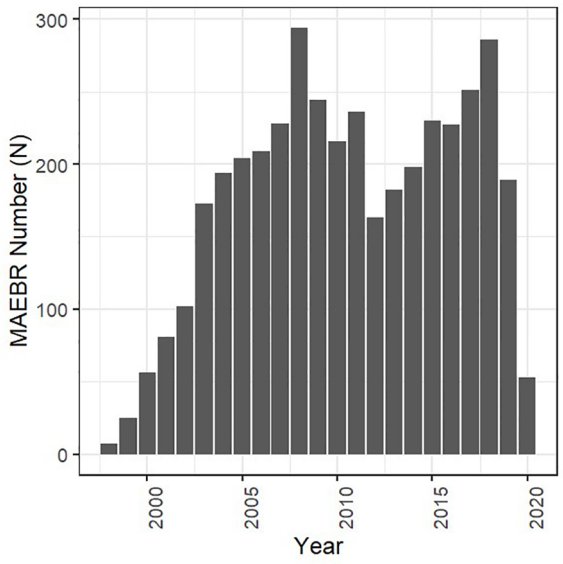

FIGURE 2
Evolution of the number of management areas with technical report submissions per year, (1998–2020).

2020, the amount of reported information decreased significantly due to the global impact of the COVID-19 pandemic.

Overall, based on an annual average of MEABR PE, the regime maintained an "acceptable" level. Annual average scores range between 75 and 80 points. In the last three evaluated periods (2018 through 2020), a steady increase was observed, reaching a maximum of 79 points in 2020 (Figure 3A). Among the evaluated dimensions, the biological domain initially had the lowest performance. In 1998, this dimension scored approximately 35 points, falling in a condition "below acceptable". In 2002, the biological dimension reached an "acceptable" level, varying around 60 points until 2016. However, from that year onward, it showed a declining trend, with an average annual decrease rate of 3.7%, dropping from 63 points in 2015 to 54 points in 2019 (Figure 3B). Performance in the economic domain generally remained within acceptable levels, fluctuating between 72 and 60 points. Over the last decade, these scores stabilized around 64 points (Figure 3C). The administrative domain exhibited the best performance, with an average score of 91 points during the observed period, ranging between 87 and 94 points (Figure 3D).

When the performance indicators for each dimension are analyzed individually, notable differences emerge in their historical trends.

The biological dimension indicates that, overall, the indicators fall within the upper range of "acceptable" levels, suggesting an increase in resource population densities relative to previous periods. Specifically, the Historical Density Trend (HTD) and the Temporal Density Ratio (TDR) achieved average scores of 77 (5.7) and 78 (6.1) points, respectively. The TDR for the most recent year exceeded the "acceptable" threshold; however, the representativeness of this data is limited due to the smaller number of areas evaluated during this period. In contrast, the Area Quality Index (AQI) consistently fell below "acceptable" levels, with an average score of 54 (6.8) points. This underperformance underscores insufficient environmental capacity to sustain adequate food resources, thereby jeopardizing the growth and long-term sustainability of marine populations.

The indicators associated with the economic dimension have remained relatively stable, averaging 68 (6.8) points. However, a declining trend is evident in the Benefit-Cost (B/C) ratio, which dropped from a benefit six times greater than costs during the 2003–2012 period to approximately four times during 2013–2018. Notably, during the 2019–2020 period, revenues experienced a significant rebound, reaching 5.85 times the costs, positioning this indicator at the upper boundary of the "acceptable" category. In contrast, the Gross Profit per Partner (GPP) exhibited a consistent upward trajectory. Average annual revenues increased from approximately US$459 between 2000 and 2010 to over US$900 annually during the 2018–2020 period. This trend reflects substantial growth in income generated per partner, attributable to the continued development of the activity.

The administrative dimension predominantly achieved "desirable" levels, demonstrating strong performance across most indicators. Nevertheless, the General Quality Index of Information (GQII) was rated at "acceptable" levels, with an average score of 88 (3.8) points. Despite this, biases were identified in the quality of information provided by technical agencies, adversely affecting decision-making processes regarding extraction quotas. Furthermore, a 5% decline in GQII scores was observed between 2009 and 2019, indicating a gradual deterioration in the quality of the information over time. Regarding report submission deadlines, compliance was generally maintained. However, certain periods—specifically 2002–2005, 2009, and 2012—experienced declines in performance, reflecting temporary inefficiencies in administrative operations (Figure 4).

