Fisheries performance indicators for assessing the ecological sustainability of wild-caught seafood products in Europe

Fabio Grati*[a], Jean-Noël Druon[b], Didier Gascuel[c], Christine Absil[d], François Bastardie[e], Sara Bonanomi[a], Gianna Fabi[a], Gildas Glemarec[e], Jerome Guitton[c], Sara Hornborg[f], Ane Iriondo[g], Armelle Jung[h], Stefanos Kalogirou[i], Daniel Li Veli[a], Josep Lloret[l], Christos Maravelias[m], Dimitrios K. Moutopoulos[n], Tiit Raid[o], Anna Rindorf[e], Antonello Sala[a], Martina Scanu[a], Giuseppe Scarcella[a], Vjekoslav Tičina[p], Clara Ulrich[q], Alessandro Lucchetti[a]

[a] National Research Council, Institute for Marine Biological Resources and Biotechnology, Ancona 60125, Italy

[b] European Commission, Joint Research Centre, Ispra 21027, Italy

[c] DECOD, L'Institut Agro, IFREMER, INRAE, 35000, Rennes

[d] Clupea Consultancy, Nijmegen 6531, The Netherlands

[e] Technical University of Denmark, National Institute of Aquatic Resources, Lyngby 2800, Denmark

[f] Agriculture and Food, RISE Research Institutes of Sweden, SE-40229 Gothenburg, Sweden

[g] AZTI, Sukarrieta, 48395, Spain

[h] Technopole Brest-Iroise, Plouzane 29280, France

[i] Agricultural University of Athens, Laboratory of Hydrobiology, Athens 11855, Greece

[l] Institut de Ciènces del Mar, Barcelona 08003, Spain

[m] University of Thessaly, Department of Ichthyology and Aquatic Environment, Fytoko Street, 38446 Volos, Greece

[n] University of Patras, Mesolongi 30200, Greece

[o] Estonian Marine Institute, University of Tartu, Tallin EE-126, Estonia

[p] Institute of Oceanography and Fisheries, Split 21000, Croatia

[q] Ifremer, Nantes 44311, France

Abstract

The increasing global demand for seafood has intensified pressure on marine resources and hence the need to adopt sustainable fishing practices and promote sustainable products. Raising consumer awareness about the variability in ecological sustainability of seafood is one tool to facilitate prevention of marine resource overexploitation, minimise the impact of fishing on ecosystems, and ensure long-term renewal of aquatic resources. Here we propose a simple but comprehensive and generic assessment framework with indicators that inform on the impact of fishing practices on seabed habitats, fish stock status, and bycatch risk of sensitive species for any given product, both coming from domestic fisheries or imported, based on publicly available information. A rating scale from 1 to 5 is used for clarity and effectiveness in communicating the risks. The indicators provide a user-friendly tool for consumers, policymakers, and industry professionals to make informed decisions about seafood sustainability. When applied, significant ecological risks are evident for certain fishing methods. Different fishing gears can catch the same seafood species with varying impacts, making it crucial for value chain actors to make informed choices that support sustainable fishing practices. A clear, transparent, and adaptable scoring system can enhance societal awareness and drive the market toward more sustainable seafood products.

Keywords

Sustainable fishing practices, sustainability indicators, fishing impact assessment, societal awareness, marine ecosystems, ecological risks, rating scale

1. Introduction

In recent decades, the global demand for seafood has surged, driven by population growth and rising per capita consumption (OECD, 2014; Cowley and Coulon, 2016; Bellmann et al., 2016; FAO, 2024). The development in developed countries is mainly driven by improved living standards, which has increased attention to healthy food choices and fish protein. As a result, marine fisheries production hit a historic high of 86 million tonnes in 1996, and has stagnated or even slowly declined since, at least partially because of overfishing and human impacts on ocean productivity. Meanwhile, the relative contribution of marine-caught products to human food has decreased globally from around 8.4 percent of animal protein intakes on average in the 1990s to about 5.5 percent in 2022 (FAO, 2024). While we consume twice as much aquatic food overall as 50 years ago, this increase is driven mostly by the rapid growth of aquaculture and masks the fisheries crisis observed in many countries (Crona et al., 2016), including some regions where fisheries still significantly contribute to human protein consumption, notably in Asia and Africa. Globally, the fishing industry is facing unprecedented challenges, with growing concerns over the depletion of marine resources, the degradation of ecosystems, and the economic well-being of fishing communities. In particular, the proportion of stocks being fished at biologically unsustainable levels, among those stocks for which that information exists, has increased from 10.0 percent in 1974 to 37.7 percent in 2021 (FAO, 2024). The concept of sustainable fishing encompasses a holistic approach that strives to balance environmental, social, and economic considerations in fisheries management (Pikitich et al., 2004, Brčić et al., 2018). Sustainable fishing products are derived from fisheries operations that adhere to principles guaranteeing the responsible use of marine resources while minimising environmental impact (among which habitat degradation and adverse effects on sensitive species), thereby contributing to the long-term well-being of coastal communities. The ecological sustainability of fishing practices is inherently a two-fold issue, consisting of:

a) Conserving the Harvested Fish Stocks - this aspect focuses on ensuring that fish populations targeted by commercial fisheries are maintained at sustainable levels. It is essential to allow these populations to replenish, thereby ensuring that fishing remains a viable activity for future generations.

b) Conserving the Broader Marine Biodiversity - beyond managing target fish stocks, it is crucial to protect the diverse array of species and habitats that constitute marine ecosystems. The health of this broader biodiversity is vital for the survival of commercial fish stocks, as these ecosystems provide essential services such as food, shelter, and breeding grounds.

These dual objectives align closely with the Ecosystem Approach to Fisheries (EAF), a comprehensive strategy for managing fisheries that takes into account the entire ecosystem, including the intricate interdependencies between species, habitats, and human activities (Pikitich et al., 2004, FAO 2021). Unlike traditional fisheries management, which focuses primarily on maximising the yield of individual fish stocks, the EAF aims to preserve the health, productivity, and resilience of the entire marine ecosystem. This holistic approach acknowledges that the sustainability of fisheries is deeply connected to the broader ecological context in which they exist.

