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

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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 an important 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 three 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, whether domestically caught or imported, based on publicly available information. A rating scale from 1 to 5 is used for clarity and effectiveness in communicating the respective risks. The indicators provide a user-friendly tool for consumers, policymakers, and industry professionals to make informed decisions about seafood sustainability. Our results show contrasted ecological risks among the main fishing methods, which is crucial for value chain actors for making informed choices that support sustainable fishing practices. Our method enables scientifically proven practices for mitigating by-catches of sensitive species to be accounted for. A clear, transparent, fair and adaptable scoring system can enhance societal awareness and steer the market towards more sustainable seafood products.

## 1. Introduction

In recent decades, the global demand for seafood has surged, driven by population growth and rising per capita consumption (OECD FAO, 2014; Cowley and Coulon, 2014; Bellmann et al., 2016; FAO, 2024). The development in developed countries is mainly driven by improved living

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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 (FAO, 2024). 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 (Garcia et al., 2003; Pikitch et al., 2004; Rindorf et al., 2017; 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 (Pikitch 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, which is commonly 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 and Ababouch, 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 and Cheung, 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. Whereas certified products are found mostly in supermarkets, ratings provide sustainability information for those products that are not certified, for example at 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 include a possible 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. Additionally, the use of fish products for purposes other than human consumption can also significantly impact fish stocks, further underscoring the need for sustainable practices. Regulation (EU) No 1379/2013, also known as the Common Market Organization (CMO) Regulation, governs the marketing of seafood products in the European Union (EU). Its objectives include promoting sustainable exploitation of marine resources, applying the Common Fisheries Policy (CFP) effectively (European Parliament and Council, 2013a), 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 to declare whether the product was previously 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, 2024a). 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 (species-area-gear), then supplemented with other data and information as described below. This specific requirement represented the most structuring challenge and 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 level 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, but not the actual absolute impact induced by the very fishery which caught the product.

Our research focused primarily on evaluating the sustainability of the seafood products available on the EU 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 the EU.

## 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 set nets, traps 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. This threat may arise through direct impact (The N2K Group, 2017) or as a result of ghost fishing (Uhlmann and Broadhurst, 2013). 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,

**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 |

referred above as the "basic rating", we apply a precautionary approach, assigning the highest impact score (Table 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 seabed 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 1000 m; e) the upper bathyal zone extends to depths between 1000 m and 2500 m; f) the lower bathyal zone extends to depths between 2500 m and 4000 m; g) the abyssal zone extends to depths >4000 m (Table 2). As such, a habitat sensitivity score could be assigned to 1850 species.

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

The score of the seabed impact indicator for the fishery product (ranging from 1 to 6) is obtained adding the score of the impact of the fishing gears (ranging from 0 to 3) with the proxy habitat sensitivity score of the target species (ranging from 1 to 3), as illustrated in Table 3.

## 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 (European Parliament and Council, 2013b). This criterion relates to the retrospective assessment of the sustainability of each fish stock, utilizing 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 Fig. 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).

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;

**Table 2**
Sensitivity scores by benthic habitat type, indicating vulnerability to physical disturbance (abrasion) induced by fishing, on a scale from 1 to 3. The value assigned to the pelagic habitat is 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 |

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

| | | **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 |

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 (Fig. 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).

### 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 seafood products. 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 only 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,

