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Review of the Ecological and Ecosystem-level Reference Points applied to trawl fisheries and their potential implementation in the Patagonian scallop (*Zygochlamys patagonica*) fishery

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Informe

REVIEW OF THE ECOLOGICAL AND ECOSYSTEM-LEVEL REFERENCE POINTS APPLIED TO TRAWL FISHERIES AND THEIR POTENTIAL IMPLEMENTATION IN THE PATAGONIAN SCALLOP (*Zygochlamys patagonica*) FISHERY

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RESUMEN. Revisión de los Puntos de Referencia Ecológicos y a nivel de Ecosistema aplicados a las pesquerías de arrastre y su posible implementación en la pesquería de vieira patagónica (*Zygochlamys patagonica*). El presente informe busca ir aportando información y posibles soluciones a las condiciones 6 y 7 realizadas en la última re-certificación de la pesquería de vieira patagónica por parte del Marine Stewardship Council (MSC). Existe una creciente preocupación en todo el mundo por los posibles efectos perjudiciales de la pesca de arrastre de fondo sobre los ecosistemas bentónicos, lo que plantea la necesidad de una gestión pesquera basada en los ecosistemas. Se han propuesto Puntos Ecológicos de Referencia (PER) como herramienta para mantener las pesquerías dentro de un rango de uso sostenible de los ecosistemas del fondo marino. Esta revisión examina los PER aplicados a las pesquerías de arrastre de fondo, centrándose en su posible aplicación en la pesquería de vieira patagónica (*Zygochlamys patagonica*). Analizamos (1) la literatura científica sobre indicadores ecosistémicos de los impactos de la pesca de arrastre, (2) los PER utilizados en las pesquerías de arrastre certificadas por el MSC, y (3) los PER factibles para la pesquería de vieira patagónica en base a los datos disponibles. Las pesquerías certificadas por el MSC utilizan una amplia gama de modelos como PER, mientras que indicadores más sencillos como la biomasa de la comunidad bentónica y la riqueza de especies resultan prometedores para el desarrollo de PER según recientes artículos científicos. Nuestros análisis preliminares no muestran relaciones importantes entre el esfuerzo pesquero (por año y unidad de manejo) y los indicadores explorados, sugiriendo que podrían ser utilizados para establecer los PER a partir de los umbrales de variación natural (Condición 6). Sin embargo, dado que la mayor resolución de la información disponible está a escala de unidad de manejo, sería deseable poder establecer estos valores utilizando la serie temporal completa y las posiciones de cada lance. Esto permitiría descartar las áreas con mucha influencia pesquera (dando mayor confianza a los valores umbrales) y contar con una mayor resolución espacial que posibilitaría desarrollar Reglas de Control de Captura más ajustadas (Condición 7). En resumen, los resultados de nuestro informe sugieren que existen indicadores simples con una buena cobertura temporal que podrían ser utilizados para, a partir del rango de variación natural, establecer los PER.

ABSTRACT. This report aims to provide information and potential solutions regarding Conditions 6 and 7 raised during the last re-certification of the Patagonian scallop (*Zygochlamys patagonica*) fishery by the Marine Stewardship Council (MSC). There is growing global concern about the potential adverse effects of bottom trawling on benthic ecosystems, highlighting the need for ecosystem-based fisheries management. Ecological Reference Points (ERPs) have been proposed as a tool to keep fisheries within a sustainable range of seabed ecosystem use. This review examines ERPs applied to bottom-trawl fisheries, focusing on their potential implementation in the Patagonian scallop fishery. We analyze (1) the scientific literature on ecosystem indicators of trawling impacts, (2) the ERPs used in MSC-certified bottom-trawl fisheries, and (3) feasible ERPs for the Patagonian scallop fishery based on available data. MSC-certified fisheries employ a wide range of models as ERPs, while simpler indicators—such as benthic community biomass and species richness—show promise for ERP development according to recent scientific studies. Our preliminary analyses reveal no significant relationships between fishing effort (per year and per management unit) and the indicators explored, suggesting they could be used to establish ERPs based on natural variation thresholds (Condition 6). However, since the highest resolution of available data is at the management-unit scale, it would be preferable to determine these values using the full time series and individual haul positions. This would allow excluding heavily fished areas (increasing confidence in threshold values) and provide finer spatial resolution to develop more precise Harvest Control Rules (Condition 7). In summary, our findings suggest that simple indicators with robust temporal coverage could be used to establish ERPs based on natural variation ranges.

Palabras clave: Pesquerías bentónicas; certificación MSC; indicadores; puntos de referencia; reglas de manejo
Key words: Benthic fisheries; Indicators; management rules; MSC certification; reference points

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INTRODUCTION

The potentially detrimental effects of bottom trawling on benthic ecosystems have been registered by marine researchers since the early 1070s (see Jones 1992), but the concerns of pervasive, widespread and long-lasting effects on ecosystem structure and function strongly increased during the last 2 decades, fueling strong public campaigns, and driving to the restriction or even prohibition of bottom trawling in some countries and regions (McConnaughey *et al.* 2020). Bottom trawling leads to the remotion, kill or damage of a variable proportion of the resident biota and to the disturbance of the seafloor sediment. Thus, as any natural or anthropogenic disturbance, it has the potential to affect community structure, environmental complexity and biogeochemical cycles (Olsgard *et al.* 2008; Morys *et al.* 2021; Bradshaw *et al.* 2021). In fact, as expected by ecological disturbance theory (Sousa 2001), the most common reported effects of bottom trawling include changes in community structure, leading to the dominance of small-bodied, short-living opportunistic species (Rijnsdorp *et al.* 2018).

Despite the generalized perception of the detrimental effects of bottom trawling, the magnitude of the effects is known to be strongly variable among locations. At a particular location, effects are driven by the design of the gear and its operation, the frequency and intensity of trawling, the biology of the biota (which influences depletion and recovery) and the natural physical regimes of the location (e.g., the background level of natural disturbance; McConnaughey *et al.* 2020). Environments exposed to high background levels of environmental disturbance, for instance, are expected to have less sensitivities to bottom trawling than complex and (otherwise) stable biogenic habitats. In addition to the variability among locations, different components of a given location can have different sensitivity to bottom trawling. Thus, in order to measure and eventually reduce bottom trawling impacts, indicators that might describe the state of ecosystem components or attributes and provide guidance for management decision-making are needed.

Traditionally, fisheries were managed focusing on the target stock status. In this context, Biological Reference Points (BRPs) are relatively simple metrics, or measurements, that allow to relativize the stock status from a biological perspective (Gabriel y Mace 1999) to identify desirable levels of stock biomass or fishing mortality for achieving objectives (Guo *et al.* 2019). During the last decades, the change to an ecosystem-based management, grounded in acknowledging that the different components of an ecosystem are interconnected and thus interdependent, drove the need to move beyond single-species BRPs. In this context, Ecological Reference Points (ERPs, also known as Ecosystem-Based Reference Points or Ecosystem-level Reference Points; Guo *et al.* 2019; Morrison *et al.* 2024) can be defined as: an ecosystem harvest level or indicator with one or more associated benchmarks (i.e., targets, limits) or thresholds that are used to identify, monitor, or maintain desirable ecosystem conditions and function (Morrison *et al.* 2024). Not surprisingly, there has been a growing discussion in the scientific literature about potential ERPs that leverage effort in collecting them, their simplicity, and their usefulness to represent fishing impacts on seabed habitats. As a result, several ERPs have been proposed as the best option to grant a decision-making process that promotes sustainable management of seabed ecosystems as a whole.

In order to provide information and potential solutions regarding Conditions 6 and 7 raised during the last re-certification of the Patagonian scallop (*Zygochlamys patagonica*) fishery by the Marine Stewardship Council (MSC), in this work we (i) review the different indicators that have been proposed in the scientific literature to be used as ERPs in the context of fishery management to assess the impact of trawling on benthic ecosystems; (ii) review the ERPs used in the management of trawl fisheries certified by the MSC and (iii) explore, based on the properties, strengths and weaknesses of each of these indices as well as on the available empirical data, which of these indices could be applied in the management of the Patagonian scallop fishery, *Zygochlamys patagonica.*

ERPs proposed in the scientific literature

The increasing number of bottom trawl fisheries implementing ecosystem-based management plans is urgently demanding fishery science to develop and test ERPs (Guo *et al.* 2019). As a startpoint, ERPs should be based on indicators that not only consider the abundance of a single target species, or the abundance of individual benthic community components, but also reflect potential changes in productivity, trophic structure, or ecological/ecosystem functions. In this context, there are strong tools that have been extensively used by expert evaluation of the sensitivity and impact of specific bottom trawl fisheries on the whole ecosystem (e.g. as part of the periodic assessment of fishery performance and impact; see Mackinson *et al.* 2018). These tools can integrate a great amount of information in complex models, particularly for trophic structure/energy flows (e.g., network models, ecopath, among others). The complexity of these models, nevertheless, makes them non-practical and extremely difficult to implement within management control rules. Instead, it has been proposed that management indicators used to derive ERPs should be easily measurable, simple indexes or parameters that provide not only a snapshot of the state of the environment, but also a rapid and reliable feedback on the efficacy of management actions (Hiddink *et al.* 2020). In addition to its ease of measurement and implementation, several authors have argued that the indicators should satisfy a number of additional requirements, but they acknowledge no single indicator may simultaneously satisfy all requirements (see Hiddink *et al.* 2006; Guo *et al.* 2019; Hiddink *et al.* 2020; Morrison *et al.* 2024. A summary of desirable properties for ERPs are presented in **Table 1**.