The severe depletion of many fish stocks, attributed to overfishing and ineffective fishery management, has become a major concern for Regional Fisheries Management Organisations (RFMOs), government agencies, environmental non-governmental organisations (NGOs), and retailers. Ocean health and resiliency are closely linked to the ecological sustainability of fishing practices, as underlined by the principle that fishing is sustainable when enough fish is left in the ocean not only to renew populations, but also to support profitable fisheries in the long-term and to maintain the functioning of marine ecosystems. At the same time, sustainable fishing must also eliminate unsustainable impacts on marine habitats and ecosystems that support ocean life and, for non-target species that may interact with fisheries, ensure that their populations are not threatened by ongoing fishing practices. In response to this growing challenge, various advocacy groups have launched campaigns to promote sustainable fisheries and responsible consumption of fish and seafood. These efforts have raised consumer awareness, leading to an increase in demand for certified seafood products (Washington et al., 2011; Thøgersen et al., 2010; Parkes et al., 2010, Richter et al., 2017). In turn, the promotion of sustainable fishery products issued from sustainable fishing practices has emerged as an incentive-based strategy for ensuring the long-term health of our oceans, safeguarding biodiversity, and supporting the livelihoods of those who depend on the fishery products. A number of certification schemes and eco-labels for fish and seafood have emerged in recent decades to promote environmentally sustainable fishing practices (Sainsbury, 2010). These schemes have the benefits of analysing sustainability criteria for a specific fishery (species, gear and area). However, regular criticism was also raised because they are private initiatives with a cost that may be a barrier to entry for the small-scale fishery and that mainly applies to fisheries providing products for the retail market for western consumers (Jones et al., 2023). Furthermore, the assessment framework for ecosystem impact has not always been sufficiently precautionary and coherently applied (Good et al., 2024). Consequently, private certification schemes are relatively specific compared to our approach that can be applied to any fishery product.

Certification may also only convey a message of "certified or not", where non-certified seafood products may simply originate from fisheries that have not been assessed, which fails to communicate the large variability gradient that exists between different fisheries, fishing practices, and species sold at retail.

In addition to independent certification schemes, several seafood sustainability rating initiatives have been developed, for example Seafood Watch by the Monterey Bay Aquarium, the Good Fish Guide by Marine Conservation Society UK, and the rating schemes by WWF. These rating schemes produce sustainability recommendations, usually in a traffic-light system. Where certification is voluntary, ratings are not. Where certified products mostly can be found with supermarkets, ratings provide sustainability information for those products that are not certified, for example with fishmongers.

Certifications usually include a Chain of Custody standard, allowing on-pack labels, while rating systems are generic tools that consumers and businesses can consult to make informed decisions. While rating schemes are valuable for promoting informed consumer choices and sustainable practices, disadvantages can be confusion created by multiple rating systems, and also the high maintenance costs of the information systems, since they have to be updated regularly. Seafood ratings following structured semi-automated methods could be a cost-effective way to provide basic sustainability information on seafood products and could help provide the necessary uniformity.

To continue providing nutrient-rich food for a rising population, it is essential to reverse any negative consequences impairing the health of targeted fish populations by safeguarding marine biodiversity and the ecosystems' productivity and resilience. Regulation (EU) No 1379/2013, also known as the Common Market Organization (CMO) Regulation, governs the marketing of seafood products in the European Union. Its objectives include promoting sustainable exploitation of marine resources, applying the Common Fisheries Policy (CFP) effectively (Regulation (EU) 1380/2013), enhancing the competitiveness of the fisheries and aquaculture industry, improving market transparency and stability, ensuring a balanced distribution of value along the supply chain, improving consumer information and awareness through clear labelling, promoting sustainable practices, ensuring a diversified supply of seafood products, and providing consumers with accurate information about the origin and production methods of the products through labelling and marking. The CMO Regulation requires producers to provide specific information when marketing seafood products in the EU. The main information used in our approach is what we refer to as the CMO triplet for wild caught products (considering that the method of production, i.e., wild caught or farmed is compulsory to declare): (i) the commercial name and scientific designation of the species, (ii) the catch location (expressed as large FAO areas or sub-areas) and (iii), the category of fishing gear employed. Additionally, the CMO requires also to declare whether the product has been thawed.

In this context, the present paper aims to provide a thorough analysis of key ecological sustainability dimensions of fishing products within the seafood system's primary production, exploring their significance, challenges for the benefit of ecosystems, economies, and society, and how they can be used to improve consumer information on ecological sustainability of fisheries. To achieve this, several indices have been developed in the frame of experts working groups set up by the Scientific, Technical and Economic Committee for Fisheries (STECF) of the European Union (STECF, 2021, 2023, 2024). These indices are based on objective evaluation criteria to assess the seafood product in terms of status of the stock and fishing practices implied to exploit such seafood products. It is important to note that the proposed system evaluates seafood products starting from the compulsory CMO triplet data, then supplemented with other data and information as described below. This specific requirement represents the most structuring challenge, which shaped the entire development of the approach. On the one hand, adapting to basic mandatory data allows scoring any fishery product available on the EU market, both domestic and imported, insuring the widest possible coverage for consumers; on the other hand, these mandatory data are very broad and convey only limited information averaged over large categories, which prevents fine scale analysis at the scale of a specific operator or fishery, as a private label would do. As such, this approach marks a significant advancement in communicating the ecological sustainability of fisheries and, consequently, in providing consumers with more informed choices; however, it still leaves some questions open regarding individual incentives within each broad CMO category, since the scores rather describe the "average potential relative impact risk" based on CMO triplet data (species-area-gear), but not the actual absolute impact induced by the very fishery who caught the product.

Our research focused primarily on evaluating the sustainability of the seafood products available on the European market, through a robust and documented assessment of the ecological risks associated with the harvesting of wild marine resources. Specifically, our goal was to assess the potential effects of seafood harvest on three essential aspects of marine ecosystems: a) the impact of fishing gear on the seabed, b) the status of exploited fish stocks, and c) the risk of interaction between fishing gear and sensitive species. By analysing these critical elements, our study aims to provide a first understanding of the environmental risks associated with the production and consumption of captured seafood products in Europe.

2. Materials and methods

2.1 General principles

We adopted a color-coded rating scale from 1 to 5 (or A to E) to define the intrinsic ecological sustainability of seafood products. This approach offers a clear and visually appealing way to communicate different levels of sustainability performance. The success and widespread recognition of the European energy label, which influences 79% of consumers, supports the effectiveness of using such a simple and intuitive scale (Kennedy, 2019).

As a general principle, the scoring system is designed to take a precautionary approach by assigning a potentially high impact rating when information is limited or unavailable

The indicators are designed to accommodate two different levels of information available for the products:

a) **Basic rating**, which consists of a simple scoring system based on the data currently required for fishery products placed on the EU market under the CMO Regulation. These are the designation of commercial species and their scientific name, the gear category (i.e., a group of fishing gears), the FAO sub-areas specifically for FAO 27 and FAO 37, and the FAO fishing area for other oceans.

b) **Advanced rating**, involves a more detailed scoring system that incorporates additional information voluntarily provided by producers. Besides the mandatory information, this may include, for example, information on specific fishing gears at higher level of detail and FAO sub-areas for all oceans, allowing a more accurate evaluation.

2.2 Indicator of fishing impact on the seabed

2.2.1 Scoring the potential seabed impact of fishing gears

For this indicator, "impact of a gear" is defined as the potential influence that a single fishing operation using a particular gear may exert on a specific habitat. It is important to note that this interpretation contrasts with the cumulative effect of past, longstanding fishing activities (i.e., without accounting for the total fishing effort deployed in a designated area over time).