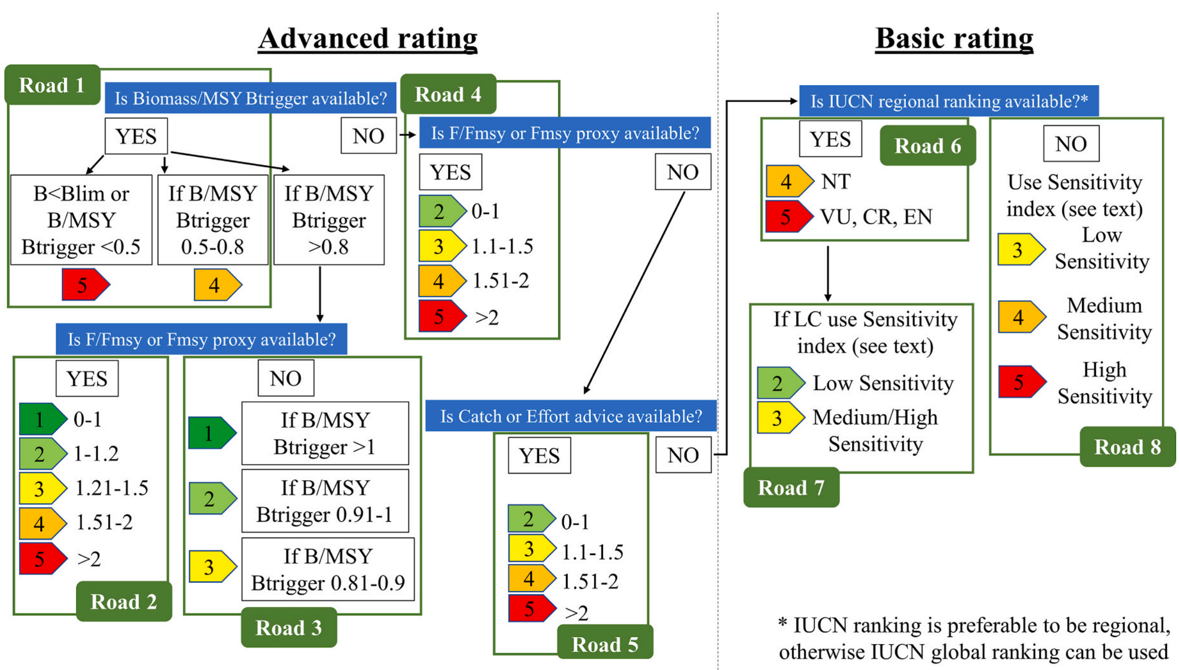


**Fig. 1.** Decision tree to grade/rate the sustainability levels of fisheries products as a function of the fishing pressure.

**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; EN = endangered; CR = critically endangered.

| Road | System | Criteria | Thresholds | Score |
|---|---|---|---|---|
| 1 | Advanced | B/MSYBtrigger | <0.5 or B < Blim<br>≥0.5 and ≤ 0.8 | 5<br>4 |
| | | ***if ≥ 0.8 and F/Fmsy available - road 2*** | | |
| 2 | Advanced | F/Fmsy | <1.0<br>≥1.0 and ≤ 1.2<br>>1.2 and ≤ 1.5<br>>1.5 and ≤ 2.0<br>>2.0 | 1<br>2<br>3<br>4<br>5 |
| | | ***if F/Fmsy not available - road 3*** | | |
| 3 | Advanced | B/MSYBtrigger | >0.8 and ≤ 0.9<br>>0.9 and ≤ 1.0<br>>1.0 | 3<br>2<br>1 |
| | | ***if B/MSYBtrigger not available - road 4*** | | |
| 4 | Advanced | F/Fmsy | ≤1.0<br>>1.0 and ≤ 1.5<br>>1.5 and ≤ 2.0<br>>2.0 | 2<br>3<br>4<br>5 |
| | | ***if F/Fmsy not available - road 5*** | | |
| 5 | Advanced | Catch/Advice | ≤1.0<br>>1.0 and ≤ 1.5<br>>1.5 and ≤ 2.0<br>>2.0 | 2<br>3<br>4<br>5 |
| | | ***if Catch/Advice not available - road 6*** | | |
| 6 | Basic | IUCN status | NT<br>VU, EN, CR | 4<br>5 |
| | | ***if LC – road 7*** | | |
| 7 | Basic | Sensitivity | Low<br>Medium and High | 2<br>3 |
| | | ***if IUCN status not available – road 8*** | | |
| 8 | Basic | Sensitivity | Low<br>Medium<br>High | 3<br>4<br>5 |

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, clade, 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 1–3. 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 (1–5) to align with the other indicators. This was achieved by applying the scale factor of 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 is capped at the value of 5.