3.2.2 Geographic evaluation

During the period 2015-2020, significant geographic differences were observed, reflecting spatial heterogeneity in the development and biological productivity capacity of the resources. In general, MEABRs located in northern (Coquimbo and Atacama regions) and southern Chile (Los Lagos region) exhibited the highest performance levels, with average scores between 76 and 78 points. In contrast, areas situated in the central and central-southern regions of the country (from Valparaíso to Los Ríos regions) were in the range of 68 to 74 points, although some MEABRs scored below 55 points (Figure 5A). The biological dimension showed marked geographic heterogeneity, 58% of the evaluated areas were at "acceptable" levels, with a notable concentration of high-performing MEABRs (85%) in the northern and southern extremes of Chile. However, some MEABRs within these extremes also had performance below acceptable levels, with scores around 55 points. In the region extending from central to central-southern Chile, 63% of the MEABRs were at "acceptable" levels, but only 23% exceeded 80 points. In the continental seas of southern Chile, areas predominantly had scores around 65 points (Figure 5B). Regarding economic dimension, 66% of the areas from central-southern to southern Chile were at "below acceptable"

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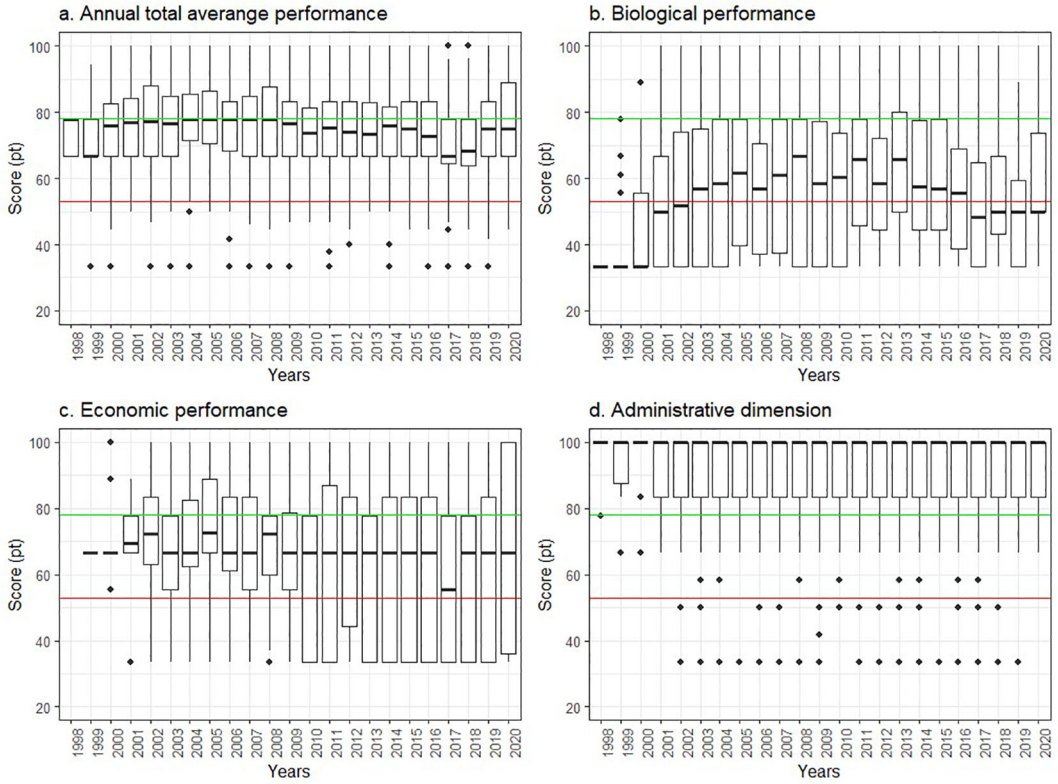

FIGURE 3
Temporal performance of the MEABR regime between 1998 and 2020, regarding: **(A)** Annual Total average; **(B)** Biological; **(C)** Economic; and **(D)** Administrative dimensions. Horizontal green and red lines represent the reference points. Under the red line the performance of the regime is "below the acceptable" level, between the red and green line, the performance is in an "acceptable" level and over the green line, the indicator is in a "desirable" level.

levels, with scores below 55 points. These areas did not meet the economic contribution expected by the State. In contrast, in the regions from central-northern to northern extremities, 76% of the areas were classified as "acceptable" or higher (Figure 5C). Administrative dimension showed a concentration of 86% of the areas at "desirable" levels, with an average score of 97 points. However, in the central part of the country, 14% of the MEABRs were identified with "acceptable" or "below acceptable" levels of compliance, with an average score of 68 points (Figure 5D).

3.2.3 Species specific performance

When we separately analyze the PE of the most important species of the MEABR regime, significant variations were observed, reflecting heterogeneity in the conservation status and biological productivity of each species within the MEABR regime. A detailed review of the main analyzed resources is presented below.

Over the last decade, the loco (*Concholepas concholepas*) has demonstrated an "acceptable" performance, averaging 57 points, placing it at the lower end of this range. Despite this, specific biological indicators, such as Historical Density Trend (HTD) and Temporal Density Ratio (TDR), have maintained "desirable" levels. The HTD revealed a reduction in variability, decreasing from 0.3 in 2003 to 0.001 in 2012. Since 2014, the TDR has shown significant improvement, reaching levels approximately 1.1 times higher than in earlier periods.