While both active and passive gears may impact benthic habitats, there is a significant scientific consensus regarding the substantial impacts of mobile bottom-contact gears on the seabed, mostly trawled gears (Eigaard et al. 2017) when compared to passive gears (Eno et al. 2001). Consequently, relative impacts on the seafloor are strongly linked to the fishing gear and its specific technology, with bottom trawls and dredges generally considered to be the fishing gear with the greatest impact per unit of effort.

It is commonly assumed that passive artisanal fishing gears such as trammel nets and bottom longlines generally have a lower impact than bottom trawls on benthic habitats. However, this assumption must not be taken for granted because in fragile habitats such as coralligenous beds in the Mediterranean or other habitat-forming species such as maërl in the North Atlantic and Mediterranean and kelps in the North Atlantic, these gears may still pose a significant threat to these fragile sessile communities (The N2K Group, 2017). Therefore, the scoring for seabed impact should be able to account for both the gear type and the habitat on which it is exerted.

For the categorization of gears, in accordance with Morgan and Chuenpagdee (2003) and the advice of the Expert Working Groups (EWGs) of the Scientific Technical and Economic Committee for Fisheries (STECF) of the European Commission (STECF, 2021, 2023), we used available scientific literature. We also adhered to the ad hoc guidelines outlined below for assessing gear scores, drawing from the materials provided in the FAO manual (FAO, 2021), which meticulously delineates the specifications of each fishing gear:

Score 0: seabed is never touched by the gear (no impact);

Score 1: seabed is touched by passive gear (low impact);

Score 2: seabed is touched by active gear (medium impact);

Score 3: seabed is touched with severe impact (high impact).

A list of gear categories (Table 1) that producers are required to declare is included in Annex III of the CMO Regulation. However, certain gear categories encompass very different fishing techniques. In particular, the category "Trawls," as defined in the CMO Regulation, combines both "Demersal Trawl" and "Pelagic Trawl," each of which has very distinct impacts on the seabed. Within Annex III of the CMO Regulation, an additional inventory of more detailed fishing gears is provided, comprising 28 distinct fishing gears, which may be voluntarily declared. The level of accuracy conveyed by this list of gears surpasses what is encompassed by the mandatory information in the CMO gear categories. Consequently, in instances where the definition of gear is too broad, referred above as the “basic rating”, we apply a precautionary approach, assigning the highest impact score (Table 1).

Table 1. Impact scores for the gear categories that producers are required to report according to the CMO Regulation, as well as for detailed fishing gears that producers may choose to report voluntarily.

The scores define the extent of a fishing gear's contact with the seafloor and the anticipated severity of this interaction, on a scale from 0 to 3.

Mandatory information on the category of fishing gear (Basic rating)	Impact score	More detailed information on corresponding gears (Advanced rating)	Impact score
Dredges	3	Boat dredges	3
Dredges	3	Hand dredges used on board a vessel	3
Dredges	3	Mechanised dredges including suction dredges	3
Gillnets and similar nets	1	Combined trammel and gillnets	1
Gillnets and similar nets	1	Driftnets	0
Gillnets and similar nets	1	Encircling gillnets	1
Gillnets and similar nets	1	Set (anchored) gillnets	1
Gillnets and similar nets	1	Trammel nets	1
Hooks and lines	1	Hand lines and pole lines (hand operated)	0
Hooks and lines	1	Hand lines and pole lines (mechanised)	0
Hooks and lines	1	Longlines (drifting)	0
Hooks and lines	1	Set longlines	1
Hooks and lines	1	Troll lines	0
Pots and traps	1	Pots (traps)	1
Seines	3	Beach seines	2
Seines	3	Danish seines	2
Seines	3	Pair seines	2
Seines	3	Scottish seines	3
Surrounding nets and lift nets	1	Boat operated lift nets	0
Surrounding nets and lift nets	1	Lampara nets	1
Surrounding nets and lift nets	1	Purse seines	1
Surrounding nets and lift nets	1	Shore-operated stationary lift nets	0
Trawls	3	Beam trawls	3
Trawls	3	Bottom otter trawls	3
Trawls	3	Bottom pair trawls	3
Trawls	3	Midwater otter trawls	2
Trawls	3	Otter twin trawls	3
Trawls	3	Pelagic pair trawls	1

2.2.2 Scoring the sensitivity of marine habitats to the potential impact of fishing gear

The second step was to account for the sensitivity of specific marine habitats to each particular fishing gear in the scoring, keeping in mind that detailed fishing location is not available in the CMO data and spatial habitat information cannot thus be used directly. To achieve this, we thus used the species information as a surrogate, linking a species with its "typical habitat". Marine habitats and commercial marine organisms (e.g., fishes, molluscs, crustaceans, etc.) preferential habitats data were issued from various sources such as fishbase.org, sealifebase.org, scientific literature, and technical reports (cf details in STECF 2023). Given the complexity of this classification, emphasis was placed on the habitat types defined in the European Nature Information Service (EUNIS) habitat classification's "habitat level 2" (https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification), which encompasses diverse marine habitats. Similar to the criteria used for assessing the potential impact of fishing gears on the seabed, the sensitivity of marine habitats to gear action was also categorised into three levels (1 = low; 2 = medium; 3 = high), following a simplified version of the approach outlined in Morgan and Chuenpagdee (2003).

In this study, given the pelagic gears rarely touch the seabed, a score of 1 was assigned to pelagic species. A score of 3 to species residing in rocky, biogenic habitats, littoral zone, and deep sea (>1000m depth), because these habitats host the most fragile species and associated habitats (Hiddink et al. 2023). In addition, water depth-related terms were assigned to each habitat as follows: a) the littoral zone extends from the high-water mark to shoreline areas that are permanently submerged; b) the infralittoral zone extends to depths < 50 m; c) the circalittoral zone extends to depths between 50 m and 200 m; d) the offshore circalittoral zone extends to depths between 200 m and 1,000 m; e) the upper bathyal zone extends to depths between 1,000 m and 2,500 m; f) the lower bathyal zone extends to depths between 2,500 m and 4,000 m; g) the abyssal zone extends to depths > 4,000 m (Table 2). As such, a habitat sensitivity score could be assigned to 1,850 species.

Table 2. Habitat sensitivity score per habitat type according to whether or not the habitat is vulnerable to physical disturbance (abrasion) induced by fishing, on a scale of 1 to 3. Pelagic habitat is set as 1.