State indicators

Jennings (2005) argues that the first step to develop ERPs for Ecosystem-based management is to identify the components and attributes that may be adversely impacted by fishing, potentially compromising management objectives. The next step is to select an indicator that can track the state of these components and attributes. In the scientific literature, there are different indices or metrics that have been suggested to track the state of ecosystem components or attributes under fishing pressure. Generally, they can be grouped into two main categories: Multispecies and Ecosystem-based (Morrison *et al.* 2024).

Multispecies reference points are probably the most straightforward and simple step from single-stock to multi-stock BRPs and just consist of commonly used BRPs (as FMSY or BMSY) calculated either individually for each involved species or using aggregated data (Moffitt *et al.* 2016). This is a simple solution to reflect potentially conflicting fishery management objectives or to account for two or more species interactions. Ecosystem-based reference points instead, usually involve indicators of benthic community (or whole ecosystem) structure and function (i.e.,

Table 1
Desirable properties of ecosystem indicators to support ecosystem-based management of bottom trawling fisheries (adapted from Jennings 2005; Guo *et al.* 2019; Hiddink *et al.* 2020; Morrison *et al.* 2024)

Desirable Property or Criteria	Description
Easy measurable and concrete	Ecosystem indicators should be easily measurable and preferentially directly observable (rather than reflecting an indirect or abstract ecosystem property).
Strong theoretical basis	Ecosystem indicators should have a strong theoretical link with fishing pressure, based on well-defined and validated theoretical knowledge.
Easy to understand	Along with the technical meaning, ecosystem indicators should be easy to understand and interpret by non-scientifics to facilitate acceptance and support among stakeholders and the wider public.
Sensitivity and responsiveness	Ecosystem indicators should be sensitive to trawling pressures and provide rapid and reliable feedback on the efficacy of management actions.
Specificity and variability	Most of the ecosystem indicator response (variability) should be explained by trawling pressure rather than to other factors and/or it should be possible to disentangle the effects of other factors from the observed response.
Cost-effective	Data collection to measure ecosystem indicators should use non-expensive tools and technology.
Derivable from historical data	To aid interpretation of trends, ecosystem indicators should be able to be estimated from data for which historical series are available.

reflecting ecosystem changes that impact more than just a few species). This category includes ERPs designed to track changes in productivity of the whole ecosystem (e.g., total biomass, total abundance, reduction of biomass relative to carrying capacity; see Rijnsdorp *et al.* 2020; Pitcher *et al.* 2022), in trophic structure (e.g., derived from biomass or mortality distribution by trophic level; see Morrison *et al.* 2024), in longevity (proportion of biomass with life span exceeding trawling interval, reduction in mean longevity; see Rijnsdorp *et al.* 2020), in functional or biological trait composition (e.g., life history trait composition as size, feeding mode, fragility) and in biodiversity (e.g., species richness, species diversity indexes, functional diversity; see van Loon *et al.* 2018; Morrison *et al.* 2024). Despite the increasing number and diversity of indicators, meta-analysis (Hiddink *et al.* 2020) and direct comparison (Hiddink *et al.* 2019; Rijnsdorp *et al.* 2020) concluded that indicators related to total ecosystem biomass gave the most reliable and consistent responses compared to other indicators.

ERPs as tipping points or thresholds

For the development of ERPs, the final step is to set thresholds or benchmarks for the chosen ecosystem indicator using the relation between state indicators and fishing pressure. If the ecosystem indicator has a nonlinear relationship with a stressor (i.e. fishing) pressure, then usually one or more tipping points or thresholds (i.e. the point where the rapid change from one set of ecosystem conditions to another occurs; Selkoe *et al.* 2015). If the relationship do not allow to derive tipping points (e.g., linear relationships), ecosystem thresholds or management benchmarks could be based on avoiding specific ecosystem conditions or based on an identified percent (or standard deviation) of change from baseline values or from historical levels (Morrison *et al.* 2024).

Pressure indicators instead of state indicators

In some cases, when there is a relatively strong knowledge on the response of the ecosystem to bottom trawling, fishing pressure (instead of ecosystem state) indicators can be directly used to provide short-term management. Pressure indicators (e.g. the proportion of the habitat impacted by different intensities of trawling) may respond directly to management action and can be estimated using the spatial and temporal distribution of fishing effort historical data often be measured precisely (Nicholson y Jennings 2004; Daan 2005). These indicators could be calculated from knowledge of the spatial distribution of habitat and the spatial and temporal distribution of fishing effort.

Ecosystem management for bottom trawling fisheries certified by MSC

During the last decade, an increasing number of bottom trawling fisheries is moving from single-stock to ecosystem-based management. Part of this movement is driven by market-based fisheries certification programs. One of the best-known international standards for fisheries sustainability is the Marine Stewardship Council (MSC), and the fact that bottom-trawl fisheries meet their standards may be considered evidence that bottom-trawl fishing can be sustainable (Hillborn et al. 2023). The sustainability evaluations of MSC consider not only the status of the target stock but also the marine environmental impacts of the fishing method and have specific criteria regarding the management of bottom-trawl impacts on benthic communities (Marine Stewardship Council, 2023). To assess whether certified bottom-trawling fisheries utilize ecosystem indicators and ERPs, we reviewed MSC Public Certification Reports. We compiled reports on May 10, 2025 at the MSC webpage (https://fisheries.msc.org/en/fisheries/) using the filters gear= BOTTOM TRAWLING and status=CERTIFIED. For each fishery included in the resulting search list, we reviewed the strategies related to Ecosystem Management (Principle Indicator 2.5.2 under MSC Fisheries standard 2.01 and Principle Indicator 2.4.2 under MSC Fisheries Standard 3.0).

We found 60 fisheries (Appendix, **Table 2**), most of them with multiple specific combinations of target stock(s), and fishing areas (i.e., Units of Assessment, following MSC). There was only one fishery (i.e., Scapeche, Euronor and Compagnie des Peches de St Malo saithe) that reported the use of an Ecosystem-based

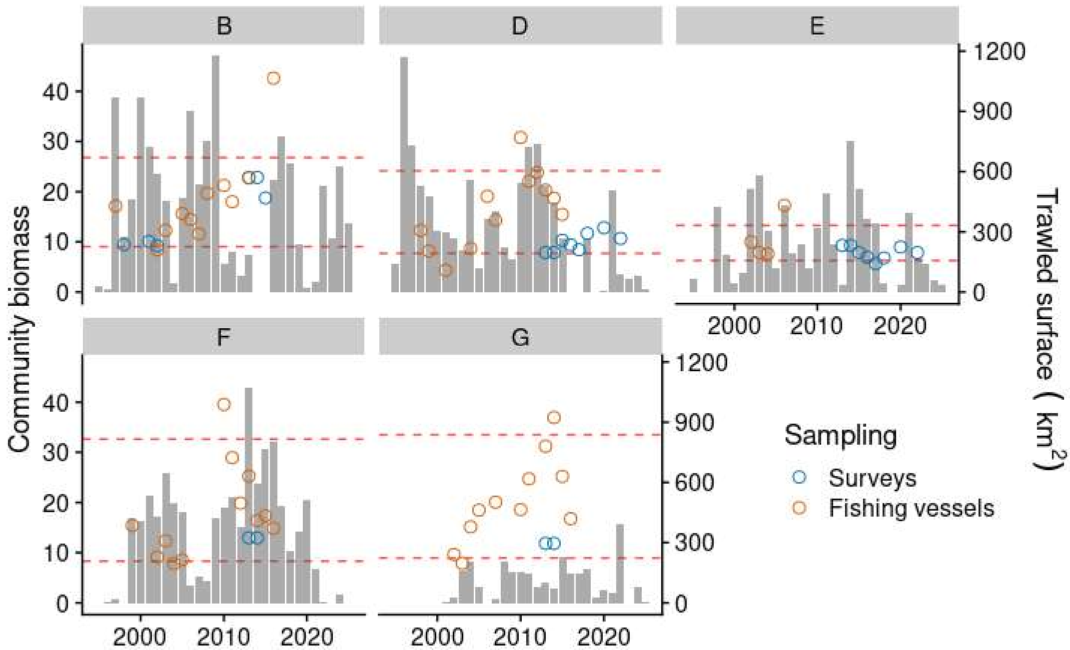

Fig. 1. Community biomass ($kg/100m^2$; circles) across years, either sampled using a dredge in survey campaigns, or through nets and registered by on-board observers on the fishing vessels. Gray bars on the background reflect the area trawled per year (km^2) in each management unit. Dashed horizontal lines illustrate what the limits (90%) of the range of natural variation could be, not separating between different samplings.