The performance evaluation of kelps at the national level is at a "below acceptable" level, with average scores between 45 and 55 points, which should be a warning for managers. From 2014 to 2020, the HTD for macroalgae declined at an annual rate of 0.7%, followed by a slight recovery at 0.4%. However, this trend is not aligned with the TDR, which has displayed high interannual variability but remained at "desirable" levels. The Area Quality Index (AQI) has steadily declined since 2015, reaching "below acceptable" levels, underscoring the deterioration in MEABR conditions for kelps.

The sea urchin (*Loxechinus albus*) has exhibited an overall score of 58 points, positioning it at the lower threshold of the "acceptable" category, with fluctuations ranging from 45 to 65 points over the past decade. Despite this, certain biological indicators remain at a "desirable" level. The Historical Trend of Density (HTD) has shown stable variation around 0.02, indicating no discernible trend and a stabilization towards historical density levels. In contrast, the Trend of Depletion Rate (TDR) has demonstrated a declining trajectory since 2015, now classified as "acceptable." Meanwhile, the Aquatic Quality Index (AQI) for sea urchins has decreased significantly, reaching a "below acceptable" level, with values approaching -2, the lowest possible score. This trend reflects a marked deterioration in the condition of the resource within the MEABRs.

The biological performance of the keyhole limpet (*Fisurrella* spp.) has improved since 2003, moving from a "below acceptable"

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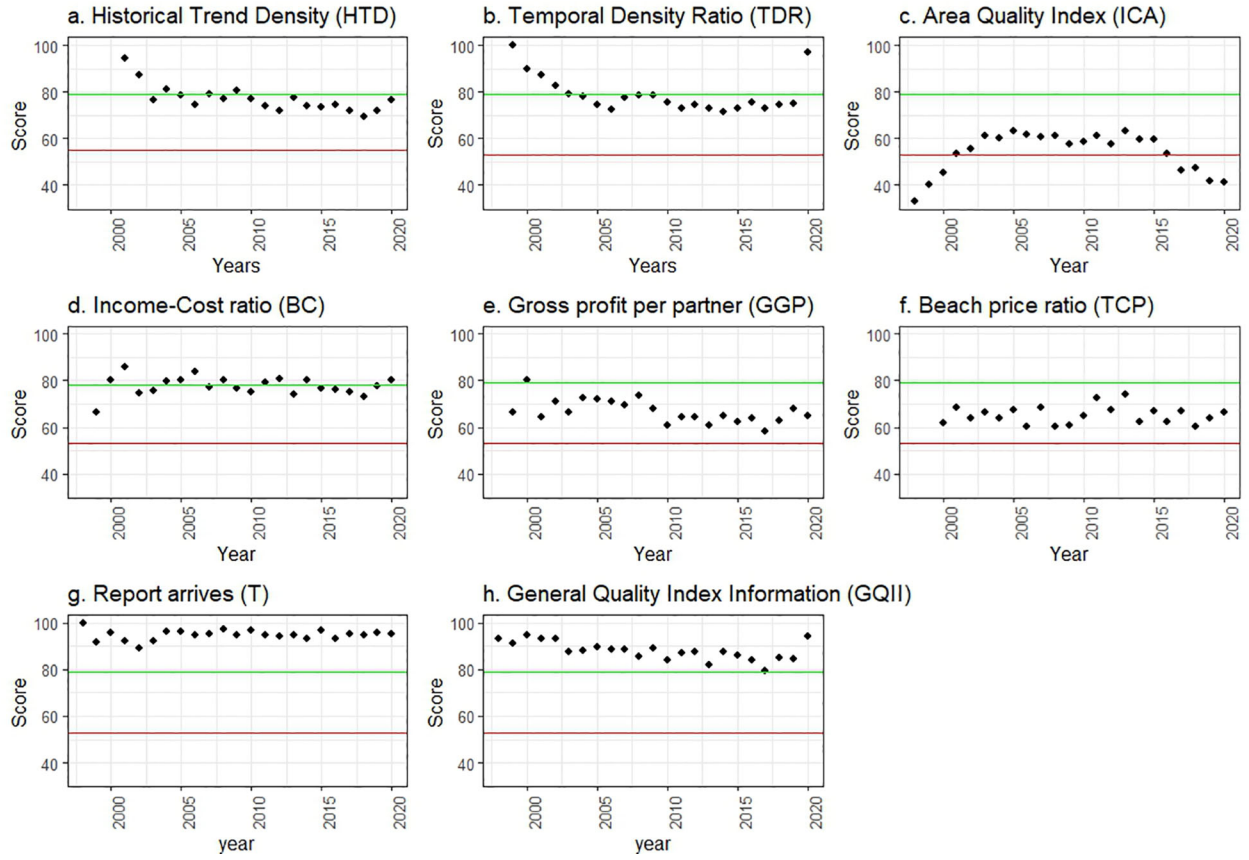