	Rock	Biogenic habitat	Coarse sediment	Mixed sediment	Sand	Mud
Littoral	3	3	3	3	3	3
Infralittoral	3	3	1	1	1	2
Circalittoral	3	3	1	1	1	2
Offshore circalittoral	3	3	1	1	1	2
Upper bathyal	3	3	3	3	3	3
Lower bathyal	3	3	3	3	3	3
Abyssal	3	3	3	3	3	3

2.2.3 Combining the sensitivity of marine habitats with the potential impact of fishing gear

To obtain an overall (final) seabed impact score for the fishery product (ranging from 1 to 6), the score determined for the impact of the fishing gears (ranging from 0 to 3) is summed with the proxy habitat sensitivity score determined for the species (ranging from 1 to 3), as illustrated in Table 3.

Table 3. Calculation of the final score (sum of fishing gears impact and habitat sensitivity) for the impact on the seabed indicator.

		Fishing gear impact			
		0	**1**	**2**	**3**
Habitat sensitivity	**1**	Very low	Very low	Low	Medium
	2	Very low	Low	Medium	High
	3	Low	Medium	High	Very high

2.3 Stock status indicator

This indicator is designed to evaluate the degree to which current fishing pressure on the stock in question aligns with the management objective of that stock at Fmsy (fishing mortality consistent with achieving Maximum Sustainable Yield) level, which has been adopted by the EU as the main target for the management of fish stocks (EU Regulation 1380/2013). This criterion relates to the retrospective assessment of the sustainability of each fish stock, utilising single-species assessment methodologies.

The process outlined in this study operates in a hierarchical manner and, to facilitate the grading process, several data sources are used depending on data availability, as illustrated by the decision tree diagram of Figure 1:

1. Stocks assessments outputs delivered by scientific bodies.

2. IUCN Red List of Threatened Species.
3. Species list and indices based on sensitivity to fisheries (Cheung et al., 2005; Osio et al. 2015; Rindorf et al., 2020).

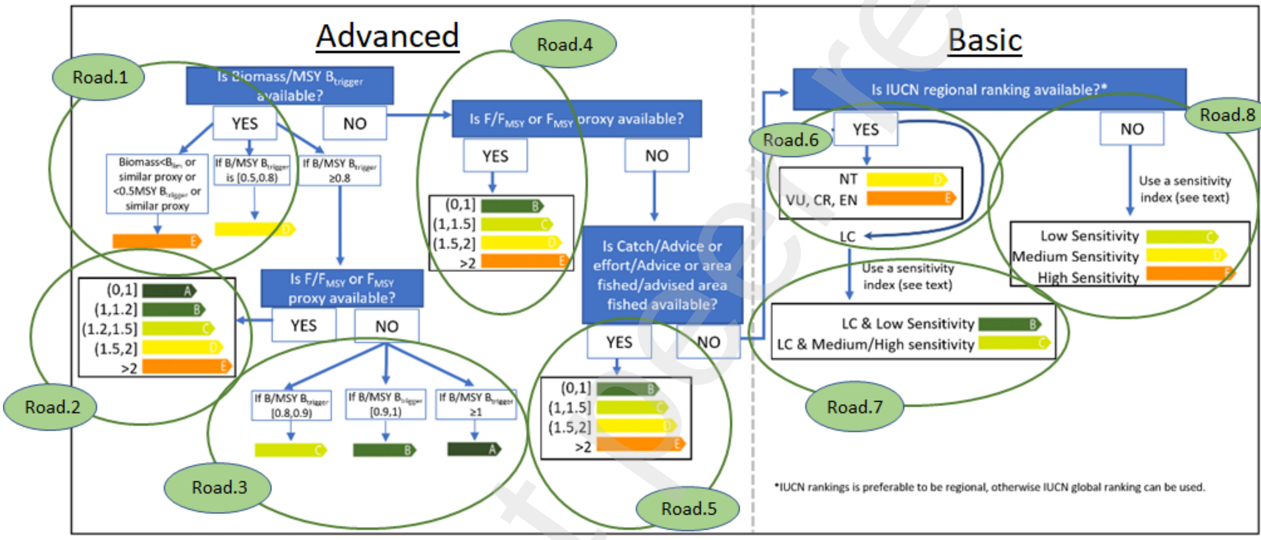

Figure 1. Decision tree to grade/rate the sustainability levels of fisheries products as a function of fishing pressure.

The general rule is to first assess whether quantitative stock assessment data are available for a combination of target species and area, which enables a score to be calculated following the more informed Advanced rating. If these data are not available, the score is calculated using Basic rating.

Advanced rating relies on quantitative values derived from stock assessment models, including metrics such as F/Fmsy (F = fishing mortality; Fmsy = fishing mortality consistent with achieving Maximum Sustainable Yield), B/MSY Btrigger (B = stock biomass; MSY Btrigger = point at which fishing pressure should be reduced to maintain or restore the stock's biomass to a level that can support maximum sustainable yield over the long term), catch advice, catches, effort advice, and effort. These values are sourced from biological reference points defined within the models, or from comparisons between advised catches or effort levels and realised catch or effort levels.

The evaluation is conducted under the Basic rating when there is no available information on biomass and fishing mortality for any stock of the species within the broad marine region, but an IUCN ranking or sensitivity analyses are accessible. If available, the regional IUCN ranking (as defined on the IUCN website) should be prioritised for scoring a stock under Basic rating; otherwise, the global ranking may be used. However, the IUCN assessments focus on species rather than specific stocks and are infrequently updated.

Species sensitivity/vulnerability to fishing was assessed using criteria from Cheung et al. (2005) (Low ≤40; Medium >40 and ≤70; High >70), Rindorf et al. (2020) (Low >3.0; Medium >0.41 and ≤3.0; High ≤0.41), and Osio et al. 2015 (Low ≤1.6; Medium >1.6 and ≤2.0; High >2.0). Sensitivity data from Cheung et al. (2005) are also available in fishbase.org.

Overall, the process is based on eight roads/paths, which have been identified based on data availability (Figure 1). The criteria used in each road are summarised in Table 4. The sustainability level of exploitation for each stock, as determined by the eight-step process, was categorised into five levels, from 1 (or A, best score) to 5 (or E, worst score).

Table 4. Criteria developed for the decision tree to assess the sustainability levels of fisheries products according to the stock status. NT = near threatened; VU = vulnerable; CR = critically endangered; EN = endangered.