referent point; it uses the Large Fish Indicator (LFI), an indicator based on the proportion of fish biomass higher than a given size, and reflects food web trophic composition (see Modica et al. 2014). Most of the fisheries (i.e., 53 out of 60) reported the use of multispecies management, which implies the simultaneous use of multiple BRPs explicitly associated within management control rules. Of these 53, 13 (22% of the total) reported, in addition to the use of BRPs for multiple target species, the use of BRPs or catch limits for species that are non-target/non-commercial (e,g., Endangered, Threatened or Protected species). There were 36 fisheries (60%) that reported the use of some kind of ecosystem modeling (including the use of ecosystem modeling softwares or Ecological/Ecosystem Risk Assesments) as part of the periodic assessment of the fishery ecosystem impacts, but in all cases there were no target or limit values that explicitly determine management control rules. When analyzed in the context of the Performance Indicator score, only 10 fisheries (17%) meet with the scoring guidepost (SG) level 100. All these fisheries present a multispecies management and have a strong level of information as reflected by the high scores obtained in Ecosystem Information (Principle Indicator 2.5.3 under MSC Fisheries standard 2.01 and Principle Indicator 2.4.3 under MSC Fisheries Standard 3.0), as well as an integrated management approach that include the use of Ecosystem Modeling or Ecological Risk Assessments. For these fisheries that meet SG level 100, MSC report considered that the range of specific measures to address management of individual ecosystem elements (incuding BRPs for comercial or endangered species along with initiatives and protocols to minimize imacts on other elements) can be considered as an ecosystem management plan. Only one fishery (i.e., Canada 0AB 2+3KLMNO Greenland halibut bottom trawl and gillnet) did not meet with the SG level 80, presenting a specific Condition for re-certification related to the impact upon an ETP species.

Ecological reference points that could be applied in the management of the Patagonian scallop fishery

As detailed above, from several potential indicators of bottom-trawl impacts on seabed habitats, community numbers (i.e. number of all individuals; particularly useful for large non-colonial species) and biomass met all selection criteria, closely followed by species richness (due to the cost of identifying all species) (Hiddink et al. 2020). Still, these indicators have some cons, given that similar indicator values can be obtained via multiple species configurations (Morrison *et al.* 2024). Time-series data of these (or other) indicators can then be used to feed different methods to set thresholds for decision-making. Among these methods, the range of natural variation provides the most ecologically sound, dependable, and clear way to establish thresholds for good status of marine ecosystems when working with small or noisy datasets (ICES 2022; McKellar *et al.* 2025), which is the case of the Patagonian Scallop fishery.

Among the many proposed ERPs that focus on ecosystem state, some of them could be used in the *Zygochlamys patagonica* fishery with the information gathered so far. Mainly to determine stock status but also to determine the status of the benthic community, INIDEP annually performs a series of survey trips to different management units, in which they sample the benthic community using a dredge (Soria *et al.* 2016). This monitoring of the benthic community has been a key aspect of the annual surveys, leading to an important and complete time series of benthic species composition and abundance that, along with the

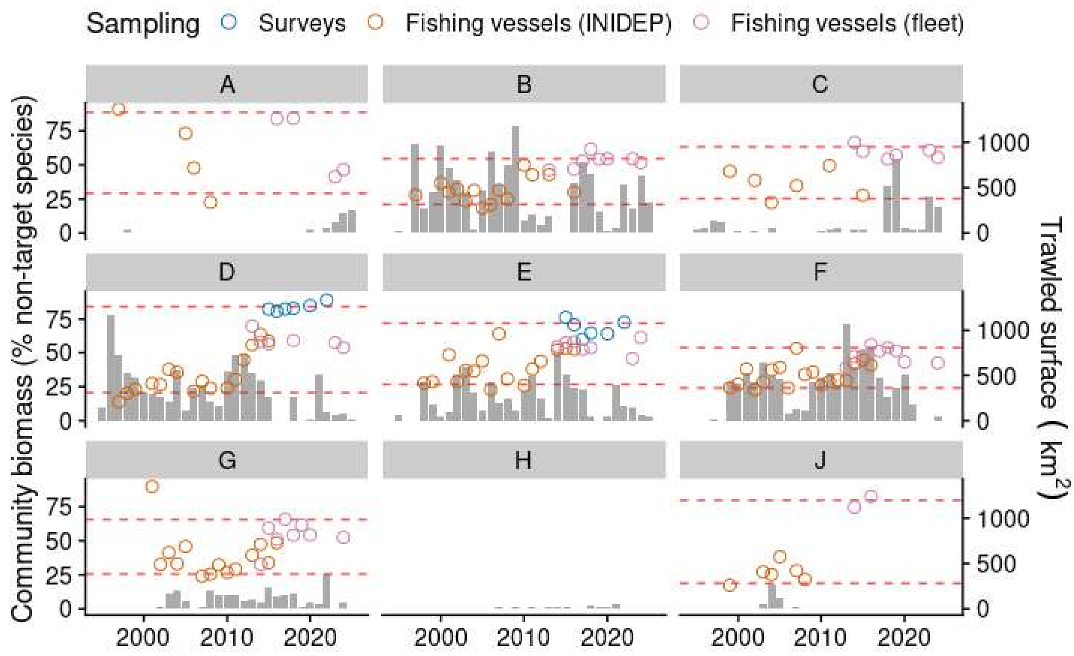

Fig. 2. Percent biomass of non-target species (circles) across years, either sampled using a dredge in survey campaigns, or through nets and registered by INIDEP on-board observers or the fishing crew on the fishing vessels. Gray bars on the background reflect the area trawled per year (km^2) in each management unit. Dashed horizontal lines illustrate what the limits (90%) of the range of natural variation could be, not separating between different samplings.

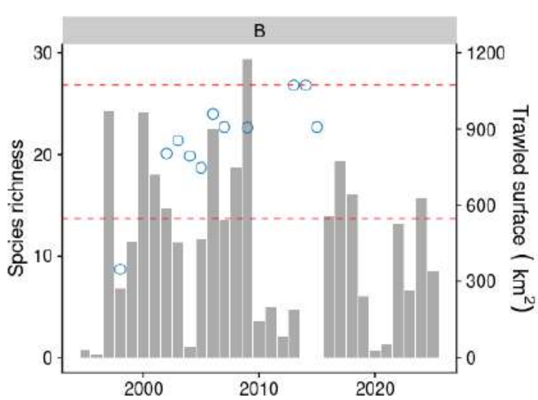

Fig. 3. Species richness (circles) across years on management unit B (the only one with a relatively long time-series data available), using a dredge in survey campaigns. Gray bars on the background reflect the area trawled per year (km^2). Dashed horizontal lines illustrate what the limits (90%) of the range of natural variation could be.

information from on-board observers (Campodónico *et al.* 2019), could be used to define ERPs.

In this report, we illustrate, based on the publicly available information, how different indicators of the benthic status behaved since the inception of this fishery, and how they could be used to determine ERPs. These analyses should not be considered as validated ERPs as they do not cover the entire period of the fishery, and they do not distinguish areas with different fishing pressure. Instead, they should be treated as preliminary approaches intending to advance in the identification and definition of potential ERPs, which could be properly defined using all data archived by INIDEP.

Making use of INIDEP's reports we extracted the best set of potential indicators (from those described above) with a relatively long time series. These indicators include community biomass, percent biomass of benthic non-target species, species richness, and richness range (min & max). Although we extracted biomass per taxa, we discarded this information as the grouping of taxa differed between reports, making comparisons difficult. Nevertheless, available information reveals no major changes in the benthic community composition, with no loss of species and only some minor changes in relative abundance (Bremec *et al.* 2015; Giberto *et al.* 2024; Escolar *et al.* 2023). In addition to these reports, we also gathered information on percent biomass of benthic non-target species provided by the fleet (i.e. "Atlantic Surf III" and "Capesante" vessels). These data are collected by both vessels in a similar way to that used by INIDEP, thus providing an extra layer of information which extends the time-frame analyzed. In the Appendix, **Tables 3 & 4**, summarize the information used in this report.