FIGURE 4
Average of Fisheries Performance Indicator to MEABR regime, period 1998-2020, regarding: **(A)** Historical Trend Density; **(B)** Temporal Density Ratio; **(C)** Area Quality Index; **(D)** Income-Cost Ratio; **(E)** Gross profit per partner; **(F)** Beach price ratio; **(G)** Report arrives; **(H)** General quality index information. Horizontal green and red lines represent the reference points. Under the red line the indicator is below the acceptable level, between the red and green line, the indicator is in an acceptable level and over the green line, the indicator is in a desirable level.

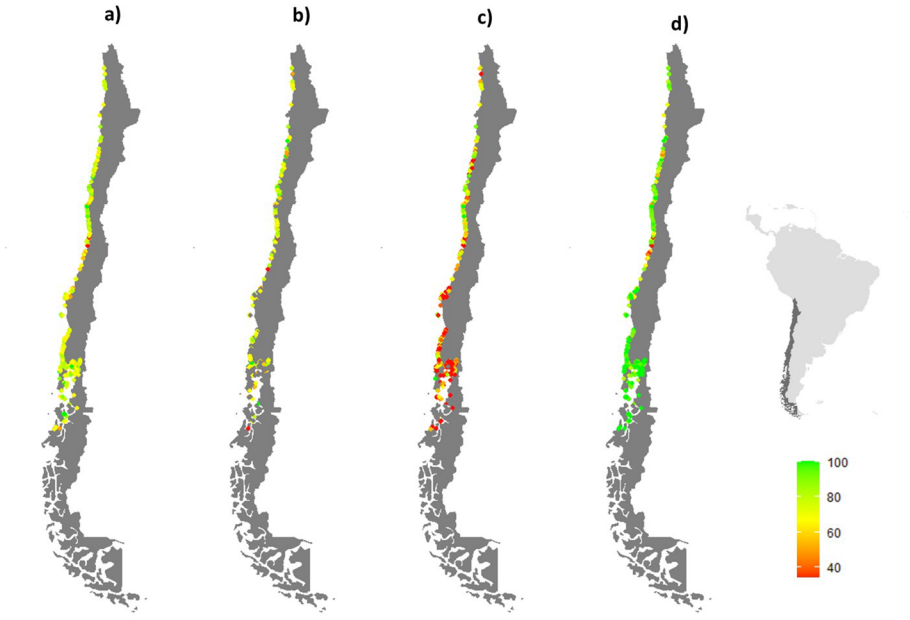

FIGURE 5
Geographic evaluation of the MEABR regime performance by using heat maps for the period 2015-2020, by dimension: **(A)** Total; **(B)** Biological; **(C)** Socio-economic; and **(D)** Administrative.

level (35 points) to an "acceptable" (59 points) level in 2020. The HTD has stabilized at levels like the initial ones, with an increase in recent years. The TDR has maintained values close to 1, at "desirable" levels. However, since 2015, the AQI has shown deterioration, indicating a decrease in the environment's capacity to provide optimal conditions for the resource.

The clams (*Mesodesma donacium*), although corresponding to a fishery developed in a discrete manner and with only a few MEABRs that have it among the mainly extracted species, MEABRs account for nearly 90% of the national landings. Its indicators show significant interannual variability, fluctuating between "acceptable" and "below acceptable" conditions. HTD showed high variability, with "unacceptable" levels between 2009 and 2015, improving to "acceptable" from 2018. The TDR has remained at "below acceptable" levels in most of the evaluated years. Finally, the AQI has decreased since 2015, indicating a deterioration in the environment's capacity to maintain optimal conditions for this resource (Figure 6).

During the period from 2015 to 2020, significant differences were observed in the biological PE resources along the Chilean coast, highlighting spatial heterogeneity in the conservation status and productive capacity of each species. The biological performance of key resources is analyzed below according to their geographical distribution.

The loco resource demonstrated "acceptable" performance with an average score of 62 (16) points. Forty-six percent of the areas evaluated were categorized as "acceptable," and 10% reached "desirable" levels. Geographically, differences in performance were identified. The central-northern region of Chile had a higher concentration of areas with "acceptable" (53%) and "desirable" (16%) performance levels, with an average score of 67 (15). In contrast, the Los Lagos region (southern zone), which hosts most of the management areas, had 46% of areas in the "acceptable" range and only 7% in the "desirable" range, with an average score of 61 (14) points (Figure 7A).