Road	System	Criteria	Thresholds	Score
1	Advanced	B/MSYBtrigger	<0.5 or B<Blim	5
			>0.5 and <0.8	4
		if ≥0.8 and F/Fmsy available - road 2		
2	Advanced	F/Fmsy	<1.0	1
			≥1.0 and <1.2	2
			≥2.0 and <1.5	3
			≥1.5 and ≤2.0	4
			>2.0	5
		if F/Fmsy not available - road 3		
3	Advanced	B/MSYBtrigger	≥0.8 and <0.9	3
			≥0.9 and <1.0	2
			≥1.0	1
		if B/MSYBtrigger not available - road 4		
4	Advanced	F/Fmsy	<1.0	2
			≥1.0 and <1.5	3
			≥1.5 and <2.0	4
			>2.0	5
		if F/Fmsy not available - road 5		
5	Advanced	Catch/Advice	<1.0	2
			≥1.0 and <1.5	3
			≥1.5 and <2.0	4
			>2.0	5
		if Catch/Advice not available - road 6		
6	Basic	IUCN status	NT	4
			VU, CR, EN	5
		if LC – road 7		
7	Basic	Sensitivity	Low	2
			Medium and High	3

if IUCN status not available – road 8				
8	Basic	Sensitivity	Low	3
			Medium	4
			High	5

2.4 Indicator on the bycatch risk of sensitive species

The aim of this indicator is to inform on the potential risk of incidental capture of sensitive species (bycatch) associated with different seafood. To assess the potential impact of a fishery on a sensitive species (or group of sensitive species), it is essential to have comprehensive data on a range of factors such as population status, total bycatch estimates, mortality rates, and other life-history characteristics. Such information is often lacking or not readily available at global level. Therefore, the proposed indicator is designed to assess potential risk for incidental bycatch of sensitive species or species groups, not the actual impact. Where information is available on actual impact, this can be used instead, scoring using similar principles.

In this context, the term "sensitive species" specifically refers to marine mammals, sea turtles, seabirds, and threatened Chondrichthyes (i.e., sharks, skates, rays, and chimaeras). Since the latter includes a few commercial species, threatened Chondrichthyes are here defined as those species listed as either prohibited under EU fishing opportunities regulations, or threatened according to the IUCN global and regional assessments (i.e., vulnerable-VU, endangered-EN or Critically endangered-CR). These species groups cover a major share of species sensitive to incidental bycatch. However, we acknowledge that other sensitive species or groups than the ones listed above may commonly interact with a range of fishing gears (e.g. certain threatened finfish, molluscs, echinoderms, corals, and marine reptiles), which may pose a risk to their populations. Noting this deficiency, a more comprehensive assessment is left for future effort, motivated from the considerable effort it would have taken to review and integrate the information on these species' groups.

The list of 28 gears outlined in Table 1 was applied for this indicator with the addition of hand implements (such as wrenching gear, clamps, tongs, rakes, and spears), which are not covered by the CMO Regulation.

To ensure consistency in the scoring of EU and imported fishery products, the scoring system was proposed to be based on data from national scientific literature, open databases, and grey literature, including technical reports. Although more detailed information on bycatch may be available for EU products, including data on specific areas and fishing gear, this could result in disparities with imported products due to potential limitations in available documentation or accessibility for experts.

We carefully considered and developed a scoring system to reduce subjectivity, particularly in the judgement of individual experts, and to ensure a consistent ranking process across regions, gears and species. This methodology is designed to be reproducible and transparent to bolster credibility and acceptance by e.g., analysing and distinguishing between different levels of information quality, and by pinpointing risk levels associated with one or more groups of sensitive species. The approach also considers the scientific understanding of the simultaneous risk posed by fishing gear to several groups of sensitive species. Furthermore, we developed an efficient and straightforward scoring process, carried out through calculation based on predefined rules. This ensures that the process remains streamlined and easy to understand.

The overall scoring process involved the following steps:

1) The potential risk of incidental bycatch for each sensitive species or species group is assessed on a scale from 0 to 3: 1 indicates low risk, 2 medium risk, 3 high risk, and 0 if no information is available. These scores are derived from a review of the available scientific literature. The

information used for scoring may be specific to individual species or aggregated at a broader level (e.g., genus, family, group, etc.), with all relevant data considered. When documents provide risk values within the 1 to 3 range, or categorise them as low, medium, or high, these are directly utilised in the assessment. If direct scoring from publications is not feasible, risk scores are assigned based on explicit and/or implicit risk information or expert judgement to interpret the available data.

2) An arithmetic mean is calculated on the scores assigned to the different groups of sensitive species (e.g., sea turtles, marine mammals, seabirds, threatened Chondrichthyes) which receive scores of 1 to 3. If multiple species within a group are assessed, the group's score is determined by calculating the arithmetic mean of the individual species scores. Zeros are excluded from the calculation as they indicate a lack of information.

3) The average score, ranging from 1 to 3, is converted into a 5-level score (1 to 5) to align with the other indicators. This was achieved by applying the scale factor 5/3 and rounding to the nearest whole number.

4) A potential increase in the score (indicating a higher risk) is applied under specific conditions to the 5-level score. These conditions include: a) adding an extra point if more than one bycatch group is assessed at medium or high risk of interaction (scores of 2 or 3), reflecting that a fishing activity impacting multiple sensitive groups poses a greater overall risk; and b) adding extra points if the quality of the available information is deemed relatively poor, based on four predefined quality criteria (as outlined in Table 5). However, if the adjusted score, including any additional points, exceeds 5, the final score will be capped at 5.

Table 5. Criteria developed for the bycatch information quality used to adjust the sustainability levels of fisheries products according to the risk of bycatch. A total quality score is attributed to each information based on four criteria (the lower the score, the higher the quality level). ERA: Ecological Risk Assessment; PBR: Potential Biological Removal.

Criteria	Maximum points
Criterion 1: Sensitive species specificity The information is relevant to document risks for bycatch of a species group (low = 1) or a certain sensitive species (high = 0)	1
Criterion 2: Sound methodology (including reliability) – The information has a sound and well documented methodology (that has been published) The presented methods should allow transparency for the replicability of the information. A sound methodology is documented in sufficient details and is available for consultation, which contains: Grey literature + qualitative information = 3 Peer reviewed publication + Bycatch rate = 2 Peer reviewed publication + ERA = 1 Peer reviewed publication + PBR = 0	3
Criterion 3: Geographical coverage - The data provides information with appropriate geographical coverage relevant to the spatial distribution of the sensitive species population Global coverage = 2 (unless if the sensitive species population is known to have a global spatial distribution, then the score is 0) FAO area = 1 (unless if the sensitive species population is known to have a spatial distribution at the FAO area level, then the score is 0) FAO subdivision = 0	2
Criterion 4: Temporal coverage Relevant information is older than 10 years = 1 Relevant information is 10 years-old or more recent = 0	1
Total	**7**

3. Results

3.1 A case study: assessing ecological sustainability indicators in FAO Area 27 (Northeast Atlantic Ocean) and FAO Area 37 (Mediterranean and Black Sea)

To evaluate the effectiveness of the three indicators for seafood products, we focused on testing the methods developed on the 390 and 303 most important commercial species landed by weight in 2022 in the FAO areas 27 (Northeast Atlantic Ocean) and 37 (Mediterranean and Black Sea), respectively. These species were caught using 27 different fishing gears across 36 subareas of FAO 27 and 28 fishing gears across 5 subareas in FAO 37 (Western, Central, Eastern, Adriatic Sea, and Black Sea). This data was sourced from the EU Fisheries Dependent Information (FDI) database 2022 (https://stecf.ec.europa.eu/data-dissemination/fdi_en), resulting in 43,810 (FAO 27) and 8,862 (FAO 37) combinations of species, area, and gear. Scores for each indicator were calculated for all combinations (Figure 2). The frequency distribution of scores shows distinct patterns for the three indicators.