Indicators analyzed here can be grouped in two categories: community biomass and species richness, which together show aspects of the quantity and quality of benthic fauna. These indicators can then be used by different methods to define ERPs. Among those methods (see above), the range of natural variation seems the best one to establish ERPs ("natural variation threshold"), given the noisy nature of the dataset (varying fishing pressure, sampling techniques, sampling intervals) of the Patagonian Scallop fishery. Briefly, the "natural variation threshold" considers ecosystem quality to be good if it falls within the range of natural temporal variability—meaning it cannot be

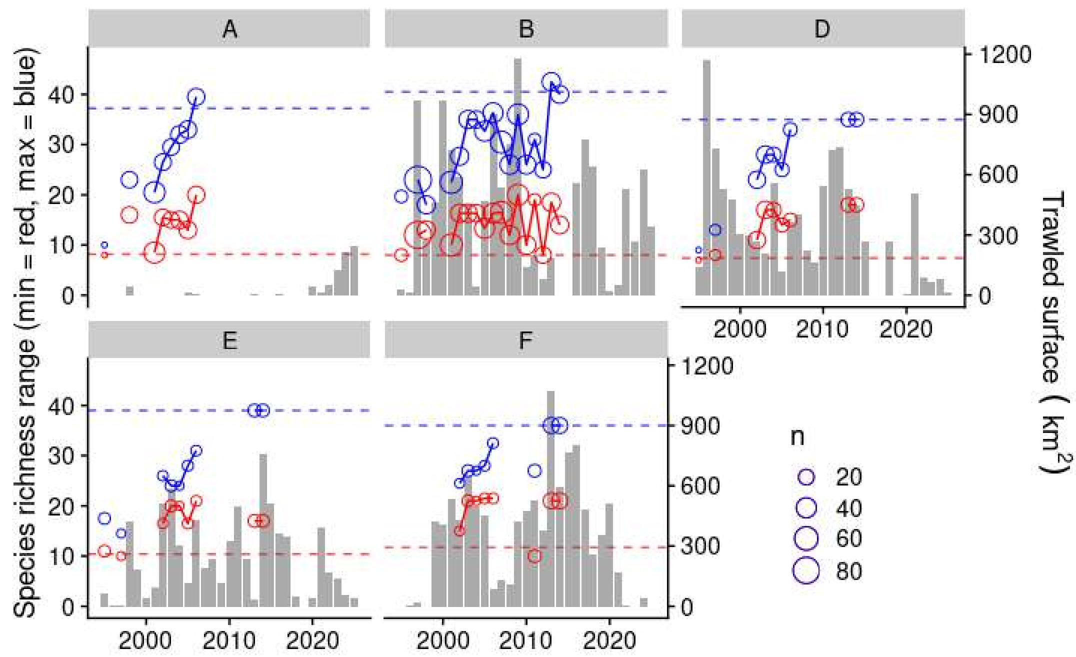

Fig. 4. Minimum (red) and maximum (blue) species richness (circles) across years, either sampled using a dredge in survey campaigns, or through nets and registered by INIDEP on-board observers on fishing vessels. Gray bars on the background reflect the area trawled per year (km^2) in each management unit. Dashed horizontal lines illustrate what the limits (90%) of the range of natural variation could be.

distinguished from an undisturbed state. This threshold can be defined as the 90% of values within which the indicator varies in undisturbed systems (Rossberg *et al.* 2017). However, finding long-term data for undisturbed fishing grounds is extremely difficult, which is why least impacted areas are generally used (McKellar *et al.* 2025).

Unfortunately, data extracted from public reports are aggregated by management unit, which precludes the establishment of the natural variation threshold by mixing areas with different fishing pressure. Rather than being homogeneous within management units, fishing pressure is highly clumped. Moreover, most management units also contain temporal and permanent trawling bans (Campodónico *et al.* 2019). Nevertheless, to illustrate the potential of these data focusing on lightly fished areas, we analyze below the temporal behavior of the four indicators, particularly considering that some management units used were far less fished than others.

Most indicators exhibit interannual variations, with no clear decreasing or increasing trends, even after experiencing large changes in fishing pressure **Figs. 1, 2, 3, 4**. Community biomass was the indicator with the greatest temporal variability, particularly associated with data gathered by INIDEP's on-board observers **Fig. 1**. Although fishing pressure greatly varied between and within management units, changes in community biomass do not resemble fishing pressure. Indeed, there was no association (Spearman correlation) between fishing pressure (trawled surface) and community biomass for any given sampling procedure (i.e. survey campaigns vs. data from on-board observers), either within management units (across years) or years (across management units; Appendix, **Tables 5, 6**). This pattern holds even when looking for associations between community biomass and fishing pressure the year before (except for only two positive associations: management unit D with on-board observers data, and management unit E with survey data). Very few associations (7 out of 84) appeared when analyzing the percentage of non-target species biomass (negative correlations for 2015 and 2020 using fleet information, either when using fishing pressure from the same year or the year before; and two positive -management units C & D- and one negative -A- for fishing vessels information using fishing pressure from the year before; **Fig. 2; Appendix, Tables 7, 8**). Neither mean species richness (**Fig. 3**) nor minimum or maximum species richness (**Fig. 4**) were associated with fishing pressure of the same year or the year before (Appendix, **Tables 9, 10**).

These analyses did not isolate areas with low fishing pressure, which makes it unreliable to assume that the interannual oscillations observed in these indicators reflect the range of natural variation. However, the lack of associations with fishing pressure, combined with the relatively low proportion of management units that are trawled each year (never above 15% for a given management unit and year, with the rest being considerably lower; Alberti 2023), might suggest that the range of natural variation could be a suitable method to estimate ERPs after removing those areas with highest fishing pressure.

CONCLUSIONS

The review reveals a significant disconnect between the ecosystem indicators proposed in the scientific literature and those actually implemented in the management of MSC-certified bottom trawl fisheries. While researchers advocate for a suite of ERPs —ranging from benthic community biomass to species richness and functional diversity— most certified fisheries continue to rely on multispecies Biological Reference Points (BRPs) or complex ecosystem models rather than adopting simpler, empirically validated indicators. This gap suggests that the transition to ecosystem-based fisheries management remains hindered by practical challenges, including data requirements, stakeholder buy-in, and the integration of scientific recommendations into policy.

Despite their theoretical robustness, complex ecosystem models face limitations in real-world management applications. Their data demands, computational intensity, and high parameter uncertainty often make them impractical for direct use in decision-making. Conversely, oversimplified models risk misrepresenting ecosystem dynamics, leading to poor management outcomes. A middle ground may lie in combining well-established, easily measurable indicators (e.g., benthic biomass, species richness) with targeted modeling efforts. This hybrid approach could provide both the responsiveness needed for adaptive management and the ecological realism required to safeguard ecosystem integrity.

Ultimately, the Patagonian scallop fishery has a unique opportunity to lead in the implementation of ecosystem-based management for benthic trawl fisheries. Its extensive historical data, combined with ongoing scientific monitoring, provide a strong foundation for adopting dynamic, responsive ERPs. By focusing on cost-effective indicators and fostering stakeholder collaboration, this fishery can transition from single-species management to a holistic framework that balances scallop productivity with the conservation of benthic ecosystems. Such progress would not only improve the sustainability of the fishery but also set a valuable precedent for other data-limited trawl fisheries worldwide.

For the Patagonian scallop (*Zygochlamys patagonica*) fishery, our preliminary assessment identifies promising avenues for ERP development. Indicators such as benthic community biomass and species richness exhibit measurable responses and could serve as practical benchmarks if anchored to natural variation thresholds (Condition 6). However, the current aggregation of data by management units obscures localized fishing impacts, complicating the distinction between anthropogenic and natural variability. To address this, future efforts should prioritize finer-scale spatial analysis, particularly in lightly trawled areas, to establish robust baselines and to grant the development of precise Harvest Control Rules (Condition 7).

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REFERENCES

Alberti, J. (2023). Footprint of the Patagonian scallop bottom trawl fishery on the Argentine shelf between 2012 and 2021. Informe Científico-Técnico 14, IIMyC-CONICET, UNMDP.

Bradshaw, C., Jakobsson, M., Brüchert, V., Bonaglia, S., Mörth, C.-M., Muchowski, J., Stranne, C., y Sköld, M. (2021). Physical disturbance by bottom trawling suspends particulate matter and alters biogeochemical processes on and near the seafloor. *Frontiers in Marine Science*, 8:683331.

Bremec, C., Escolar, M., Schejter, L., y Marecos, A. (2011). Fauna de invertebrados bentónicos asociados a la pesquería de Zygochlamys patagonica en áreas del frente de talud explotadas y no explotadas comercialmente. Informe de Investigación 43, INIDEP.

Bremec, C., Schejter, L., y Giberto, D. (2015). Synoptic post fishery structure of invertebrate bycatch associated to *Zygochlamys patagonica* fishing grounds at the Southwest Atlantic shelf-break front (39° S, Argentina). *Journal of Shellfish Research*, 34(3):729–736.

Bremec, C., Schejter, L., y Marecos, A. (2006). Riqueza específica y asociaciones faunísticas en los bancos comerciales de vieira patagónica (Zygochlamys patagonica) a lo largo del frente de talud. Período 1995- 2006. Informe Técnico 106, INIDEP.

Campodónico, S., Escolar, M., García, J., y Aubone, A. (2019). Síntesis histórica y estado actual de la pesquería de vieira patagónica zygochlamys patagonica (king 1832) en la argentina. biología, evaluación de biomasa y manejo. *Marine & Fishery Sciences (MAFIS)*, 32(2):125–148.

Daan, N. (2005). An afterthought: ecosystem metrics and pressure indicators.