The biological performance of the keyhole limpet species was predominantly "below acceptable," with 67% of areas in this category and an average score of 55 points, placing it at the upper end of this range. However, in the northernmost regions (from Parinacota to Antofagasta), 58% of areas were rated as "acceptable" (41%) to "desirable" (5%), suggesting better biological conditions in this zone (Figure 7B).

For kelps, the performance during 2015-2020 was predominantly "below acceptable," with 79% of areas in this category and an average score of 49 (11) points. HTD indicated stability, with density levels comparable to those recorded during initial assessments. Conversely, other areas exhibited density reductions of approximately 10%, reaching levels classified as "below acceptable" relative to their initial states. Despite this decline in density, the TDR remained at "acceptable" levels, suggesting that densities were still comparable to historical benchmarks. However, AQI presented values below -1, highlighting a significant decline in the environment's capacity to sustain optimal conditions for the biological and productive development of these resources (Figure 7C).

The sea urchin resource had a biological performance with an average score of 58 points, at the lower end of "acceptable" levels. Sixty-one percent of areas were rated as "below acceptable." Despite this, the indicators associated with the biological state remained at "desirable" levels. During 2015-2020, significant geographical variations were observed, with regional scores ranging from 48 to 72 points, fluctuating between "below acceptable" and "acceptable,"

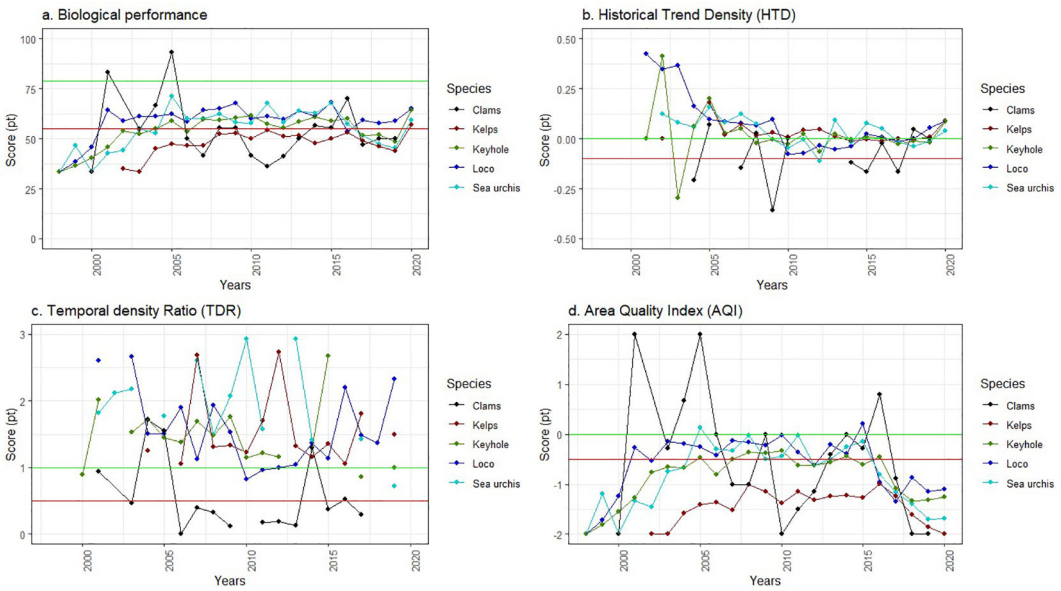

FIGURE 6
Biological performance evaluation of the main resources extracted from MEABR, between 1998 and 2020, regarding: **(A)** Biological performance; **(B)** Historical trend density; **(C)** Temporal density ratio; **(D)** Area quality index. Horizontal green and red lines represent the reference points. Under the red line the indicator is below the acceptable level, between the red and green line, the indicator is in an acceptable level and over the green line, the indicator is in a desirable level.