The stock status indicator follows a normal distribution in both FAO 27 and FAO 37, with a clear predominance of score 3 (medium impact). The seabed impact indicator also exhibits a similar trend in both areas, but is characterised by a predominance of score 1 (very low impact) and a change towards unsustainable score levels (reddish colours, scores of 4 and 5). In contrast, the bycatch risk of sensitive species indicator shows a different trend between the two FAO areas. In FAO 27, 34% of the scores are 2 (low impact), while scores of 4 (high impact) and 5 (very high impact) each account for around 30% of the total. In FAO 37, this indicator follows a normal distribution with a predominance of score 3 (medium impact) and no combinations scoring 5 (very high impact).

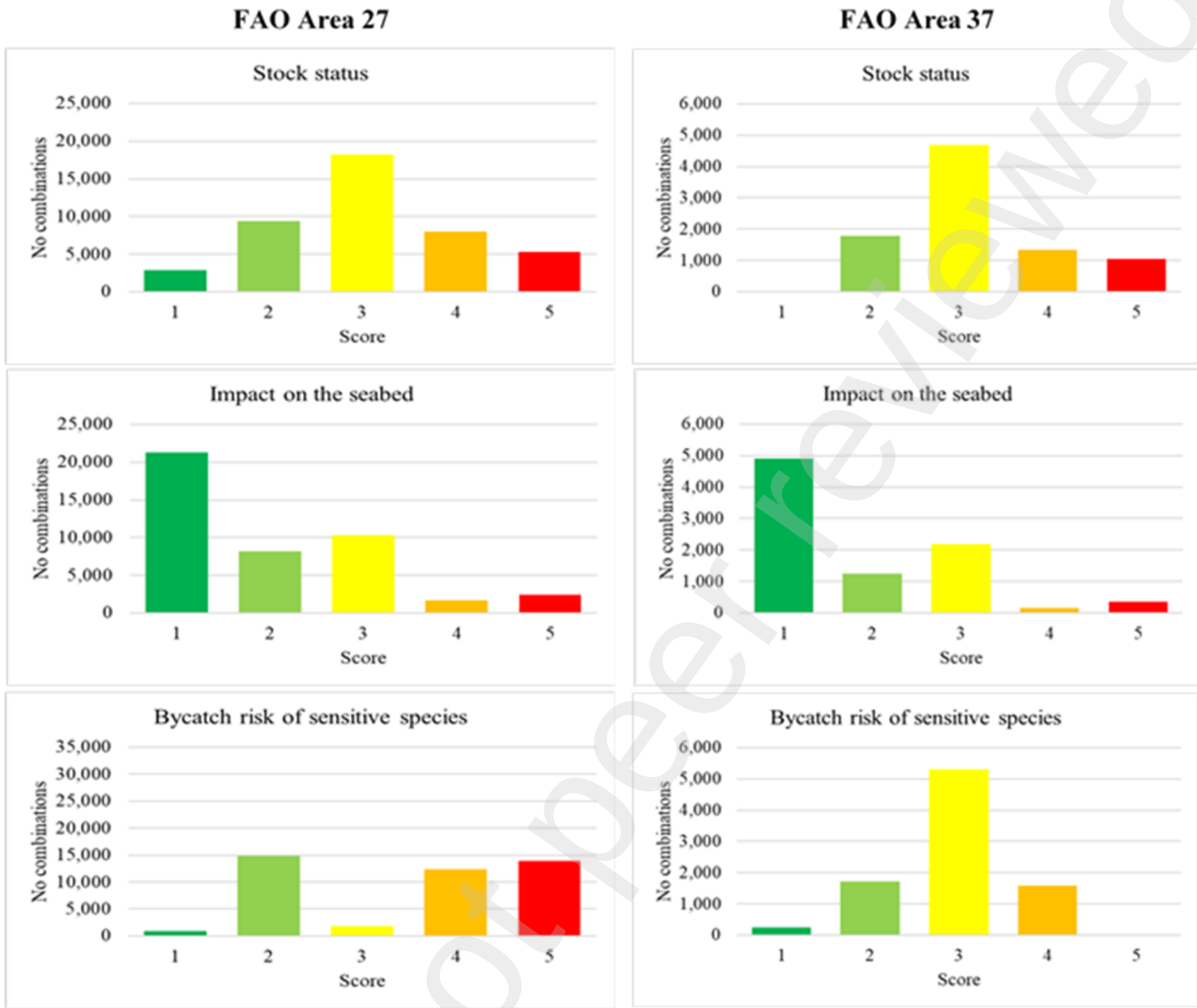

Figure 2. Frequency distributions of the fisheries sustainability indicator scores for gear-species-subarea combinations in FAO 27 (Northeast Atlantic Ocean) and FAO 37 (Mediterranean and Black Sea). Source: EU Fisheries Dependent Information database 2022 (https://stecf.ec.europa.eu/data-dissemination/fdi_en)

Figure 3 shows the spatial distribution of scores for each target species, fishing gear, and area combination across the subareas of FAO 27 and 37. These scores represent the average of the Stock Status, Seabed Impact, and Sensitive Species indicators, weighted by the official landing biomass of each target species. For the stock status indicator, sustainable scores are predominant in FAO 27, whereas in the Mediterranean, most subareas display moderately unsustainable scores, with the Black Sea being an exception. The impact of fishing gears on the seabed is more favourable, with sustainable scores prevailing in most regions, except for 27.3.A (Skagerrak and Kattegat). In contrast, the bycatch risk indicator for sensitive species shows generally unsustainable scores across most subareas in FAO 27, while it performs better in the Mediterranean and Black Sea.