Escolar, M. y Campodónico, S. (2022). Análisis de la captura incidental en la pesquería de vieira patagónica (Zygochlamys patagonica King, 1832). Informe de Asesoramiento y Transferencia 108-22, Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP), Mar del Plata.

Escolar, M., Campodónico, S., Marecos, A., y Schejter, L. (2015). Efecto del arrastre pesquero en la comunidad bentónica asociada a la vieira patagónica. Informe de Investigación 84, INIDEP.

Escolar, M., Herrera, S., y Campodónico, S. (2018). Captura incidental de invertebrados bentónicos en la pesquería de vieira patagónica. Informe de Investigación 23, INIDEP.

Escolar, M., Marecos, A., y Bremec, C. (2014). Análisis de la comunidad de invertebrados bentónicos asociada a la pesquería de vieira patagónica (Zygochlamys patagonica King, 1832). Datos de observadores a bordo 1997- 2009. Informe de Investigación 14, INIDEP.

Escolar, M., Schejter, L., Marecos, Á. C., Bastida, J., Bento, L. P., y Chahade, N. N. (2023). Invertebrados bentónicos asociados con la pesquería de vieira patagónica (Zygochlamys patagonica King, 1832) en las Unidades de Manejo D y E. Informe de Investigación 141-23, Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP), Mar del Plata.

Gabriel, W. L. y Mace, P. M. (1999). A review of biological reference points in the context of the precautionary approach. En *Proceedings of the fifth national NMFS stock assessment workshop: providing scientific advice to implement the precautionary approach under the Magnuson-Stevens fishery conservation and management act. NOAA Tech Memo NMFS-F/SPO-40*, pp. 34–45.

Giberto, D., Schejter, L., Romero, M., Belleggia, M., y Bremec, C. (2024). Benthic assemblages and biodiversity patterns of the shelf-break front. En Acha, E. M., Iribarne, O., y Piola, A. R., editores, *The Patagonian Shelfbreak Front*, volumen 13 de *Aquatic Ecology Series*, pp. 137–164. Springer Nature, Switzerland.

Guo, C., Fu, C., Forrest, R. E., Olsen, N., Liu, H., Verley, P., y Shin, Y.-J. (2019). Ecosystem-based reference points under varying plankton productivity states and fisheries management strategies. *ICES Journal of Marine Science*, 76(7):2045–2059.

Hiddink, J. G., Jennings, S., y Kaiser, M. (2006). Indicators of the ecological impact of bottom-trawl disturbance on seabed communities. *Ecosystems*, 9:1190–1199.

Hiddink, J. G., Jennings, S., Sciberras, M., Bolam, S. G., Cambiè, G., McConnaughey, R. A., Mazor, T., Hilborn, R., Collie, J. S., y Pitcher, C Roland, e. a. (2019). Assessing bottom trawling impacts based on the longevity of benthic invertebrates. *Journal of Applied Ecology*, 56(5):1075–1084.

Hiddink, J. G., Kaiser, M. J., Sciberras, M., McConnaughey, R. A., Mazor, T., Hilborn, R., Collie, J. S., Pitcher, C. R., Parma, A. M., y Suuronen, Petri, e. a. (2020). Selection of indicators for assessing and managing the impacts of bottom trawling on seabed habitats. *Journal of Applied Ecology*, 57(7):1199–1209.

ICES (2022). Workshop to scope assessment methods to set thresholds (wkbenth2).

Jennings, S. (2005). Indicators to support an ecosystem approach to fisheries. *Fish and Fisheries*, 6(3):212–232.

Jones, J. (1992). Environmental impact of trawling on the seabed: a review. *New Zealand Journal of Marine and Freshwater Research*, 26(1):59–67.

Mackinson, S., Platts, M., Garcia, C., y Lynam, C. (2018). Evaluating the fishery and ecological consequences of the proposed north sea multi-annual plan. *PLoS One*, 13(1):e0190015.

McConnaughey, R. A., Hiddink, J. G., Jennings, S., Pitcher, C. R., Kaiser, M. J., Suuronen, P., Sciberras, M., Rijnsdorp, A. D., Collie, J. S., y Mazor, Tessa, e. a. (2020). Choosing best practices for managing impacts of trawl fishing on seabed habitats and biota. *Fish and Fisheries*, 21(2):319–337.

McKellar, L., McQuatters-Gollop, A., Chaigneau, T., Vina-Herbon, C., Valanko, S., y Hiddink, J. G. (2025). Evaluating methods for setting thresholds for good status in marine ecosystems. *ICES Journal of Marine Science*, 82(3):fsaf019.

Moffitt, E. A., Punt, A. E., Holsman, K., Aydin, K. Y., Ianelli, J. N., y Ortiz, I. (2016). Moving towards ecosystem-based fisheries management: options for parameterizing multi-species biological reference points. *Deep Sea Research Part II: Topical Studies in Oceanography*, 134:350–359.

Morrison, W. E., Oakes, S. A., Karp, M. A., Appelman, M. H., y Link, J. S. (2024). Ecosystem-level reference points: Moving toward ecosystem-based fisheries management. *Marine and Coastal Fisheries*, 16(2):e210285.

Morys, C., Brüchert, V., y Bradshaw, C. (2021). Impacts of bottom trawling on benthic biogeochemistry in muddy sediments: Removal of surface sediment using an experimental field study. *Marine Environmental Research*, 169:105384.

Nicholson, M. D. y Jennings, S. (2004). Testing candidate indicators to support ecosystem-based management: the power of monitoring surveys to detect temporal trends in fish community metrics. *ICES Journal of marine Science*, 61(1):35–42.

Olsgard, F., Schaanning, M. T., Widdicombe, S., Kendall, M. A., y Austen, M. C. (2008). Effects of bottom trawling on ecosystem functioning. *Journal of Experimental Marine Biology and Ecology*, 366(1-2):123–133.

Pitcher, C. R., Hiddink, J. G., Jennings, S., Collie, J., Parma, A. M., Amoroso, R., Mazor, T., Sciberras, M., McConnaughey, R. A., y Rijnsdorp, Adriaan D, e. a. (2022). Trawl impacts on the relative status of biotic communities of seabed sedimentary habitats in 24 regions worldwide. *Proceedings of the National Academy of Sciences*, 119(2):e2109449119.

Rijnsdorp, A., Hiddink, J. G., Van Denderen, P., Hintzen, N., Eigaard, O. R., Valanko, S., Bastardie, F., Bolam, S., Boulcott, P., y Egekvist, Josefine, e. a. (2020). Different bottom trawl fisheries have a differential impact on the status of the north sea seafloor habitats. *ICES Journal of Marine Science*, 77(5):1772–1786.

Rijnsdorp, A. D., Bolam, S. G., Garcia, C., Hiddink, J. G., Hintzen, N. T., van Denderen, P. D., y van Kooten, T. (2018). Estimating sensitivity of seabed habitats to disturbance by bottom trawling based on the longevity of benthic fauna. *Ecological Applications*, 28(5):1302–1312.

Rossberg, A. G., Uusitalo, L., Berg, T., Zaiko, A., Chenuil, A., Uyarra, M. C., Borja, A., y Lynam, C. P. (2017). Quantitative criteria for choosing targets and indicators for sustainable use of ecosystems. *Ecological Indicators*, 72:215–224.

Schejter, L., Bremec, C., Hernández, D., y Mianzan, H. (2008). Comparación de áreas perturbadas y no perturbadas en el banco de vieira patagónica “Reclutas”, Mar Argentino. Informe de Investigación 30, INIDEP.

Schejter, L. y Escolar, M. (2015). Estudios de riqueza específica en la Unidad de Manejo B de la pesquería de vieira patagónica. Periodo 1995-2013. Informe de Investigación 36, INIDEP.

Schejter, L., Escolar, M., y Bremec, C. (2012). Caracterización de la comunidad de invertebrados bentónicos en las Unidades de Manejo 9 y 10 de la vieira patagónica Zygochlamys patagonica y en sus áreas de exclusión de actividades pesqueras (Reservas Reproductivas) de estas UM. Período 2011. Informe de Investigación 107, INIDEP.

Schejter, L., Escolar, M., y Giberto, D. (2016). Comunidad de invertebrados bentónicos en áreas de pesca y de reserva en bancos de vieira patagónica: Estado general en el año 2015 y comparación con datos del 2013. Informe de Investigación 38, INIDEP.

Schejter, L., Marecos, A., y Bremec, C. (2014). La comunidad de invertebrados bentónicos en la “Unidad de Manejo B” de la pesquería de vieira patagónica: Comparación entre el área de reserva y el área de pesca a partir de datos obtenidos en el 2013. Informe de Investigación 58, INIDEP.

Schejter, L., Webb, J., Marecos, A., y Escolar, M. (2015). Fauna asociada a la pesquería de vieira patagónica (Zygochlamys patagónica) en el frente de talud. Monitoreo anual, período 2014. Technical Report 037, INIDEP.