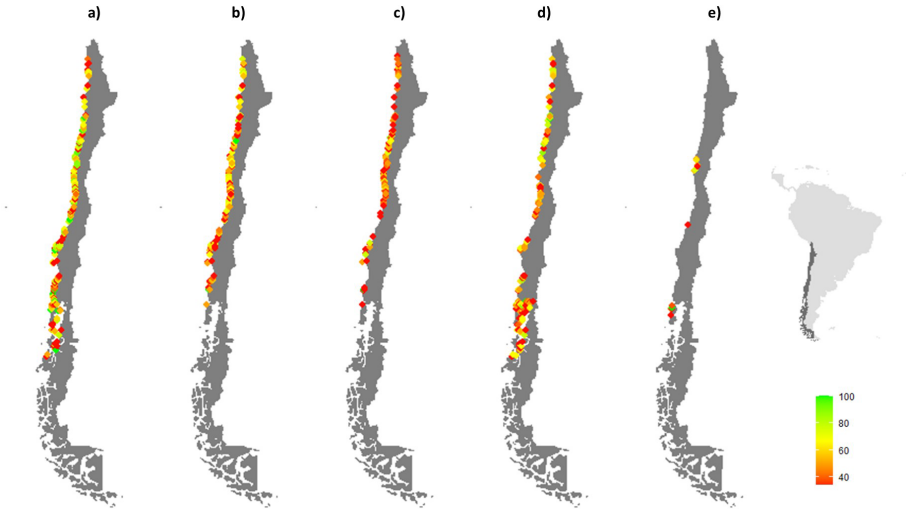

FIGURE 7
Evaluation of Biological Performance (score: 33 – 100) Using Heat Maps for Major Resources Extracted from the MEABR Regime: **(A)** Locos; **(B)** Keyhole limpets; **(C)** Kelps; **(D)** Sea urchins; **(E)** Clams, during 2015-2020.

suggesting a complex range for the sustainability of the activity. The northern zone had the highest performance level for the resource, with 89% of its areas at "acceptable" (54%) to "desirable" (35%) levels (Figure 7D).

The clam's performance was predominantly in a "below acceptable" condition, with the Los Lagos region showing the poorest performance. HTD and TDR in the Coquimbo region remained at "acceptable" levels, while in the Los Lagos region, it was "below acceptable". The AQI also showed poor performance in both regions, reflecting a complex biological-productive environment for this resource (Figure 7E).

4 Discussion

In the past, fisheries management and governance were primarily centered on ensuring biological sustainability to maximize harvests while achieving economic efficiency. However, contemporary governance approaches increasingly emphasize the dual objectives of ecological sustainability and human well-being (Bennett et al., 2021). This paradigm shift reflects a growing recognition of the need for more holistic and integrated management strategies that balance ecological and socio-economic outcomes.

The Performance Evaluation (PE) serves as a critical tool for assessing the extent to which fisheries management objectives are achieved. By establishing a baseline, PE reveals progress toward institutional goals and facilitates the development of strategies to address gaps in achieving desirable outcomes. The results of this study provide a comprehensive historical perspective on the evolution of the MEABR regime, offering insights into its effectiveness in meeting sustainability objectives. From the perspective of decision-makers, the findings reduce uncertainty regarding the success of this management measure, demonstrating that while the MEABR model is subject to improvement, it has successfully maintained fisheries at "acceptable" levels. These levels align with the administrative authority's expectations across biological, economic, and administrative dimensions.

Integrated management is widely regarded as a global ideal in resource governance (Anderson et al., 2015). However, in practice, public resource management decisions often suffer from inadequate planning (Alencar et al., 2020). It is, therefore, crucial to advance multidisciplinary and multidimensional evaluation models that support sustainable development and promote a more integrated understanding of resource systems (Franco-Meléndez et al., 2021; Hernández Aguado et al., 2016). In this context, the multidimensional analysis of the MEABR regime enabled the establishment of clear institutional and formal objectives across three evaluation dimensions, contributing to a transition toward a public management model that transcends traditional decision-making focused solely on biological parameters, such as quota allocation.

The multidimensional performance evaluation contributes to a more integrated governance model. Previous studies have highlighted the positive effects of Chilean MEABRs on ecological, economic, and social dimensions, including conservation benefits and the regime's ability to foster self-organization among fishers (Gelcich et al., 2008; Defeo and Vasconcellos, 2020; Basurto et al., 2013). Additionally, MEABRs represent the first legal framework for co-management in Chilean fisheries governance, further underscoring their importance in advancing sustainable practices (Defeo and Vasconcellos, 2020).

From a biological dimension of our performance analysis, the key MEABR resources evaluated in this study demonstrated either positive trends or stable temporal variations in density indices. These findings indicate a positive conservation effect on these resources within the MEABR regime. Such trends are consistent with the effectiveness of co-management mechanisms, as evidenced by sustained or increasing resource densities in many instances.

However, certain biological indicators have negatively influenced the overall performance. Although population densities of key resources, including loco, sea urchins, limpets, and others, have remained stable or increased, the Area Quality Index (AQI) has consistently fallen below acceptable thresholds.

The AQI can be considered an indicator of the carrying capacity of MEABRs, as it links changes in species density with variations in their condition index. AQI results may indicate insufficient environmental capacity to provide optimal growth conditions for resources, suggesting the need to manage not only the primary resources within MEABRs but also to address the ecological requirements of these resources. For example, the loco (*Concholepas concholepas*) is a carnivorous snail that feeds on bivalves, barnacles, and tunicates. The absence of sustainable management ensuring food availability for the loco or other exploited species within the MEABR could ultimately affect the system's carrying capacity.