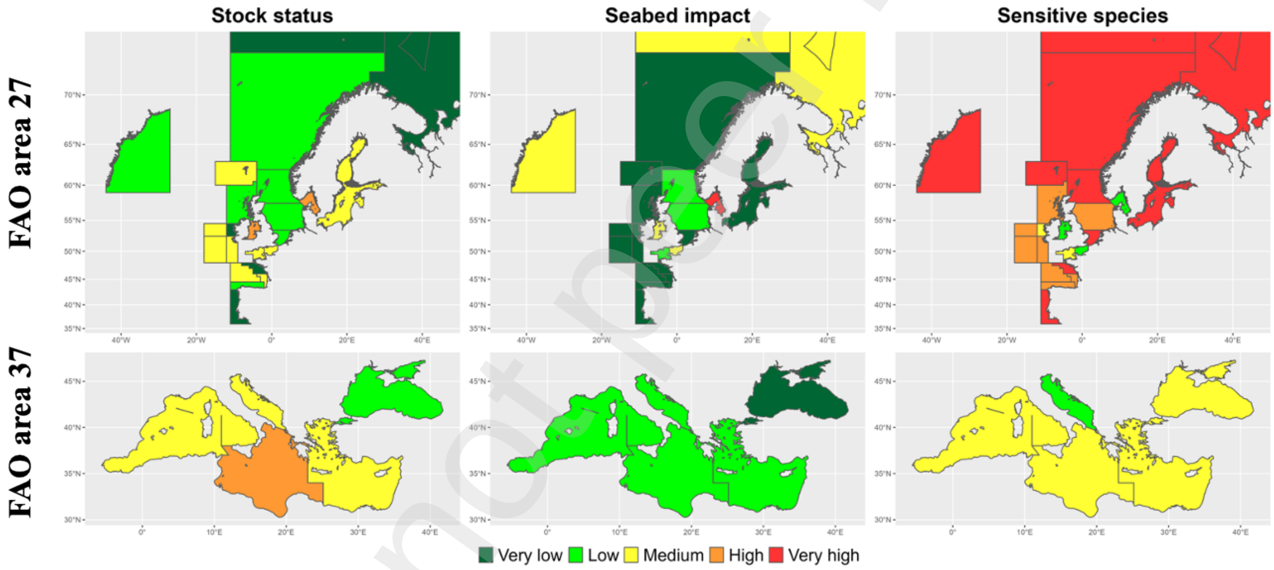

Figure 3. Maps showing the average scores weighed by landings (1: very low impact; 2: low impact; 3: medium impact; 4: high impact; 5: very high impact) of each sustainability indicator (stock status, seabed impact and sensitive species) across subareas of FAO area 27 (Northeast Atlantic Ocean) and FAO area 37 (Mediterranean and Black Sea). Note that these mean score levels weighted by landings are mostly driven by pelagic species (see Table 6).

To assess the scores for the most iconic species landed by European fleets, we selected the nine most abundant species in the European seas: Atlantic herring (*Clupea harengus*), European anchovy

(*Engraulis encrasicolus*), European hake (*Merluccius merluccius*), blue whiting (*Micromesistius poutassou*), great Atlantic scallop (*Pecten maximus*), European pilchard (*Sardina pilchardus*), Atlantic mackerel (*Scombrus scombrus*), European sprat (*Sprattus sprattus*), and Atlantic horse mackerel (*Trachurus trachurus*). In 2022, these species contributed to 60% of the landing biomass and to 29% of the landing value in FAO 27 (Northeast Atlantic) and FAO 37 (Mediterranean Sea) (Table 6). The scores indicate that the stock status is generally good to medium, with exceptions for Atlantic herring in the Baltic Sea and Atlantic horse mackerel in southwest Ireland, both caught with midwater pair trawls. The seabed impact scores show almost exclusively high sustainability as most of these species are caught with pelagic or passive gears. However, the risk of bycatching sensitive species is high in most cases, except for purse seines in the Adriatic Sea and dredges in the English Channel.

Table 6. Ecological sustainability scores calculated for the nine most important species in weight landed by EU fleets (FDI data 2022), of which seven are pelagic species (+) and two are demersal species (*). ST: stock status. SB: seabed impact. SN: bycatch risk of sensitive species.

Species	Areas	Fishing gears	ST	SB	SN
Atlantic herring+	North Sea	Midwater otter trawls	2	1	5
Atlantic herring+	Baltic Sea	Midwater otter trawls	5	1	5
European anchovy+	North Adriatic Sea	Purse seines	3	1	1
European anchovy+	North Adriatic Sea	Pelagic pair trawls	3	1	3
European anchovy+	Bay of Biscay	Purse seines	2	1	4
European hake*	Bay of Biscay	Set gillnets	2	1	5
European hake*	Bay of Biscay	Set longlines	2	1	4
European hake*	Southwest Ireland	Set gillnets	1	1	5
European hake*	Southwest Ireland	Set longlines	1	1	4
Blue whiting+	West Scotland	Midwater otter trawls	3	1	4
Blue whiting+	Porcupine Bank	Midwater otter trawls	3	1	4
Great Atlantic scallop*	East English Channel	Boat dredges	3	3	2
Great Atlantic scallop*	West English Channel	Boat dredges	3	3	2
European pilchard+	North Adriatic Sea	Purse seines	3	1	1
European pilchard+	North Adriatic Sea	Pelagic pair trawls	3	1	3

European pilchard+	Portuguese Waters	Purse seines	1	1	5
Atlantic mackerel+	North Sea	Midwater otter trawls	1	1	5
Atlantic mackerel+	West Scotland	Pelagic pair trawls	1	1	4
European sprat+	Baltic Sea	Midwater otter trawls	2	1	5
European sprat+	North Sea	Midwater otter trawls	1	1	5
European sprat+	North Sea	Pelagic pair trawls	1	1	5
Atlantic horse mackerel+	Portuguese Waters	Purse seines	1	1	5
Atlantic horse mackerel+	Southwest Ireland	Midwater otter trawls	4	1	4

4. Discussion

4.1 Advantages of the proposed scoring system

The fisheries performance system developed in this study distinguishes between high and low ecological sustainability performances of seafood products by incorporating three major impact categories. This approach offers an initial assessment of fishery sustainability at the ecosystem level, going beyond the traditional and often inadequate focus solely on the status of harvested marine resources. Rigorous criteria and methodologies ensure that fisheries products are accurately categorised, facilitating informed decision-making for seafood consumers and industry stakeholders. The indicators used are designed to be verifiable, relying on robust and accessible data from sound sources, including scientific research. Although data collection can be complex, we have established a transparent protocol to streamline this process and ensure consistency. This transparency, combined with the availability of necessary data, enhances the credibility and reliability of our sustainability assessments. The system is designed to evaluate a wide range of product attributes, currently including species, catch methods, and geographical origin on a global scale. However, it is also adaptable, accommodating evolving data and standards to maintain accuracy and relevance over time. The system can be easily expanded to incorporate additional criteria, such as greenhouse gas emissions (Gephart et al., 2021; Bastardie et al., 2022) or the risk of ghost fishing (Adey et al., 2008). It offers simplicity and clarity, which are important for effective communication throughout the supply chain. By presenting sustainability information in an easily understandable format, it ensures that key messages are conveyed clearly. This user-friendly approach supports transparency, a prerequisite for trust among stakeholders, facilitating informed choices and promoting responsible fishing practices. Multiple specialised working groups (STECF 2021, 2023, 2024) have rigorously analysed the system's methodology, criteria, and results across several case studies to ensure its accuracy and reliability. This comprehensive approach ensures relevant and thorough sustainability assessments, enabling informed consumer choices across various seafood products. This is crucial for the seafood market as the concept of "sustainability" is becoming a key driver in consumers' choices (Lawley et al., 2019).