Selkoe, K. A., Blenckner, T., Caldwell, M. R., Crowder, L. B., Erickson, A. L., Essington, T. E., Estes, J. A., Fujita, R. M., Halpern, B. S., y Hunsicker, Mary E, e. a. (2015). Principles for managing marine ecosystems prone to tipping points. *Ecosystem Health and Sustainability*, 1(5):1–18.

Soria, G., (Lobo) Orensanz, J. M., Morsán, E. M., Parma, A. M., y Amoroso, R. O. (2016). Scallops biology, fisheries, and management in Argentina. En Shumway, S. E. y Parsons, G. J., editores, *Developments in Aquaculture and Fisheries Science*, volumen 40 de *Scallops*, pp. 1019–1046. Elsevier.

Sousa, W. (2001). Natural disturbance and the dynamics of marine benthic communities. *Marine community ecology*, pp. 85–130.

van Loon, W. M., Walvoort, D. J., Van Hoey, G., Vina-Herbon, C., Blandon, A., Pesch, R., Schmitt, P., Scholle, J., Heyer, K., y Lavaleye, Marc, e. a. (2018). A regional benthic fauna assessment method for the southern north sea using margalef diversity and reference value modelling. *Ecological Indicators*, 89:667–679.

APPENDIX

Table 2
Summary of the components involved in the Ecosystem Management for bottom trawling fisheries certified by MSC

MSC Denomination for the Fishery	Year of (Re)assess.	Target Species	Multispecies BRPs?	ERPs?	Ecosystem Modeling?	PI Score
Argentine red shrimp (*Pleoticus muelleri*) coastal trawling fishery in waters of province of Chubut	2025	Argentine red shrimp (*Pleoticus muelleri*)	no	no	no	80
Bering Sea and Aleutian Islands (BSAI) Atka Mackerel, Pacific Ocean perch, and northern rockfish and Gulf of Alaska (GOA) Pacific Ocean perch, northern rockfish, and dusky rockfish	2020	Atka Mackerel (*Pleurogrammus monopterygius*), Pacific Ocean perch (*Sebastes alutus*), Northern rockfish (*S. polyspinis*), Dusky Rockfish (*S. variabilis*)	yes	no	yes	90
ISF Iceland northern shrimp - inshore and offshore	2024	Northern prawn (*Pandalus borealis*)	yes	no	yes	85
Murmanseld 2 Barents Sea cod and haddock	2020	Haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*)	yes	no	no	100
Norwegian & Barents Seas cod, haddock & saithe	2020	Haddock (*M. aeglefinus*), Atlantic cod (*G. morhua*), Saithe(=Pollock) (*Pollachius virens*)	yes	no	no	85
Barents Sea cod, haddock and saithe	2022	Haddock (*M. aeglefinus*), Atlantic cod (*G. morhua*), Saithe(=Pollock) (*P. virens*)	yes	no	no	85
«GELA» Ltd North East Arctic cod, haddock and saithe	2022	Haddock (*M. aeglefinus*), Atlantic cod (*G. morhua*), Saithe(=Pollock) (*P. virens*)	yes	no	no	80
New Zealand orange roughy	2022	Orange roughy (*H. atlanticus*)	yes	no	yes	95
Greenland cod, haddock and saithe trawl fishery	2019	Haddock (*M. aeglefinus*), Atlantic cod (*G. morhua*), Saithe(=Pollock) (*P. virens*)	yes	no	no	80
BSAI and GOA flatfish	2020	Kamchatka flounder (*Atheresthes evermanni*), Flathead sole	yes	no	yes	100
Norway sandeel and North Sea sprat	2023	European sprat (*Sprattus sprattus*), Lesser sand-eel (*Ammodytes marinus*), Norway pout (*Trisopterus esmarkii*)	yes	no	yes	85
Northeast Arctic cod and haddock demersal fishery	2024	Haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*)	yes	no	no	80
Scapeche, Euronor and Compagnie des Peches de St Malo saithe	2022	Saithe(=Pollock) (*Pollachius virens*)	yes	LFI, weight proportion of fish >40 cm	no	80-85

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MSC Denomination for the Fishery	Year of (Re)assess.	Target Species	Multispecies BRPs?	ERPs?	Ecosystem Modeling?	PI Score
Australia Northern prawn	2024	Blue endeavour prawn (*Metapenaeus endeavouri*), Grooved tiger prawn (*Penaeus semisulcatus*), Indian white prawn (*Fenneropenaeus indicus*), Brown tiger prawn (*Penaeus esculentus*), Red endeavour prawn (*Metapenaeus ensis*), Banana prawn (*Fenneropenaeus merguiensis*)	yes	no	no	85
U.S. Northeastern Coast Longfin Inshore Squid and Northern Shortfin Squid Bottom Trawl Fishery	2020	Northern shortfin squid (*Illex illecebrosus*), Longfin squid (*Doryteuthis (Amerigo) pealeii*)	yes	no	yes	85
US West Coast pink shrimp (*Pandalus jordani*) trawl fishery	2023	Oregon pink shrimp (*Pandalus jordani*)	yes	no	yes	100
Chile squat lobsters and nylon shrimp Crustáceos Sur S.A. demersal trawl fishery	2022	Chilean nylon shrimp (*Heterocarpus reedi*), Carrot squat lobster (*Pleuroncodes monodon*), Blue squat lobster (*Cervimunida johni*)	yes	no	yes	80
Exmouth Gulf Prawns	2020	Blue endeavour prawn (*Metapenaeus endeavouri*), Western king prawn (*Penaeus (Melicertus) latisulcatus*), Brown tiger prawn (*Penaeus esculentus*)	yes	no	yes	95
Spencer Gulf king prawn	2021	Western king prawn (*Penaeus (Melicertus) latisulcatus*)	yes	no	no	85
«GELA» Ltd North East Atlantic European plaice	2022	European plaice (*Pleuronectes platessa*)	yes	no	no	80
FISF Faroe Islands North East Arctic cod, haddock and saithe	2023	Haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*), Saithe(=Pollock) (*Pollachius virens*)	yes	no	yes	80
Faroe Islands silver smelt	2023	Silver smelt (*Argentina silus*)	yes	no	no	85
OCI Grand Bank yellowtail flounder trawl	2020	Yellowtail flounder (*Limanda ferruginea*)	yes	no	no	85
UK Fisheries Ltd/DFFU/Doggerbank Northeast Arctic cod, haddock and saithe	2023	Haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*), Saithe(=Pollock) (*Pollachius virens*)	yes	no	no	80
ISF Iceland greater silver smelt	2023	Silver smelt (*Argentina silus*)	yes	no	no	80

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MSC Denomination for the Fishery	Year of (Re)assess.	Target Species	Multispecies BRPs?	ERPs?	Ecosystem Modeling?	PI Score
Australia orange roughy - eastern zone trawl	2025	Orange roughy (*Hoplostethus atlanticus*)	no	no	yes	90
South Africa hake trawl	2021	Shallow-water Cape hake (*Merluccius capensis*), Deep-water Cape hake (*Merluccius paradoxus*)	yes	no	yes	85
Chile squat lobsters and nylon shrimp modified Trawl	2022	Chilean nylon shrimp (*Heterocarpus reedi*), Carrot squat lobster (*Pleuroncodes monodon*), Blue squat lobster (*Cervimunida johni*)	yes	no	no	80
SFSAG Northern Demersal Stocks	2022	Haddock (*Melanogrammus aeglefinus*), Saithe(=Pollock) (*Pollachius virens*), European hake (*Merluccius merluccius*), European plaice (*Pleuronectes platessa*), Whiting (*Merlangius merlangus*)	yes	no	yes	85
FIUN Barents & Norwegian Seas cod and haddock	2025	Haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*)	yes	no	yes	85
Namibia hake trawl and longline fishery	2020	Cape hakes (*Merluccius capensis*, *M. paradoxus*)	yes	no	yes	80
Southern New England winter and little skate	2021	Little skate (*Leucoraja erinaceus*), Winter skate (*L. ocellata*)	yes	no	yes	80
Canada 3LN redfish	2022	Acadian redfish (*Sebastes fasciatus*)	yes	no	yes	80
Australia Heard Island and McDonald Islands toothfish & icefish	2022	Patagonian toothfish (*Dissostichus eleginoides*), Mackerel icefish (*Champsocephalus gunnari*)	yes	no	yes	85
BSAI and GOA Pacific cod	2020	Pacific cod (*Gadus macrocephalus*)	yes	no	yes	100
Canada 0AB 2+3KLMNO Greenland halibut bottom trawl and gillnet	2021	Greenland halibut (*Reinhardtius hippoglossoides*)	yes	no	yes	75-80
Canada Atlantic halibut	2022	Atlantic halibut (*Hippoglossus hippoglossus*)	yes	no	yes	80
FISF Faroe Islands demersal	2024	Angler (*Lophius piscatorius*), Tusk(=Cusk) (*Brosme brosme*), Haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*), Lemon sole (*Microstomus kitt*), Saithe(=Pollock) (*Pollachius virens*), European plaice (*Pleuronectes platessa*), Ling (*Molva molva*)	yes	no	no	85