One critical factor contributing to the low AQI performance for various analyzed species could be the interaction between the extraction of multiple resources within each MEABR, which are often managed independently. For instance, the increased harvesting of brown algae, a resource that has become the most exploited species (in terms of annual tonnage) within the MEABR over the last decade (Servicio Nacional de Pesca y Acuicultura (SERNAPESCA), 2023), may have a general impact. Brown algae are foundational species, and their extraction has been shown to affect commonly exploited species within MEABRs, such as the loco (Bularz et al., 2022). Understanding and managing the interconnections between different components of MEABR diversity according to the extracted resources could lead to better resource management within each MEABR.

The performance evaluation of brown algae within the MEABR regime was conducted using aggregated data from the *Lessonia* genus, without differentiating between intertidal species (*Lessonia berteroana* and *L. spicata*) and subtidal species (*L. trabeculata*). This aggregation may lead to inaccuracies in the assessment, as species-specific responses to management practices can vary significantly. Evidence suggests that intertidal and subtidal algae exhibit distinct recovery dynamics in response to fishing pressure. Intertidal algae, for instance, have demonstrated relatively rapid recovery after harvesting (Canales et al., 2018). In contrast, subtidal algae exhibit a slower recovery rate following extraction (Bularz et al., 2022). Despite these differences, the current evaluation provides a general understanding of brown algae performance, which remains at a "below acceptable" level within the MEABR regime. This poor performance is primarily driven by the Area Quality Index (AQI), even though density indices such as the Historical Trend of Density (HTD) and the Temporal Density Ratio (TDR) were observed at desirable levels. Notably, increased densities in brown algae populations have been interpreted as a negative signal when growth predominantly consists of juveniles (Figueroa-Fábrega et al., 2017). The AQI, which incorporates indicators of body condition, likely reflects a trend of population "juvenilization," characterized by low individual biomass relative to size. The underperformance of brown algae within MEABRs is a critical concern for fisheries managers, as artisanal harvesting represents the primary threat to these species along the Chilean coast (Krumhansl et al., 2016). This situation underscores the need for revisions to algae management strategies under the MEABR and other fisheries regimes. While the current condition of brown algae within MEABRs is suboptimal, evidence suggests that their status is comparatively better than under other Chilean fisheries management systems, such as Management Plans (González-Roca et al., 2021; Gouraguine et al., 2021). These findings highlight the potential of the MEABR to support improved conservation outcomes, provided that management practices are adapted to address the specific vulnerabilities of intertidal and subtidal algae species.

Keyhole limpets were analyzed similarly to brown algae, with the evaluation conducted at the genus level (*Fissurella*), integrating multiple species. The four most harvested species in MEABRs are *F. latimarginata*, *F. cumingi*, *F. nigra*, and *F. maxima*. All these species are predominantly subtidal; however, some intertidal species, such as *F. crassa*, are also harvested. Generally, keyhole limpets within MEABRs have been reported to perform better than in open-access fisheries (Castilla and Fernandez, 1998; Gelcich et al., 2008; Defeo et al., 2014; Andreu-Cazenave et al., 2017). This study reinforces this evidence, as our analysis found that keyhole limpets achieve an "acceptable" performance level within the MEABR regime. However, certain issues related to illegal fishing within MEABRs must be addressed in the management of these resources (de Juan et al., 2022), as this is a common problem within the MEABR (e.g., in the case of the loco; Romero et al., 2022).

Regarding the macha (*Mesodesma donacium*), our results indicate an overall performance level categorized as "below acceptable," which aligns with the reported collapse of this fishery in Tongoy Bay, Chile (Aburto and Stotz, 2013). The collapse observed in Tongoy Bay has been associated with a lack of recruitment and high natural mortality rates (Aburto and Stotz, 2013). These highly variable conditions might be a general characteristic of *macha*, potentially explaining the significant interannual variability observed in the performance analysis conducted in our study.

In the economic dimension, performance has generally remained within acceptable levels, with the regime generating positive returns for its users, as previously reported (Romero and Melo, 2021). However, as evidenced in this evaluation, there are sectors where economic benefits fall below desirable thresholds. While the MEABR regime represents an economic activity, its purpose is not solely to maximize short-term profits but rather to ensure the conservation and sustainable management of fishery resources. This perspective aligns with various studies highlighting the non-intensive nature of extractive activities under this regime. Romero and Melo (2021) emphasize that the MEABR regime provides supplementary income to artisanal fishers rather than serving as their primary source of income. Thus, fishers do not rely exclusively on MEABR fisheries as their sole source of revenue, contrary to assumptions made in other contexts (Arias and Stotz, 2023). Furthermore, the greater the availability of alternative economic activities (including fisheries under other regimes), the lower the likelihood of external threats such as illegal fishing. This approach has significant implications for resource management and

utilization within the MEABR. Fishers operating under this regime are not committed to intensive exploitation but tend to adopt moderate and sustainable resource-use strategies (Carpenter and Seki, 2011). In this context, resource-use indicators may exhibit biases related to fisheries administration decision-making if a lack of extraction is mistakenly interpreted as a lack of resources within the MEABR.