## 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). These data were obtained from the EU Fisheries Dependent Information (FDI) database 2022 (https://stecf.ec.europa.eu/data-dissemination/fdi_en), resulting in 43,810and 8862 combinations of species, area, and gear in FAO 27 and 37, respectively. Scores for each indicator were calculated for all combinations (Fig. 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 does not show a clear trend in both 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

**Table 5**
Criteria developed for the bycatch information quality used to adjust the sustainability levels of seafood 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**<br>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)**<br>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:<br>Grey literature + qualitative information = 3<br>Peer reviewed publication + bycatch rate = 2<br>Peer reviewed publication + ERA = 1<br>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**<br>Global coverage = 2 (except if the sensitive species population is known to have a global spatial distribution, then the score is 0)<br>FAO area = 1 (except if the sensitive species population is known to have a spatial distribution at the FAO area level, then the score is 0)<br>FAO subdivision = 0 | 2 |
| **Criterion 4: Temporal coverage**<br>Relevant information is older than 10 years = 1<br>Relevant information is 10 years-old or more recent = 0 | 1 |
| **Total** | **7** |

indicator is predominantly represented by score 4 (high impact, 65%), followed by scores 1 and 3 (very low and medium impact, both at 13%), with a minimal contribution from score 5 (very high impact, 1%).

Fig. 3 shows the distribution of scores for each target species, fishing gear, and area combination across the subdivisions of FAO 27 and subareas of FAO 37.

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, FDI data show that 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 mid-water 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.

## 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 (i.e., stock status, seabed impact and bycatch risk of sensitive species). This approach offers an initial assessment of fishery sustainability at the ecosystem level, going beyond the traditional and often inadequate method that focuses solely on the status of the 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 and are based on robust and accessible data from reliable 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), which is particularly

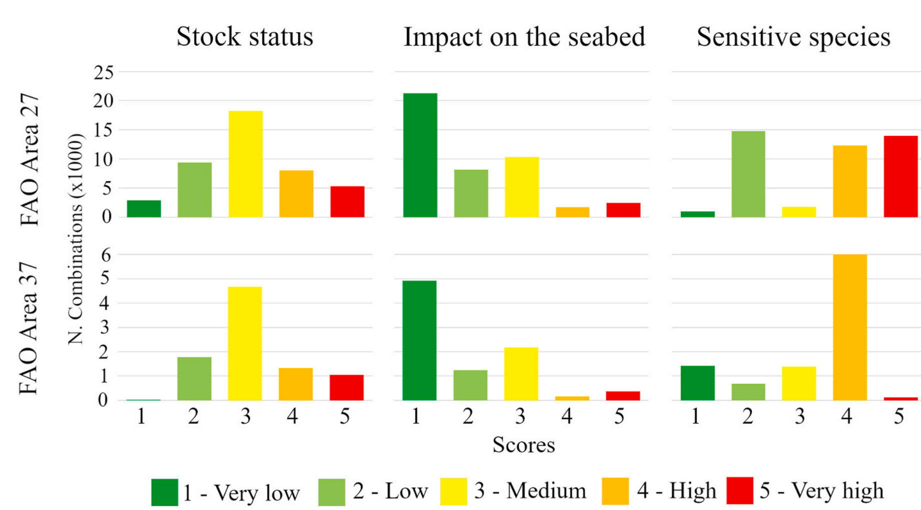


**Fig. 2.** Frequency distributions of the fisheries sustainability indicator scores for species-area-gear combinations in FAO 27 (Northeast Atlantic Ocean, upper panel) and FAO 37 (Mediterranean and Black Sea, lower panel). Source: EU Fisheries Dependent Information database 2022 (https://stecf.ec.europa.eu/data-dissemination/fdi_en).