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MSC Denomination for the Fishery	Year of (Re)assess.	Target Species	Multispecies BRPs?	ERPs?	Ecosystem Modeling?	PI Score
FIUN Russian Barents Sea shrimp	2021	Northern prawn (*Pandalus borealis*)	yes	no	no	80
ISF Iceland Cod	2023	Atlantic cod (*Gadus morhua*)	yes	no	no	80
ISF Iceland haddock	2023	Haddock (*Melanogrammus aeglefinus*)	yes	no	no	80
ISF Iceland multi-species demersal fishery	2019	Tusk(=Cusk) (*Brosme brosme*), Atlantic wolffish (*Anarhichas lupus*), Golden redfish (*Sebastes marinus / Sebastes norvegicus*), Saithe(=Pollock) (*Pollachius virens*), Blue ling (*Molva dypterygia*), European plaice (*Pleuronectes platessa*), Ling (*M. molva*)	yes	no	no	85
New Zealand hake, hoki, ling and Southern blue whiting	2018	Southern hake (*M. australis*), Southern blue whiting (*Micromesistius australis*), Ling (*Genypterus blacodes*), Hoki (*Macruronus novaezelandiae*)	yes	no	yes	90
Norway Greenland halibut	2023	Greenland halibut (*R. hippoglossoides*)	yes	no	yes	80
Norway North East Arctic cod	2021	Atlantic cod (*G. morhua*)	yes	no	yes	80
Norway North East Arctic haddock	2021	Haddock (*M. aeglefinus*)	yes	no	yes	80
Norway North East Arctic saithe	2023	Saithe(=Pollock) (*P. virens*)	yes	no	yes	80
Norway North Sea demersal	2024	Haddock (*M. aeglefinus*), Atlantic cod (*G. morhua*), Saithe(=Pollock) (*P. virens*), European hake (*M. merluccius*)	yes	no	yes	85
US Atlantic spiny dogfish, winter skate and little skate	2023	Little skate (*L. erinaceus*), Winter skate (*L. ocellata*)	yes	no	yes	85
West Greenland offshore Greenland halibut	2022	Greenland halibut (*R. hippoglossoides*)	yes	no	yes	85
Shark Bay prawn	2020	Western king prawn (*Penaeus (Melicertus) latisulcatus*), Brown tiger prawn (*P. esculentus*)	yes	no	yes	95
Patagonian scallop (*Zygochlamys patagonica*) bottom otter trawl fishery	2023	Patagonian scallop (*Zygochlamys patagonica*)	no	no	no	80
Abrolhos Island and Mid-West scallop trawl fishery	2021	Saucer scallop (*Ylistrum balloti*)	no	no	yes	95
Canada northern and striped shrimp	2022	Northern prawn (*P. borealis*), Striped shrimp (*P. montagui*)	no	no	yes	80

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MSC Denomination for the Fishery	Year of (Re)assess.	Target Species	Multispecies BRPs?	ERPs?	Ecosystem Modeling?	PI Score
Estonia North East Arctic cold water prawn and cod	2024	Northern prawn (*P. borealis*), Atlantic cod (*G. morhua*)	yes	no	yes	80
FISF Faroe Islands North East Arctic cold water prawn	2024	Northern prawn (*P. borealis*)	yes	no	yes	80
Guyana seabob	2019	Atlantic seabob (*Xiphopenaeus kroyeri*)	no	no	no	85
ISF Greenland halibut	2023	Greenland halibut (*R. hippoglossoides*)	yes	no	yes	85
Norway North East Arctic cold water prawn	2024	Northern prawn (*P. borealis*)	yes	no	yes	80

Table 3
Data sources and sampling techniques for the community biomass indicators analyzed in this report, as well as when and where they were obtained

Data source	Sampling	Management units (years)
Community biomass		
Escolar *et al.* 2014	Fishing vessels (INIDEP)	B: (1997, 2002:2003, 2005:2008) - D: (1998, 1999, 2001, 2004, 2006:2007) - E: (2002:2004, 2006) - F: (1999, 2002:2005) - G: (2002:2005, 2007) - J: (2004:2005, 2007)
Escolar *et al.* 2018	Fishing vessels (INIDEP)	B: (2010:2011, 2013, 2016) - C: (2011, 2015) - D: (2010:2015) - F: (2010:2016) - G: (2010:2011, 2013:2016)
Escolar *et al.* 2023	Surveys	D, E: (2015:2018, 2020, 2022)
Escolar y Campodónico 2022	Fishing vessels (INIDEP)	all together: (2010:2019)
Schejter *et al.* 2008	Surveys	B: (1998, 2001, 2002)
Schejter *et al.* 2014	Surveys	B, D, E, F, G: (2013)
Schejter *et al.* 2015	Surveys	B, D, E, F, G: (2014)
Schejter *et al.* 2016	Surveys	B: (2015)
Community biomass (% non-target species)		
Escolar *et al.* 2014	Fishing vessels (INIDEP)	A: (1997, 2005, 2006, 2008) - B: (1997, 2001:2003, 2005:2008) - C: (1999, 2002, 2004, 2007) - D: (1997:1999, 2001:2004, 2006:2008) - E: (1998:1999, 2001:2008) - F: (1999:2009) - G: (2001:2005, 2007:2009) - J: (1999, 2003:2005, 2007, 2008)
Escolar *et al.* 2018	Fishing vessels (INIDEP)	B: (2010, 2011, 2013, 2016) - C: (2011, 2015) - D: (2010:2015) - E: (2010:2012, 2014:2016) - F: (2010:2016) - G: (2010, 2011, 2013, 2014:2016)
Escolar *et al.* 2023	Surveys	D, E: (2015:2018, 2020, 2022)
Escolar y Campodónico 2022	Fishing vessels (INIDEP)	all together: (2010:2019)
Fleet	Fishing vessels (fleet)	A: (2016 (1), 2018 (4), 2023 (50), 2024 (21)) - B: (2013 (59), 2016 (472), 2017 (791), 2018 (502), 2019 (175), 2020 (1), 2023 (84), 2024 (639)) - C: (2014 (16), 2015 (57), 2018 (390), 2019 (717), 2023 (294), 2024 (116)) - D: (2013 (46), 2014 (161), 2015 (124), 2018 (209), 2023 (26), 2024 (39)) - E: (2014 (200), 2015 (454), 2016 (276), 2017 (209), 2018 (22), 2023 (34), 2024 (41)) - F: (2013 (137), 2014 (234), 2015 (616), 2016 (425), 2017 (412), 2018 (194), 2019 (200), 2020 (106), 2024 (31)) - G: (2014 (59), 2015 (115), 2016 (76), 2017 (111), 2018 (94), 2019 (26), 2020 (2), 2024 (36)) - H: (2014 (8), 2015 (14), 2016 (6), 2018 (47), 2019 (31), 2020 (17), 2024 (15)) - J: (2014 (5), 2016 (2))[1]

(1) Numbers between brackets after year denote the number of fishing tows considered

Table 4
Data sources and sampling techniques for the species richness indicators analyzed in this report, as well as when and where they were obtained

Data source	Sampling	Management units (years)
Species richness		
Schejter *et al.* 2014	Surveys	B: (2013)
Escolar *et al.* 2015	Surveys	B: (1998, 2002:2007, 2009)
Bremec *et al.* 2015	Surveys	B: (2007)
Schejter *et al.* 2015	Surveys	B: (2014)
Schejter *et al.* 2016	Surveys	B: (2015)
Species richness range		
Bremec *et al.* 2006	Surveys	A, B: (1995, 1998 , 2001:2006) - C: (1995, 2006) - D, E: (1995, 1997, 2002:2006) - F: (2002:2006)
Bremec *et al.* 2011	Surveys	C: (2011)
Bremec *et al.* 2015	Surveys	B: (2007)
Schejter *et al.* 2012	Surveys	F, G: (2011)
Schejter *et al.* 2014	Surveys	B, D, E, F, G: (2013)
Schejter y Escolar 2015	Surveys	B: (1995, 1997, 2001:2013)
Schejter *et al.* 2015	Surveys	B, D, E, F, G: (2014)

Table 5
Spearman correlations between fishing pressure (same or previous year) and community biomass for a given management unit (across years) and sampling technique. Asterisks next to p-value highlight significant correlations.

MU	n	correlation	p-value	
Same year - Fishing vessels (INIDEP)				
B	11	-0.309	0.356	
D	12	0.503	0.099	
E	4	0.200	0.917	
F	12	0.147	0.651	
G	11	-0.145	0.673	
Same year - Surveys				
B	6	-0.638	0.173	
D	8	-0.386	0.346	
E	8	-0.132	0.756	
Previous year - Fishing vessels (INIDEP)				
B	11	-0.055	0.881	
D	12	0.678	0.019	*
E	4	0.400	0.750	
F	12	0.315	0.319	
G	11	-0.082	0.818	
Previous year - Surveys				
B	6	-0.464	0.354	
D	8	-0.184	0.663	
E	8	0.898	0.002	*

Table 6
Spearman correlations between fishing pressure (same or previous year) and community biomass for a given year (across management units) and sampling technique. None of these correlations was significant.