Another advantage of the proposed scoring system is its ability to provide sustainability assessments even in data-poor situations, allowing to generate basic sustainability information on any fishery. By incorporating a precautionary approach and utilizing broad categories of impact, this system allows for an initial assessment of sustainability that can guide decision-making, even when complete data sets are unavailable. This flexibility ensures that fisheries operating in regions with less data can still be evaluated, providing a baseline sustainability score that encourages improvement over time. Thus, the proposed scoring system can play a crucial role in identifying sustainability issues on the one hand, and promoting sustainable practices across a wider range of fisheries on the other hand, including those in data-limited situations, thereby supporting broader efforts to protect marine ecosystems.

Raising awareness among consumers of the importance of choosing sustainable fish and seafood is an essential element for limiting the risk of depleting marine ecosystems and overexploiting marine living resources ensuring long-term access to aquatic resources (Bastardie et al. 2024).

To ensure fairness and competitiveness in the EU market, creating a label for fisheries (and aquaculture) products originating from non-EU countries was recently recommended to the PECH Committee of the European Parliament (Aranda et al., 2024). By promoting sustainable fishing practices and products, we can work towards a future where marine ecosystems thrive, fishing communities prosper, and consumers enjoy healthy seafood in a responsible manner.

The case studies conducted in FAO Areas 27 and 37 demonstrate the system's effectiveness in highlighting the ecological sustainability performance of various species and fishing methods. The results underscore the importance of adopting a multi-criteria assessment to capture the diverse ecological challenges faced by fisheries.

4.2 Limitations and Challenges of the Proposed Scoring System

While the Basic rating system is simpler and easier to manage, it often lacks reliability for some criteria, and its scientific soundness and effectiveness can be uncertain. It may also convey a low sustainability score due to lack of specific data which would have yielded a better score. Conversely, the Advanced rating system, though more complex and harder to verify, offers greater reliability, scientific rigour, and effectiveness. However, it faces limitations in covering all wild-caught seafood products comprehensively. Another limitation of the scoring system proposed in this paper is that it relies on broad categories such as species, gear type, and fishing area to determine scores, rather than considering the specific practices of individual producers. This generalised approach may unintentionally reduce the motivation for producers to enhance their practices, as their scores are influenced by the overall category rather than their own efforts. As a result, the primary option for a producer to improve their score might involve switching to a different gear type, which may not be feasible or desirable for many operators. In contrast, private certification schemes are specifically designed to incentivize individual improvements within a given gear category. By allowing producers to document and demonstrate that they are achieving sustainability levels above the average, these schemes offer opportunities for recognition and market differentiation. This is made possible by the use of fine-scale, spatialized data that captures the nuances of individual practices.

Our indicators focus on informing value chain stakeholders including consumers between products from different fisheries rather than assessing the overall environmental footprint of wild-caught seafood (Sala et al., 2022). By providing clear and accessible information, these indicators enable consumers to compare products and select those that are more sustainably sourced. The valorisation of fisheries products is one of the primary activities promoted by Axis 4 of the European Fisheries Fund, which serves as a tool to support fisheries growth (Regulation EU 508/2014).

Currently, the proposed indicators apply only to fresh and chilled products, mainly due to the lack of standardised consumer information rules for processed and canned products which hinders accurate sustainability assessment. To extend the rating system to processed and canned products, legislation should enforce the same stringent information requirements as for fresh and chilled products. Once comprehensive data on the origin, catch methods, and processing practices becomes available, the indicators can be expanded to include processed products, providing insights into a broader range of seafood products and promoting better management practices across the industry.

Successfully providing sustainability information, even when price is the primary driver in consumer choice, requires strategic efforts to shape consumer behavior and market dynamics. Transparency and scientific validation of eco-scored products can build consumer trust, encouraging them to pay a premium (Sun and Sung, 2022). Furthermore, educating consumers on the long-term benefits, such as ecosystem preservation and resource availability, can reinforce the value of this price premium (Graça and Kharé, 2023). The challenge now lies in determining to what extent sustainability information, such as a seafood eco-score, will drive sustainable production. This largely depends on how the proposed system is implemented. For example, it depends whether a system will be mandatory (as suggested by Penca, 2020) or voluntary. It also depends whether fisheries information will become more detailed e.g., through a new CMO regulation, and how producers could add specific information, e.g. on gear modifications, and how traceability is guaranteed. The system could serve as a basic measure of ecological sustainability, highlighting areas for improvement, and incentivizing data collection, especially in data-limited scenarios. For consumers, this system could enhance awareness and understanding of seafood sustainability issues broadly and provide detailed insights into specific species, catch methods, and origins.

In this study, we intentionally did not combine the three developed indicators into a single score, recognizing the complexities involved. Combining these indicators would require assigning weights based on the varying perceptions and priorities of stakeholders, but this issue extends far beyond the scope of this present article. Thus, we only focused on evaluating each indicator independently to provide a nuanced understanding of various aspects of seafood sustainability. However, we acknowledge that a consolidated score might be more practical for end-users. While different approaches exist for combining these indicators, alike what is done in Life Cycle Assessment that weight 16 different indicators into a single metric; we suggest starting with using a simple average of the three indicators, impact on seabed habitats, fish stock status, and bycatch risk of sensitive species, to create a unified score. This method ensures a balanced representation of each aspect, offering a holistic view of fisheries' product ecological sustainability.

5. Conclusions

This study presents a comprehensive fisheries performance system designed to assess the ecological sustainability of wild-caught seafood products in Europe. By integrating the three key impact categories of seabed habitat impact, stock status, and bycatch risk of sensitive species, this system offers a robust and nuanced evaluation of fishery sustainability at the ecosystem level. The approach transcends traditional assessments focused solely on the status of harvested resources, providing a more holistic view of the environmental impacts associated with different fishing practices. Moreover, provided it is employed in a mandatory way, this system empowers consumers, policymakers, and industry stakeholders to make informed decisions, promoting sustainable fishing practices that are crucial for the long-term health of marine ecosystems. Such a system could be rapidly deployed and could refer to all domestic and imported fresh and chilled fish products circulating on the EU market. Moreover, our scoring system effectively communicates the ecological risks of various fishing methods, it also incentivizes individual producers to make continuous improvements from low to high scores by, e.g., providing relevant information.

However, the study also acknowledges the limitations and challenges inherent in the proposed scoring system, particularly the balance between simplicity and scientific rigour. While the system provides valuable insights, further refinement and expansion are necessary to encompass a broader range of seafood products, including processed items and more sensitive species groups. Additionally, future efforts should explore the potential of consolidating the three indicators into a unified score, making the system more accessible and practical for end-users.

Overall, this fisheries performance system represents a significant step forward in the effort to promote sustainability in the seafood industry, contributing to ensure that marine resources are managed responsibly for future generations.

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