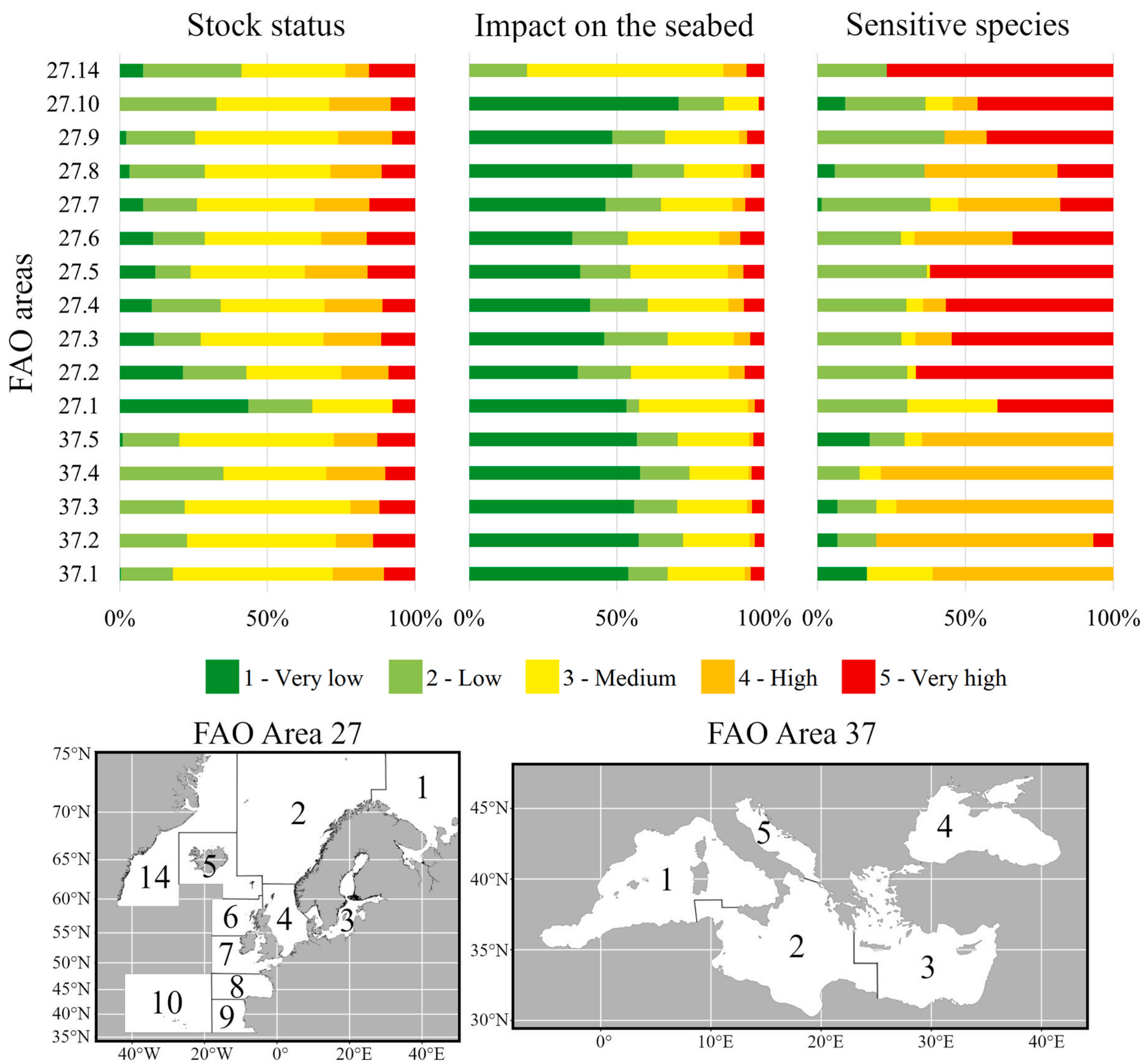


**Fig. 3.** Distribution of relative scores (1: very low impact; 2: low impact; 3: medium impact; 4: high impact; 5: very high impact) for the fisheries sustainability indicators for gear-species-sub-area combinations in FAO 27 (North-East Atlantic Ocean) and FAO 37 (Mediterranean and Black Sea). It should be noted that these score distributions reflect the frequency of occurrence in each sub-region independently of the volume of the respective landings. Source: EU Fisheries Dependent Information database 2022 (https://stecf.ec.europa.eu/data-dissemination/fdi_en).

relevant given that passive gears like gillnets and traps can continue to cause unintended mortalities when abandoned or lost (Uhlmann and Broadhurst, 2013).