Geographically, significant differences in economic performance are evident, with northern Chile exhibiting the highest profitability in the sector. This observation aligns with findings by Arenas et al. (2021) and Romero et al. (2020), who reported similar patterns regarding the distribution of economic benefits. The results in northern Chile are primarily attributed to income derived from the extraction of brown algae, an economic activity concentrated in the northern regions of Antofagasta, Atacama, and Coquimbo, which account for over 80% of this activity (Romero et al., 2020). Additionally, the contribution from *loco* (*Concholepas concholepas*) extraction in the Coquimbo region, which accounts for approximately 22% of the total national landings, further supports this trend (Romero et al., 2019).

The administrative dimension of the MEABR regime has notably outperformed other domains, achieving "desirable" levels, as observed here and in other studies (Arias and Stotz, 2020). The integrity of information and the timeliness of report submissions are well-managed, although some anomalies have been identified. It is essential for future evaluations to incorporate quality indicators that assess not only the temporal relevance of information but also the quality and representativeness of the data used to analyze the state of resources.

The comprehensive analysis offers valuable insights into the current status of the MEABR regime and identifies opportunities for its improvement. It is important to emphasize that the indicators considered in the analysis indicate potential areas for enhancement. For instance, the biological indices primarily focus on density, with one case relating the temporal change in density to the body condition index (AQI). However, the biological dimension could be expanded to include other relevant factors, such as the size structure of the population. This would provide information about the presence of mature individuals and the recruitment of new individuals into the population, offering a more complete understanding of the resource dynamics. Moreover, it is essential to prioritize the inclusion of sensitive and high-risk indicators, particularly those related to data quality, ensuring a realistic and accurate assessment of the data provided by the Territorial Resource (TR) entities.

Nevertheless, several limitations must be addressed, particularly those arising from the lack of data necessary to estimate or propose additional indicators. The absence of clear standards and robust procedures for the collection of biological and economic data introduces biases into the methodologies employed and compromises the presentation of information, which ultimately affects the analysis and interpretation of results (Stotz et al., 2005; Parma and Orensanz, 2012; Ariz et al., 2018). Furthermore, the lack of institutional requirements for the submission of information exacerbates the issue, particularly in the economic dimension, limiting the availability of data and reducing the certainty of its results. Therefore, it is imperative to prioritize the improvement of data quality in future evaluations. This could involve the development of quality standards and the establishment of clear procedures for data collection, engaging both the fisheries systems and their stakeholders, including fishers (Bennett et al., 2021).

One significant advantage of the comprehensive analysis over the current administrative approach lies in its broader evaluation horizon, which extends beyond the mere establishment of quotas for each species exploited within the MEABR. By incorporating economic and administrative dimensions, the analysis considers factors related to the incentives that fishers face when making decisions about managing these areas. Although this study offers a generalized overview of the evolution of the MEABR regime, future research should delve deeper into the factors that enhance the success of achieving its objectives, exploring additional aspects that could further strengthen the governance and sustainability of the system.

5 Conclusion

The multidimensional performance evaluation, grounded in the state's objectives, serves as a valuable tool for fisheries management. It provides crucial insights into the extent to which the expected sustainable development goals for the MEABR regime have been achieved, while also highlighting key gaps associated with the measure. By identifying these gaps, the evaluation offers decision-makers a robust foundation for developing targeted strategies and programs that address the identified needs, ultimately enhancing the effectiveness and sustainability of the management regime.

In general, the MEABR regime has demonstrated "acceptable" performance, successfully meeting the objectives of public institutions across various dimensions. However, areas for improvement have been identified, particularly within the biological dimension and the economic sustainability of certain sectors.

To enhance performance outcomes, it is essential to improve the systematization and quality of the data, ensuring both the accuracy and effectiveness of future performance evaluations. Adopting a continuous improvement framework, alongside the implementation of a robust action plan, will be crucial for ensuring the long-term sustainability and success of the MEABR regime.

Furthermore, to refine performance evaluation processes and increase the representativeness of the results, it is necessary to incorporate additional indicators that either complement or replace the current metrics. It is also advisable to persist in evaluating the causal factors that contribute to the success of certain areas, providing valuable insights for decision-making on which factors require strengthening to optimize the performance of the MEABR regime.

Given the defined objectives across the three key dimensions, we propose that the institution consider adopting an integrated

management evaluation for the MEABRs. This approach could help address one of the principal challenges in implementing an ecosystem-based approach to fisheries management in Chile.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.subpesca.cl/transparencia/solicitud_informacion.html.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements. Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because the work was conducted with databases and not directly with animals.

Author contributions

PR: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. BB: Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. GA-P: Conceptualization, Investigation, Supervision, Writing – review & editing. DM: Conceptualization, Data curation, Formal analysis, Software, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2025.1502422/full#supplementary-material

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