Year	n	correlation	p-value
Same year - Fishing vessels (INIDEP)			
2002	4	-0.400	0.750
2003	4	0.400	0.750
2004	4	-0.200	0.917
2005	3	-0.500	1.000
2006	3	-1.000	0.333
2007	3	-1.000	0.333
2010	4	0.600	0.417
2011	4	0.000	1.000
2013	4	-0.400	0.750
2014	3	-1.000	0.333
2015	3	-0.500	1.000
2016	3	-0.500	1.000
Same year - Surveys			
2013	5	0.200	0.783
2014	5	-0.500	0.450
2015	3	-1.000	0.333
Previous year - Fishing vessels (INIDEP)			
2002	4	0.000	1.000
2003	4	0.200	0.917
2004	4	-0.800	0.333
2005	3	-0.500	1.000
2006	3	-0.500	1.000
2007	3	-1.000	0.333
2010	4	0.800	0.333
2011	4	0.000	1.000
2013	4	0.000	1.000
2014	3	-1.000	0.333
2015	3	0.500	1.000
2016	3	0.500	1.000
Previous year - Surveys			
2013	5	-0.500	0.450
2014	5	-0.300	0.683
2015	3	0.500	1.000

Table 7
Spearman correlations between fishing pressure (same or previous year) and community biomass (% non-target species) for a given management unit (across years) and sampling technique. Asterisks next to p-value highlight significant correlations.

MU	n	correlation	p-value	
Same year - Fishing vessels (INIDEP)				
A	4	0.353	0.647	
B	14	-0.505	0.065	
C	6	-0.550	0.258	
D	16	-0.086	0.751	
E	16	-0.051	0.852	
F	18	0.044	0.863	
G	14	-0.466	0.093	
J	6	0.326	0.528	
Same year - Fishing vessels (fleet)				
A	4	-0.900	0.100	
B	8	0.135	0.749	
C	6	-0.604	0.204	
D	6	0.756	0.082	
E	7	0.096	0.839	
F	9	-0.173	0.657	
G	8	0.257	0.539	
H	7	-0.338	0.458	
Same year - Surveys				
D	6	-0.051	0.923	
E	6	0.488	0.327	
Previous year - Fishing vessels (INIDEP)				
A	4	0.749	0.251	
B	14	-0.516	0.059	
C	6	0.870	0.024	*
D	16	-0.275	0.303	
E	16	0.206	0.444	
F	18	-0.133	0.600	
G	14	-0.426	0.128	
J	6	0.028	0.959	
Previous year - Fishing vessels (fleet)				
A	4	-0.982	0.018	*
B	8	-0.163	0.699	
C	6	-0.448	0.373	
D	6	0.845	0.034	*
E	7	0.273	0.554	
F	9	0.115	0.769	
G	8	-0.371	0.366	
H	7	-0.582	0.171	
Previous year - Surveys				
D	6	0.201	0.703	
E	6	0.491	0.323	

Table 8
Spearman correlations between fishing pressure (same or previous year) and community biomass (% non-target species) for a given year (across management units) and sampling technique. Asterisks next to p-value highlight significant correlations.

Year	n	correlation	p-value	
Same year - Fishing vessels (INIDEP)				
1997	3	-0.915	0.265	
1999	5	-0.365	0.546	
2001	5	-0.733	0.159	
2002	6	-0.538	0.271	
2003	6	-0.215	0.682	
2004	7	0.653	0.112	
2005	6	-0.753	0.084	
2006	5	-0.632	0.252	
2007	7	-0.021	0.964	
2008	7	0.051	0.913	
2010	5	-0.628	0.257	
2011	6	-0.618	0.191	
2012	3	0.307	0.801	
2013	4	-0.422	0.578	
2014	4	0.046	0.954	
2015	5	0.461	0.435	
2016	4	-0.558	0.442	
Same year - Fishing vessels (fleet)				
2013	3	-0.362	0.764	
2014	7	-0.307	0.503	
2015	6	-0.887	0.018	*
2016	7	-0.659	0.108	
2017	4	-0.703	0.297	
2018	8	-0.239	0.569	
2019	5	-0.476	0.418	
2020	4	-0.998	0.002	*
2023	5	0.545	0.342	
2024	8	-0.155	0.714	
Previous year - Fishing vessels (INIDEP)				
1997	3	-0.927	0.246	
1999	5	-0.287	0.639	
2001	5	-0.734	0.158	
2002	6	-0.739	0.093	
2003	6	0.323	0.533	
2004	7	0.434	0.331	
2005	6	-0.688	0.131	
2006	5	-0.724	0.166	
2007	7	-0.069	0.883	
2008	7	0.165	0.723	
2010	5	-0.579	0.307	
2011	6	-0.564	0.243	
2012	3	-0.849	0.354	
2013	4	-0.140	0.860	
2014	4	-0.625	0.375	
2015	5	0.158	0.800	
2016	4	-0.887	0.113	
Previous year - Fishing vessels (fleet)				
2013	3	0.051	0.967	
2014	7	-0.557	0.194	
2015	6	-0.825	0.043	*
2016	7	-0.750	0.052	
2017	4	-0.253	0.747	
2018	8	-0.281	0.500	
2019	5	-0.689	0.198	
2020	4	-0.995	0.005	*
2023	5	0.265	0.667	
2024	8	-0.285	0.494	

Table 9

Spearman correlations between fishing pressure (same or previous year) and species richness indicators for a given management unit (across years). None of these correlations was significant.

MU	Indicator	n	correlation	p-value
Same year				
B	Mean species richness	11	0.021	0.952
A	Minimum species richness	8	0.488	0.220
B	Minimum species richness	17	0.243	0.347
D	Minimum species richness	9	0.303	0.429
E	Minimum species richness	9	0.549	0.126
F	Minimum species richness	8	-0.268	0.521
A	Maximum species richness	8	0.275	0.509
B	Maximum species richness	17	-0.031	0.907
D	Maximum species richness	9	0.286	0.456
E	Maximum species richness	9	0.370	0.327
F	Maximum species richness	8	0.344	0.404
Previous year				
B	Mean species richness	11	-0.392	0.233
A	Minimum species richness	8	-0.614	0.105
B	Minimum species richness	17	-0.142	0.587
D	Minimum species richness	9	-0.336	0.376
E	Minimum species richness	9	-0.152	0.696
F	Minimum species richness	8	-0.485	0.223
A	Maximum species richness	8	-0.072	0.866
B	Maximum species richness	17	-0.281	0.275
D	Maximum species richness	9	-0.319	0.402
E	Maximum species richness	9	0.605	0.084
F	Maximum species richness	8	0.074	0.862

Table 10
Spearman correlations between fishing pressure (same or previous year) and the indicator values for a given year (across management units). None of these correlations was significant.

Year	Indicator	n	correlation	p-value
Same year				
1995	Minimum species richness	4	-0.316	0.684
1997	Minimum species richness	3	0.500	1.000
2002	Minimum species richness	5	0.600	0.350
2003	Minimum species richness	5	0.900	0.083
2004	Minimum species richness	5	0.700	0.233
2005	Minimum species richness	5	0.400	0.517
2006	Minimum species richness	5	-0.300	0.683
2013	Minimum species richness	4	0.800	0.333
2014	Minimum species richness	4	0.400	0.750
1995	Maximum species richness	4	-0.400	0.750
1997	Maximum species richness	3	0.500	1.000
2002	Maximum species richness	5	0.400	0.517
2003	Maximum species richness	5	-0.600	0.350
2004	Maximum species richness	5	-0.500	0.450
2005	Maximum species richness	5	-0.051	0.935
2006	Maximum species richness	5	-0.300	0.683
2013	Maximum species richness	4	-0.600	0.417
2014	Maximum species richness	4	-0.200	0.917
Previous year				
1995	Minimum species richness	4	-0.632	0.368
1997	Minimum species richness	3	-1.000	0.333
2002	Minimum species richness	5	0.200	0.783
2003	Minimum species richness	5	0.700	0.233
2004	Minimum species richness	5	0.400	0.517
2005	Minimum species richness	5	0.100	0.950
2006	Minimum species richness	5	-0.600	0.350
2013	Minimum species richness	4	-0.400	0.750
2014	Minimum species richness	4	0.800	0.333
1995	Maximum species richness	4	-0.200	0.917
1997	Maximum species richness	3	-1.000	0.333
2002	Maximum species richness	5	-0.200	0.783
2003	Maximum species richness	5	-0.500	0.450
2004	Maximum species richness	5	0.100	0.950
2005	Maximum species richness	5	-0.205	0.741
2006	Maximum species richness	5	-0.100	0.950
2013	Maximum species richness	4	-0.200	0.917
2014	Maximum species richness	4	-0.400	0.750