This system 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 fosters transparency, a prerequisite for trust among stakeholders, facilitating informed choices and promoting responsible fishing practices. Multiple expert working groups (STECF, 2021, 2023, 2024a) 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 consistent sustainability assessments, enabling informed consumer choices across various seafood products. This information element 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 incentivizes the provision of more detailed data to enable reaching higher scores. 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 general 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

**Table 6**
Examples of the three 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 | 2 |
| European anchovy+ | North Adriatic Sea | Pelagic pair trawls | 3 | 1 | 4 |
| 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 | 2 |
| European pilchard+ | North Adriatic Sea | Pelagic pair trawls | 3 | 1 | 4 |
| 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 |

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*

The presented scoring system includes two levels that correspond to different levels of available information, and therefore different uncertainties. 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. This system however enhances the precautionary approach. Conversely, the advanced rating system, which requires more complex data, offers greater reliability, scientific rigour, and effectiveness but faces limitations in covering all wild-caught seafood products comprehensively. Both system levels are therefore complementary, with an important incentive to provide detailed information for an eventual higher scoring.

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, the generally more specific private certification schemes are 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 are opportunities, against a given cost, for recognition and market differentiation. This is made possible by the use of fine-scale, spatialized data that captures the nuances of individual practices.

Among the three indicators developed in this study, the one addressing the risk of bycatch of sensitive species is notably more conservative than the other two, as also demonstrated by the case study presented in this paper. This precautionary approach is evidenced by the high frequency of poor scores (4 and 5) across almost all European seas. The primary driver of this outcome is criterion 2 in Table 5, which increases the risk score (indicating higher risk) when the quality of available information is considered relatively low. While this approach may seem overly stringent in certain instances, it serves as a strong incentive for producers to provide robust scientific evidence demonstrating lower risks of sensitive species bycatch, thereby improving the overall score of their product.

The results on the status of stocks between the North-East Atlantic and the Mediterranean and Black Sea (FAO 27 and 37, respectively) in Fig. 3, which appear similar at first sight, may seem to contrast with the overall different fraction of sustainably exploited stocks estimated by the Common Fisheries Policies (CFP) monitoring (70% in FAO 27 and 39% in FAO 37 in 2021; STECF, 2024b). However, the best score (value 1, dark green) is virtually non-existent in the Mediterranean and Black Sea and is replaced by a higher proportion of medium scores (value 3, yellow). Furthermore, despite the differences between the years analysed (2022 and 2021), such a direct comparison cannot be made strictly because the present results describe the distribution of a much larger number of stocks (390 and 303, respectively, compared with 83 and 64 in the CFP monitoring with a time series since 2003 and trend analysis). Efforts to reach 100% of stocks exploited sustainably, as set out in the CFP, are still largely necessary, particularly in the Mediterranean and Black Sea.

The examples of the three ecological sustainability scores calculated for the nine most important species in weight landed by EU fleets

(Table 6) offers an overview of the scoring variability for important landings, but is importantly biased by the high number of pelagic species (seven over nine species) that unlikely characterize direct human consumption (as mostly used for feed), and for which the fishing gears have no impact on the seabed. This example however shows that such sustainability information may be used to assess feed products for aquaculture in conjunction with other indicators, such as GHG emissions (Bianchi et al., 2022).

Our indicators focus on informing value chain stakeholders, including consumers, about the main relative sustainability levels between products from different fisheries rather than assessing the absolute and exhaustive 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 the Axis 4 of the European Fisheries Fund, which serves as a tool to support fisheries growth (European Parliament and Council, 2014; FAO, 2022).

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 behaviour 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, and a potential basis for internalizing the long-term ecological costs. For consumers, this system is able to easily 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, also recognizing the three evaluations favours the educational aspect to the consumers. 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, in addition to the individual scores on the 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 could empower 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. Beside communicating the ecological risks associated with various fishing methods, our scoring system seeks to encourage individual producers to make continuous improvements from lower to higher 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 and aquaculture 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 ensuring that marine resources are managed responsibly for future generations, but its widespread implementation would require consensus and standardization among the involved parties.

**CRediT authorship contribution statement**

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Methodology, Formal analysis, Data curation. **Antonello Sala:** Writing – original draft, Validation, Formal analysis, Data curation. **Martina Scanu:** Writing – original draft, Validation, Formal analysis, Data curation. **Giuseppe Scarcella:** Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Vjekoslav Tičina:** Writing – original draft, Validation, Formal analysis, Data curation. **Clara Ulrich:** Writing – original draft, Validation, Formal analysis, Data curation. **Alessandro Lucchetti:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization.

### Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Fabio Grati reports financial support was provided by European Commission. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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